F

FABA BEAN. Feedstuffs.

FABRICATED FOOD. Meat; Seafoods (Processing; Soybean Processing; Texture.

FACTORY SHIP. Seafoods; Seafoods (Processing).

FALLING-FILM EVAPORATOR. Evaporating.

FANNED MASS METHOD. Plant Breeding.

FAO. Abbreviation for Food and Agriculture Organization of the United Nations. See also **Food and Agriculture Organization.**

FATTY ACIDS. Feedstuffs; Meat Byproducts; Milk and Dairy Products; Oilseeds and Related Products; Palm Oil.

FEEDER (Hay). Hay and Forage Equipment

FEEDER CATTLE. Beef and Dairy Cattle.

FEED-GRADE ANIMAL FAT. Feedstuffs.

FEEDING SYSTEM. Poultry.

FEEDLOT. Feedstuffs.

FEEDSTUFFS. The feed industry is the largest agricultural input industry in terms of producers' expenditures. Total feed expenditures account for almost one-fifth of total production expenses and for about one-fourth of current operating expenses.

Content of this Entry. Because of the importance of feedstuffs and the nutrition of food animals, this topic cannot be concentrated fully in one entry of this volume. Feeds are mentioned in numerous entries, including those on the cereals, the entry on **Grasses; Hay and Forage Crops; Silage**; and the various entries on the food animal species. This immediate entry contains the following sections: Feed and Feed Processing Terms; General Nutritional Aspects of Animal Feeding; Minerals and Trace Elements in Animal Feeds; Vitamins in Animal Feeds; Specific Feedstuffs and Trends; Water in the Animal Diet; Feedstuff Manufacturing; and a comprehensive list of References.

Special feed additives, such as drugs and hormones are described in the various entries on animal species because frequently these substances are specific to given species and their diseases.

General Characteristics of Feed Industry. In the United States, as of the late 1970s, commercially prepared feeds accounted for nearly 70 percent of all feed expenses. In addition, many livestock and poultry producers either manufacture feed for their own needs or have feed custom-mixed from their own grains. This feed, although not marketed in commercial channels, is a real part of the mixed feed industry. Consumption of feed by food animal species is shown in Table 1A. Classes of feed consumed are shown in Table 1B.

Surveys of the feed industry are made by the U.S. Department of Agriculture every 5 to 6 years. As of the late 1970s, the last such survey was made in 1975. A few additional statistics from this survey (See Vosloh reference listed at end of this entry) provide some comprehension of the characteristics of this industry:

1. Corporations accounted for about 51% of the establishments. Cooperatives made up 26%, and single-owner establishments, 16%.
2. Of the 104.5 million tons (94.1 million metric tons) produced in 1975, primary feed tonnage equaled about 71% of the total output. Secondary feed made up the re-

TABLE 1A. FEED CONSUMPTION BY ANIMAL SPECIES (United States)

Type of Feed	Number of Manufacturing Establishments	Formula Feed Produced	
		1000 Tons	1000 Metric Tons
Dairy feed	2122	14,209	12,788
Beef and sheep feed	2216	17,217	15,495
Horse feed	1269	1,540	1,386
Hog feed	2370	9,882	8,894
Turkey feed	465	3,078	2,770
Broiler feed	527	12,695	11,426
Starter-grower/layer-breeder feed	1959	12,132	10,919
All other	1005	3,079	2,771
Total	3385*	73,832	66,449

*Not total of column because many feed manufacturers prepare more than one kind of feed.

Poultry	37.8% of total
Beef cattle and sheep	23.3%
Dairy cattle	19.2%
Swine	13.4%
Horses	2.1%
All other	4.2%

D. M. Considine et al. (eds.), *Foods and Food Production Encyclopedia*

TABLE 1B. CONSUMPTION OF FEED CONCENTRATES AND ANIMAL UNITS ON FEED

	Year Commencing October 1				
	1973	1974	1975	1976	1977
Concentrates consumed	Million Metric Tons				
Corn (Maize)	106.2	81.0	90.4	90.1	95.9
Sorghum	17.8	11.1	13.0	10.9	12.1
Oats	9.3	8.4	7.9	7.5	7.0
Barley	4.8	4.0	4.1	3.6	3.3
Wheat and rye	1.8	1.9	1.7	6.8	5.6
Oilseed meals	14.8	13.2	15.7	14.4	16.0
Animal protein feeds	2.6	2.5	2.6	2.7	2.7
Grain protein feeds	1.9	1.8	2.0	1.8	1.8
Other byproduct feeds	11.8	12.0	13.0	12.6	12.2
Total	171.0	135.9	150.4	150.4	156.6
Grain-consuming animal units (GCAUs)*	Million				
Dairy cattle	12.5	12.5	12.3	12.2	12.1
Cattle on feed	20.8	15.4	19.8	19.2	19.6
Other cattle	5.4	5.6	5.5	5.2	5.0
Hogs	20.0	17.6	17.5	19.5	21.5
Poultry	18.0	17.2	18.1	18.3	18.9
Other livestock	1.8	1.5	1.8	1.8	1.7
Total	78.5	69.8	75.0	76.2	78.8
Concentrates fed/GCAU	Tons per Unit				
Four feed grains	1.76	1.50	1.54	1.47	1.51
All concentrates	2.18	1.95	2.01	1.97	2.00

*One animal unit = 1 mature cow or its equivalent. One animal unit approximates 1 horse; 5 sheep; or 2 yearling calves.

maining 29%. Corporations produced 67% of the primary feed. (Definitions are given a bit later in this entry).

3. Grain accounted for about 53% of the ingredients received by primary manufacturers; oilseed meal made up 17%; and millfeed accounted for 11%.

4. About one-third of the primary feed manufactured was packaged. Slightly more than 98% of the finished feed left the plant by truck, with an average delivery by company truck of 69 miles (111 kilometers).

5. On the average, feed manufacturers maintained about a 62-day inventory of grains; 20 days of proteins; and 25 days of by product feeds. Premix inventories were maintained at a 30-day-supply; and drugs at 41 days.

6. Capacity for pelleting accounted for about 23% of total United States milling capacity, although this is increasing.

7. The Corn Belt had the greatest number of liquid feed processors, accounting for 25% of the total. Annual capacity was largest in the Northern Plains states, accounting for 30% of the total capacity.

Feedstuffs—A Major Objective of Food Production Research. Goals as established by the U.S. Agricultural Research Policy Advisory Committee in 1977 placed considerable emphasis upon feedstuffs:

1. Develop methods to increase production from range, silage and pasture with new forages, fertilization, mechanical soil treatments, forage management and livestock grazing management systems.
2. Improve ways to use noncompetitive feeds, such as crop residues, by-products, etc. and to remove residues (animals as filters).
3. Identify products and ways to use additives to increase animal production, including benefits, regulation and safety.
4. Determine the land, animal, human and feed resources available and potentially available in the future for beef production and consumption.
5. Improve methods for feed production with minimum concentrates.

European Trends. The proportion of commercially compounded feeds in the total European Community feed use, went from under 40% in 1960 to over 50% in 1975. Country-to-country variations noted in a 1975 survey are significant. It was noted that producers in the Netherlands use predominately compounded feeds whereas producers in France use relatively little. Most of the growth in compounded feed use in the Netherlands is attributable to growth in demand for meat for domestic and export consumption, while most of the growth in compounded feeds in France is attributed to such feeds forming an increased share of the total feedstuff use.

Feed and Feed Processing Terms[1]

Additive. An ingredient or combination of ingredients added to the basic feed mix or parts thereof to fulfill a specific need. Usually used in micro quantities and requires careful handling and mixing.

Antibiotic. A drug, usually synthesized by a living microorganism, that, in the proper concentration, inhibits the growth of other microorganisms.

Artificial drying. Removal of moisture by other than natural (such as sun drying) means. The application of hot air streams, microwave energy, infrared radiation are examples of artificial means.

Aspirating. The operation of removing chaff, dust, and other light materials from feed mix ingredients and raw materials by the use of an air stream.

Balanced feed (or diet or ration). A feed mix that has all the known required nutrients in proper amount and proportion based upon recommendations of recognized authorities in the field of animal nutrition (as, for example, in the United States, the National Research Council) for a given set of physiological animal requirements. The species for which the balanced feed is intended and the functions, such as maintenance or maintenance plus production (such as growth, fetus, fat, milk, eggs, wool, feathers, or work), must be specified.

Blending. The operating of mingling or combining two or more ingredients of feed. The term does not imply the absolute uniformity of the resulting mixture.

Blocking. The operation of bringing together or agglomerating individual ingredients of a feed into larger pieces or masses.

---

[1] Some of these terms are actual definitions (or modifications) of official 1979 terms used by the Association of American Feed Control Officials and the U.S. Food and Drug Administration. Some terms, such as amino acid, vitamin, etc. are purposely omitted because these topics are discussed in detail in several entries in this volume.

Cake. The mass (or cake) resulting from the pressing of seeds, meat, or fish in order to expel oils, fats, and other liquids.

Carrier. An edible material to which ingredients are added to facilitate uniform incorporation of such added ingredients into the feed. The active parti-

Chaff. Material made up of glumes, husks, or other seed covering, together with other plant parts, that are separated from seed in threshing or processing.

Cleaning. The removal of undesirable and foreign materials, such as weed seeds, dust, nails and other metal parts, from cereal grains and any other feed raw materials.

Clipping. The operation of removing the ends of whole grain.

Complete feed. A nutritionally adequate feed for livestock and poultry. Compounded to a specific formula, the feed can be used as the sole ration for the animal specified and is capable of maintaining life and/or promoting production without any additional substance being added with exception of water.

Concentrate. A feed used with another (different) feed to improve the nutritive balance of the total feed administered. Generally, a concentrate is intended to be diluted and mixed with other feedstuffs to produce a supplement or a complete feed.

Condensing. The operation of removing moisture to produce a denser form of feedstuff.

Conditioning. The preadjustment of moisture, temperature, or any other pertinent variables of the ingredients of a feed prior to further processing. Preconditioning is an appropriate synonym.

Cooking. The operation of heating feed materials in the presence of moisture in the interest of bringing about chemical and/or physical alterations of the materials; or to sterilize the materials.

Cooling. The lowering of feed temperature after processing, usually effected by a moving cool-air stream. Some drying usually accompanies cooling.

Cracking. The operation of reducing the particle size of feed ingredients (or final product) by a combined breaking and crushing action.

Crumbling. The operation of reducing pellets to granular form. The resulting material is sometimes referred to as *crumble.*

Cube. A form of pellet. See Pellet; Range Cube this list.

Custom-grinding and mixing. Grinding customer-owned feed ingredients and usually mixing supplements with them. This is mainly a service provided to producers who feed their own animals. However, toll milling (milling performed for other feed manufacturers) is usually included in this category.

Dehulling. The operation of removing the outer covering from grains or other seeds.

Dehydrating. Removal of moisture by thermal means.

Diet. The feedstuff, often a mixture of ingredients including water, that is administered to livestock and poultry. Good animal management requires a careful specification of the diet.

Diluent. An edible substance used to mix with and reduce the concentration of nutrients and/or additives to make them more acceptable to animals, safer to use, and more capable of being mixed uniformly in the feed. A diluent may play the role of carrier (which also see in this list).

Dressing. The operation of improving the uniformity of texture of a feedstuff. This may involve the breaking or screening of lumps from feed and/or the application of one or more liquid ingredients.

Drug. A substance that is intended for use in the diagnosis, cure, mitigation, treatment or prevention of disease in livestock and poultry; or a substance intended to affect the structure or any function of the body of animals (excepting materials of a nutritive value).

Dust. Very fine, dry particles of material that usually result from the cleaning and grinding of grain. Such dusts can constitute a serious explosion hazard.

Emulsifier. A substance capable of causing fat or oils to remain in liquid suspension.

Evaporation. The operation of reducing feed ingredients or mixtures to a denser form by the removal of water and volatiles. The term, in the feed industry, is also sometimes applied to a distilling operation.

Expanding. In the feed industry, this term usually refers to the gelatinization of the starch portion of a feed ingredient by applying pressure, temperature, and moisture. When extruded, the volume of the material is increased due to abrupt reduction in pressure.

Extracting. The removal of fat or oil from materials by the use of organic solvents. The term is also sometimes used in connection with mechanically expelling (or extracting) fats or oils from materials.

Extruding. The forcing of feed materials through an orifice under pressure to form a product of desired cross-section (depending upon shape of die used).

Feed additive concentrate. A complete feed or a feed additive supplement that must be diluted prior to consumption by the animal. The extent of concentration varies and hence must always be specified. Reductions may range from 10 to 1000 to 1. Some concentrates, while obviously not poisoning, can cause very serious problems if fed to the animal in an undiluted form because of the severe imbalance of diet that may occur. On the other hand, some feed additive concentrates can be fed as "free choice" items to the animal. Directions supplied by the manufacturer must be carefully followed.

Feed additive premix. A feed additive that contains additives at levels for which safety to the animal has not been fully demonstrated and/or which may result when fed undiluted in residues that will later be consumed by humans after the animal has been slaughtered and for which safe human levels of tolerance have not been established.

Feeding own animals. A term used to describe the feeding of livestock that may be owned by a feedmill owner. It also includes feed fed to a feed manufacturer's livestock or poultry grown under contract by a farmer-producer.

Feed-milling establishment. This is usually a stationary mill operation at a single location together with any mobile mills based at that location. It may consist of one or more mobile mills not associated with a stationary mill, but based at one location. An establishment is not necessarily the same as a business firm, which may include a number of establishments. The feed-milling activities of establishments are classified as: (1) Primary feed manufacturing; and (2) secondary feed manufacturing.

Fines. Any material which will pass through a screen, the openings of which are smaller than the specified minimum crumble size or pellet diameter of a feed.

Flakes. A feed ingredient that is rolled or cut into flat pieces with or without prior steam conditioning.

Flour. Soft, finely ground and bolted meal obtained from the milling of cereal grains, other seeds, or products. It consists essentially of the starch and gluten of the endosperm.

Formula feed. Two or more ingredients proportioned, mixed, and processed into animal feed according to specifications.

Free choice. A feeding system which allows animals unlimited access to the separate components or groups of components constituting the diet.

Gelatinizing. An operation whereby starch granules are completely ruptured through the application of moisture, heat, and pressure, and, in some instances, by application of mechanical shear.

Grain. The seed of cereal plants.

GRAS. Acronym for "Generally recognized as safe." Thus, a substance which is generally recognized by experts as safe.

Grits. Coarsely ground grain from which the bran and germ have been removed and frequently screened to a uniform particle size.

Groats. Grain from which the hulls have been removed.

Hull. Outer covering of grain or other seed.

Kibbling. The operation of cracking or crushing a baked dough, or extruded feed that has been cooked prior to or during the extrusion process.

Mash. A mixture of ingredients in meal form. Frequently called *mash feed.*

Meal. An ingredient which has been ground or otherwise reduced in particle size, but still not as fine as a flour.

Medicated feed. Any feed which contains drug ingredients intended or represented for the cure, mitigation, treatment, or prevention of diseases of animals; or a substance intended to affect the structure or any function of the body of animals (excepting materials of a nutritive nature). Example: a feed containing an antibiotic or hormone.

Microingredient. Substances added to feeds in very small amounts (usually measured in terms of milligrams, micrograms or parts per million (ppm)) and including various minerals, vitamins, antibiotics, drugs, etc.

Mill dust. Fine feed particles of various origin resulting from handling and processing feed and feed ingredients. Such dusts can constitute a serious explosion hazard.

Mill run. The condition in which feed ingredients arrive from the mill, that is, ungraded and uninspected.

Mineralizing. Operation in which mineral compounds are added to feed. The operation may be one of thorough mixing, using a carrier, one involving impregnation, etc.

Pearling. The operation by which dehulled grains are reduced by machine brushing into smaller, smoother particles.

Pellet. An agglomerated feed formed by compacting and forcing through die openings, or otherwise made into cubes, dice, and other shapes, suitable for convenient consumption by the animal. Some pellets are rather hard; others are soft, such as high-molasses pellets. In their manufacture, soft pellets usually require immediate dusting and cooling to retain their form.

PPB (or ppb). Abbreviation for "parts per billion."

PPM (or ppm). Abbreviation for "parts per million."

Premix. A uniform mixture of one or more microingredients with diluent and/or carrier. Premixes are used to facilitate uniform dispersion of the microingredients in a larger mix.

Primary feed manufacturing. The processing and mixing of individual feed ingredients, sometimes with the addition of a premix, at a rate less than 100 pounds per ton (50 kilograms per metric ton) of finished feed. Examples of specific feed ingredients are feed grains, mill byproducts, oilseed meals, and animal proteins.

Range cube. Feed in the form of a large pellet designed to be fed on the ground. Another term is *range wafer.*

Ration. Usually considered to be the amount of the total feed which is provided to one animal over a 24-hour period.

Rolling. The operation of altering the shape and/or size of feed particles by compressing them between rollers. The process may entail tempering or conditioning.

Scalping. The operation of removing large pieces from a mass of material by means of screening.

Scratch. Whole, cracked, or coarsely cut grain. Also called *scratch grain* and *scratch feed.*

Secondary feed manufacturing. The processing and the mixing of one or more ingredients with formula feed supplements. Supplements are usually used at the rate of 300 pounds per ton (150 kilograms per metric ton) of finished feed, depending on protein content of the supplement and percentage of protein desired in the finished feeds.

Self-feeding. A feeding system where animals have continuous free access to some or all components of a ration, either individually, or as mixtures.

Steaming. The operation of treating ingredients of a feed with steam to alter physical and/or chemical properties. Such feed may be referred to as *steam cooked, steam rendered,* or *tanked.*

Supplement. A feed used with another feed to improve the nutritive balance or performance of the total and intended to be: (1) Fed undiluted as a supplement to other feeds; or (2) offered free choice with other parts of the ration separately available; or (3) further diluted and mixed to produce a complete feed.

Toasting. The operation in which all or some of the ingredients of a feed are browned, dried, or parched by exposure to heat.

Trace mineral. Any of a number of mineral nutrients required by animals in very small amounts (usually measured in terms of micro- or milligrams).

Wafering. The operation of compressing or otherwise forming an agglomerated feed into a solid piece, the diameter or cross section measurement of which is greater than its thickness (disk or coin shaped). Like pellets and cubes, another convenient form for feed consumption by the animal.

General Nutritional Aspects of Animal Feeding

When looked upon broadly, the feeding of livestock and poultry is indeed quite complex. Some of the variables which make the tasks of the scientists, agronomists, and producers in this field difficult include:

1. The several major species or classes of food animals, such as beef cattle, dairy cows, swine, sheep, goats, buffalo, rabbits, and poultry (chickens, ducks, geese, and turkeys), each class of which presents different nutritional needs. While there are many physiological similarities and parallels among the various animal species, nevertheless there are significant differences in the manner in which these species utilize their feed inputs to bring about optimum productivity and quality of meat, milk, and eggs. Contrast, for example, the digestive and metabolic systems of the sheep, dairy cow, and chicken. *See separate entries in this volume on the various major species.*

2. The scores of breeds found among each species, each having somewhat different nutritional requirements and responses.

3. The numerous differences in terms of end objectives of the livestock and poultry producers, as reflected by the differences in the feeding requirements of growing-finishing steer calves and yearlings, a beef cattle breeding herd, veal calves, lactating cows, broiler chickens, laying and breeding chickens, etc.

4. The hundreds of substances that can be considered for feeding livestock and poultry, ranging from the obvious grasses and grains to many materials that not too many decades ago were considered as waste products as, for example, citrus pulp, fishmeal, bagasse, etc., each substance presenting a different spectrum of nutritional advantages and limitations, as well as differences in local availability and cost.

5. The growing understanding of the complexities of animal nutrition that essentially dictates customized feeding, but that increases the problems of selecting the one or many feed ingredients that will achieve the proper balance of energy, vitamins, minerals, trace elements, amino acids for the animal to be fed for a given set of production objectives.

6. The numerous kinds of feeds offered, ranging from bulk, pelletized, and waferized solids to liquid feeds, and weighing the advantages of partial or exclusive use of commercial feeds against foraging on rangelands and pasture, or locally produced and prepared silages, fodders, and grain mixtures.

7. The feed scientists and producers who are concerned with the international aspects of animal feeding must consider the vast differences in the economics and availability of feed raw materials.

8. The incorporation of nonfeed ingredients into animal feeds, including numerous drugs, such as antibiotics, sulfa compounds, to prevent or treat animal diseases and deformities within the past several years has added still another dimension to the problem of specifying and selecting the optimum feedstuff for a given situation. Also, the inclusion in feedstuffs of hormonal and other growth-promoting substances that influence the physiological development or performance of the animal, with the objectives of more rapid fattening of cattle, improving the characteristics of egg shells, etc.

9. The capability of feedstuffs to store and keep well differs over a wide range, making this an important selection decision on the part of the animal producer and also introduces the problems of feed contamination where control chemicals are required.

10. The very important interface between the feed for animals and the food for people, the animal serving as a converting link in the food chain. Chemicals which contribute to the well-being of the animal or to the preservation of feedstuffs may, in residual forms, become harmful to the persons who consume the animal products. This factor not only contributes to the difficulty of feed selection, but also to the management of feeding programs so that intolerable levels of certain chemicals will not be exceeded at the time the animals are slaughtered or when the milk or eggs are marketed.

Feed Energy. Important as are such factors as the proper balance of amino acids, the presence of needed vitamins, minerals, and trace elements, the paramount characteristic of a feedstuff and the starting point of most feedstuff discussions is the metabolizable energy which the feed makes available to the consuming animal for the maintenance of normal living activities. Feed energy definitions include:

Total Digestible Nutrients, abbreviated TDN, is one of the older ways of expressing feed energy and is based upon chemical analysis of the various digestible organic components, including proteins, nitrogen-free extract,[1] fiber, and fat. A factor of 1 is used for all components except, to which is assigned a value of 2.25 so as to place fat energy value on the same basis as the other nutrients. The system is based upon nutrient experience with humans and dogs rather than farm animals and consequently does not apply directly to ruminants. The relative factors of 1 and 2.25 just mentioned are not always necessarily constant, tending to overstate roughages (feeds with a high fiber content) and to understate concentrates (low-fiber components), mainly because of the higher heat loss associated with high-fiber feeds. Although TDN does not directly express energy, TDN values can be converted to energy terms as follows:

1 TDN (pounds) = 1.814 million calories (small)
= 1.814 thousand Calories (large)[2]
= 1.814 therms
1 TDN (kilograms) = 4 million calories (small)
= 4 thousand Calories (large)
= 4 therms
1 TDN (grams) = 4 thousand calories (small)
= 4 Calories (large) = 0.004 therm

---

[1] Nitrogen-free extract is the unanalyzed portion of a plant that remains after the protein, ash, crude fiber, ether extracts, and moisture content have been determined. It consists largely of carboyhydrates.

[2] 1 small calorie is the heat necessary to raise the temperature of 1 gram of water from 14.5° to 15.5°C. 1 Large Calorie = 1000 small calories. 1000 Large Calories = 1 Therm.

In tabulations of feedstuffs, the quantity of dry matter is usually also given along with TDN values to make sure that the stipulated amount of TDN is fed.

Digestible Energy, abbreviated DE, is the energy in the feed minus the energy equivalent of the feces of the consuming animal. Such determinations are made with a bomb calorimeter. In the average situation, digestible energy will represent about 56% of available energy, with the remaining 44% represented in the feces. See Table 2.

Digestible protein is determined by a separate chemical analysis for nitrogen of the feed minus the nitrogen content of the feces. Digestible protein equals nitrogen X 6.25 (in most instances).

Metabolizable Energy, abbreviated ME, is a measure of actual nutritive value and takes into account the losses in production of methane gas and urine by the animal. The tests require special equipment, such as a respiration chamber. Research has shown a good correlation between digestible energy and metabolizable energy and thus the former value serves well for comparing one feed with another.

Basic methods for determining the metabolizable energy (ME) have been developed under the sponsor ship of the Animal Nutrition Research Council (ANRC). The method most widely used currently for measuring ME employs chromic oxide as an indigestible indicator. Considerable variation is experienced between laboratories making this determination and this has led to consideration of a concept known as the true metabolizable energy system. See also Carew reference listed at the end of this entry.

Net Energy (or Gain), abbreviated NE_g, is the energy (actually a small portion of the total) that is used in producing a weight gain of the animal.

Net Energy (NE_g) = Total Daily Energy Intake
less Energy loss (in feces)
less Energy loss (in urine)
less Energy loss (in methane gas)
less Energy loss (used in heat production)

The relationship of the various categories of energy is diagrammed in Fig. 1. The general characteristics of various natural feed ingredients are given in Table 3.

True Metabolizable Energy, abbreviated TME, represents a concept developed by I. R. Sibbald, Animal Research Institute, Agriculture Canada, Ottawa and used by some feed manufacturers, but not all. The concept, described in considerable detail in the Sibbald references listed, was developed mainly in connection with poultry feeding. A brief abstract follows. The metabolizable energy values widely used in poultry feed formulation are more correctly described as apparent metabolizable energy (AME) values. In the measurement of AME, it is assumed that the energy excreted as feces and urine comes directly from the feed, but this is incorrect. The feces consist of unabsorbed feed residues plus metabolic products, such as bile, digestive juices, and cells from the lining of the digestive tract. The energy of these products is termed the metabolic fecal energy (FE_m). The urine contains some compounds obtained directly from the feed plus the products of tissue break-

TABLE 2. ENERGY CHARACTERISTICS OF VARIOUS NATURAL FEED INGREDIENTS

	Digestible Energy DE		Net Energy for Maintenance (NE_m)		Net Energy for Growth (NE_g)	
Feedstuff Ingredient	Mcal/ Pound	Mcal/ Kilogram	Mcal/ Pound	Mcal/ Kilogram	Mcal/ Pound	Mcal/ Kilogram
Alfalfa meal, 17% dehydrated	1.24	2.73	0.60	1.32	0.33	0.73
Alfalfa silage	1.08	2.38	0.52	1.15	0.20	0.44
Barley grain	1.62	3.57	0.97	2.14	0.64	1.41
Beet pulp (dried)	1.44	3.18	0.73	1.61	0.47	1.04
Bermudagrass hay	0.98	2.16	0.47	1.04	0.09	0.20
Citrus pulp (dried)	1.54	3.40	0.89	1.96	0.60	1.32
Clover (ladino hay)	1.22	2.69	0.59	1.30	0.31	0.68
Corn gluten meal	1.68	3.70	0.90	1.98	0.60	1.32
Corn grain (yellow)	1.82	4.01	1.03	2.27	0.67	1.48
Cottonseed meal, solvent, 40%	1.50	3.31	0.77	1.70	0.50	1.10
Distillers grains, corn	1.68	3.70	0.90	1.98	0.60	1.32
Feather meal	1.32	2.91	0.89	1.96	0.59	1.30
Lespedeza hay	1.16	2.56	0.87	1.92	0.56	1.23
Molasses (beet)	1.68	3.70	0.87	1.92	0.56	1.23
Oat silage	1.50	3.31	0.78	1.72	0.52	1.15
Peanut (groundnut) meal, solvent	1.54	3.40	0.80	1.76	0.53	1.17
Rice polishings	1.78	3.92	0.99	2.18	0.65	1.43
Sagebrush (fresh)	1.00	2.20	0.54	1.19	0.23	0.51
Soybean meal, solvent, 49%	1.68	3.70	0.91	2.01	0.61	1.35
Sunflower meal, solvent	1.30	2.87	0.64	1.41	0.38	0.84
Wheat bran	1.40	3.09	0.69	1.52	0.44	0.97
Wheat middlings	1.80	3.97	0.98	2.16	0.66	1.46
Wheat (soft) grain	1.80	3.97	0.98	2.16	0.63	1.39
Whey (dried)	1.68	3.70	0.93	2.05	0.61	1.35

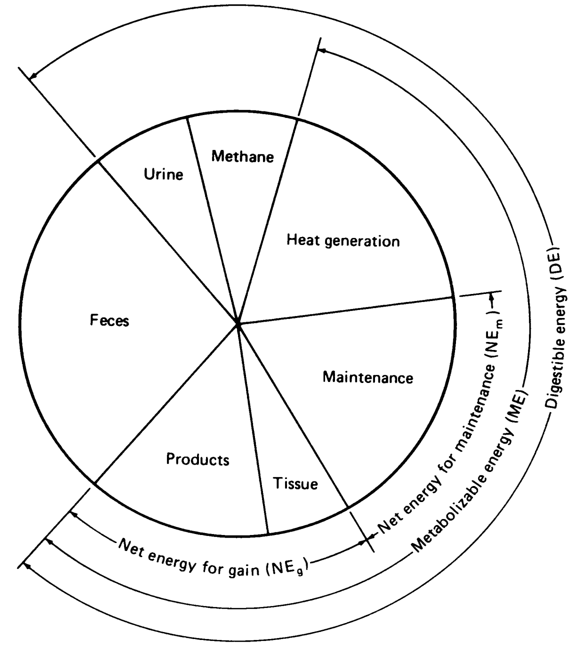


Fig. 1. Representative energy utilization pattern of a food-producing animal. The proportions shown will vary rather widely, depending upon the species, breed, and type of feed administered. All energy (Gross Energy, GE) is considered digestible with the exception of that portion which is represented in the feces. Metabolizable Energy (ME) is the Digestible Energy (DE) less the energy represented in the urine and methane gas generated during digestion. Metabolizable energy goes into heat generation and for producing Net Energy for Maintenance (NE_m) and Net Energy for Gain (NE_g). The latter energy is made up of that portion utilized to create new tissue (weight gain) and is the primary concern, for example, with beef cattle and swine; and that portion utilized to create products, such as milk and eggs.

down which occurs during body maintenance. The latter represent the endogenous urinary energy (UE_e). When AME is corrected for FE_m + UE_e losses, a true metabolizable energy (TME) value is obtained. This is shown by:

$$\text{AME} = \text{Feed Energy} - \text{Excreta Energy}$$

$$\text{TME} = \text{Feed Energy} - [\text{Excreta Energy} - (FE_m + UE_e)];$$

$$\text{or TME} = \text{AME} + FE_m + UE_e$$

The finding that the relationship between excreta energy and feed intake is linear provided the key to the development of a TME bioassay. The next step was to confirm that the relationship is linear for a variety of feedstuffs. Then (1976), it was possible to describe a simple rapid bioassay. In making the test, selected birds are starved to empty their digestive tracts. This usually can be accomplished in 18 to 24 hours. A bird is selected and force-fed the material to be assayed. When the bird is fed, it is placed in a clean cage. Twenty-four hours later, the collected excreta is dried and assayed in a calorimeter for gross energy. Within each replicated group of birds there must be one control bird which is used to measure the FE_m + UE_e loss. The bird is selected from the group of starved birds and is placed in a cage over a plastic tray, without being force-fed, and the time is recorded.

The TME value of the feedstuff is calculated as follows:

$$\text{TME (kcal/gram)} = \frac{GE_i - (GE_f - GE_c)}{\text{Weight of feed}}$$

where: GE_i is gross energy of the feedstuff (kcal/gram) multiplied by the weight fed

GE_f is the energy excreted by the fed bird (kcal)

GE_c is the energy excreted by the control bird (i.e., FE_m + UE_e) (kcal).

Advantages for the TME system are claimed as follows:

1. The assay can be completed in about 60 hours compared to about 6 weeks for an AME chick assay.
2. The birds can be used for many assays. Some have been used 40 times and are in good health.
3. By maintaining a flock of birds, it is possible to initiate an assay upon short notice.
4. The amount of test material is small. Consequently, the cost of shipping samples to a quality control laboratory is minimized.
5. The cost of cages for roosters is less than that of chick batteries and the maintenance costs are lower.
6. Labor requirement is small.
7. The total cost of the TME assay is considerably lower than that of an AME assay.

While the TME system has several advantages, there may be a delay in its adoption. Most energy requirements data used in feeding and feed formulation are expressed in terms of AME. It will be time-consuming and costly to obtain similar TME requirement data.

Energy for heat production becomes important in times of temperature stress when animals are in the field. When heat loss exceeds heat gain, the rate of loss depends upon the effective coldness of the environment as well as the ability of the animal to resist heat flow from its body. Temperature alone is not always sufficient to describe the effective coldness of an environment. Wind, moisture, snow, and radiation combine with temperature in various ways to determine the level of cold stress. In addition to increase in chill factor from the wind, moisture evaporation from the animal also contributes to cold stress. There is some unavoidable evaporation of moisture through the skin and respiratory tract at all times. However, researchers at the University of Alberta have found that it is evaporation from the animal's coat of the added moisture from rain, mud or snow that can be a serious heat drain. Wind increases the rate of evaporation of moisture as well as reduces the insulative effect of the hair coat. Melting of snow as well as evaporation of moisture uses heat energy. In the northern prairies, temperatures are below freezing much of the winter and high moisture is not a problem, but contributes in a major way to cold stress problems in fall and spring. During long, cloudless winter nights, the radiant heat loss from the animal's body to the night sky may be substantial. A simple overhead shelter or natural tree cover can eliminate this loss.

TABLE 3. GENERAL CHARACTERISTICS OF VARIOUS NATURAL FEED INGREDIENTS

	Percent						
					Total Digestible Nutrients (TDN)		Digestible Protein
Feedstuff Ingredient	Dry Matter	Crude Protein	Crude Fat	Crude Fiber	Ruminants	Swine	Ruminants
Alfalfa meal, 20% dehydrated	93.1	20	3.5	20	58	50	14
Alfalfa meal, 17% dehydrated	93	17	3	24	58	32	12
Barley, 12% grain	89	11.5	2	5	74	70	8.5
Corn distillers dried solubles	93.8	27	9	13	79	92	19
Corn gluten meal	88	21	2	10	75	75	19
Corn (yellow), grain	88	9	3.5	3	80	80	6
Cottonseed meal, solvent, 40%	91.4	41	4	13	71	67	33
Feather meal	93.2	85	2.5	1.5	63	63	70
Fishmeal, herring	93	72	10	1	73	70	57
Fishmeal, menhaden	92	62	10	1	71	62	49
Fishmeal, Peruvian	91	65	10	1	73	70	53
Meat and bone meal, 50%	92.6	50	8.5	3	68	65	40
Poultry by-product meal	94	58	14	2.5	74	74	46
Sorghum grain	88.8	11	3	2	71	78	6
Soybean meal, 44%	89.6	44	0.5	7	78	71	38
Wheat bran	89	15	4	10	62	57	11.5
Wheat middlings	89	18	4	7	81	73	12
Wheat (soft), 10%	86	11	2	3	79	83	8.5
Whey (dry)	94	12	1	0	79	78	11

There is continual production of heat through the breakdown and utilization of food for normal body functions. If the heat produced from normal metabolic processes is not sufficient to keep up with the rate of loss during cold weather and it isn't possible for the rate of heat loss to be reduced, then the animal must increase its rate of heat production. Shivering, increased muscular tone and metabolic acclimatization are used to increase heat production. The latter condition involves changes in the metabolic processes that develop after exposure to cold for an extended period.

Acclimatization, while important to survival during acute stress, affects the animal over the entire winter period, even when conditions are mild. This occurs because it takes considerable time for the animal to develop and to lost winter acclimatization. The overall effect of acclimatization, viewed in practical terms as a decrease in ration digestibility and an increase in metabolism, results in a substantial increase in the winter maintenance requirements of cattle. From a base of comfortable effective temperatures of 15° to 20°C (59° to 68°F), the increase in maintenance requirement of feed energy is about 1% for each 1 degree Celsius reduction in effective temperature. If feed intake is not increased to meet this requirement, then the level of performance will decline. If the environmental temperature drops below the lower critical temperature of the animal, then in addition to the increased maintenance requirements from the reduced ration digestibility and increased metabolism, there will be a further increase in maintenance requirements to meet the immediate energy demand of direct cold stress. Further information on this topic can be found in the Kendall reference.

Early investigators assumed that energy required by an animal for maintenance was a function of body surface. As a general rule, the surface area of an animal's body is proportional to the 2/3 power of the body weight and thus early energy requirements for maintenance were expressed in terms of weight to the 2/3 power. As of the late 1920s, detailed investigations were made by various researchers to more scientifically confirm this relationship. Animal performance, ranging from mice to horses, was studied. Brody developed a classical formula to specify NE_m (the net energy required for maintenance) for animals:

$$NE_m = 70.4 \text{ kcal} \times \text{Body Weight (kilograms)}^{0.73}$$

Later, in the early 1930s, Kleiber independently deduced a similar equation:

$$NE_m = 70 \text{ kcal} \times \text{Body Weight (kilograms)}^{0.75}$$

The Kleiber equation covered the resting energy requirement per day. Net energy requirements are lowered during sleep by about 10%, but stress during waking hours increases the requirement by about 5%.

As pointed out by M. L. Scott: "Experimental studies have shown that the metabolizable energy requirements are approximately 18% higher than the net energy requirement. This is due to the fact that consumption of protein causes approximately 30% increase in heat production (specific dynamic action of the protein), while consumption of carbohydrate produces a 15% heat increment and fat produces approximately 10% heat increment. In a well-balanced diet containing 20% protein, 5% fat, and 65% carbohydrate, the average heat increment is 18%. Thus, the net energy requirements (NE_m) are approximately 82% of the metabolizable energy requirements (ME).

Poultry have a higher body temperature than livestock and, consequently, their energy expenditure for maintenance is greater. Further information can be found in the Scott reference listed.

Amino Acids. As pointed out in the entries on **Amino Acid**; and **Protein**, about one-half of the dry weight of the animal body is made up of a number of amino acids in various combinations and configurations that comprise protein substances. Although the proteins resulting from amino acid assembly are ultimately among the most important chemicals in the animal body, the so-called infrastructure of the proteins is dependent upon the amino acid building blocks. Although there are hundreds of amino acids, from 20 to 23 of these are considered very important to life processes, of which from 6 to 10 of the compounds are classified as *essential;* another 3 or 4 may be classified as *quasi-essential;* and from 10 to 12 of the amino acids may be categorized as *nonessential.* Authorities still differ to some degree in these matters. Most authorities regard the definition *essential* as applying to those amino acids which cannot be synthesized within the animal body and hence must be consumed as part of the diet. The various animal species differ as regards their requirements for the essential amino acids. With exception of from 10 to 12 of the amino acids, the single-stomached animals (dogs, humans, poultry, swine) can modify many of the amino acids consumed and thus provide what is required for the growth and maintenance of their bodies. In contrast, the ruminant animals (cattle, sheep) can meet all of their amino acid requirements by modifying the amino acids that are present in their diet. In theory, at least, ruminant animals could synthesize all of their amino acid requirements from non-amino acid sources, such as urea and related nitrogen compounds. But, in practice, it should not be expected that ruminants synthesize over one-third of their amino acid requirements except in cases of feeding stress.

Until the 1970s, most ruminant nutritionists considered all protein or nitrogen sources to be approximately equal. Little was discussed concerning the protein quality for ruminants, because the popular view at that time was that most all of the dietary protein is first degraded and then synthesized into microbial protein by the rumen microflora. In that light, amino acid content of feed proteins for ruminants seemed relatively unimportant. It was not appreciated then that significant amounts of some feed proteins escape ruminal degradation and further that dietary proteins are essential if animals are to reach their genetic potential for meat, milk, and wool production. Fortunately, as of the late 1970s, these earlier views had been corrected.

Considering the fact that there are over 20 important amino acids, different species and breed requirements, and scores of different feeds (each with different amino acid content), selecting and administering animal feeds with just the proper amino acid balance consistent with feed costs becomes difficult and requires much basic research in order to relate each feed with the minimal basic requirements of each animal to be fed. Over the years, extensive tables of these values have been constructed. Such tabulated information can be found in numerous publications, as published by the National Academy of Sciences, the Animal Nutrition Research Council, by various feed suppliers, university research centers, and summaries as appear annually in various technical and trade publications, such as the reference issue of *Feedstuffs* magazine which appears each year in September. Such tabular information is subject to revision and bias because various authorities interpret such information differently. Further, literally hundreds of tests are made each year on various new and old feeds, singly and in combination, by government agencies, universities, manufacturers, cooperatives and any other organization that is interested in the manufacture or consumption of animal feedstuffs. An example of such information is Table 4. The amino acid content of feedstuffs is not only important to the welfare of the food animal during its lifetime, but also to the persons who later will consume animal products (meat, milk, eggs).

In addition to the deficiencies of one or more essential amino acids in the regular diet of a food animal, considerable recent interest has been shown in the nutritional interactions of amino acids. Such interactions can occur when diets contain levels of protein in excess of the requirement, but are accentuated at low levels of protein. R. E. Austic, Department of Poultry Science and Division of Nutritional Sciences, Cornell University (see Austic reference listed at end of this entry) states, in part: "Amino acids constitute a major expense in foods for monogastric animals. The practicing nutritionist must satisfy the requirements of animals for amino acids without providing a costly surplus of protein in the diet. This task would be a simple exercise in mathematics were it not for the lack of precise information

TABLE 4. AMINO ACID LEVELS OF VARIOUS NATURAL FEED INGREDIENTS

Feedstuff Ingredient	Methionine	Cystine	Lysine	Trypto-phan	Threonine	Isoleucine	Histidine	Valine	Leucine	Arginine	Phenyl-alanine	Glycine
Alfalfa meal, 20% dehydrated	.33	*.23*	.87	.46	.88	.98	.42	1.2	1.5	1	1	1
Alfalfa meal, 17% dehydrated	.3	*.2*	.7	.45	.75	.84	.35	1	1.3	.75	.9	.9
Barley, 12% grain	.2	*.25*	.53	.17	.36	*.42*	*.23*	.6	*.8*	.5	.6	*.4*
Corn distillers dried solubles	.6	.6	.9	.2	1	1.2	.6	1.6	2.1	1	1.5	1.1
Corn gluten meal	**1.9**	**1.1**	1	.3	2	2.3	1.2	2.7	**9.4**	1.9	**3.8**	1.6
Corn (yellow), grain	.2	*.13*	*.2*	*.1*	*.34*	*.37*	*.2*	*.4*	1	.5	.4	*.3*
Cottonseed meal, solvent, 40%	.5	.6	1.7	.5	1.3	1.3	1.1	1.9	2.4	**4.6**	2.2	1.7
Feather meal	.55	3	1.1	.4	2.8	2.7	.3	4.6	7.8	**3.9**	**2.7**	**4.8**
Fishmeal, herring	**2.2**	.7	**5.7**	**.8**	**2.9**	**3**	**1.9**	**5.7**	5.1	**5.6**	2.6	**4.6**
Fishmeal, menhaden	1.8	.6	**4.7**	**.7**	**2.3**	**2.8**	1.4	**3.4**	6	3.2	2.3	3.9
Fishmeal, Peruvian	**1.9**	.6	**4.9**	**.8**	**2.7**	**3**	**1.5**	**3.4**	5	3.4	2.4	4.1
Meat and bone meal, 50%	.7	.3	2.6	.3	1.6	1.7	1	2.3	3.2	3.4	1.7	**6.9**
Poultry byproduct meal	**1**	**1**	2.6	.6	2	2.3	**1.6**	2.7	4.4	3.8	1.8	2.9
Sorghum grain	*.1*	*.2*	*.3*	*.1*	*.3*	.6	.3	*.5*	1.4	*.4*	*.5*	*.3*
Soybean meal, solvent 50%	.7	.7	2.9	.7	1.7	2.5	1.1	2.4	3.4	3.4	2.2	2.4
Soybean meal, 44%	.8	.7	3.2	.6	2	2.6	1.3	2.7	3.8	3.8	**2.7**	2.3
Wheat bran	.2	.3	.6	.3	.5	*.6*	.3	.7	*.9*	1.1	.6	.9
Wheat middlings	*.1*	*.2*	.6	.2	.5	.7	.4	.8	1.1	1	*.5*	*.4*
Wheat (soft), 10%	*.1*	*.2*	*.3*	*.1*	*.3*	*.4*	*.2*	*.5*	*.6*	*.4*	*.5*	.5
Whey (dry)	.2	.3	1.1	.2	.8	.9	*.2*	.7	1.2	*.4*	*.4*	–

Notes: Comparatively high values are shown boldface; low values are shown in italics.

on amino acid requirements, the contents and availabilities of amino acids in feedstuffs and the potential for amino acid interactions. Amino acid interactions are an often-neglected aspect of protein nutrition which must be considered in formulation of animal feeds. Their effects range from subtle depressions of growth or food consumption to pathological changes, depending on the amino acids involved. Harper (see references listed) was among the first to clarify interactions by carefully grouping them according to common characteristics into four major categories: (1) Deficiencies; (2) imbalances; (3) antagonisms; and (4) toxicities."

In the most extreme case, a deficiency indicates the lack of an essential amino acid in the diet. Usually this is a matter of degree because few feeds are fully deficient of any of the essential amino acids. There may be one or several deficiencies in any given feedstuff. A few examples were cited by Harper: (1) For example, the case of a feed which had adequate amounts of all essential amino acids, but one, namely, lysine; or (2) the case of a feed which exhibited three deficiencies of varying degrees, namely, about 90% of the required content of methionine; about 80% of the required amount of threonine; and about 50% of the needed lysine. Imbalance connotes the given balance of amino acids in a diet results in poorer performance than might be expected on the basis of levels of limiting amino acids. This can be explained as the result of interactions. Reduction in performance can be prevented by supplementation of the diet with the limiting amino acids. Antagonism is indicated where there are specific interactions resulting from an excessive level of one amino acid which increases the requirement for a structurally or chemically related amino acid. The toxicity situation arises when there is an excess of one or more individual amino acids in the absence of other amino acids which, if present, would prevent toxicity. When one or more amino acids are present in such a situation, histopathological lesions can occur.

As further stated by Austic: "One of the consistent physiological consequences of imbalance is a depression in the concentration of the first-limiting amino acid in blood and a marked increase in the levels of amino acids added to the diet. There is now considerable evidence that altered proportions of amino acids in the blood may cause reduced food intake and that the brain is involved in detection of the differences in plasma amino acid levels. The signal elicited by the imbalanced diet is so strong that, given a choice of a protein-free diet or the imbalanced diet, an animal will consume the diet lacking protein." A number of amino acid interactions have been investigated and are reported in the Austic reference.

Further reference to amino acids in feed is made later in this entry. See also various entries on food animals and on **Amino Acid; Hay and Forage Crops**; and **Protein.**

Minerals and Trace Elements in Animal Feeds

Few, if any, inorganic materials such as minerals and trace elements, play a neutral role in the nutrition of livestock and poultry. Once sufficient research is completed, it is usually found that a mineral or element will exert a positive or negative effect upon nutrition. The understanding of animal feedstuffs and nutrition has advanced steadily over the last few decades, mainly as the result of breakthroughs in enzyme and protein chemistry, aided by advancements in analytical techniques, such as chromatography and electrophoresis. Much has been learned concerning the effects of many of these materials, even in milli- and microgram concentrations. A number of diseases and deformities have been explained over the years as the result of relating such conditions directly with dietary deficiencies and toxicities.

Early research efforts in this field tended to concentrate on single minerals and elements. In more recent years, feed research has been directed more and more toward improving the understanding of the interrelationships between the concentrations of various minerals and elements, one to the other and in combination, as well as the interrelationships between the minerals and elements with vitamins, amino acids, and some factors which still are termed "growth factors" because they are not yet fully understood. The important interrelationship between calcium, phosphorus, and vitamin D is exemplary of how synergistic effects can occur from combinations of feed components, either with positive or negative results on the animal being fed. The relative concentrations (proportions) of each substance in a combination can be quite critical. Even though hundreds, if not thousands, of serious investigations are made in this area each year, no end to the required research into substance interactions appears in view.

The mineral levels of various natural feed ingredients are listed in Table 5.

In the paragraphs that follow, the minerals and trace elements are discussed in alphabetical order. *There are additional mentions of these topics under the various entries devoted to specific animal species.*

Calcium. Because calcium occurs in many natural feedstuffs, particularly in hays, pastures, and silages that incorporate legumes, calcium deficiencies are less frequently encountered than with some of the other minerals and elements. Grains, however, are often deficient in calcium and supplements must be used. When dietary deficiencies are predicted, calcium-rich supplements are relatively easy and economical to obtain—as, for example, limestone (must be low in fluorine; calcitic limestone preferred), oyster shells, marl, gypsum (calcium sulfate; satisfactory for cattle, but not laying hens); bone meal; and basic slag (satisfactory for pigs).

Almost 99% of the calcium in the animal body is found in bones and teeth, but calcium is also an essential constituent of all living cells. The role of calcium still is not fully understood, but it is believed to play a part in decreasing the permeability of cell membranes and the irritability of cells in general. When there is a general decline of calcium in the animal body, effects on neuro-muscular membranes may appear, with the possible development of hyper-irritability and tetany as a result of a lowered content of calcium in the blood. Calcium is required for blood clotting. Milk fever or tetany results when a lactating cow suffers a rapid decline in calcium level of the blood. Too little calcium in the diet results in the deforming disease known as rickets (bending and turning of the long bones). But, even with sufficient calcium present, vitamin D must also be present to permit full utilization of the calcium by the animal.

TABLE 5. MINERAL LEVELS OF VARIOUS NATURAL FEED INGREDIENTS

	Percent						Parts per million				
Feedstuff Ingredient	Calcium	Phosphorus	Sodium	Potassium	Magnesium	Sulfur	Manganese	Iron	Copper	Zinc	Selenium
Alfalfa meal, 20% dehydrated	1.5	0.3	0.08	2.5	0.3	0.4	34	281	9	19	0.5
Alfalfa meal, 17% dehydrated	1.3	0.2	0.08	2.4	0.3	0.2	28	309	8	17	0.6
Barley, 12% grain	0.08	0.4	0.02	0.6	0.1	0.2	16	50	8	15	0.4
Corn distillers dried solubles	0.09	0.4	0.9	1	0.4	0.3	30	200	45	85	0.4
Corn gluten meal	0.3	0.9	1	0.6	0.3	0.2	24	500	48	88	0.3
Corn (yellow), grain	0.01	0.3	–	0.3	0.2	0.1	4	35	3	10	0.04
Cottonseed meal, solvent, 40%	0.2	1	0.04	1.2	0.4	–	21	90	16	57	0.9
Feather meal	0.2	0.7	0.7	0.3	0.2	–	–	–	–	–	–
Fishmeal, herring	2	1	0.7	1.5	0.2	0.6	4	82	4.5	100	2
Fishmeal, menhaden	5	3	0.3	0.7	0.1	–	36	438	11	151	2.2
Fishmeal, Peruvian	4	3	1.1	0.9	0.3	–	9	226	9	100	1–4
Meat and bone meal, 50%	11	6	0.6	1.3	1	0.3	10	500	–	–	0.3
Poultry byproduct meal	4	2.4	0.3	0.6	0.2	–	–	–	–	–	0.8
Sorghum grain	0.04	0.3	0.01	0.3	0.2	0.1	13	52	14	14	–
Soybean meal, 44%	0.25	0.6	0.3	2	0.3	0.4	28	120	36	–	0.1
Wheat bran	0.14	1.2	0.06	1.2	0.6	0.2	100	170	10	95	0.8
Wheat middlings	0.2	0.9	0.6	0.6	0.3	0.2	43	60	4.4	62	0.8
Wheat (soft), 10%	0.1	0.3	0.06	0.4	0.1	–	51	43	10	14	0.07
Whey (dry)	0.9	0.8	2.5	1.2	0.1	1	4.6	160	43	–	0.06

Fattening calves (in the 500- to 600-pound range; 227 to 272 kilograms) at the start require about 0.35% of calcium in their ration. As they grow heavier, the percent of calcium drops. An 800-pound (363-kilogram) animal will require only about 0.25% of calcium in the ration. A lactating cow will require close to 0.4% of calcium in her ration.

In contrast with beef cattle and swine, the calcium requirements of poultry are considerably higher. In starting poultry, calcium requirements represent about 1% of the daily ration. This is also true of growing turkeys. Calcium requirements are even higher in the case of laying hens. The requirement goes up with the weight of the bird and the rate of egg production. Research has shown that hens require about 3% calcium. However, when the energy level of the feed is increased, then calcium percentage should be increased proportionately up to about 3.5%. Research indicates that an improved egg shell results when calcium level is maintained at about 5%, but his practice also can result in problems. High calcium levels tend to produce more, but smaller eggs, with a net decrease in egg weight. Also, overall feed intake by the bird may tend to decrease. Caged birds require more calcium than floor layers.

An interesting and innovative way of adding calcium to the diet has been reported (September 1978) by Colorado State University. It has been reported that Portland cement[1] dust when included in the diet of growing chicks at a level of 1.5% produces a significant increase in growth rate. Prior researchers have reported that the addition of cement dust improved the rate of gain and feed conversion for finishing steers. These and scores of other experiments have shown that maintaining adequate calcium levels in the diets, provided other feed ingredients are in balance, is a significant factor in promoting animal growth and weight gain.

The important factor of maintaining the proper ratio of calcium to phosphorus is discussed in this entry under "Phosphorus."

Cadmium. Traditionally, cadmium has been considered one of the toxic minor substances sometimes found in feeds. Normally the element is not reported in feedstuff ingredient tables. The toxicity of cadmium is about equal to that of arsenic. When it occurs in feeds, cadmium usually derives from the fat of cereals, nuts, and vegetables. Researchers have found that cadmium tends to reduce iron absorption.

Chloride. In terms of animal feeds, chloride is almost exclusively associated with salt (sodium chloride); and infrequently with potassium chloride which may be present in some soils and pastures as the result of certain fertilizer practices. In the animal's metabolic processes, sodium chloride intake reduces to a consideration of the sodium and chloride ions. Whereas quite a lot of knowledge has been collected as regards the importance of sodium, there is considerably less known about the role of chloride. As pointed out by Coppock and Fettman (see reference at end of this entry), "Despite important physiological functions and its presence in milk at about 0.11%, chloride is a neglected element (chlorine) in large-animal nutrition. The practice of adding salt (NaCl) to concentrate mixtures and free-choice feeding seem to have precluded the possibility of a practical deficiency problem. When salt was omitted from the diet, Aines and Smith (see reference) found that under the conditions used in their study, sodium was the first limiting element. This was true because sodium is present in most natural ingredients at much lower levels, relative to the cow's requirement, than is chloride. Those who formulate diets usually ignore sodium levels in the natural ingredients (which are usually low in forages, but may be appreciable in certain concentrate ingredients, because of the traditional value of salt as a condiment. In addition, other sodium salts are often included in concentrate mixtures: sodium sulfate as a sulfur supplement, the sodium phosphates as phosphorus supplements, and sodium bicarbonate as a buffer. Even when these supplements are used, salt is still often included because of tradition."

With such practices, gross overfeeding of sodium and chloride can occur. Inasmuch as high dietary levels of sodium and chloride do not increase the levels of these elements in milk, excesses must be excreted in urine and manure. Excess salt intake may result in greater consumption of water, waste transport, bedding requirements and transfer of sodium and chloride to the soil. Sodium and chloride introduction into the soil can aggravate situations where previous problems with salinity and alkalinity prevail. High salt intakes have been shown to increase udder edema in heifers. But because of the importance of chloride in nutrition and metabolism, research is required to define the chloride requirements of the various food animals, of the lactating cow in particular, and to clarify sodium and chloride concentration effects on other minerals and feed components.

Researchers in the Netherlands indicate that a cow yielding 30 kilograms (66.2 pounds) of milk daily requires from 0.3 to 0.35% chloride in the ration. It is apparent that the widespread use of salt at 1% of the concentrate or 0.5% of the total diet has prevented the occurrence of either a sodium or chloride deficiency under most feeding conditions, regardless of the level of these two elements present in the basal diet. But modern practices as regards chloride may have to be revised as additional information on the role of chloride is gained.

Physiologists and nutritionists in the past have described chloride as playing a passive role in maintaining the body's ionic and fluid balance. With the exception of the "chloride shift" in venous blood, its movements have usually been considered secondary to those of the major cations, sodium and potassium. Coppock and Fettman state, however, "In light of the increasing amount of evidence being accumulated that demonstrates the function of active chloride-conserving mechanisms in the body, it now appears that an anion may also play a vital role in maintaining electrochemical homeostasis." Studies reported by Coppock reference include the gastrointestinal absorption of chloride, chloride in cerebrospinal fluid, the role of chloride in the humoral regulation of sodium and potassium, and the importance of chloride in renal function.

---

[1] Portland cement is a mixture of chemical compounds of calcium, silicon, aluminum, iron, and magnesium, present as calcium silicates, calcium aluminates, calcium-alumina ferrits and lesser amounts of sodium and potassium as sulfates, or as oxides. Generally, about 75% of content will be calcium silicates; 10% calcium aluminates; and 5% as calcium sulfate.

Another authority, H. R. Halloran states in mid-1978: "More attention has been given lately to levels of sodium in feeds. Usually salt is added to poultry feeds at 0.2 to 0.4%. The standard used to be 1% salt. Since salt contains both sodium and chloride ions, there could be a chloride deficiency."

A Cornell University study has shown that sodium and chloride levels can be high if they are balanced. In this study, 0.75% sodium and 0.45% chloride (with 0.40% potassium) gave optimum growth in chickens. National Research Council publications (1977) have shown 1.5% chlorine as toxic, with a toxic level for sodium of 0.89%, with a diet low in chloride ion.

Traditionally, grazing animals require the most salt. Salt stimulates saliva and promotes the actions of certain enzymes. Chlorine is required for furnishing hydrochloric acid in the gastric juices. Under range conditions, from 20 to 30 pounds (9 to 13.6 kilograms) of salt per year per head are given to beef cattle. Sheep are particularly fond of salt and usually consume more than cattle per 100 pounds (45 kilograms) of weight. Given free access to a salt supply, ewes will consume from 1/4 to 1/2 ounce (7 to 14 grams) per day, while fattening lambs will consume from 1/5 to 1/4 ounce (5.6 to 7 grams) per day.

Swine require less salt than cattle or sheep. Swine much prefer flake salt over block salt. Many producers routinely include 20% salt in the regular calcium-phosphorus containing feeds for swine. The amount should not exceed 0.5 pound per 100 pounds of feed (0.22 kilograms per 45 kilograms). Where swine are provided with plenty of meat scraps and other salt-containing materials, supplemental salt can be markedly reduced.

As more research data come in on the detailed role of chloride in animal nutrition and as more information is gained pertaining to the ratios of chloride with sodium, potassium, and other elements, the producer must frequently review traditional practices against new knowledge.

Chromium. This element, present in trace amounts in some feeds, is known to be related to diabetes and heart disease in some animals when absent from the diet. Research has shown that the absence of chromium causes an impairment in glucose tolerance, with an accompanying depressing effect on growth. Organic chromium is better utilized for synthesis of glucose tolerance factor than inorganic sources of the element. As of the late 1970s, the actual form of the organic ligand has not been established. Further details are given in the Mertz reference listed.

Cobalt. For many years, the producers of ruminant animals observed and suffered serious losses from time to time of animals that became listless, lost their appetite, and over a period gradually wasted away. The disease, until 1935, of a mysterious nature was limited to certain regions of the world, including parts of Australia, New Zealand, South Africa, the United Kingdom (notably Scotland) and the United States (Florida mainly, but also found in New York, Pennsylvania, North Carolina, Wisconsin, New Hampshire and a few other states). Depending upon geographic location, the disease was variously termed "coast disease," "pining disease," "bush sickness," and "salt sick." Single-stomached animals did not develop the symptoms.

Researchers in Australia in 1935 first related the disease to vitamin B_{12}, and found that sheep injected with B_{12} recovered from the disease. Cobalt is present in B_{12} to the extent of about 4% and it was further found that a lack of cobalt in the soil and feedstuffs prevented the ruminants from synthesizing their own B_{12} requirements. B_{12} cannot be synthesized by nonruminant animals. The vitamin is required by tissue that produces hemoglobin and red blood cells. About 0.2 ounce (5.6 grams) of cobalt (as the chloride, sulfate, oxide, or carbonate) in 100 pounds (45.4 kilograms) of feed is sufficient to serve the needs of beef cattle. In Scotland, where the salt content of soil is high, about 3 pounds per acre (3.4 kilograms per hectare) of cobalt sulfate are mixed with superphosphate and then spread over the pasture.

Generally, under normal conditions, a cobalt deficiency among ruminants is more apt to result than a cobalt toxicity. But, in efforts to alleviate the deficiency, there have been cases of oversupplementation of cobalt in livestock and poultry diets. Toxic quantities of cobalt reduce feed intake and body weight, cause emaciation, anemia, debility, increased hemoglobin and packed-cell volume, as well as elevated liver cobalt. Lacrimation (excess tear formation), salivation, and dyspnea (difficult breathing) also may be noted. It should be noted that clinical cobalt toxicity signs resemble those of cobalt deficiency. The estimated maximum safe dietary cobalt level in which adverse effects are not likely to occur in cattle is 20 parts per million. A value of 10 ppm is very much on the safe side.

In the diet of chicks, more than 5 ppm of cobalt reduced growth, whereas over 50 ppm was lethal. (See Turk reference listed). Cobalt toxicity can be partially alleviated by increasing the dietary fat-soluble vitamins or by the use of antioxidants. Turk found that Ethylenediaminetetraacetic acid (EDTA), cystine or cysteine completely alleviated cobalt toxicity in chicks. Although data are limited, the estimated maximum safe cobalt content in growing chick diets is about 4 ppm.

Copper. In its metabolic involvement, copper and iron are closely related. Depending upon animal and stage of growth, the ratio of copper to iron will range from 1:4 to 1:10. Copper deficiencies are found in a number of regions of the world, including Australia, New Zealand, parts of Africa, Peru, the Netherlands, Sweden and mainly in Florida in the United States. In such areas, from 0.25 to 0.5% of copper sulfate or copper oxide will be added to the salt or mineral mixtures. In addition to noting copper deficiency in animals that graze on land deficient in copper or consume feeds grown in such areas, the deficiency is also sometimes noted in beef calves that have been kept on nurse cows for periods beyond the normal weaning age.

Symptoms of the disease include loss of appetite, emaciation, weakness, and blood low in hemoglobin. Copper deficiency is also related to molybdenum toxicity (see "Molybdenum" later in this entry) because high levels of molybdenum can cause copper deficiencies. Depending upon degree of deficiency, affected animals show slow growth, failure to fatten, as well as anemia in various stages. Some calves may be born rachitic. In sheep, wool will lose its crimp. In western and southern Australia, this condition is called "stringy" or "steely" wool and the disease is termed *enzootic ataxia.* Deficiencies of copper in the diet cause "falling disease" or "sudden death" among dairy cows of western Australia. In the United Kingdom (particularly Scotland), a condition known as "swayback" occurs among newborn and young lambs. There is extensive incoordination and paralysis of legs. To counteract this condition, producers feed the ewes during pregnancy with about 0.3 pounds (about 0.1 kilogram) of copper sulfate per 100 pounds (45.3 kilograms) of salt.

A number of copper-containing protein compounds are enzymes with an oxidase function (ascorbic acid oxidase, urocase, etc.) and thus play an important role in the oxidation-reduction system. The relationship of copper with iron is in connection with the utilization of iron in hemoglobin formation.

Copper absorption is depressed by ascorbic acid, dietary phytates, cadmium, mercury, silver, and zinc. It appears that the metals impede copper absorption through competition for metal-binding sites. Dietary copper, molybdenum, and sulfur are closely interrelated in the optimum copper and molybdenum nutrition of ruminants. Increased pasture molybdenum content and low pasture copper results in a condition known as "peat scours." Increasing copper intake alleviates the syndrome. Prevention of molybdenum toxicity is dependent upon a copper-molybdenum ratio of more than 2.0–4.0.

Copper utilization depends upon the chemical form. Copper oxides are less available to ruminants than the sulfate, nitrate, carbonate, and other water-soluble forms. Copper availability from animal protein sources is generally considered greater than plant protein sources.

As with the other minor minerals and elements, toxicity can occur as the result of overcorrecting a deficiency. Chronic copper poisoning may occur in cattle under grazing conditions or from excessive consumption of copper-containing salt licks or mixtures, unwise use of copper-containing drenches, or ingestion of feeds contaminated with copper-containing fungicides. The severity of copper toxicity depends upon animal species (see McGhee and Sullivan references), the chemical form of dietary copper, the amounts of copper, molybdenum, sulfate, iron, zinc, and protein as well as antioxidants in the diet. In all animals, the continued ingestion of excess copper results in accumulation in the tissues, especially the liver. The capacity of the liver to store copper without copper poisoning varies with species. Sheep are most susceptible to poisoning. The toxicity signs, at least in cattle and sheep, usually are not evident until the liver threshold is reached and copper is rapidly liberated into the blood, causing a hemolytic crisis. In cattle and sheep, following the hemolytic crisis, hemoglobinemia and hemoglobinuria associated with marked jaundice and widespread liver necrosis have been observed. General signs of copper toxicity in cattle include reduced weight gain, decreased hemoglobin and hematocrit levels, and jaundice. The maximum amount of copper tolerated by cattle is not well defined. It has been estimated that they can safely tolerate 71 to 100 ppm of copper for up to 112 days. It appears that cattle can safely tolerate up to 100 ppm copper under most conditions. However, the level of molybdenum and other variables have a major effect on the safe level.

Often practical swine diets are supplemented with 200 to 250 ppm of copper for pharmacological effect. Under most practical feeding conditions, the copper toxicity level in swine diets begins at about 500 ppm. Copper, from different chemical forms in increasing order of toxicity potential, are copper oxide, copper sulfide, and copper sulfate. (See Wallace reference listed). When adding high copper levels to swine diets, it is advisable to have adequate zinc and iron.

Copper poisoning is a practical problem for grazing sheep, especially where soil is high in copper and normal-to-low in molybdenum. In past years, a copper sulfate drench has frequently been used as an antihelmintic for sheep. Because of the high amount required to control internal parasites, overdosing often caused death. Chronic poisoning from copper has occurred in sheep grazing pastures previously sprayed with a 1% copper sulfate solution (See Gracey reference). The susceptibility to copper toxicity is affected by the genetics of the sheep. Researchers have found that hemolytic crises occurred in Border-Leicester sheep which had received 100 milligrams of copper per day; but Merinos given the same quantity of copper suffered no ill effects. The estimated maximum safe level of copper varies from 5 ppm to up to 20 to 30 ppm, depending upon molybdenum level and other factors.

Researchers have found that chick growth was not adversely affected by feeding up to 500 ppm of copper for a period of 8 weeks. In similar experiments, chicks receiving 1180 ppm of copper showed a weight loss of 49% in 10 weeks (See Mehring reference). The tolerance of chicks and and turkeys for copper is reduced considerably by low dietary iron or by feeding fishmeal without the addition of an antioxidant.

Fluorine. This element has been found useful when added to drinking water at a rate of from 0.7 to 1 ppm as a prevention of dental caries in humans. With food animals, the longterm preservation and cosmetic appearance of teeth is not important and, consequently, in livestock and poultry nutrition, the primary concern is fluorine toxicity. Whatever unproven advantages there may be from trace values of fluorine in animal feeds, these trace amounts are present in natural feedstuffs and, therefore, no additives are required.

Fluorine occurs in the soil and water in several parts of the world. Waters with excessive fluorine content can be found in the United States in parts of Arkansas, California, South Carolina, and Texas. Excessive consumption of fluorine-containing substances by food animals can result in tooth and bone damage, ranging from mottling and minor softening to highly eroded and soft teeth, and soft, enlarged bones. Poor appetite and subnormal growth accompany moderate toxicity. In more severe cases, there will be serious diarrhea and emaciation. In addition to the presence of fluorine in natural waters and soils, it is sometimes found in the vicinity of industrial and smelting operations where fluorine-containing gases and dusts are produced. Although fertilizers prepared from phosphate rock contain fluorine, this does not seem to be a major cause of fluorine toxicity among animals. However, it has been shown that more than 290 ppm of fluorine as sodium fluoride or 330 ppm as rock phosphate in swine diets will result in reduced growth, increased bone thickness, loss of normal bone color, presence of exostosis, and decreased breaking strength of bones. Other workers have reported that a fluoride level of 140 ppm as rock phosphate had no effect on pig gains and effects from 217 to 293 ppm fluorine were variable. Other research has shown that feeding up to 650 ppm fluorine as rock phosphate to breeder sows did not affect reproduction, but that this amount lowered milk production, presumably through a decreased feed consumption. Breeder sows, commonly, do not remain in the herd over 2 years. Thus, the maximum safe dietary fluorine from all sources is about 150 ppm for breeder sows and finishing pigs.

Beef and dairy cattle diets usually do not contain sufficient fluorine to cause adverse effects on performance. However, practical fluorine toxicity problems have arisen with continuous use of high-fluorine phosphates and with ingestion of forages contaminated from fluoride-bearing dusts, fumes, or water. The National Research Council subcommittee on fluorisis has summarized rather voluminous data on fluorine toxicity. The data show: (1) Discernible dental mottling occurs when fluorine levels exceed 20 ppm in diets; (2) significant incidence of lameness may occur when levels exceed 50 ppm; (3) milk production decreases at levels above 50 ppm. Far less fluorine is tolerated by all species when it is administered in drinking water, or as soluble sources, versus its presence in dry feeds and in less-soluble forms (such as in phosphates). Generally, the fluoride concentration of the diet of young cattle raised for milk production or as replacements for beef herds should not exceed 30 ppm. It is recognized that older cattle (first exposed to excess fluoride at 3–4 years of age) in dairy or beef herds may be fed as much as 50 ppm fluorine in their diets without influencing performance. Cattle raised for slaughter purposes may tolerate up to 100 ppm dietary fluorine.

Unlike animals in which dental effects are used as criterion for fluorine toxicity, in poultry, diagnosis and evaluation of fluoride toxicosis is more difficult. Research has shown that rock phosphate fluorine (a relatively insoluble form) at levels up to 530 ppm does not depress chick growth. Similarly, tests indicate that levels up to 700 ppm do not affect egg production or hatchability. In contrast, growth depressions have been noted in chicks receiving supplemental fluorine as sodium fluoride (relatively soluble) at concentrations of 410 ppm and higher. Turkeys have been shown to tolerate 100 ppm fluorine as sodium fluoride for 16 weeks, but levels as high as 400 to 800 ppm reduce weight gain and increase bone fluoride. As a general conclusion, it appears that growing chicks, laying hens, and turkeys can tolerate 300 ppm fluorine in their diets, and somewhat lesser amounts in water.

Iodine. It is estimated that the mature animal contains only 0.00004% iodine, most of which is present in the thyroid gland. This micro amount is extremely important and must be established and maintained throughout the life of the animal as the result of ingesting small quantities of the element in various feed inputs. Iodine deficiency is manifested by an impairment of thyroid gland function. This gland generates thyroxine, an iodine-containing hormone which controls the rate of body metabolism or heat production. Iodine deficiency is identified with various geographic areas in the world. In the United States, the north central states around the Great Lakes Region (Michigan, Wisconsin, Iowa, and Minnesota and westward to North Dakota, Wyoming, Montana, Idaho, Oregon, and Washington have iodine-deficient soils. Deficiencies are also reported from parts of Texas. Iodine deficiency is easily correctable through the use of iodized salt, administered at a rate of about 0.1% of the weight of the dry diet; or calcium iodate or ethylenediamine dihydriodide can be used as supplements. Early symptoms of iodine deficiency are the appearance of a swelling or slight goiter, depressed appetite, listlessness, difficulty in swallowing, a hacking cough, and a tendency for the eyes to be tear-filled. Since corrective measures are simple, iodine toxicity does not usually occur. However, overtreatment can occur.

Generally, through effective homeostatic mechanisms, livestock can tolerate iodine levels far greater than the minimum needed. Prolonged administration of large doses markedly reduce thyroidal uptake, thus causing antithyroidal or goitrogenic effect. Dietary iodine is rapidly and almost completely absorbed. Excessive body iodine is excreted mainly in urine. Care must be used in applying excessive amounts of iodine for medicinal purposes (as for foot rot). When diets contain 50 to 200 ppm of iodine, toxicity signs may appear. In cattle, this toxicity reduces feed intake and growth, excessive tear formation, abnormal saliva formation, watery nasal discharge, and tracheal congestion. Recovery is rapid when excess iodine is removed. The estimated maximum safe dietary level of iodine for cattle is about 20 ppm for young animals and 50 ppm for mature cattle.

Generally the maximum safe level of iodine for young growing pigs is about 400 ppm, but low dietary iron may reduce this value. The minimum level that reduces feed intake, decreases rate of gain, lowers hemoglobin and causes eye lesions is about 800 ppm. The maximum safe dietary iodine level for growing pigs appears to be about 400 ppm and that for pregnant or lactating sows, somewhat higher. Information is limited on the maximum safe amount of dietary iodine for poultry. Some researchers found that chicks were not adversely affected by 500 ppm of iodine up to 6 weeks of age; and 180 ppm from 6 weeks of age through maturity and the laying period. Other researchers have shown that a level of 2500 ppm reduced chick growth rate by 30% in 21 days, whereas 5000 ppm lowered growth by 80% and increased mortality to 85%. See Akerib reference listed.

Inasmuch as a considerable portion of excess iodine is transferred to eggs, the iodine content of hens' diets requires special attention. As little as 50 ppm of iodine in hens' diets reduce hatchability and chick quality. Levels close to 5000 ppm cause a progressive reduction in egg production, egg size, and hatchability. Egg production ceases at a level of about 5000 ppm. The estimated safe dietary iodine content is about 150 ppm for growing chickens, and 40 ppm for laying hens. These concentrations are about 428 and 133 times, respectively, the minimum requirement for growing chicks and laying hens.

Iron. This element is a constituent of hemoglobin in the red blood cells which act as carriers of oxygen needed for cellular metabolism. Iron is also needed for the respiratory or oxidizing enzymes as, for example, cytochrome for oxidizing catylase. Deficiency of iron may result in nutritional anemia, a decrease in hemoglobin and in the size of red blood cells. These important functions are carried out satisfactorily even though the animal body contains only approximately 0.004% iron. More than half of the iron in the body is in the form of hemoglobin. A portion of the iron is also incorporated in the protein, myoglobulin, while the remainder is stored in the liver (primarily) and in the spleen and kidneys. Because hemoglobin is being destroyed at a continuous rate and immediately replaced, iron per se undergoes minimal metabolism.

Other than milk, most animal feedstuffs contain more than adequate iron for the needs of food animals. Leafy materials and seeds are particularly rich in iron.

Iron in the form of heme is much greater utilized than most inorganic iron sources. The iron in wheat has recently been demonstrated to be monoferric phytate. Phytic acid has been generally regarded as a limiting factor in plant iron availability. However, recent research has indicated that compounds other than phytate are limiting iron availability from plants. In general, with both ruminants and nonruminants, ferrous sulfate, chloride, fumarate or ammonium sulfate are excellent sources of available iron. The carbonates are low-to-intermediate and ferric orthophosphate and the pyrophosphates are poorly utilized.

Iron absorption is influenced by many other dietary ingredients and the hemeostatic mechanism of animals attempts to overcome these to maintain optimum body conditions. Many of these nutrient factors act as chelates with iron, some of which enhance iron absorption, while others depress it. Ascorbic acid, citric, lactic, pyruvic, and succinic acid enhance the absorption of inorganic iron salts from the intestine. Ascorbate acts as a reducing agent while the organic acids increase or promote increased iron solubility. Histidine, lysine, and cystine increase absorption of ferric iron through formation of chelates with the iron atoms. The interdependence of iron and copper has been established for a number of years. Iron absorption is markedly reduced in copper deficiency, whereas copper absorption is not similarly depressed in iron deficiency. Also, excess cobalt can markedly depress iron absorption. Zinc, cadmium, and phosphorus also decrease iron absorption. See Forth, Layrisse, Martinez, Underwood, and Welch references listed.

Cattle have a relatively high tolerance for excessive dietary iron. Although the amounts are quite variable, feeds of plant or animal origin are not likely to cause an iron toxicity problem. The estimated safe level of dietary iron for cattle is about 400 to 1000 ppm, depending primarily on the chemical form of the iron. Sufficient data are not available for a good estimation of the maximum safe level of iron in sheep diets. However, approximately 280 ppm or possibly much greater quantities can be safely fed.

Under practical feeding conditions, iron toxicity is of little significance in swine husbandry. Normal swine feeds, with the exception of tankage (meat scraps) are relatively low in iron content. However, care must be taken in giving iron therapy for baby pig anemia. Campbell has suggested that the toxic dose is about 110 milligrams to 367 milligrams of iron as ferrous sulfate. The estimated maximum safe dietary level of iron in growing and mature swine diets is about 2500 ppm.

Although data are limited, the estimated maximum safe content of iron in poultry diets is about 1600 ppm under conditions of normal dietary copper.

E. R. Miller (See Miller reference listed) explains: "With the exception of the nursing pig, the iron needs of most domestic mammals and of poultry are supplied by the diet. The nursing pig is somewhat unique in that its tremendous ability to grow, with a high demand for iron for heme synthesis while consuming its dam's milk which is very low in iron, developed over ages of time in which pigs were reared out of doors where they could obtain adequate dietary iron by rooting in the soil. The pig was blessed with a powerful snout well designed for doing this. Modern confinement rearing of swine has severely curtailed the use of this feature. Administration of iron to the nursing pig in confinement years ago was accomplished by repeated oral doses of iron, principally from ferrous sulfate or some other inorganic iron salt. The advent of parenteral iron dextran provided a means of administering iron to the nursing pig in a single dose which was safe, effective and economical and provided positive protection against anemia for the 4 to 5 week nursing period. The iron needs of a majority of nursing pigs in central farrowing facilities in the United States, Canada, and Europe are now met in this way. Studies by Braude *et al.* (1962) and Miller *et al.* (1973) demonstrated that over 90% of an injection of 100–200 milligrams of iron from iron dextran given in the first few days of life is incorporated into hemoglobin over the ensuing 4 weeks."

Magnesium. This element is present in the animal body only to the extent of 0.02 to 0.05% of body weight. Most attention to deficiency of magnesium in animal forage and feeds has been directed to grass tetany or hypomagnesemia, which results from cattle foraging grasses that are low in magnesium content. The symptoms of grass staggers or pasture poisoning are described in the entry on **Hay and Forage Crops.** If diagnosed in time, this condition can be corrected by adding a supplement of 20 grams of magnesium per head per day (for lactating cows which are most susceptible to the disease). In the late 1970s, increased incidence of grass tetany has been reported, indicating perhaps continuous cropping of the land is gradually depleting the stores of magnesium deposited there originally. G. K. Davis (See reference listed) provides an excellent review of magnesium in animal nutrition. As pointed out by Davis, "Put on the 'back burner' for a long time as a subject for mineral element research, magnesium has currently become the object of much exciting research which promises to lead to possible solutions for a wide variety of perplexing problems in animal and human nutrition. Magnesium generally has not been considered a major factor in bone formation and strength, but recent studies suggest that closer attention to dietary magnesium levels may be required if a suboptimal level of intake is not to result in poor bone quality." Recent research also has commenced to probe the metabolic effects of magnesium, including changes in heart muscle cells as a result of magnesium deficiency. Because of the close interrelationship with calcium, it is not surprising to see research findings of magnesium interfering with calcium entry into cells of the islets of the pancreas in studies of diabetes. Magnesium appears to be closely related to the normal excretion of calcium and phosphorus. The recognized presence of magnesium as a part of numerous enzyme systems has led to observations of the reduction in carbohydrate metabolism associated with a deficiency and to beneficial effects in reducing blood cholesterol and lipids associated with other dietary agents with addition of supplemental magnesium to the diet. The relationship to calcium also shows up on a report that adding magnesium to the rations of laying hens causes an increase in shell thickness of the eggs with a reduction in the number of broken eggs.

Manganese. This is an important element associated with reproduction in all species. Manganese occurs mainly in the liver of the animal body. Authorities are less certain concerning the quantitative dietary requirements for manganese for the various species than is the case with the majority of trace elements. Some researchers have indicated a requirement of about 25 milligrams per pound (0.45 kilogram) of feed for chicks and 15 milligrams per pound for breeding hens. Improvements in growth and feed efficiency for swine have been reported at levels of from 5.4 to 18 milligrams per pound of feed. For dairy cattle, 9 milligrams per pound have been suggested; for beet cattle, from 2.7 to 4.5 milligrams per pound. With exception of corn (11 milligrams per pound), most roughages contain from 20 to 65 milligrams per pound and thus most feedstuffs appear to be well above minimal requirements. Thus, the problem of manganese deficiency generally involves two situations: (1) Poultry feeding with grains which may contain deficient manganese concentration; and (2) livestock that subsist on forage grown in areas where the soil is deficient in manganese. Such soil deficiencies occur in some areas of the northwestern United States.

Among cattle, manganese deficiency sometimes is manifested by "crooked calves," which are born with enlarged joints, stiffness, and twisted legs. Where deficiencies are less pronounced, cattle may develop ataxia and show retarded growth. Among poultry, manganese deficiency may result in a disease known as *perosis* or "slipped tendon," which is an enlargement and malfunction of the tibial metatarsal joint followed by slipping of the Achilles tendon from the chondyles. A deficiency also causes poor egg hatchability and eggs with a poor texture of the shell. Feed supplements usually administered are manganese sulfate. Manganese absorption is decreased by high calcium and iron levels.

As regards manganese toxicity, feeding 1000 ppm of manganese in one research test did not adversely affect egg production or embryo development. The maximum safe level of manganese for chicks is not fully described, but for turkeys, 4000 ppm manganese appears to be the minimum toxic level. Because of extreme conflicts in the literature, an estimated maximum safe level of manganese for swine is not available. In most species, excessive dietary manganese reduces feed consumption, daily gain, hemoglobin formation, and packed cell volume. A decreased fiber digestion in cattle also has been associated with high manganese diets. Biochemically, excess manganese interferes with iron metabolism by antagonizing the enzyme system that oxidizes or reduces iron at the absorption site, thus affecting iron availability. Although data are limited, it has been suggested that excess manganese in ruminant diets may induce hypomagnesia. Based upon limited data from controlled experiments, it appears that the maximum safe dietary level of manganese for cattle and sheep is about 1000 ppm. (See also Grummer and Hartman references listed).

Molybdenum. Over the years, this element has concerned animal scientists more from the standpoint of toxicity than essentiality. Much more is known concerning its toxicity than its positive role in nutrition. Molybdenum participates in an enzyme reaction (xanthine oxidase) which converts purines to uric acid for excretion. Some observers also attribute the growth promoting activity of distillers dried solubles to a somewhat elevated content of molybdenum, but still below the toxic level.

Most forage and grain feedstuffs contain from 3 to 5 ppm molybdenum, well below the toxicity threshold. Molybdenum toxicity, also known as *teartness,* was first noted (but not diagnosed) in the United Kingdom well over 100 years ago. Problems with dairy cattle were encountered in areas where the pasture contained from 10 to 20 ppm molybdenum. The early English investigators noted a similarity of teartness with the symptoms of copper deficiency already well known in the Netherlands. Thus, a relationship between copper and molybdenum was established early and, in fact, some English producers administered copper sulfate to cattle with teartness and found that the severe diarrhea associated with the disease was alleviated. It was not until 1938, however, when Ferguson identified molybdenum toxicity as essentially copper deficiency. The disease is manifested when forage contains over 0.02% molybdenum. Low phosphorus aggravates the disease and a relation with zinc also has been demonstrated.

A recent study of molybdenum toxicity is well explained by Hoelscher (see reference listed) who states: "High molybdenum intake produces in ruminants a condition referred to as molybdenosis, hypocuprosis, or conditional copper deficiency. The presence of excess sulfate in the ruminant diet also has a role in copper deficiency. The intake of elevated levels of molybdenum and sulfur appear to reduce copper solubility in the digestive tract. In the rumen, sulfate and sulfur from sulfur-containing amino acids are converted to sulfide which serves as a sulfide pool for the synthesis of sulfur-containing amino acids by rumen bacteria. Molybdenum decreases sulfide production from sulfate, but not from methionine and decreases sulfide absorption from the rumen. In the liver, increased molybdenum reduces synthesis of cerulopasmin, the copper transport protein in the liver, thus making the copper, in a normally adequate store, biologically unavailable. The level of phosphorus in the bone is adversely affected by rations high in molybdenum and low in copper, resulting in leg stiffness and an unusual gait. Cattle are the least tolerant to excess molybdenum. Sheep are more tolerant."

High molybdenum in the feed supply comes from two sources: (1) Soils high in molybdenum; or (2) contamination from industrial sources, such as smelters. Areas of high soil molybdenum are limited to a few thousand acres in North America and these are found in California, Hawaii, Manitoba, Nevada, and Oregon. The areas have been fully mapped for the guidance of producers.

Copper deficiency will be produced when the feed has a ratio of copper-to-molybdenum of less than 2:1.

It is estimated that 6 ppm molybdenum is a safe level for cattle under most conditions. However, if the diet contains sufficient copper, cattle are able to safely tolerate substantially more than 6 ppm. Likewise, 50 ppm of added inorganic molybdenum usually does not appear to cause adverse effects. After cattle, sheep are the next most susceptible to molybdenum toxicity. As little as 5 to 50 ppm molybdenum in dry grass has produced severe scouring and weight loss in sheep. Supplemental copper sulfate, thiosulfate, and methionine or cystine (capable of being oxidized to sulfate in tissue) alleviated molybdenum toxicity. These substances may counteract molybdenum toxicity by reducing molybdenum retention in the tissues and increasing its excretion in the urine.

Pigs are the most tolerant of farm livestock to excessive dietary molybdenum. Feeding 1000 ppm molybdenum for 3 months produced no ill effects in one test.

The maximum safe content of molybdenum for poultry has not been clearly established. The lowest level of the element causing growth depression, in various tests, has ranged from 200 ppm to 500 ppm. Research in the U.S.S.R. has shown that 300 ppm is not toxic to broiler chickens, but that 600 ppm reduces liveweight gains. Egg production was found to be reduced from 20% to 85% when molybdenum is fed to hens in amounts ranging from 500 to 2000 ppm. Molybdenum toxicity symptoms in chicks include a reduction in weight, embryonic mortality, and an increase in egg molybdenum, especially in the yolk. Depending on several dietary factors, the estimated maximum safe dietary molybdenum for poultry is about 150 ppm.

Nickel. It was not until the early 1970s that convincing evidence to the effect that nickel is an essential element for some animal species appeared. As of the early 1980s, the physiological role in the biological system remains essentially unexplained. *In vitro,* nickel can activate various enzymes, but this is true of most of the trace elements. In 1976, urease was found to contain 6–8 atoms of nickel per mole of enzyme. As reported by J. W. Spears and E. E. Hatfield (see listed reference), ribonucleic acid preparations from diverse sources consistently contain nickel in concentrations many times higher than that found in the native material from which the RNA was isolated. Some authorities believe that nickel may serve to stabilize the ordered structure of RNA. It is also believed that nickel may act to stimulate or inhibit the release of various hormones. The biological importance of nickel to animal nutrition is in an early stage of investigation and several additional years of research may be required before definitive guidelines can be developed. Particularly, more research is required on the interrelationship between nickel and other trace elements. As of early 1979, the state of the art is measured by the fact that few of the major animal feeding texts even list nickel in their alphabetical indexes.

Phosphorus. This element makes up approximately 0.74% of the animal body (weight). Second only to calcium among the mineral elements, phosphorus is associated with calcium in the bones and teeth. Several biological roles of phosphorus have been known for many years. Phosphorus enters into several reactions of the body that are concerned with the release of energy contained in the fats (through the intermediary formation of lecithins) and carbohydrates (through the formation of hexose phosphates and other complex phosphates) of the diet. Phosphates also assist in regulating the acid-base balance of the body. More recent research indicates that phosphate takes part in the absorption of sugars across the intestinal wall. Phospholipids, found in all tissues of the body, also contain phosphorus. Even though phosphorus, along with calcium, has been studied more frequently and with more intensity than any other mineral element taking part in animal nutrition, there still is not a full understanding of all of the roles of phosphorus in nutrition and some rethinking of past concepts also may be in order.

The animal producer is concerned with phosphorus deficiencies per se and also with maintaining the proper ratios between phosphorus, calcium, and vitamin D. The latter is the most frequent concern. The producer is also concerned that phosphorus bioavailability in terms of various feeds and supplements is determined and expressed accurately.

Some regions of the world, particularly those of a semiarid characteristic, show pronounced deficiencies of phosphorus concentration in the soils. Forage, rangeland plants, and other plants grown in such areas also exhibit abnormally low phosphorus content, a condition that worsens as the land is continuously used without enrichment. According to a 24-state survey conducted by the Washington Agricultural Experiment Station, phosphorus deficiency is twelfth among causes of beet cattle nutritional diseases and ailments, affecting to some degree 1.1% of the cattle population surveyed.

Cattle that have grazed phosphorus-deficient ranges for a period develop poor appetites and unnatural cravings. Affected cattle will chew on old bones and almost anything they can find that is chewable. Researchers at the Florida Agricultural Experiment Station found the following materials in the stomach of a cow that was suffering from phosphorus deficiency: Considerable quantities of oyster shells, 6 pieces of old, cracked porcelain, 3 teeth, an inner tube, a tire casing, 8 pieces of metal, and 11 pebbles. The deficiency, which is prevalent in Florida, produces symptoms which are locally termed "stiffs" or "Sweeney" disease. Other phosphorus-deficient areas of the United States include the Gulf Coast, ranging from southeastern Texas, southern Louisiana, Mississippi, Alabama, and Florida. There are also deficiencies in the soils of northwestern and central Texas, central Tennessee, as well as in parts of several western states, including Minnesota, North Dakota, Montana, Idaho, Oregon, Nevada, and New Mexico.

The relationship between phosphorus and calcium nutrition has been known since 1842, when Chossat in France first discovered that pigeons developed a poor bone structure when fed on a diet low in calcium. A few years later, the fundamental relationship of calcium with phosphorus in animal diets was developed by French and German researchers, but it was not until 1922, with the discovery of vitamin D, that it was realized that there is triangular relationship of these three substances—calcium, phosphorus, and vitamin D—that interact to provide proper nutrition and that when the ratios of these materials become seriously imbalanced, undesirable effects occur. The first basic in feeding, of course, is the presence of each of these materials in adequate quantities. Research has repeatedly demonstrated that a sufficiency of calcium and phosphorus does not insure efficient assimilation of both elements. For example, a ration containing 10 parts of calcium to 1 part of phosphorus (minimum requirement or greater) will not promote efficient assimilation. A reversal of these quantities is equally unsatisfactory. Over the years, most authorities have placed the limits between 2 Ca: 1 P and 1 Ca: 2 P. Where vitamin D is available in generous quantity, the ratios become less important. And, even when the ratios are within their limits, assimilation of the two elements is poor when vitamin D is not present. The most desirable ratio is dependent upon a number of factors, including the species of animal.

It has been mentioned that forage from phosphorus-deficient soils provides subnormal phosphorus to the feeding animal. This is particularly true of mature, weathered range forage. Although the cereal grains are lacking in calcium content, the phosphorus content is relatively higher (0.27 to 0.39%). Many of the standard feed additives are sufficiently rich in phosphorus, but not all of these are. Thus, the desired phosphorus-calcium ratio must always be acknowledged in selecting a final feed formula, including, of course, sufficient vitamin D. Where sufficient phosphorus is not available from natural feed ingredients, supplements include, in order of diminishing phosphorus content: Monosodium phosphate, diammonium phosphate, dicalcium phosphate, defluorinated phosphate, steamed bone meal, and spent bone meal. Sometimes the phosphorus supplements are administered in the drinking water. Other phosphate supplements used include disodium phosphate, sodium tripoly phosphate, ammonium polyphosphate, and phosphoric acid. An evaluation of the biological value of these phosphorus supplements can be found in the McGillivray reference listed at the end of this entry.

For beef cattle, some authorities suggest that the phosphorus content (in percent of diet dry matter) should lie between 0.18 and 0.7%; for dry pregnant cows, 0.18%; for breeding bulls and lactating cows, 0.18 and 0.39%.

As regards poultry, the National Research Council has suggested a calcium-phosphorus ratio of 1.67:1 for broilers, based on total phosphorus. If available phosphorus is used, the ratio becomes 2.2:1. It is further suggested that broiler rations should contain a minimum of 0.45% available phosphorus; starting hens, 0.5% available phosphorus; and growing turkeys, 0.5 to 0.6% available phosphorus.

Recent data (See Harms reference) have indicated that dietary phosphorus above that required for normal production is detrimental to eggshell quality. But, the researchers hasten to point out that care must be taken to insure that the diet contains adequate phosphorus to avoid a decrease in egg production and prevent mortality from "cage layer fatigue." Very high mortality has been reported to occur when hens are fed a phosphorus-deficient diet and kept in cages. Apparently, feeding a low level of phosphorus will not result in fatigue of hens maintained in floor pens on litter. Thus, the term *cage paralysis syndrome.* An excellent description of this syndrome is given by Grumbles (see reference list). Since eggshell problems usually do not occur during the first 7 months of production, and this is the time when most of the paralysis syndrome cases occur, authorities suggest that a level of not less than 0.6% phosphorus be used in the diet.

Selenium. Although firmly established as an essential trace element, selenium has a long history of problems related to toxicity. Recent authors have explained the problems with the beasts of burden used by Marco Polo in western China about 1295 as arising from grazing on plants with excessive selenium content. The cause of diseases of army horses in the mid-1850s also have been attributable to selenium poisoning. There have been heavy losses of livestock in various parts of the world from conditions referred to as "alkali disease" or "blind staggers," definitely resulting from selenium toxicity.

The distribution of selenium in soils of the United States ranges from high concentrations to areas of serious inadequacy. Toxicity is a problem mainly in the Plains and Rocky Mountain states (Kansas, Nebraska, North and South Dakota, Montana, Wyoming, Colorado, and northern New Mexico, northern Arizona, and southern Nevada and southern Utah). Selenium levels are too low to meet requirements of livestock throughout the New England states and westward through New York, Pennsylvania, West Virginia, Ohio, Indiana, eastern Illinois and eastern Wisconsin—as well as the west coastal regions of Washington, Oregon, and northern California. Florida is also deficient in selenium.

One of the striking features of selenium is that it occurs naturally in several compounds and these vary greatly in their toxicity and in their value in preventing selenium-deficiency diseases. In its elemental form, selenium is insoluble and biologically inactive. Inorganic selenates or selenites and some of the selenoamino acids in plants are very active biologically, whereas some of their metabolites that are excreted by animals are not biologically active. In well-drained alkaline soils, selenium tends to be oxidized to selenates and these are readily taken up by plants, even to levels that may be toxic to the animals that eat the plants. In acid and neutral soils, selenium tends to form selenites and these are insoluble and unavailable to plants. Selenium deficiency in livestock is most often found on farms with acid soils and especially soils formed from rocks low in selenium.

In 1934, the previously mysterious livestock maladies encountered in the aforementioned areas of selenium toxicity were discovered to be due to plants with so much selenium that they were poisonous to animals grazing there. Affected animals had sore feet, lost some of their hair, and many died. Over the next 20 years, scientists found that the high levels of selenium occurred only in soils derived from certain geological formations of high selenium content. Another important discovery was that a certain group of plants, called the *selenium accumulators,* had an extraordinary ability to extract selenium from the soil. These selenium accumulators are primarily shrubs and weeds native to semiarid and desert rangelands. They usually contain 50 ppm or more of selenium, whereas range grasses and field crops growing nearby may contain less than 5 ppm selenium.

These observations assisted animal producers to avoid the most dangerous areas when grazing their livestock. Range-management practices that encourage the spread of perennial grasses and that eliminate selenium accumulator plants have been quite helpful.

In 1957, selenium was found to be essential in preventing liver degeneration of laboratory rats. Since then, research workers have found that certain selenium compounds, either added to the diet or injected into the animal, will prevent serious diseases of lambs, calves, and chicks. Selenium is now well established as an essential nutrient element for birds and animals. The dietary requirements and toxic levels of selenium for livestock, as summarized by the National Research Council, are:

	Selenium, parts per million	
Species	Requirement	Toxic Level
Dairy cattle	0.1	5
Beef cattle	0.1	10–30
Sheep	0.1	3–20
Swine	0.1	5–10
Chickens (0–8 weeks)	0.1	10

Signs of pronounced selenium deficiency in ruminants include reduced growth and white muscle disease (nutritional muscular dystrophy) in young animals, and poor reproductive performance in older animals. Positive responses have been obtained in grazing ruminants with oral or injected supplemental selenium as either sodium selenate or sodium selenite. Selenate is preferable. Injections of selenium and/or vitamin E have been used in many countries when needed and have given good results under field conditions for a number of years. Injections, of course, are time-consuming and costly, limiting their use primarily to therapy rather than as preventive measures. Australian workers have used intraruminal selenium pellets successfully in grazing sheep. Heavy pellets made of 1 gram of elemental selenium and 9 grams of iron were found to be well retained and remained free of calcium phosphate coating. (See Kuchel reference listed) Other workers have controlled nutritional muscular dystrophy in lambs by implanting selenium pellets in the loose connective tissue behind the shoulder. (Hidiroglou reference) The use of selenium-fortified mineral mixtures appears to be a promising procedure for the prevention of nutritional muscular dystrophy (See Ammerman reference) and associated problems in ruminants grazing selenium-deficient areas. Injectable preparations of selenium-vitamin E combinations have been used for ruminants under veterinary supervision for several years. In 1974, the U.S. Food and Drug Administration allowed 0.1 ppm supplemental selenium for feeding to all classes of swine and chickens (0–16 weeks). A quantity of 0.2 ppm selenium was approved for turkeys.

In early 1978, the New York State Pork Congress suggested that fly ash may have potential as a source of selenium in pig diets. An advantage of fly ash, as opposed to Na_2SeO_3, would be the relative ease with which the selenium can be mixed in the diet. Because fly ash is a variable product, considerable further research will be required before approval can be obtained.

Selenium easily complexes with heavy metals and thus it interacts with arsenic, silver, mercury, cadmium, and copper. Arsenic successfully alleviates selenium toxicity in pigs, chicks, and cattle. However, the effect appears to be postabsorptive through increased liver selenium turnover. Mercury, silver, and cadmium afford their protective effects on selenium toxicity by formation of insoluble complexes in the digestive tract. See Underwood reference.

Sodium. Approximately 0.2% of the animal body is sodium. Most of this sodium is contained in the extracellular fluids where it plays an active role in metabolism. Sodium is the principal basic element in neutrality regulation and constitutes approximately 93% of the bases of the blood serum. The role of sodium in salt (sodium chloride) is discussed earlier in this entry under "Chloride."

Sodium bentonite, anhydrous silicate clay, has been used as a pellet binder in the feed industry for 30 years or more. In late 1977, researchers at Michigan State University undertook an investigation to determine if the substance had any nutritional effects on the animal diet. In the starting period, pigs receiving the sodium bentonite diets gained more rapidly and consumed more feed than pigs on the diet containing no sodium bentonite. But, in the grower period, addition of sodium bentonite depressed the average daily gain and thus although feed intake increased, feed efficiency dropped. The greatest potential for use of sodium bentonite as well as sodium bicarbonate appears to be in lowering the risk of rumen acidosis during any switch to high-concentrate diets. Researchers in South Dakota have found that these two compounds alter conditions in the rumen and may offer protection against rumen acidosis. These benefits are increasingly important as backgrounding periods are extended and finishing periods are shortened. This research is reported in *Feedstuffs*, page 19 (December 12, 1977). In beef and dairy cattle, sodium bicarbonate plays an important role in the normal acid-base balance of the rumen. Too much acidity can depress appetite and feed efficiency or lower milk and milk fat production. Ruminants produce sodium bicarbonate naturally in their saliva, enough to maintain the normal acid-base balance in grazing cattle, but not enough for high-energy, grain fed cattle.

Sulfur. An interesting feature of sulfur in the food chain is that plants use inorganic sulfur compounds to make sulfur amino acids, whereas animals use the sulfur amino acids for their own processes and excrete inorganic sulfur compounds resulting from the metabolism of the amino acids. Such ruminants as cattle, sheep, and goats can use inorganic sulfur in their diets because the microorganisms in the rumen convert the inorganic sulfur into the sulfur amino acids, including cystine and methionine.

In the United States, soils very low in available sulfur are common in the Pacific northwest and in some parts of the Great Lakes region. For many years, sulfur in the form of calcium sulfate was an accessory part of most commercial phosphate fertilizers and this probably helped to prevent development of widespread sulfur deficiency in crops grown with such fertilizers. The trend toward high analysis fertilizers without sulfur and toward abatement of air pollution diminishes some of the inadvertent sources of sulfur for plants and is bringing about a need for more deliberate use of sulfur fertilizers.

Sulfur deficiency in animals has not proved to be a major problem because the requirements are small and most well-balanced rations contain more than adequate quantities of sulfur. Because wool contains cystine, sheep have a greater requirement for sulfur than other livestock. However, experiments over a number of years have not proved that supplementing sheep diets with sulfur proves beneficial.

Finely powdered sulfur, when added to poultry mash, tends to prevent coccidiosis. See **Poultry**. Sulfur is also contained in a number of drugs for treatment of animal diseases.

Zinc. Evidence of zinc deficiency in crops is being recognized in new areas and the use of zinc fertilizers has increased steadily in recent years. A dry, cracked condition of the skin of pigs, called *parakeratosis,* has been a zinc-deficiency problem to pork producers. Laboratory animals deficient in zinc may be subject to serious reproductive problems, including infertility of males, failure of conception or implantation of the embryo, difficult births, and deformed offsprings. Additional research is needed to determine the extent to which zinc deficiency is a primary cause of reproductive problems in livestock.

Plant proteins generally are considered inferior to animal proteins with regard to zinc availability. Zinc utilization often can be attributed to the difficulty of utilization from the phytates of plants. Inorganic zinc sources also differ in their availability. Chemical grade zinc oxides, carbonate, and sulfate are equally well utilized, whereas naturally occurring oxides (sphalerite and franklinite) are poorly utilized. In *parakeratosis* of swine, high levels of calcium tie up zinc and prevent absorption of it from the digestive tract. Swine fed over 1% calcium may suffer from zinc deficiency.

The role of zinc in beef cattle nutrition has not been firmly established. Research at Purdue University has indicated that beef cattle do respond to supplemental zinc. A zinc deficiency in dairy cattle has been known to produce excessive itching for a number of years and was first observed in the Netherlands. Optimum levels of zinc for feeding beef cattle have not been fully established. For swine, a satisfactory level is considered between 50 and 100 ppm. As reported by Neathery (see reference listed), cattle can tolerate high amounts of dietary zinc without adversely affecting performance or general health. Zinc may cause borderline deficiencies of copper and iron. Young dairy calves fed 600 ppm supplemental zinc for 21 days did not develop any clinical toxicity symptoms. However, liver, kidney and pancreatic zinc increased several fold, as compared to calves consuming 33 to 38 ppm zinc, indicating a breakdown in zinc homeostasis at the 600 ppm level. Lactating dairy cows fed normal rations consumed 1279 ppm zinc with no adverse effect. With growing cattle fed a corn-corncomb concentrate ration, 500 ppm zinc did not affect performance; 900 ppm reduced gains and lowered feed efficiency; and 1700 ppm reduced feed consumption and caused depraved appetite.

Signs of extreme zinc toxicity in sheep include extension of limbs, convulsions, opisthotonos, and death. The prolonged feeding of excessive amounts may result in a depletion of liver copper. However, zinc can protect against copper toxicity. With adequate dietary levels of copper, iron, and calcium, it appears that the maximum safe dietary level of zinc for sheep is about 600 ppm.

Limited data indicate that the maximum safe dietary level of zinc in growing pigs is about 1000 ppm in the diet. Feeding 2000 ppm zinc as zinc carbonate caused a reduction in gains and feed intake, arthritis, hemorrhage in axillary space, and gastritis. High dietary calcium levels may increase the tolerance for excess zinc. The estimated maximum safe dietary zinc concentration for swine is about 1000 ppm.

Zinc concentrations up to 1000 ppm, as zinc or zinc carbonate, did not adversely affect growth rate, feed efficiency or liveability of chicks for a 4-week period. The estimated maximum safe dietary zinc level for chicks is about 1000 ppm; and for turkeys, about 2000 ppm.

Vitamins in Animal Feeds

Prior to the early 1900s, producers of livestock and poultry believed that adequate supplies of carbohydrates, fats, minerals, and proteins would meet all of the nutritional needs of healthy animals—efficient converters of their feed intake, free of deficiency diseases and abnormalities, and capable of reliably reproducing their kind. From time to time, of course, inexplainable problems in raising livestock and poultry arose, but these were not related to diet by their observers and thus remained unresolved. The concept and the word *vitamin* were not established until after 1912, the year when a "mysterious substance," later to be called thiamine*, was found capable of preventing and curing the disease beri-beri when administered to laboratory animals. Subsequently, the term vitamin was used to describe other mysterious substances that are essential to nutrition, but in exceptionally low concentrations. Other than their variety of essential functions, the vitamins are not strongly related, except they are organic. Where an inorganic substance or chemical element plays a similar role, it is commonly called a *trace element* or a *trace mineral,* but not a vitamin. An excellent chronology of vitamin development and progress is given in the Schaible reference (see list). There are now over 15 vitamins for which information is sufficiently complete and definitive to merit the general acceptance of authorities in the field. Before briefly describing the vitamins individually, references to Tables 6 and 7 demonstrate the importance of the presence of these materials in the animal diet.

TABLE 6. POSSIBLE VITAMIN DEFICIENCIES IN BEEF CATTLE

	Deficiency of		
Symptom	Vitamin A	Vitamin D	Vitamin E
Reduced growth rate	X	X	X
Impaired feed conversion			X
Reduced feed intake	X	X	X
Impaired vision or blindness	X		
Poor reproductive performance	X	X	X
Bone deformities or swollen joints	X	X	
Lameness or unsteady gait	X	X	X
Muscular incoordination or other nervous signs	X	X	X
Difficult breathing, irritability, and weakness		X	
Degeneration of heart and skeletal muscle			X
Sudden heart failure			X
Rough hair coat	X		
Digestive disturbances	X	X	

Data from: Hoffman-La Roche Inc.

---

*Some authorities attribute the discovery of thiamine to Ejikman, who related the "mysterious substance" to polyneuritis in chicks in 1897.

TABLE 7. POSSIBLE VITAMIN DEFICIENCIES IN SWINE

Symptom	Deficiency of												
	Vitamin A	Vitamin D	Vitamin E	Vitamin B_{12}	Riboflavin	Niacin	Pantothenic Acid	Choline	Vitamin K	Folic Acid	Thiamine B_1	Pyridoxine B_6	Biotin
Retarded growth	X	X	X	X	X	X	X	X	X	X	X	X	X
Impaired feed conversion				X		X						X	X
Increased mortality			X					X			X		
Weakness or increased mortality of newborn pigs*	X		X		X		X	X			X		
Lameness or unsteady gait	X	X	X		X	X	X					X	X
Bone deformities	X	X											
Poor reproductive performance	X		X	X	X	X	X	X	X	X	X	X	X
Poor coordination or other nervous signs	X	X	X	X			X	X				X	X
Rough hair coat	X			X	X	X	X					X	X
Skin problems	X			X	X	X						X	X
Excessive hair loss					X	X							X
Scours and/or vomiting				X	X	X	X	X			X	X	
Impaired vision or blindness	X			X								X	
Reduced feed intake		X	X	X	X	X	X			X	X	X	X
Anemia			X	X		X	X		X	X		X	
Hemorrhaging			X						X				

Data from: Hoffman-La Roche Inc.

*Due to deficiency in sow.

It is not practical in this volume to list the vitamin levels in all natural feed ingredients. A representative listing is given in Table 8.

Changes in Animal Management Alter Vitamin Requirements. Just as the interrelationships between one vitamin and the next, between one mineral or trace element and the next, and between vitamins and trace elements sometimes markedly alter the requirements of these substances in animal feedstuffs, so do animal management procedures interrelate with feedstuff requirements. Thus, as production techniques change, feedstuff requirements should be assessed frequently. In an excellent paper, Krautmann and Zimmerman (see references listed) comment on those factors which currently are tending to alter the dietary vitamin requirements of layers. These observations relating to poultry are equally applicable in principle to other species of food animals and thus are abstracted here.

Factors, in recent years, which have tended to reduce vitamin levels supplied by feedstuffs include: (1) Modern least-cost formulation methods have sometimes led to the exclusion or use of reduced amounts of vitamin-rich ingredients, such as alfalfa, distillers solubles, brewers grains, fermentation products, and meat and fish byproducts. (2) New crop varieties, intensive cropping, and changes in methods of harvesting and storing, sometimes result in reduced levels of certain vitamins and trace minerals in feedstuffs. The published tables of ingredient requirements do not always keep up with the effects of such changes, plus such crop production practices range widely from one producer and from one area to the next.

Management practices which have tended to increase vitamin requirements of layers are several: (1) Increased egg production rates require increased metabolic activity. It follows that an increase in the dietary levels of vitamins and various other nutrients may be required to assure that production. In the Krautmann-Zimmerman reference, revised feed intake, resulting from raising smaller-size hens, tends to lower the total vitamin intake per hen. (3) Environmental stress associated with confinement in high density, minimal flock maintenance operations can increase the needs for certain vitamins. (4) A decrease in vitamin B and vitamin K recycling, when layers are housed in wire cages elevated from the feces, lowers the effective intake of these vitamins by the birds. (5) Diseases affecting the gastrointestinal tract may reduce absorption of various vitamins from the intestine into the bloodstream, thus increasing the dietary requirements for vitamins. (6) Antimetabolites of some vitamins are produced by certain microorganisms, such as molds in feedstuffs. These substances can impair the absorption and/or utilization of these vitamins, thereby increasing the dietary vitamin requirements.

Several resources are available for use as guidelines in reviewing and/or adjusting the vitamin fortification levels in layer rations. One is the National Research Council (NRC) minimum requirements for vitamins. However, these do not include a margin of safety for modern, intensive egg production. In the Krautmann-Zimmermann reference, revised recommended vitamin fortification levels for layers, based upon an extensive regional survey of practices and needs, are included. The survey demonstrated a rather wide spread of vitamin fortification levels in practical layer rations from one geographic region to the next.

Vitamin A. This vitamin is found in all vertebrates. Animals either ingest the vitamin preformed from other animal sources or synthesize it from various provitamin carotenoids found in plants. See also **Carotenoids.** Most animal species store appreciable amounts of the vitamin in their livers, have low concentrations in the blood and undetectable quantities in most other tissues. A deficiency of the vitamin produces a variety of symptoms, the most uniform being eye lesions, nerve degeneration, bone abnormalities, membrane keratinization, reproductive failure, and congenital abnormalities. Toxic symptoms from large doses of vitamin A are readily produced in animals. Vitamin A appears to have at least 2 different biochemical functions, one clearly elucidated in the retina and one unknown but thought to involve many tissues, particularly those with a mucous epithelium.

Both carotene and vitamin A are readily destroyed by oxidation. Thus, much loss occurs when making hay from green forage. See also **Hay and Forage Crops.** Vitamin A deficiencies can occur as the result of prolonged drought situations where livestock graze on very dry and bleached pastures; or when they are winterfed on overripe cereal hays or straws with little or no green hay present in the feed. A deficiency also can result from the drylot feeding of cattle where no green forage or yellow corn are administered, particularly when such periods exceed 2 to 3 months. A high nitrate intake in water and feed also depress vitamin A availability. Deficiencies always manifest symptoms in young livestock earlier than with more mature animals. Natural and effective sources of vitamin A include green pasture, yellow corn, moist, green hay less than 1-year old, legume hays and dehydrated alfalfa are good sources. See also **Alfalfa.**

As may be expected, vitamin A requirements range widely, depending upon species and stage of growth and function. See Table 9.

Amplifying on vitamin A deficiency effects given in Tables 6 and 7, these include *for cattle:*

Abortion or birth of dead, malformed, blind, or weak calves
Convulsions
Cysts on pituitary and adrenal glands
Diarrhea
Edema (generalized—excessive fluid in tissues)
Lameness in hock and knee joints
Localized paralysis
Lung complications, leading to pneumonia
Muscular incoordination
Night blindness in cattle; total, permanent blindness in newborn calves. Additional ocular disorders—excessive lacrimation and keratinization (formation of hard protein of cornea)
Retained placenta and reduced pregnancy rate
Sexual activity decline in breeding bulls
Spongy bone tissue formation
Staggering gait
Urinary calculi (gravel) increase

And *for swine:*

Blindness
Malformations in newborn pigs due to sow deficiency
Nervous disorders (poor coordination, paralysis, herniation of spinal cord, and nerve degeneration)

TABLE 8. VITAMIN LEVELS OF VARIOUS NATURAL FEED INGREDIENTS

	Vitamin A* (T.I.U.)** per		Vitamin E (I.U.)*** per		Vitamin B_{12} (mcg) per		Riboflavin (mg) per		Niacin (mg) per		Pantothenic Acid (mg) per		Choline (mg) per		Folic Acid (mg) per		Thiamine B_1 (mg) per		Pyridoxine B_6 (mg) per	
	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram	Pound	Kilo-gram
Feed Ingredient	of Feed		of Feed		of Feed		of Feed		of Feed		of Feed		of Feed		of Feed		of Feed		of Feed	
Alfalfa meal, 20% dehydrated	**49**	**108**	**70**	**154**	5	11	7	15	24.5	54	14.9	32.9	735	1621	**1.2**	**2.6**	1.8	4.0	3.6	7.9
Alfalfa meal, 17% dehydrated	**36**	**79**	**60**	**132**	5	11	5.6	12.3	20.5	45.2	13.6	30	689	1519	**1**	**2.2**	1.5	3.3	3.0	6.6
Barley, 12% grain	–	–	16	35	–	–	*0.9*	*2*	26	57	*2.9*	6.4	467	1030	0.2	0.4	2.3	5.1	1.8	4
Corn distillers dried solubles	*0.35*	*0.77*	37	82	13	29	7.7	17	**52**	**115**	9.5	20.9	**2185**	**4818**	0.5	1.1	**3.1**	**6.8**	**5**	**11**
Corn gluten meal	7.5	16.5	17	37	–	–	*0.7*	*1.5*	25	55	*3.8*	*8.4*	*150*	*331*	0.1	2.2	*0.1*	**2.2**	2.9	6.4
Corn (yellow, grain	*0.95*	*2.1*	13	29	–	–	*0.5*	*1.1*	10.5	23.2	*2.3*	*5.1*	*244*	*538*	0.1	2.2	1.8	4.0	2.5	5.5
Cottonseed meal solvent, 40%	–	–	6	13	–	–	2.3	5.1	18	40	14	31	1300	2867	**1**	**2.2**	**3**	**6.6**	3	6.6
Feather meal	–	–	–	–	39	86	*0.9*	*2.0*	*8*	*18*	*2.7*	*6*	400	882	0.1	0.2	*0.1*	*0.2*	2	4.4
Fishmeal, herring	–	–	10	22	**99**	**218**	4.1	9	40	88	5.2	11.5	**1831**	**4037**	0.1	0.2	0.3	0.7	2.2	2.6

Fishmeal, menhaden	–	–	6	13	84	185	2.2	4.9	25	55	4	8.8	1400	3087	0.1	0.2	0.3	0.7	1.2	2.6
Fishmeal, Peruvian	–	–	*2*	*4.4*	84	185	3	6.6	29	64	4	8.8	1678	3700	0.1	0.2	0.3	0.7	1.6	3.5
Meat and bone meal, 50%	–	–	*1*	*2.2*	20	44	1.7	3.7	19	42	1.6	3.5	990	2183	0.2	0.4	0.5	1.1	*0.7*	*1.5*
Poultry byproduct meal	–	–	*2*	*4.4*	**120**	**265**	5.1	11.2	**46**	**101**	8.8	19.4	**2700**	**5954**	0.2	0.4	*0.1*	*2.2*	2	**4.4**
Sorghum grain	–	–	8	17.6	–	–	*0.5*	*1.1*	19	42	5.2	11.5	*308*	*679*	0.1	0.2	1.8	4	1.7	3.7
Soybean meal, solvent 50%	–	–	*2*	*4.4*	*1*	*2.2*	1.4	3.1	*10*	*22*	6	13.2	1252	2751	0.3	0.7	1.1	2.2	3.2	7.1
Soybean meal, 44%	–	–	*2*	*4.4*	*1*	*2.2*	1.5	3.3	*12*	*26.5*	6.6	14.6	1244	2743	0.3	0.7	**3**	**6.6**	3	6.6
Wheat bran	–	–	12	26	–	–	1.4	3.1	**95.5**	**211**	13.2	29.1	450	992	0.8	1.8	**3**	**6.6**	**4.2**	**9.3**
Wheat middlings	–	–	20	44	–	–	*0.9*	*2*	43	95	8	17.6	480	1058	0.5	1.1	**7.1**	**15.7**	**4.2**	**9.3**
Wheat (soft), 10%	–	–	9	19.8	0.5	1.1	*0.6*	*1.3*	27	60	5.8	12.8	*358*	*789*	0.1	2.2	2.2	4.9	1.5	3.3
Whey, partially delactosed	–	–	–	–	11	24	**25.2**	**55.6**	27	60	**31.3**	**69**	802	1768	0.4	0.9	1.7	3.7	1.8	4

Data from: Hoffman-La Roche Inc.

*Equivalent to stabilized vitamin A activity

**Thousand international units

***International units

Notes: Comparatively high values are shown boldface; low values are shown in italics.

TABLE 9. VITAMIN A REQUIREMENTS OF VARIOUS SPECIES

Species	Vitamin A Requirements* International Units per Pound of Feed	International Units per Kilogram of Feed
Swine:		
Starter, grower, finisher	1500	3308
Gestating gilt	2500	5513
Dairy Cattle:		
Maintenance of mature lactating cow (weight 1540 pounds; 699 kilograms)	30000	66150
Maintenance and pregnancy of cow (same weight; last 2 months of gestation)	53000	116865
Beef Cattle:		
Growing-finishing steer calves and yearlings:		
Weight, 220 pounds (100 kilograms)	6-7000	13230-15435
600 pounds (300 kilograms)	16000	35280
1100 pounds (499 kilograms)	23000	50715
Bull (weight 2200 pounds; 998 kilograms)	48000	105600
Chickens:		
Starting	5000	10584
Growing	3000	6615
Laying	4000	8820
Breeding	5000	10584
Turkeys:		
Growing	3000	6615
Finishing	3000	6615
Breeding	5000	10584

*1 International Unit (I.U.) = 0.344 microgram vitamin A acetate = 0.3 microgram retinol.

Reproductive problems and failures

Xerophthalmia (extremely dry conjunctiva—mucous membrane lining inner surface of eyelid and exposed surface of eyeball)

In connection with beef cattle, corn and most roughages fed to finishing beef cattle are satisfactory sources of provitamin A carotenoids, but they contain little or no preformed vitamin A. Inasmuch as it was demonstrated that green or yellow materials are abundant in carotene, much of the interest in vitamin A was set aside while the mysteries of other vitamins were probed. But, within the last few years, the incidence of vitamin A deficiency has increased. Research at the Illinois Agricultural Experiment Station points toward interference by nitrates in the sequence required to convert carotene to vitamin A. Additional research at the University of Illinois and Purdue University has indicated typical vitamin A deficiency symptoms in beef cattle that have been fed on typical corn fattening ration, normally considered an ample source of carotene. Because of increasing incidence of vitamin A deficiency, considerably more research is required.

Vitamin D. While the term "vitamin D" (singular) is frequently used in nutritional discussions, it is unsatisfactory when used in a strict biochemical context, because there are several different substances each of which is capable of performing the nutritional functions of vitamin D, namely, that of promoting growth, including bone growth, and preventing rickets in young animals. The most important or at least the best known members of the family of D vitamins are vitamin D_2 (calciferol), which can be produced by ultraviolet irradiation of ergosterol, and vitamin D_3 which may be produced by the irradiation of 7-dehydrocholesterol. It should be noted that subscript numerals have a different connotation here than they have in connection with the B vitamins. Vitamins B_1, B_2, B_6, B_{12}, etc. represent individual substances which have little or no chemical resemblance to each other and perform different metabolic functions. The various vitamin D's, however, have very similar structures, differing only in the side chains, and perform the same functions.

Different species of animals respond distinctively to the different members of the vitamin D family. The most striking example of this is the fact that vitamin D_2 (calciferol) has practically no vitamin D activity for chickens. Rats respond about equally to D_2 and D_3. Humans respond both to D_2 and D_3. The requirements of animals for vitamin D in terms of actual weight are extremely small. See Table 10.

Amplifying on vitamin D deficiency effects given in Tables 6 and 7, these include:

Birth of dead, weak, or deformed calves.

Rickets in calves and osteomalacia in adult cattle, characterized by (1) Decreased growth rate and feed intake, digestive disturbances, stiff gait, labored breathing, irritability, weakness and occasionally, tetany and convulsions, followed by (2) enlarged joints, slight arching of back, bowing of legs and erosion of joint surfaces, causing difficulty in movement. Paralysis may follow fracture of vertebrae.

Rickets in young pigs and osteomalacia in mature swine.

For many years, it has been recognized that all cells need calcium to function because their growth and development is related with changes in their intracellular calcium content. Reasoning further, it has been postulated that calcium may serve as a cellular regulatory agent. Growing interest has been shown by investigators in a steroid that is derived from vitamin D and that regulates the amount of calcium in the animal's blood. This substance has been referred to as 1,25-dihydroxyvitamin D_3 and is metabolized from vitamin D. In response to a skeletal need for calcium, the hormone is secreted by the kidney and transported to the intestine and bones.

It has been pointed out for many years that there is an increased need for vitamin D when the ratio of calcium to phosphorus is in imbalance. Although vitamin D is identified with the overall absorption of calcium from the intestine, and in the deposition of the bone cells, its strict biochemical action has not been fully identified.

Cattle exposed to sunlight rarely require supplemental vitamin D.

Vitamin E. This vitamin is sometimes referred to as alpha-Tocopherol or the antisterility vitamin. The principal roles of vitamin E are its function as an antioxidant, includ-

TABLE 10. VITAMIN D REQUIREMENTS OF VARIOUS SPECIES

Species	Vitamin D Requirements* International Units per Pound of Feed	Vitamin D Requirements* International Units per Kilogram of Feed
Swine:		
Starter	300	662
Grower	150	331
Finisher	75	165
Breeder	150	331
Dairy Cattle:		
Growing heifer (440 pounds; 200 kilograms)	1320	2911
Growing bull (440 pounds; 200 kilograms)	1320	2911
Beef Cattle:		
Weight, 660 pounds (300 kilograms)	1980	4366
Chickens (Vitamin D_3):		
Starters, growers, layers, breeders	1000	2205
Turkeys (Vitamin D_3):		
Finishers	1500	3308
Starters, growers, breeders	1000	2205

*1 International Unit (I.U.) = 0.025 milligram vitamin D_3.

ing its protection of vitamin A, and in the prevention of muscular dystrophy (or "white muscle") in animals. Considerable research is required to fully determine the need for supplementation of animal diets unless typical symptoms of a deficiency are apparent. Vitamin E deficiencies have appeared where there are deficiencies of selenium in the soil and also where there are excessively high levels of nitrites in the soil.

Amplifying on vitamin E deficiency effects given in Tables 6 and 7, these include:

Nutritional muscular dystrophy (white muscle disease), generally characterized by muscular weakness, degeneration and/or calcification in cattle. Specific symptoms include weakening of leg muscles; relaxation of pastern portions of legs; spreading of hooves; lameness; erratic movement; inability to hold up head or to stand; inability of calves to suckle; paralysis; degeneration of heart, skeletal and tongue muscles; abnormal white areas in heart muscle; heart failure. This disease also can be caused by a selenium deficiency.

Testicular degeneration in calves; debility and muscular deterioration in newborn calves.

Excessive fluid in the cavities of the chest and abdomen.

Congestion and necrosis of liver tissue.

Excessive fluid and streaks in kidneys. This and the foregoing two conditions also may result from selenium deficiency.

In swine, vitamin E deficiencies may be manifested by:

Degeneration of liver tissue. Mortality often occurs without gross symptoms.

Nutritional muscular dystrophy.

Straw-colored fluid under skin, in thoracic cavity, abdomen and heart sac.

Lactation failure.

Mulberry heart (acute congestive heart failure).

Cecal and colonic hemorrhages.

Reproductive problems.

Sensitivity reaction to iron injection, often resulting in death in newborn pigs from deficient sows.

The biological assay for vitamin E is complex and time-consuming, but is being replaced by more sophisticated instrumental methods. Vitamin E is abundant in whole cereal grains, notably in the germ. Green forage and other leafy materials are also good sources. Wheat-germ oil is the most concentrated natural source. Soybean, groundnut (peanut) and cottonseed are rich in the vitamin. Under practical feeding conditions, researchers at Purdue University to date have found no benefit from vitamin E supplementation for the rather typical Corn Belt rations. But since Vitamin E deficiencies continue to occur, additional research is needed.

Research undertaken during the mid-1970s has revealed a better understanding of the modes of action of vitamin E and selenium in the prevention of nutritional deficiency diseases. Vitamin E appears to function in at least two closely associated metabolic roles: (1) As a nonspecific fat-soluble antioxidant, and (2) in a more specific role intimately associated with selenium in protection of vital phospholipids from peroxidative damage. Rotruck *et al.* in 1972 demonstrated that selenium is an integral part of the enzyme, glutathione peroxidase, and that this enzyme contains four atoms of selenium per molecule of enzyme. See also "Feed and Off-flavor in Turkey" in entry on **Poultry**.

Vitamin K. This is an antihemorrhagic vitamin that is necessary for the synthesis of prothrombin and other blood clotting protein factors in the liver. Prothrombin is produced in the fully active form only in the presence of adequate vitamin K activity. Knowledge of compounds possessing vitamin K activity commonly used in animal feeds has lagged behind other feed vitamin information. A number of synthetic vitamin K active products are available. Modern poultry diets usually contain supplemental synthetic vitamin K activity. Until the late 1970s, vitamin K deficiency was not regarded as a problem in nonavian domestic livestock. Recent experience, however, has shown that it is in order to fortify swine diets with vitamin K activity during periods of dietary and environmental stresses. One of these commercial products is menadione (2-methyl-1, 4-naphthoquinone) is sometimes designated as "oil-soluble" vitamin K_3. Initially, two other compounds, phylloquinone (K_1) and prenylmenaquinone (K_2) were used. These compounds were isolated respectively from plant sources and from putrefying plant and animal products. K_3 is a derivative of nephthoquinone. Today, menadione sodium bisulfite, menadione sodium bisulfite complex, and menadione pyrimidinol bisulfite are the predominate synthetic vitamin K forms used in animal feeds. These menadione derivatives were developed as vitamin K active products because of relatively expensive synthesis of naturally occurring vitamin K compounds and the poor stability and handling characteristics of menadione. Although synthetic vitamin K compounds may appear similar in structure, manufacturing and process differences make it necessary to evaluate the relative stability and biological activity of each.

Vitamin B_1—Thiamine. In practice, the vitamin is used in the form of the hydrochloride. It is present in both blood cells and serum in small quantities, and is excreted in the animal's urine in amounts which reflect intake and storage. In animals, it has been demonstrated to be abundant in liver, heart, kidneys, and voluntary muscle. Vitamin B_1 plays an important role in the fundamental process of oxidation in the body. In the oxidation of carbohydrate, it is a coenzyme factor in the enzyme carboxylase. Although much is known of the chemistry of thiamine in the animal body, less is known of the mechanism by which the clinical picture of B_1 deficiency is produced. The vitamin seems necessary for the maintenance of the health of nerve tissue, intestinal and cardiovascular function, appetite, and growth.

In cattle, a deficiency of thiamine produces polioencephalomalacia (PEM) characterized by blindness, decreased feed intake, incoordination, failure of rumen to contract, spasms, and paralysis. In swine, a deficiency retards growth, causes cyanosis (blue color due to inadequate oxygen in the blood) in skin and mucous membranes of head, an enlarged heart and fatty degeneration of heart muscle, and digestive tract disorders and reproduction problems. Chicks suffer more than a 6% loss in efficiency of metabolizable energy utilization when insufficient thiamine is present in the diet. In poultry a serious deficiency causes polyneuritis (where head is drawn back due to paralysis of peripheral nerves), lessened appetite and digestion, constipation, edema, and ultimately starvation. In practice, an average poultry ration made up of ground whole grains and cereal byproducts, and perhaps alfalfa meal, furnish more than three times the minimum requirement. For testing purposes, thiamine deficiency can be produced by feeding caged birds for one month exclusively on polished rice.

Under most conditions, there is little apparent need for additional B_1 in the case of beef animals once rumen development has approached maturity. Some scattered research results from various sources have shown benefit, but not generally.

One International Unit (I.U.)= 1.3 micrograms thiamine hydrochloride.

Vitamin B_2—Riboflavin. This is a complex pigment with a green fluorescence sometimes also called lactoflavin. Riboflavin, like nicotinic acid, forms an oxidation enzyme and, as such, acts as an oxygen carrier to cells. Riboflavin has been shown to be a constituent of 2 coenzymes: (1) Flavin mononucleotide (FMN); and (2) flavin adenine dinucleotide (FAD). See also **Coenzymes.** Riboflavin is essential for growth, body maintenance and health. In poultry, it prevents curled-toe paralysis (enlarged sciatic nerve). It also contributes to improved hatchability. Good sources of riboflavin for animal diets include dried whey, dried milk products, corn distillers dried products, dried yeast, and alfalfa meal. Synthetic riboflavin supplements are readily available. Riboflavin is subject to deterioration by exposure to sunlight and therefore feeds should not be left in bright sunlight, especially if they are spread in thin layers. Riboflavin was identified with leg paralysis in chickens as early as 1929 by Norris.

Vitamin B_6—Pyridoxine. This vitamin was first identified in 1934 during research on thiamine and riboflavin. Vitamin B_6 is an essential metabolic substance for ruminants. Once the rumen has developed, cattle and sheep no longer require an outside source of the vitamin in their diet. In the horse, the vitamin is synthesized in the cecum. Pyridoxine is found in several enzyme systems concerned in protein metabolism. It serves as a coenzyme for enzymes which decarboxylate a number of amino acids. It also serves as a coenzyme for transaminases, which catalyze the transfer of the amino group of glutamic acid and other amino acids to keto acids. The complete metabolism of tryptophan is dependent upon vitamin B_6. In swine, a deficiency of pyridoxine causes convulsions, slow growth rate and digestive tract disturbances, dermatitis around the eyes and snout, and poor vision, often blindness. Such conditions when found early can be corrected by using pyridoxine hydrochloride supplements in the animal diet. It is estimated that between 0.75 and 1 milligram of the supplement (or natural equivalent) is required per kilogram of feed for baby pigs. About 1.3 milligrams per pound of feed (2.9 milligrams per kilogram) are required for starting chickens.

Niacin (Nicotinamide). Also called nicotinic acid, this vitamin is essential to animals and was the result of a long research for a cure for pellagra. In 1937, Elvehjem and associates working at the University of Wisconsin discovered that nicotinic acid was a cure for black tongue of dog, a disease that closely resembled pellagra. In the animal body, niacin functions as a part of two coenzymes: Diphosphopyridine nucleotide (DPN); and triphosphopyridine nucleotide (TPN). In conjunction with flavoprotein enzymes, these coenzymes act in cell respiration. The coenzymes are important to many aspects of carbohydrate, lipid, and protein metabolism. Niacin deficiency in chicken diets causes perosis and poor feathering; in swine, it slows the growth rate and causes dermatitis and digestive problems.

In early studies of pellagra in humans, consumption of corn (maize) was frequently associated with the disease. The discovery that pellagra was due to a lack of niacin still did not completely dismiss the factor of corn by some researchers. It was not until 1947 that researchers showed that tryptophan served as a precursor for the synthesis of niacin in the animal body. Thus, the early suspicion that corn (low in tryptophan) was related with niacin.

Ruminants have no requirement for niacin because of their ability to synthesize the vitamin. Because of tryptophan interference, biological assays for niacin are difficult and often uncertain.

Biotin. The discovery and isolation of this vitamin represents a convergence of several paths of research. In 1927, Boas (England) reported that feeding Chinese egg white to rats produced a typical dermatitis. In 1933, Parsons of Wisconsin investigated "egg white injury" and found that there was a protective factor in some foods, notably liver and kidney. They also found that egg white injury does not occur if the whites are cooked. Also, in 1933, researchers discovered a factor that was essential for the growth of nodule bacteria and named the substance "coenzyme R." In 1936, Kögl and Tonnis in Germany isolated a factor necessary for the growth of yeast. They named this factor *biotin* and later found that it was identical with coenzyme R. Based upon the work of Parsons, another researcher, György, investigated the chemistry of Parsons' protective factor and, in 1937, called it "factor H." In 1938, György and another researcher, du Vigneaud, collaborated on the problem and found that factor (or vitamin) H and biotin were identical. Later, Williams isolated from egg white a substance that rendered biotin inactive for yeast growth. Du Vigneaud first synthesized biotin in 1943. Later it was found that biotin plays an expanded role for animal metabolism.

Biotin reacts with an oxidized carbon fragment (denoted as CO_2) and an energy-rich compound, adenosine triphosphate (ATP), to form carboxy biotin, which is "activated carbon dioxide." Biotin is firmly bound to its enzyme protein by a peptide linkage. Biotin enzymes are believed to function primarily in reversible carboxylation-decarboxylation reactions. For example, a biotin enzyme mediates the carboxylation of propionic acid to methylmalonic acid which is subsequently converted to succinic acid, a citric acid cycle intermediate. A vitamin B_{12} coenzyme and coenzyme A are also essential to this overall reaction, pointing out the interdependence of the B vitamin coenzymes. Another biotin enzyme-mediated reaction is the formation of malonyl-CoA by carboxylation of acetyl-CoA ("active acetate"). Malonyl-CoA is believed to be a key intermediate in fatty acid synthesis.

Symptoms of biotin deficiency can be induced by feeding raw egg white or by use of biotin-free diets plus a sulfa drug to prevent intestinal synthesis. The common symptoms in all species are dermatitis, loss of hair, and poor growth. The test animals can be cured rapidly by administration of the vitamin. Biotin also has been noted as having a role in preventing perosis. Organ meats of animals are rich in biotin, as are the seeds of many plants. Whole grains thus are good sources. Milk and molasses also contain generous quantities of biotin.

At the World's Poultry Congress (1978) held in Rio de Janeiro, Brazil, C. Whitehead of the Poultry Research Centre in Edinburgh, Scotland, observed that biotin requirement of broilers on litter to be 0.17 milligram per kilogram of feed, somewhat higher than the previously accepted figure. The speaker also stated that broilers housed on wire floors or in cages would require about 10% more biotin than those on litter. The droppings provide a source of "microbial" biotin and wire floors deny the birds access to their droppings and this source. Whitehead also described how, by supplementing existing broiler diets with extra biotin, the condition known as *fat liver and kidney syndrome* (FLKS) can be prevented. It has been estimated that this disease is costing the industry several millions of dollars per year. Further details of Whitehead's report can be found in *Feedstuffs,* page 3 (September 25, 1978).

Pantothenic Acid. Sometimes called vitamin B_3, this vitamin is unique among the vitamin group, in that it was one of the first to be isolated using as a basis a microbiological assay method. Even more unique is the fact that its structure was largely determined, using a highly quantitative biological yeast test, long before it was isolated or obtained in concentrated form. The first hint as to the existence of this substance arose in 1901 (Wildiers) in which a hypothetical "bios" was found to be a growth-promoting factor essential for yeast. The first evidence that a substance answering the general description of pantothenic acid is required by higher animals was gained in 1928 by Williams and Waterman, who found a "third factor" in vitamin B in addition to thiamine and a thermostable one. It was destroyed by dry heat, or by long autoclaving, and was essential to weight maintenance and health in pigeons. If pure pantothenic acid had been available to these investigators, they would doubtless have recognized it as their unknown.

Pantothenic acid is a constituent of coenzyme A (CoA), which participates in numerous enzyme reactions. See also **Coenzymes.** CoA was discovered as an essential cofactor for the acetylation of sulfanilamide in the liver and of choline in the brain. CoA is also known to be involved in many biochemical reactions as an "activator" of normally less reactive carbon fragments and a "transfer" of these fragments to different molecules. CoA is particularly important in the initial reaction of the citric acid cycle of carbohydrate metabolism and energy production. CoA is also necessary for the activation, synthesis, and degradation of fatty acids. Synthesis of cholesterol and ultimately the production of steroid hormones are also coenzyme A dependent.

Pantothenic acid for supplemental uses is synthesized, but natural material can also be used in the form of concentrates from rice bran and yeast. Research has shown that pantothenic acid is quite valuable for very young and rapidly growing animals. It has been determined essential for growth, feather growth, healthy nerves, and prevention of dermatitis in poultry. Symptoms of deficiency are poor growth, ragged feather development, sores in corners of mouth, scabs around eyes, and a scaly body and cracked foot pads. In pigs, a deficiency causes "goose-stepping," a poor coordination condition with little or no bending of leg joints. The pigs also have a brown exudate around their eyes, and there may be digestive tract disorders, poor reproduction, lactation failure in sows, adrenal disturbances, and anemia.

Swine feeds should provide pantothenic acid levels of 20 to 23 grams per ton (22 to 25.3 grams per metric ton) of feed, although some research groups have suggested a level as high as 50 grams per ton (55 grams per metric ton) of feed. Pantothenic acid levels for poultry layer feeds vary with geographic location, ranging from 2 to 7.5 grams per ton (2.2 to 8.3 grams per metric ton) for the west coast and mid-Atlantic regions of the United States to 6 to 18 grams per ton (6.6 to 19.8 grams per metric ton) of total feed in the northeastern region.

Folic Acid Pteroylglutamic Acid. Also known as anti-anemia factor, folic acid has a number of physiologically active derivatives. One folic acid coenzyme, methyltetrahydrofolate, transfers its methyl group to homocystine to yield methionine, in a reaction which also requires a vitamin B_{12} coenzyme. Other folic acid enzymes are involved in the transfer of one-carbon fragments in the synthesis of serine and the degradation of histidine. They also participate in the biosynthesis of purines and pyrimidines, important constituents of nucleic acids, the genetic material in the chromosomes. Synthesis of folic acid occurs in the rumen, but some researchers believe that newborn lambs require a dietary supply. In species affected by a deficiency of folic acid, a characteristic macrocytic, hyperchromic anemia (called *megaloblastic anemia*) occurs. There are bone marrow changes and red cells are large and immature. *Leucopenia* (reduction of white cell numbers) also may occur. In poultry, a deficiency retards growth, with poor feathering and a depigmentation of colored feathers. Most natural animal feeds contain more than adequate supplies of folic acid. Supplementation is usually confined to poultry. Supplementation ranges from 0.2 to 0.5 gram per ton of feed (slightly more per metric ton).

Vitamin B_{12}—Cobalamin. Also known as *cyano-cobalamin,* this vitamin was first isolated in 1948. The complete biochemical role of vitamin B_{12} is not fully understood. It has been established that the vitamin is required for normal blood formation, normal growth, for some metabolic processes, and for maintenance of neural function. The first synthesis was completed in 1973 by Woodward (Harvard) and Eschenmoser (Eidgenössische Technische Hochschule Zurich) in a joint effort. Dietary sources of the vitamin are animal tissues and liver. Vitamin B_{12} is not synthesized in animals, but rather it results from bacterial or fungal fermentation in the rumen, after which it is absorbed and concentrated during metabolism. Among the known vitamins, this exclusive microbial synthesis is unqiue. One of the major results of vitamin B_{12} deficiency is pernicious anemia.

At one time, the vitamin was designated as the *animal protein factor* (APF) because at that time it was an unidentified factor(s) found to be essential for the growth of chicks fed diets entirely of plant origin, but found that the condition could be improved by feeding fish meal, fish solubles, liver, meat scraps, and other animal products. Cow manure was also found to contain the substance. The term *cobalamin* comes from the fact that the vitamin molecule contains the element cobalt.

For poultry (layers), the level of vitamin B_{12} required in the feed ranges from 5 to 40 milligrams per ton of complete feed, depending upon geographical area and materials fed.

Choline. This is an essential metabolic substance for building and maintaining cell structure. Choline is usually described along with the B complex vitamins although it is essential as a structural component of tissues rather than as a metabolic catalyst. Choline is a part of the structure of phospholipids and acetylcholine (participates in transmission of nerve inpulses). Choline participates in normal fat metabolism and interrelates with methionine in a biochemical manipulation referred to as transmethylation. Choline, when in adequate quantity, can replace the essential amino acid methionine, when the latter is in limited quantity; or the reverse may occur, wherein methionine can be dismantled to replace choline. Although not fully explained, vitamin B_{12} appears to play a role in this manipulation.

Without sufficient choline, animals develop fatty livers and hemorrhagic kidneys. The absence of choline for long periods causes basic physiological changes in the animal that shorten life span. Perosis (slipped tendon) in poultry, a condition described under "Manganese" in this entry, can result from a deficiency of choline (or manganese). In pigs, a choline deficiency may result in spraddled hind legs in the newborn; fatty infiltration of liver; and poor reproduction and lactation in sows. Suggested choline levels among authorities vary considerably. For example, for finishing swine, the suggested level ranges from as low as 100 grams per ton (110 grams per metric ton) to 1995 grams per ton (2195 grams per metric ton) of complete feed. For poultry layers, the amounts of choline required vary with geography and traditional area feed substances. Levels from 70 to 300 grams per ton (77 to 330 grams per metric ton) are suggested for the northeastern United States, whereas the much higher levels of 300 to 500 grams per ton (330 to 550 grams per metric ton) are suggested for the midwestern states.

Choline occurs in fats and usually is in sufficient supply in feeds that contain fats with the exception of those that may be very limited in methionine.

Betaine. This is an amino acid derivative and like choline participates in transmethylation manipulations and in protein metabolism. The addition of betaine to feeds (particularly poultry) conserves both the choline and methionine that are naturally present in the feed. Chemically, betaine is the oxidized or acid form of choline. Although betaine cannot replace methionine in protein formation, it can furnish methyl groups that otherwise might be taken from the methionine present. The substance is found in many natural sources. Commercial supplements are usually prepared from sugar beet leaves.

Vitamin C—Ascorbic Acid. This vitamin is a powerful oxidation-reduction agent and has been isolated in the pure form and synthesized in large quantities. Some animals are capable of synthesizing the vitamin; others are not. For example, humans and guinea pigs do not have the ability, but rats, chickens, and dogs do. The ability of pigs to synthesize the vitamin has been demonstrated. In humans, the major symptom of a serious vitamin C deficiency is the disease known as scurvy, which produces swollen, bleeding and ulcerated gums; weak bones; loosening of teeth; and fragility of the capillaries with resulting hemorrhages throughout the body. A serious vitamin C deficiency in other animals produces similar effects.

In animal tissues, it is easily demonstrated that as the vitamin content of tissues is depleted, many enzyme systems in the body are decreased in activity, but the specific nature of the decreased activity is not well understood. In the total animal and in isolated tissues from animals with scurvy, there is an accelerated rate of oxygen consumption even though the animal becomes very weak in mechanical strength and many physiologic functions are disorganized. With the onset of scurvy, the most conspicuous tissue change is the failure to maintain normal collagen. Sugar tolerance is decreased and lipid metabolism is altered. There is also marked structural disorganization in the odontoblast cells in the teeth and in bone-forming cells in skeletal structures. In parallel with the foregoing changes, there is a decrease in many hydroxylation reactions. The hydroxylation of organic compounds is one of the most characteristic features disturbed by the vitamin deficiency: These reactions are believed to constitute an important part of the vitamin's regulation of respiration, hormone formations, and control of collagen structure.

Only in rare instances is it desirable to supplement livestock and poultry feed with vitamin C. Past tests have shown, for example, that dairy cows confined to barns for a period of 3 to 4 years and fed rations with practically no vitamin C had sufficient amounts in their blood and other tissues, proving their ability to synthesize sufficient quantities of the vitamin for their metabolic requirements. Vitamin C is formed during the germination of seeds and thus sprouted seeds are rich in the substance. Tests to relate vitamin C deficiency as a cause of sterility in cows and bulls have generally proved negative.

Specific Feedstuffs and Trends

A reasonably complete list of the more commonly used dry feed ingredients is given in Table 11, along with the density of each feed. Several of the major feed materials are described in other entries of this volume, notably the various entries on grains (**Barley**, **Maize(Corn)**, **Oats**, etc.); **Grasses**; **Hay and Forage Crops**, and **Silage**, as well as the entries on the various food animals. A volume of this nature does not permit lengthy descriptions of the several score of feedstuffs. The following paragraphs are devoted to observations pertaining to innovations and trends among the feedstuffs, with references to other entries in this volume as well as in the general literature.

Alfalfa. See **Alfalfa.** In mid-1978 trials at Arizona State University, it became apparent that the feeding value for alfalfa hay is higher than normally accepted when hay is fed with concentrate diets. According to W. H. Hale, "There is an 80% utilization of alfalfa hay in high grain rations, which is not true for other roughages." Hale reported an experiment which showed that with a mixture of 68% alfalfa hay and 32% cottonseed hulls, decreasing the roughage level with high grain rations resulted in an improvement in feed requirements as the roughage decreased. However, with alfalfa alone as the roughage source, there was no difference in feed requirements at the low roughage levels. In early 1977, researchers at Washington State University found that gestating sows fed alfalfa meal rations showed reproductive performance equal to or better than that of sows hand-fed barley-based rations. Researcher J. A. Froseth conducted the experiment to determine if sows could be maintained during gestation on self-fed rations containing 80 or 96.5% alfalfa with normal reproduction and without excessive weight gains. The effects of the inclusion of supplemental methionine were also determined. (See Froseth reference listed)

Barley. See **Barley.** Trials at Agriculture Canada research station, Agassiz, British Columbia, in late 1977 showed that the extra costs of steam cooking and flaking barley are not recovered when compared with steam-rolled barley as a starter ration for calves. The researchers reported that calves fed the starter rations based on steam-rolled barley were on test for fewer days and gained weight more rapidly than those fed a basal ration consisting of steam-cooked and flaked barley. (See Waldern reference listed) Researchers at Montana State University have reported that barley-based diets are low in energy and compensation must be made for this by adding approximately 5% fat to the ration.

Beans (Faba). See also **Bean.** Based upon research carried out at the Agricultural Research Council's Poultry Research Center, Edinburgh, Scotland in the late 1970s, the potential of new varieties of faba bean (*Vicia faba* L.), such as *Ackerperle, Diana* and *Herz Freya* in Canada; and *Maris Bean* and *Minor's Tic* (spring varieties) and *Throws MS* (winter variety) in the United Kingdom, appears excellent for livestock and poultry. Faba beans are a useful protein feed although they are relatively low in energy. A common replacement scheme is that 2 units of Faba beans are equivalent to 1 unit of soybean meal (44%), plus 1 unit of barley. Faba beans do not appear to create any problems in handling and storing, although grinding is reported to be difficult and slow. The beans contain growth inhibitors, but these appear to have little practical significance provided the ration is supplemented with methionine and is subjected to heat processing during manufacture. Excellent performance with poultry and livestock feed rations containing 10% Faba beans and even higher levels has been reported. It appears that Canada may become one of the main suppliers of Faba beans for the industry. (See Blair reference listed)

Bermudagrass. See **Grasses; Hay and Forage Crops.** Costs of feed grains during the latter 1970s encouraged interest in increased use of lower-cost forages for swine. Dehydrated alfalfa meal is frequently used in drylot rations for all classes of swines. Several studies have indicated that dehydrated Coastal bermudagrass can be substituted for dehydrated alfalfa in swine rations. Coastal bermudagrass may be used to reduce the energy intake of gilts that are self-fed during gestation. Reproductive performance is satisfactory when these forage meals made up 76% of the ration. Rations containing bermudagrass meals (or alfalfa meals) result in larger litters at weaning and greater litter weights than rations containing meals made from the whole green corn (maize) plant. L. W. Davis of the South Carolina Agricultural Experiment Station concluded that gestating gilts can be successfully self-fed on a pelleted balanced ration containing as much as 80% dehydrated Coastal bermudagrass. (See Trotter reference listed)

Brewers Dried Grains. See also **Beer and Other Malt Beverages.** The byproduct feeds of the fermentation industries make up an important segment of the commercial concentrates fed to dairy cows in the United States. Brewers grains produced throughout the country are used primarily as dry feed ingredients. In the late 1970s, the scarcity of fuel for drying and the associated economic pressures have stimulated interest in the direct use of brewers wet grains. Brewers dried grains are an important source of protein in commercial dairy feeds and could possibly be used directly as a medium-level protein supplement. Relatively large quantities of brewers wet grains are available in Ohio and some other states. H. R. Conrad and associates at Ohio Agricultural Research and Development Center conducted research to establish the comparative nutritive value of brewers dried grains versus brewers wet grains. Brewers rewetted grains were also tested.

There were no differences in milk production associated with the supplementation of the lactating cow ration of either brewers wet grain or brewers dried grains. There was a decrease in dry matter intake with a consequent savings in feed for the groups fed with brewers wet grains. There were no significant differences in gain per day in the calf study with the ration supplement with either wet or dried

TABLE 11. DENSITY OF DRY FEED INGREDIENTS[1]

Ingredient	Pounds per Cubic Foot	Kilograms per Cubic Meter
ALFALFA PRODUCTS		
Meal, dehydrated, 13%	16-18	256.3-288.4
Meal, dehydrated, 17%	18-22	288.4-352.4
Meal, suncured, 13%	14	224.3
Pellets, 17% reground	32	512.6
Pellets, 17%	41-43	656.8-688.9
Pellets, dehydrated, 22%	44	704.9
Seed	48	769.0
ANIMAL PRODUCTS		
Blood flour	30	480.6
Blood meal	38.5	616.8
Bone meal	50-60	801.0-961.2
Poultry byproduct meal	34-37	544.7-592.7
Tankage (digester)	49	785.0
BARLEY PRODUCTS		
Barley, ground	24-26	384.4-416.5
Barley, malt	30-31	480.6-496.6
Barley, rolled	21-24	336.4-384.4
Barley, whole	38-43	608.8-688.9
BREWERS PRODUCTS		
Brewers dried grains	14-15	224.3-240.3
Malt sprouts	13-16	208.3-256.3
CITRUS PRODUCTS		
Dried citrus pulp	20.5	328.4
CORN PRODUCTS (Maize)		
Corn (whole shelled)	45	720.9
Corn bran	14	208.3
Corn chops (coarse)	40-44	640.8-704.9
Corn chops (fine)	36-39	576.6-624.8
Corn chops (medium)	38-42	608.8-672.8
Corn feed meal	33.5	436.2
Corn germ meal	35	560.7
Corn gluten feed	26-33	416.5-528.7
Corn gluten meal	32-43	512.6-688.9
Corn grits (fine)	40-43	640.8-688.9
Corn meal	38-40	608.8-640.8
Corn oil meal	33-36	528.7-576.7
Ear corn	28	448.6
Ear corn chops	35	560.7
Ground cobs	17	272.3
Hominy feed	25-28	400.5-448.6
Kibbled corn	35	560.7
Popcorn (ear)	28	448.6
Popcorn (shelled)	44-45	704.9-720.9
COTTONSEED PRODUCTS		
Cake	37-40	592.7-640.8
Cake (cracked)	41	656.8
Delinted	25-35	400.5-560.7
Hulls	12	192.2
Oil meal	37-40	592.7-640.8
With lint	18-25	288.4-400.5
DISTILLERS PRODUCTS		
Corn (dried grains)	18-20	288.4-320.4
Corn (dried solubles)	36-40	576.7-640.8
GRAIN SORGHUMS (Milo)		
Milo (ground)	32-36	512.6-576.7
Seed (whole)	40-45	640.8-720.9
LINSEED AND FLAX PRODUCTS		
Flaxseed	43-45	688.9-720.9
Flaxseed screenings	26-28	416.5-448.6
Linseed feed	20-21	320.4-336.4
Linseed oil cake	45-50	720.9-801.0
Linseed oil meal (solvent extracted)	25-33	400.5-528.7
MARINE PRODUCTS		
Fishmeal	30-40	480.6-640.8
Shrimpmeal	25	400.5
MILK PRODUCTS		
Buttermilk (condensed)	31	496.6
Milk (powdered)	20	320.4
Whey (dried whole)	35-46	560.7-736.9
MINERAL FEED		
Bentonite	50-60	801.0-961.2
Calcium carbonate	75	1202.0
Cobalt sulfate	48	769.0
Copper sulfate	62	993.2
Ferrous carbonate	85-90	1361.7-1441.8
Limestone	68	1089.4
Oyster shells (under ½ inch; 1.3 centimeters)	53	849.1
Phosphate	75	1201.0
Phosphate (defluorinated)	97	1553.9
Phosphate (tricalcium)	21	336.4
Potassium iodide	22	352.4
Salt (coarse)	45-50	720.9-801.0
Salt (fine)	70-80	1121.4-1281.6
Sodium bentonite	41	656.8
Sulfur	13	208.3
Zinc sulfate	85-88	1361.7-1409.8
OAT PRODUCTS		
Feed oatmeal	16-32	256.3-512.6
Groats	46-47	736.9-752.9
Hulls (ground)	11-12	176.2-192.2
Hulls (unground)	8-9	128.2-144.2
Middlings	38	608.8
Oat chops	30	480.6
Oats (crimped)	19-25	304.4-400.5
Oats (crushed)	22	352.4
Oats (pulverized)	19-21	304.4-336.4
Oats (rolled)	19-24	304.4-384.4
Oats (whole)	25-35	400.5-560.7
GROUNDNUT (Peanut) PRODUCTS		
Meal	29	464.6
Shelled	15-19	240.3-304.4
Unshelled	17-24	272.3-384.4
RICE PRODUCTS		
Bran	20-21	320.4-336.4
Grits	42-45	672.8-720.9
Hulls	20-21	320.4-336.4
Rice (hulled)	45-49	720.9-785.0
Rice (polished)	30	480.6
Rice (rough)	32-36	512.6-576.7
RYE PRODUCTS		
Bran	15-20	240.3-320.4
Feed	33	528.7
Middlings	42	672.8
Rye (whole)	43-45	688.9-720.9
Shorts	32-33	512.6-528.7
SCREENINGS		
Chaff and dust	20	320.4
Dust	11	176.2
Grain screenings	30	480.6
SOYBEAN PRODUCTS		
Hulls (ground)	20	320.4
Hulls (unground)	6-7	96.1-112.1
Millfeed	25-27	400.5-432.5
Millfeed pellets	37-38	592.7-608.8
Oil meal (expeller)	36-40	576.7-640.8

TABLE 11. DENSITY OF DRY FEED INGREDIENTS[1] (cont.)

Ingredient	Pounds per Cubic Foot	Kilograms per Cubic Meter
Oil meal (solvent extracted, 44%)	35-38	560.7-608.8
Oil meal (solvent extracted, 50%)	41-42	656.8-672.8
Soybeans (ground)	25-34	400.5-544.7
Soybeans (whole)	46-48	736.9-769.0
VITAMINS		
Riboflavin	37	592.7
Vitamin A (dry)	48	769.0
WHEAT PRODUCTS		
Bran	11-16	176.2-256.3
Flakes	31-33	496.6-528.7
Flour	32-42	512.6-672.8
Germ meal	28-32	448.6-512.6
Middlings (standard)	18-25	288.4-400.5
Red dog	22-28	352.4-448.6
Screenings	17-25	272.3-400.5
Wheat (coarse cracked)	35-38	560.7-608.8
Wheat (ground)	38-39	608.8-624.8
Wheat (whole)	45-52	720.9-836.2
YEAST		
Dried yeast	41	656.8
MISCELLANEOUS PRODUCTS		
Bagasse	7-10	112.1-160.2
Beans, castor (whole)	36	576.7
Beans, lima (dry)	45	720.9
Beet pulp (dry)	11-16	176.2-256.3
Beets	48	769.0
Broomcorn (seed)	41-42	656.8-672.8
Buckwheat bran	15-16	240.3-256.3
Buckwheat hulls	12-13	192.2-208.3
Buckwheat middlings	22	352.4
Buckwheat (whole)	37-42	592.7-672.8
Clover (seed)	48	769.0
Copra meal	40-45	640.8-720.9
Copra oil cake	23	368.5
Copra oil meal	27	432.5
Corn and oats chops	17-18	272.3-288.4
Cowpeas	48	769.0
Dairy feed (concentrate)	43	688.9
Dairy feed (heavy)	20-28	320.4-448.6
Dairy feed (light)	18-22	288.4-352.4
Dextrose (corn sugar)	32	512.6
Egg powder	16	256.3
Hay (loose)	5	80.1
Hay (pressed)	8	128.2
Hops, spent (dry)	35	560.7
Malt (dry)	27-32	432.5-512.6
Malt (wet)	60-65	961.2-1041.3
Malt meal	36-40	576.7-640.8
Millet	38-40	608.8-640.8
Molasses feed	20-25	320.4-400.5
Mustard	46-58	736.9-769.0
Peas (dry)	48-50	769.0-801.0
Pellets, hog (¼-inch; 6 millimeters)	39	624.8
Pellets, rabbit (3/8-inch; 9 millimeters)	37	592.7
Sea coll	65	1041.3
Sesame	37	592.7
Sugar	50-65	801.0-1041.3
Sunflower (seed)	26-38	416.5-608.8
Urea	34-42	544.7-672.8
Velvet beans (hulled)	48	769.0
Vermiculite (expanded)	16	256.3

[1] Principal source: American Feed Manufacturers Association.

grains. There was a significant increase in nitrogen retention in calves fed the supplemented brewers wet grain over those fed the grains. The researchers suggested that protein digestion was depressed in calves fed brewers dried grains due to protein denaturation from heat damage. It is interesting to note that although the calves fed brewers wet grains had a higher nitrogen retention, those fed the dried grains had a greater weight gain per day. The researchers concluded that brewers dried grains were used more efficiently for milk production and suggested that this was associated with more rumen digestion and more microbial protein production. Brewers wet grains have a major disadvantage in that ingredients may spoil rather quickly and longhaul transportation is costly. (See Conrad reference listed)

Researchers at the University of Florida have shown that the addition of brewers dried grains to the diet of laying and breeding hens at the levels of 5% and 10% significantly improved interior egg quality as measured by Haugh units. This research also has been confirmed by workers at the University of Georgia. Brewers dried grains can be used in commercial egg feed formulation up to a level of 20% without adversely affecting the rate of egg production. (See Harms reference listed)

The increase in drying costs and environmental concerns of brewers yeast indicates the need for seeking alternate ways of handling the product for feeding, as pointed out in the late 1970s by D. G. Grieve of the University of Guelph, Ontario. In an experiment, 48 Hereford calves were used. The performance of cattle fed liquid brewers yeast was excellent and comparable with that of steers fed supplemental soybean meal, indicating that brewers yeast is a good potential alternative protein source. Disadvantages of the liquid yeast product include high transportation costs, the need for liquid feed handling equipment, and the tendency of the yeast to settle out of the slurry during storage. (See Grieve reference listed)

Cottonseed Meal. The introduction of glandless cottonseed meal may be advantageous to the feed industry. A glandless cottonseed meal has a higher confidence factor for use in animal feeds because users would be sure there would be no toxic reactions, and the metabolizable energy value of the meal would likely be greater. Gossypol has not been of concern to feeders of ruminant animals, cottonseed meal often being the supplement of choice for the beef cattle breeding industry, but poultry and swine have problems with gossypol. Gossypol in cottonseed will react with lysine, making some of the lysine in a meal unavailable to the monogastric animal. H. L. Wilcke, an authority in this field, has stated, "The severity of the effects depends on the level of gossypol in the total product.

According to University of California reserachers, better growth can be achieved with cottonseed meal than with urea, when used as a nitrogen source to supplement straw. This observation was made on the basis of feeding trials using cereal straws formulated by a computer least-cost ration program. The growing phase compared barley straw with wheat straw, with a further comparison of cottonseed meal and urea as the nitrogen sources. (See Hull reference listed)

Corn (Maize). See also **Maize (Corn).** Corn is a major forage crop as well as grain throughout the world. The whole corn plant is utilized for feed, particularly for beef, lamb and milk production. The corn (maize) plantings have been increasing throughout western Europe. Currently western Europe is about 50% self-sufficient in utilization of corn by animals. Large potentials for corn (maize) production in Yugoslavia are forecast by some authorities.

Increasing concern is being given to overdried corn. Researchers at the University of Nebraska are conducting a number of experiments to determine the effect of increased drying temperature on (1) Nutritional quality of corn protein; and (2) availability of several amino acids. Numerous drying conditions are used in the experiments, ranging from natural drying at 25°C (77°F) to temperatures as high as 125°C (251°F). The animals used in the test are weanling crossbred rats, weighing approximately 50 grams. Inasmuch as the data obtained are most likely applicable to swine rations, the following conclusions are of interest: (1) A significant decrease in grain, feed intake and feed efficiency of rats as the drying temperature increased, were noted. This suggests an impairment of the protein quality of corn to varying degrees, depending upon the severity of the heat treatment. (2) The protein quality of normal corn is affected more by heat treatment than opaque-2 corn. (3) Prolonged heating has a detrimental effect on the quality of both corn (maize) varieties. (4) The amino acids most affected by heat treatment are lysine, threonine, isoleucine, methionine, valine, and tryptophan. Lysine was particularly affected by prolonged heating at 50°C (122°F). Corn as a source of energy is also impaired by high drying temperatures.

Particularly at times of large harvests, there is a tendency to hasten the drying process by turning up the temperature. Sometimes feed supplements are falsely blamed for poor performance, but the quality of the feed corn is taken for granted. In such instances, the quality of the corn also should be questioned. (See Goihl reference listed)

Ohio State University researchers have found that high-moisture shelled corn fed to cattle shows a consistent and positive advantage over dry corn. H. W. Newland reports an overall average improvement in feed efficiency of 3.31% for ensiled high-moisture corn and 3.2% for acid-treated high-moisture corn. With high-moisture ground-ear corn, feed conversion was improved 6.51% over dry corn in trials with yearling steers.

As of mid-1978, feedlots have not yet changed their operating or processing methods as the result of rising energy costs—according to a panel of Arizona cattle feeders. Alternative methods doubtless will be used when the feeders are forced by economics. Some attention has been given to the cost of steam flaking, but the process has not been abandoned. One alternative to steam flaking would be "reconstitution" of milo or corn (maize), in which dry grain is soaked to a moisture level of about 30% and stored in air-tight structures 3 weeks before being ground or rolled and fed. Studies have shown an 8% improvement in digestibility of reconstituted milo over dry-rolled, both with and without nitrogen supplementation.

Feed-grade Animal Fat. Abbreviated FGAF, feed-grade animal fats are triglycerides, ranging from the more unsaturated poultry and pork fats (greases) to the more saturated beef tallow. Lower-melting fats with a higher level of unsaturated fatty acids are to some extent digested more efficiently and rapidly than saturated fats, such as hydrogenated oils and tallows, as shown by Table 12. The nutritive effect of fat is due primarily to its caloric content. The range of caloric values for various fat sources is also shown in Table 12.

There are additional, indirect advantages of fat in animal feed: Improvement of overall nutrient efficiency and digestibility by lowering feed spoilage through reduced dustiness and improved physical acceptability. In feeds, small levels of added FGAF bind smaller, dustier particles of cereal starch into aggregates. A decrease in the incidence of pneumonia and respiratory difficulties among swine has been attributed to reducing the dust particle count. The color, improved appearance, and palatability tend to aid in appetite control and increase feed consumption and hence to improve feed consumption and growth rate. Some authorities also regard fat as a means for improving the availability and absorption of fat-soluble vitamins, pigments, and amino acids. The so-called "protein-sparing effect" can lead to weight gain in excess of calculated caloric value, when protein or amino acids, such as lysine, are growth limiting.

In feeds without added fats, the low content of preformed fatty acids will be almost entirely oxidized and utilized for energy production. Animals need certain amounts and types of fatty acids for the synthesis of special body fats. The growing pig puts on between 500 and 800 grams of liveweight per day. Of this a substantial amount (20 to 30%) is laid down as fat; this is because the genetics of the pig and its temperature threshold dictate a layer of insulating fat in addition to fat which is laid down between the muscles. Unless a minimum amount of preformed fatty acids is already provided in the feeds, they must be obtained from the metabolic breakdown of carbohydrates and/or proteins. From the economics standpoint, the latter is an inefficient and wasteful process because such chemical transformations involve losses of energy. Consequently, the

TABLE 12. CHARACTERISTICS OF VARIOUS FATS

Fat Source	Melting Point Range °C	°F	Digestibility (%) Range (In monogastrics)	Metabolizable Energy (Kcal/kilogram)
Food-grade animal fat	34-38	93-100	93	8750
Pork fat	32-38	90-100	94	8850
Poultry fat	28-35	82- 95	96	9000
All-beef tallow	38-42	100-108	84	7800
Vegetable fat (palm oil)	28-36	82- 97	96	8900

avoidance of such steps results in higher energy utilization, being proportional to the amounts of preformed fatty acids which are directly absorbed through the gut wall and moved to the side of deposition with less energy loss. Once this requirement is met, the value of fat reverts to its energy contribution.

Since each species of animal stores body fat in a characteristic manner, poultry fat would be the logical choice for poultry rations, for example.

Inclusion of fat in the finishing rations of pigs usually has been associated with increased energy intake, a faster rate of gain, and improved feed efficiency. Added dietary fat, especially at levels exceeding 10% of the total diet, has generally led to increased carcass fat. Market demand is for lean meat products and thus any nutritional factor which increases carcass fat can be undesirable. However, if performance of finishing pigs could be improved without adversely affecting carcass fat content, then addition of ingredients such as tallow would be desirable. This problem has been under investigation by R. Waterman and associates at Michigan State University. It has been found from a series of trials involving 75 Yorkshire-Hampshire crossbred pigs that 3% tallow supplementation resulted in a reduction in time to market weight by about 4 days, while metabolizable energy consumed per unit gain was reduced by approximately 4%. Carcass composition was not adversely affected by addition of 3% tallow to the diet. Carcass backfat thickness was reduced by about 4%, while fat trim was approximately 2% less in pigs fed diets containing 3% tallow. Hydrogenated flaked tallow did not improve performance, probably due to its poor digestibility. (See Waterman reference listed)

Moser and Fritschen at the University of Nebraska in a separate study found that adding tallow to the diet of growing-finishing swine improves average daily gain and feed conversion. The researchers observed that a significant increase in average daily gain may not be observed until the added tallow level is about 5% of the diet. Adding tallow at low levels (2–3%) had little effect, if any, on backfat thickness. Levels higher than 4% and up probably slightly increase backfat thickness. The amount of increase appears to depend upon the type of pig and the level of tallow added. The fat-type pig has a tendency to respond to high-tallow diets by increasing backfat thickness more than the naturally lean-type pig. The study also indicated that improvement in feed conversion begins with the first level of added tallow and increases with additional increments of tallow until the 8–10% added tallow level is reached. The researchers observed that because there is a lower heat increment in fat metabolism, pigs should respond to high fat diets better in a warmer environment than in a colder environment. This observation was confirmed by a study made at the University of Georgia College of Agriculture. (See Moser–Fritschen reference listed)

Baby pigs have shown a preference for a pig starter or creep diet when lard has been added to the diet. This has been true for several different formulations, experimental procedures and locations, according to a study conducted by V. C. Speer and associates at Iowa State University. The minimum dietary level of lard that will accomplish the result has not been established. There are indications that tallow and hydrolyzed animal-vegetable fat possess similar attributes, but the responses are not as consistent as with lard. (See Speer reference listed)

Additional work on use of tallow in swine diets has been conducted at the University of Minnesota. (See Meade reference listed) Advantages, limitations, problems, and solutions of adding fat to pelleted feeds have been investigated at Kansas State University. (See Kershner-Headley reference listed).

Means for adding fat to feeds locally and in comparatively small quantities is illustrated and described in Fig. 2.

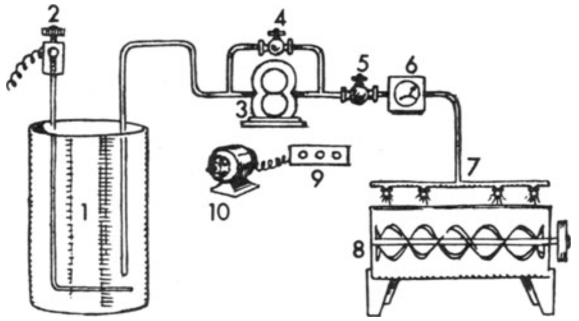


Fig. 2. Simple arrangement for adding tallows in feeds in comparatively small feeding operations: (1) Electric heater for melting fat in drums; (2) thermostat; (3) gear pump; (4) overload valve; (5) gate valve; (6) meter for correct dosage of fat; (7) nozzles; (8) horizontal batch mixer; (9) three-post switch to reverse rotation of pump, thus permitting the clearance of pipes; (10) three-phase electric motor. (*National Renderers Association*)

In ruminants, the rumen plays a special role in the digestion and utilization of fat. The fat entering the rumen is first hydrolyzed and then the fatty acids are hydrogenated by the rumen microorganisms. As a result, regardless of the characteristics of the fat included in the ration, the composition of the fat deposited in the carcasses is usually of a homogenous and highly saturated nature.

Previous studies have indicated that in cattle rations the maximum level of fat in the ration which can be efficiently utilized is approximately 5%. At levels in excess of this, severe depressions in consumption and digestive disturbances may be noted. In addition, higher levels of fat may depress cellulose digestibility.

In 1970, workers in Australia reported the development of a process for treating fat which completely changed its mode of utilization by ruminants. The process involves encapsulating fat particles with a layer of protein (casein) and then treating the protein with formaldehyde. This process "protects" the fat from rumen digestion and fermentation and thus is bypassed to the abomasum where the protein is digested and the fat released and utilized as it would be by a monogastric animal. Fat treated in this manner has many potential advantages as compared to conventional fat. A major emphasis by the Australian workers was on the effect of the protected fat on the composition of the fat deposited in the tissues. The Australian workers reported that if polyunsaturated oil particles were treated, the result would be a marked increase in the deposition of polyunsaturated fat in the tissue and milk.

Because of the suspected link between saturated fat in the diet and arteriosclerosis in some humans, it was felt that the process could have important medical implications. Furthermore, increasing the polyunsaturated fat content in lamb carcasses altered the flavor and aroma of the meat, resulting in a greater acceptability by some consumers. Progress of this "protected fat" procedure is reviewed by K. S. Eng. (See Eng, Cook, and Scott references listed)

Feather Meal. Hydrolyzed poultry feathers is the product resulting from the treatment under pressure of clean, undecomposed feathers from slaughtered poultry, free of additives and/or accelerators. Specifications require that not less than 75% of the crude protein of the meal shall consist of digestible protein (as determined by the pepsin digestibility method).

Feathers are almost pure protein. Most of this is keratin protein, which in the raw or natural state is not readily digestible by animals. Processing with live steam to partially hydrolyze the protein breaks apart some of the chemical bonds that account for the peculiar structure of the feather fibers. The resulting feather meal is a free-flowing, palatable product that is easily digested by all classes of livestock and poultry. Processed feather meal is quite uniform because it is a single-source protein and such proteins have a relatively constant composition and amino acid pattern. Feather meal is a rich source of cystine and thus conserves methionine which otherwise must be used to provide the required cystine. Tests have shown that the amino acids in feather meal are from 94 to 98% available to chicks. In swine feeds, a 2:1 ratio of soybean meal and feather meal provides a protein supplement of good quality for growing pigs. As a protein source for ruminants, the comparative value of feather meal and the oilseed meals is roughly proportioned to their respective protein contents. Tests have shown that feather meals serves as an effective ingredient in cattle concentrates that contain high urea levels. When high urea cattle concentrates contain about 7.5 to 10% feather meal, the power requirements for pelleting are reduced and handling properties of the pelleted concentrate are improved. Some feather meal is now incorporated in pet foods—to the extent of 2 to 4%. Tests have indicated that an improvement in hair and coat of animal pets improved as the result of cystine availability.

Fishmeal. Fish protein in the form of meal contains relatively high levels of lysine and methionine and other essential amino acids, and consequently is especially valuable in supplementing cereal grain and oilseed proteins used in feeding poultry and swine. Most of the vegetable proteins fail to supply completely the dietary amino acid requirements of these animals. In addition, fish meal is rich in a number of minerals and vitamins.

The oil fraction of fishmeal is composed of unsaturated triglycerides and phospholipids with high iodine value. In the presence of atmospheric oxygen, these two components autoxidize during storage of fishmeal. The autoxidation reaction is exothermic and results in the formation of primary and secondary oxidation products, that is, hydroperoxides, nonvolatile carbonyls, etc. As the autoxidation reaction progresses, high-molecular-weight polymerized compounds are also formed. One of the results of the autoxidation reaction is the decrease in the degree of unsaturation of the meal-oil fraction. The oxidative deterioration of fishmeal during storage is well recognized as conducive to decline in nutritive value. The antioxidants, butylated hydroxytoluene and 6-ethoxy-2, 2,4-trimethyl-1, 2-dihydroquinoline, are commonly added to fishmeal after the drying operation so as to regard the progress of the autoxidation reaction during storage. Autoxidation commences during the drying operations. More powerful antioxidants are required to improve storage capabilities. A more effective antioxidant is tertiary butyhydroquinone, approved in 1972 as a direct food and feed additive. Considerable progress is being made in the investigation and development of more effective antioxidants. (See Chahine reference listed)

Meat and Bone Meal. This is a major by-product of the rendering process and, for over 50 years, has served as one of the most important protein supplements and, at the same time, one of the most important sources of phosphorus for poultry and swine rations. Through years of experience, the producers have developed reliable means for maintaining uniformity of protein values, amino acids, calcium, and phosphorus in their product.

The biological values, that is, the levels of all essential amino acids of muscle tissue and organ tissue are very high. The biological values of collagen and blood are low. In order to produce a feed supplement of uniform amino acid value and, therefore, of uniform usefulness to the nutritionist in computer formulating of feed to exactly meet amino acid requirements, it is necessary to blend all elements uniformly. It is also important to heat-treat the product so as to sterilize it, particularly to eliminate Salmonella; to dry the product to a moisture content of less than 10%; and to avoid overheating the product so that irreversible binding of lysine and destruction of methionine and cystine will not occur. When the moisture content is above 10%, there is the danger of a mold, *Candida albicans*, forming and this can produce fungus infections in the feeding animals.

In poultry, about 9% of meat and bone meal can be used in a corn-soy a diet to provide all of the necessary calcium and phosphorus, but still not at levels which are excessive to the extent of reducing growth and feed conversion, or enhancing onset of perosis or other leg weaknesses. This topic is described in interesting and valuable detail by M. L. Scott (See references listed).

Pea Screenings. Austrian winter peas are an important crop grown principally in northern Idaho. Small grains are often grown in conjunction with Austrian winter peas to facilitate their production and harvest. When field-run Austrian winter peas are screened to produce No. 1 grade peas, a by-product generated is Austrian winter pea screenings. Typically, small grains make up 40 to 80% of the total of the screenings, with small, cracked, shriveled and otherwise unacceptable peas making up the balance. This by-product is usually economically priced and can be an excellent feed for swine due to high energy content and protein concentrations. Results of tests made at Washington State University in 1977 show a good potential for this feed source. (See Kendall reference listed).

Rapeseed. See also **Rape.** During the last decade, increasing attention to rapeseed as a feed source has been reported. In mid-1977, researchers at the University of Guelph (Ontario) reported that rapeseed may be beneficial for improving the carcass quality of heavy-weight hogs. The rapeseed meal used in the tests is the relatively new variety with low glucosinolate levels. (See Bowland; and Grandhi references listed)

Roughage. Since the early 1970s, there has been an accelerated interest in processing straw and other roughages, growing out of increasing grain costs and air pollution laws that prohibit the burning of straw in many areas. As of the early 1980s, several plants have commenced operation in which the sodium hydroxide treatment of straw is used.

At the Hoosier Cow-Calf Days conference in December 1977, researchers from the Miller-Purdue University Agricultural Center observed that residue feeds, such as wheat straw and dry harvested corn (maize) stalks could provide at least one-half the energy and from 25 to 30% of the protein required by pregnant beef cows with minimal weight loss during late gestation. In a study made by Hendrix, Nelson, and Huber, the ability of low quality roughage to maintain gestating cows did not appear to vary greatly among breed. Three beef herds were involved in the test. (See Hendrix reference listed)

Among the feed sources that could potentially replace the large quantities of roughage presently obtained from grazing by beef cows are the numerous crop residues. Costs restrictions in the past have limited the feeding (both to sheep and cattle) of crop residues to about 25% of that potentially available for livestock feed. The costs of machinery for collecting residues from the fields and the costs for fencing cattle in for grazing have prohibited the widespread use of crop residues. An inventory of crop residues is available from a study conducted by the Stanford Research Institute in 1976. (See reference listed). The main objective of this study was to evaluate crop residues as a potential energy source. An interest in the feed sources available for alternate beef production systems led to an evaluation of the potential feed value of crop residues. Thirteen of the 50 residues studied by Stanford Research Institute were selected as have potential cattle feed values. These were reported by J. M. Blanchard and associates in an excellent article in 1977 and are summarized in Table 13. (See Blanchard reference listed)

Although massive quantities of wheat straw are created each year, the substance is low in digestibility and energy. These barriers for using wheat straw efficiently with feedlot cattle may have been partially overcome by work done by G. V. Davis at Kansas State University. (See Davis reference listed) More rapid gains were achieved with a ration containing wheat straw treated wth aqueous ammonia (cropland fertilizer), supplemented with cottonseed meal, that were achieved with the control group fed conventional corn silage. The most efficient and economical gains were observed when the traditional corn silage was fed. Research is also being conducted on the use of high energy corn and milo stover.

Considerable progress has been in the Netherlands as regards the chemical processing of straws. One of these processes involves the use of sodium hydroxide at a rate of 40 grams NaOH per kilogram of dry matter. As of the early 1980s, five plants are operating in the Netherlands, each producing about 25,000 metric tons (22,500 tons) of treated straw per year. The processed straw is used mainly as an ingredient for the manufacture of mixed feeds for ruminants. Suitable equipment for farms is also available, but it is rather costly and also sodium hydroxide is a dangerous chemical to use and requires experience. Calcium hydroxide is safer and more suitable for local applications. It has been estimated that the amount of straw produced in Europe, if treated with sodium hydroxide, could provide for the maintenance of nearly 90% of the some 125 million head of cattle. Some researchers suggest that from 10 to 15% of the processed straw could be used in dairy concentrates and possibly up to 30% in beef rations, as a partial replacement for grain.

TABLE 13. NUTRITIONAL VALUES OF CROP RESIDUES
(Dry Basis)

Residue	Dry Matter %	Total Digestible Nutrients %	Protein %
Barley straw	87	44	4.1
Cotton field residue	92	41	6.2
Cotton gin trash	90	45	7.4
Field corn (field residue)	77	70	8.8
Flax field residue	93	38	7.7
Groundnut (peanut) hay	91	58	5.5
Oat straw	89	52	4.2
Sorghum straw	85	57	5.3
Sugar beet tops	18	58	16.7
Soybean field residue	88	42	5.1
Sweet corn field residue	22	65	7.3
Sweet corn shed	77	70	8.8
Wheat straw	88	49	3.6

Data Source: Stanford Institute

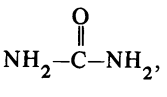
For some years, the Melfort Research Station in Saskatchewan has been studying the possible advantages of feeding ground versus bulk roughage. Results indicate that greater weight gains can be achieved with the ground material. Research at the University of Minnesota also has shown that cattle gain significantly faster if fed 3 pounds (1.3 kilograms) of ground alfalfa/brome hay per day than the same amount fed long. In addition, higher percentages of ground roughage in a fattening ration for feeder cattle production reduces the overall cost of the ration, yet results in comparable gains with low roughage rations. Authorities state that higher weight gains are due primarily to increased feed intake by the animal because ground hay requires less breakdown, and the rumen is not filled with long bulky hay, which takes a longer time to break down before traveling down the digestive tract. If advantage is taken of this increased intake capability more rapid gains result. The higher the level of roughage in the diet, the greater the response to grinding.

Silage. See **Silage**; also **Hay and Forage Crops.**

Sudangrass. According to a study at the University of California at Davis, sudangrass hay supplemented with energy, nitrogen, and calcium can effectively replace alfalfa hay in beef finishing rations. See also **Grasses**; and **Hay and Forage Crops.** Researchers Lofgreen and Prokop observed that if the cost per unit of nutrient for fat, urea, and limestone remains constant, the cattle feeder may have an economic incentive for using sudangrass, which is marked below its economic feeding value. In the study, 72 good-quality steers of Hereford, Angus, and Hereford X Angus breeding were randomly assigned to 12 outcome groups of six heads each. Six groups were assigned to the control ration containing 7% alfalfa hay and 3% sudangrass hay. The remaining outcome groups were assigned to the experimental ration containing 8.7% sudangrass hay, along with added fat, urea, and limestone. Tests showed that animals fed the experimental ration gained weight at the same rate as the control fed group. (See Lofgreen reference listed).

Sunflower Meal. See also **Sunflower Oil and Meal.** Sunflower meal is equal to cottonseed meal as a protein supplement, according to a Texas Tech University study conducted during early 1978. Two metabolism studies were conducted using growing steers to evaluate sunflower meal as a protein supplement as compared with cottonseed meal and to determine the digestibility of sunflower meal. Digestibility of sunflower meal alone tended to increase as the percent in the diet increased. The results indicate that sunflower meal can be used as a protein supplement for ruminants and that no essential differences exist between the digestibility and utilization of sunflower meal and cottonseed meal. These findings are particularly important in light of increased plantings of sunflowers and declining cotton acreage in some regions. In contrast to some protein concentrates, sunflower meal is not known to contain any growth depressing or toxic substances which would limit the amount used in livestock and poultry rations.

Urea. This simple nitrogen-containing organic compound,



$$NH_2-\overset{\overset{\large O}{\|}}{C}-NH_2,$$

obviously contains no proteins or amino acids, but because of the ability of ruminants to synthesize complex organic substances from comparatively simple sources, urea can be used as a nitrogen-supplying supplement for feed supplies. Most available feeding urea contains 45% nitrogen. Protein equivalent is estimated by multiplying the percent nitrogen by 6.25 (common protein factor), thus giving feeding urea a protein equivalent value of 281%. Actions of the rumen bacteria are difficult to express quantitatively. Most authorities estimate that 1 pound (0.45 kilogram) of urea, when fed with 6 pounds (2.7 kilograms) of corn (maize) is equivalent to 7 pounds (3.2 kilograms) of cottonseed or soybean meal. The availability of urea as a supplement accentuated interest in feeding comparatively low-cost roughages, such as corncobs, straws, and low-grade hays.

Precautions must be taken when formulating urea-containing diets because urea contains no minerals, vitamins, or trace elements. Also, if used with large proportions of low-grade carbohydrate sources for energy, the ability of the rumen to convert such materials into protein may not be adequate. Some authorities believe that urea content should not exceed one-third of the total diet. This amount is lowered to one-fourth in the case of pregnant and lactating cows. Hazards involved in feeding urea include the possible breakdown of urea into ammonia and carbon dioxide instead of into needed proteins. This situation can occur when urea is fed with beans (including raw soybeans) and alfalfa, lespedeza, and wild mustard seeds. This makes the feed less attractive to the cattle and importantly reduces the conversion of urea into proteins. High urea intake also can cause urea toxicity, manifested by bloat, muscular incoordination, convulsions and, in extreme cases, death of the affected animals. Opinions vary among producers as regards the palatability and hence intake of feeds containing relatively high amounts of urea.

As pointed out by M. A. Hoelscher (see reference listed), urea is most useful in situations where there is a surplus of energy available to bacteria or when rumen ammonia levels are low because of protein levels or solubility. Practical examples of these situations are a high-grain ration where there is a surplus of available energy or low-quality roughage ration, such as corn stover, where there are low rumen ammonia levels. The need to balance energy and ammonia levels in rumen inspired the search for a nonprotein nitrogen system.

A slow-release form of urea is being developed. A coated urea that releases ammonia slowly has shown in tests to be superior to conventional urea for wintering range cows.

Waste Materials. With the escalating feed costs of the 1970s, increasing attention has turned to alternative feeds, particularly feeds prepared from low-cost waste materials.

(Animal Blood). It is estimated that some 2 billion pounds (0.9 billion kilograms) of livestock and poultry blood are discarded in the United States each year. Worldwide, the quantity is much greater. Considering that blood is about 20% solids, there is a potential of some 200,000 tons (180,000 metric tons) of bloodmeal per year. How to get is handled and processed, and how to persuade slaughterers and processing plants to develop means of saving the blood and converting it into a more useful form than waste was considered at length at the 1977 meeting of the National Renderers Association.

Bloodmeal processed by some of the newer procedures contains all of the solids, cellular and plasmal, of whole blood. The principal interest in bloodmeal is its high protein content and, in particular, the high amount of the critically limiting amino acid, lysine. Bloodmeal has been in limited use in livestock rations in the past because extended vat-drying procedures result in a product of poor palatability and poor bioavailability of lysine. Flash-drying procedures have improved both of these factors. The processing techniques which destroy lysine are actually, the improper use of the basic tools of the renderer, that is, the improper application of heat to remove moisture. Some loss of lysine during rendering is inevitable, the loss can be cut considerably by flash-drying. Research going on at Michigan State University and at the Richard E. Russell Research Center in Athens, Georgia is summarized in the R. H. Brown (listed reference) article.

(Dried Poultry Waste). Relatively recent research in Europe indicates that broilers can utilize nonprotein nitrogen (NPN) in low concentration in well-balanced rations containing adequate amino acids. Advantages of using dried poultry waste, as summarized by researchers at the Agricultural University in Wageninger (Netherlands) include: (1) Poultry waste, dried and after proper treatment, contains undigested feed, metabolic excretory products and residues resulting from microbial synthesis; (2) it contains microorganisms, which convert some of the uric acid in the poultry excreta into microbial protein, which can then be utilized by the fowl; (3) it is well known that it provides an unknown growth factor; (4) it contains some true protein besides the nonprotein nitrogen; and (5) its use can contribute to a reduction in pollution problems. Tests to date indicate that additions of dried poultry waste up to 5% of the total diet appear reasonable. (See El Boushy reference listed)

Numerous other waste materials have been suggested and tested and, as of the late 1970s, are not in a fully proven state. These include **feedlot wastes**, as reported in the Hoelscher reference; recycled **swine wastes**, as being investigated by the University of Kentucky and reported in the Ross; and Overhults references; and **algae**. It is estimated that up to 70% of the nitrogen fed to swine is lost to spillage and excretion. This would indicate that at least 30% of the waste nitrogen can be recovered as algal protein. In University of Florida trials, researchers are using the continuous mass culture of algae with swine wastes as a nutrient source and eventually refeeding the algal product. Manure nitrogen, according to the researchers, is a naturally renewable resource and, in its present quantities, is potentially of commercial value as a raw material for the production of plant protein. Estimates have been made that in the United States alone, the production of nitrogen in animal wastes amounts to some 30 billion grams daily, an amount sufficient to supply protein nitrogen requirements for every person on earth. Details of the present research, algae growing methods, etc. are given in the Lincoln reference listed.

Many **candidates for alternative feeds** have been suggested during the 1970s. According to industry authorities, only relatively few of these will be commercially successful. At the 1978 meeting of the American Feed Manufacturers Association, the following materials were considered most likely to succeed: (1) Flash-dried blood meal; (2) bark; (3) encapsulated "or protected" fat; (4) corrugated box paper; (5) ground almond hulls or shells; (6) processed food wastes; (7) low-chlorine dicalcium phosphate; and (8) processed animal wastes. According to one authority, processed animal wastes (or recylced nutrients) probably has more potential than the others. (See Brown reference listed)

Whey. As manufacturers increase production of cheese, more whey becomes available to the livestock industry. According to A. A. Jimenez, the most practical and economical way of disposing of this by-product is to feed it directly to the livestock without condensing it or evaporating it. Some of it is being blended with other liquid feed ingredients into liquid supplements; other portions go direct to the livestock producer. Questions have arisen as regards liquid whey increasing dry matter intake; and depressing fiber digestibility. Researchers in Vermont have concluded that dairy cows can consume as much as 5.2 pounds (2.4 kilograms) of whey dry matter without detrimental effects. Furthermore, total dry matter intake is enhanced by whey solids and fiber digestibility is not adversely affected.

Simplified Mixed-feed Calculations

Assume that it is desired to mix:

1. Grain with a protein concentration of 9%, with
2. Concentrate with a protein concentration of 48%, to form a
3. Mixture with a protein concentration of 19%

This problem can be solved algebraically, or by means of the Pearson Square method.

Algebraic Solution

Weight of Grain X .09 + Weight of Concentrate X .48 = Weight of Mixture X .19

Let total weight of mixture = 100 pounds (kilograms); Protein = 19 pounds (kilograms)

Weight of Grain = 100 – Weight of Concentrate
(WG) (WC)

Thus,

$$(100 - WC) \times .09 + WC \times .48 = 19$$

$$9 - .09\,WC + .48\,WC = 19$$

$$.39\,WC = 10$$

WC = 25.64 pounds (kilograms) or Percent

WG = 100.00 – 25.64
= 74.36 pounds (kilograms) or Percent

Proof

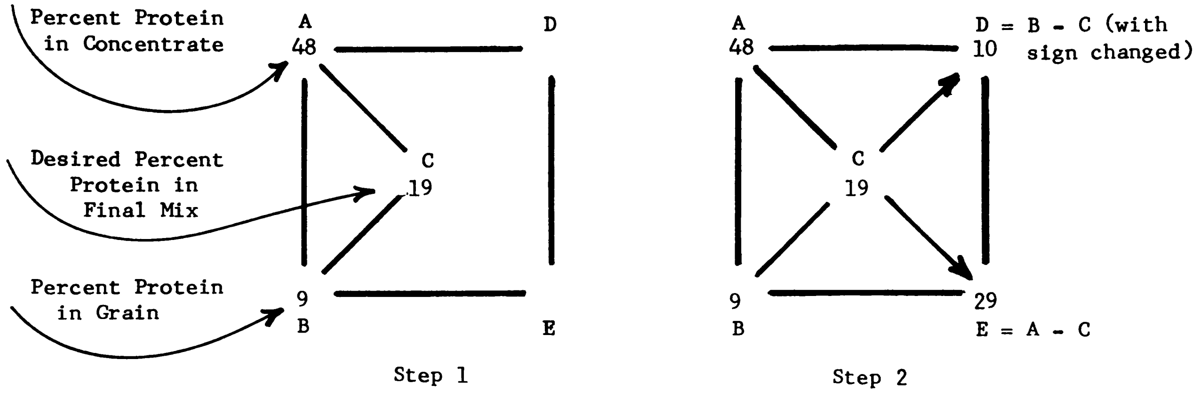
25.64% X 48% = 12.31% protein contributed by concentrate
74.36% X 9% = 6.69% protein contributed by grain
19.00% protein total

Pearson Square Method

Some producers prefer to use the square method as illustrated in Fig. 3.

Water in the Animal Diet

In the great amount of attention given to various feedstuffs for the nutrition of food animals, sometimes the matter of water as part of the total diet is deemphasized. Considerable attention has been given to the water requirements of milk cows. It has been established that a milk cow requires from 4 to 5 pounds (1.8 to 2.3 kilograms) of drinking water for each pound (0.45 kilogram) of milk produced. It is also established that the easier it is for cows to gain access to good water of the right temperature, the more water they will consume and the more milk they will produce. Other animals may not have been studied as well as the milk cow, but it is generally recognized that decreased water intake



Step 3: $\frac{D \times 100}{D + E} = \%\ A$ $\qquad \frac{10 \times 100}{39} = 25.64\%\ A$

$100 - 25.64 = \%\ B \qquad = 74.36\%\ B$

25.64 pounds (kilograms A

25.64 pounds (kilograms) A X 48% = 12.31 pounds (kilograms) protein
74.36 pounds (kilograms) B X 9% = 6.69 pounds (kilograms) protein

100.00 pounds (kilograms) A + B 19.00 pounds (kilograms) protein
= 19% protein

Fig. 3. Pearson Square method of calculating feed mixes when 3 factors are known. Step 1 entails filling in values for A, B, and C. Step 2 requires calculation of D and E. Step 3 requires use of two very simple formulas.

reduces feed intake, thus adversely affecting growth rate of young animals or production rate of mature animals.

Of importance to nutrition, there are four basic classifications of water: (1) Drinking water (free water); (2) Feed water which is present in highly succulent feeds, but which is found even in drier feeds. Dry hay, for example, may contain from 9 to 12% water; (3) Metabolic water, which results from the "burning" of feedstuffs in the animal body; and (4) Bound water, which is water bound intimately within the molecule of a substance.

In an excellent review of the importance of water to animals, E. W. Kienholz lists and elaborates 13 reasons why water is "the most important substance on earth" and these are abstracted here:

1. Water is an excellent solvent. Glucose, amino acids and several mineral ions and water-soluble vitamins and metabolic wastes are solubilized in water before being transported in the body.

2. Water has a very high specific heat. This means that water absorbs a tremendous amount of heat as its temperature increases. If ethanol were the heat-carrying fluid in the blood, the blood could carry only about one-half as much heat from working muscles to the body surface and the lungs. This would greatly limit an animal's work capacity.

3. Water has at least twice the heat of vaporization of other common fluids. With ethanol having only about 40% of the heat of vaporization of water, another problem would occur in the lungs. The lungs would need to evaporate 2.5 times as much ethanol as water to get equal cooling of the blood.

4. Water promotes hydrate formation. Strong polar ions attract many water molecules, which bunch up around that ion, greatly increasing the solubility of that ion in water. Thus, certain proteins are soluble when they might otherwise not be expected to be.

5. Water has a high dielectric constant. This quality aids in separation of a salt into its component ions. For example, it aids in separation and dissolution of common salt into positive sodium and negative chloride ions.

6. Water is chemically involved in digestion. Digestion is the hydrolysis of bonds that hold the food's subunits together. Thus, starch is hydrolyzed to sugar; fat to fatty acids and glycerol; and protein to amino acids. They are then absorbed across the gut wall and travel in water (in the blood) to the liver for redirection.

7. Water is an excellent lubricant. In body joints there seems to be little problem with keeping sufficient water present and there is very little friction from bending of joints in living animals.

8. Water is a product of energy metabolism. Metabolic water is made from oxygen and spent fuel. How could you devise a better way of deriving energy from fuels and have so little trouble with the waste products?

9. Water transmits light and sound. This characteristics may not seem so important, but were it not the case, other liquids would have to be devised lest animals exist without sight or hearing.

10. Water vapor is lighter than air. If water vapor were heavier than air, it would ten to cause a water-saturated, stagnant air in the few feet above the earth's surface where animals live. That would limit the ability of animals to load

body heat onto air because the air would already be saturated with water. This characteristic also enables the evaporation of sweat from the surface of the animal.

11. Water has a very low viscosity. This makes it easy for water to move through small tubes. With a minimum of pressure, it is important to move animal blood through tiny capillary vessels. If the animal were to pump automobile oil through the blood system at the normal flow rate, a heart of over 10 times the size of the animal heart would probably be required.

12. Water has an appropriate surface tension. This is the ability of water to coalesce or hold tightly together at any interface with some other substance. Water has sufficient surface tension so that it does not readily wet nonpolar surface, such as fatty materials, thus allowing fatty materials to exist in the animal body undisturbed by water. This translates, for example, into terms of cell-wall barriers that have high levels of lipids which rather easily confine watery material in a cell. But, water wets polar materials, such as many food substances and the metabolic products produced in the cell, thus allowing their needed transport.

13. The last reason given by Dr. Kienholz is that water changes weight with changing temperature, the colder water being denser (4°C; 39°F = temperature of maximum density) up to a point. This phenomenon is very important to fishes. When a lake, for example, is cooled down, warmer bottom water rises, carrying with it many of the dissolved minerals and organic materials which had rotted and sunk to the bottom of the lake. Thus, the lake brings back to the surface a renewal of nutrients each year that helps to sustain fish life.

As listed by A. A. Jiminez (See Jiminez reference listed), some of the common water problems for livestock and poultry producers include: (1) Nitrates and nitrites; (2) Salmonella contamination; (3) rotten stagnant water; (4) *E. Coli* contamination; and (5) algae contamination.

Where nitrites or nitrates are suspected, their presence may indicate either bacterial contamination of the water source or subsoil leaching of a nitrite/nitrate source. Various kinds of fishes grown in large water troughs are considered carriers of the bacteria. Usually removal of the fishes, and cleaning and disinfecting the troughs clears up the problem. Stagnant water can cause severe diarrhea problems in milking cows. Cows should not be permitted to drink dead, stagnant, foul-smelling water from drainage ditches. *E. Coli* contamination results in severe diarrheas and may cause serious mastitis problems. Although algae contamination is common where poultry and livestock are handled, such as in feedlots, the livestock are subject to poisoning from toxins derived from algae blooms.

Liquid Supplements

Only one-fifth or less of all supplements used in the United States are in the liquid phase. Some authorities believe that there will be a marked increase in the use of liquid feeds, particularly as grain costs, relative to other feed costs, increase. Other authorities believe that liquid supplements will increase in use, but at a fairly slow rate. The greater portion of the research effort to date has been directed toward dry components, this causing a slower rate of acceptance of liquid supplements. In the United States, the use of liquid feeds is concentrated in three regions, notably the Northern Plains (30%); the mountain states (28%); and the Corn Belt (25%). Various estimates place the number of liquid feed manufacturing plants as between 130 and 200. Approval of the use of drugs in liquid feeds also has been slow. Whether such feeds are used for direct feeding or for spraying onto solid feeds, the materials are considered liquid feeds by the regulatory agencies.

One of the major ingredients in liquid supplement formulations is molasses—primarily cane molasses. There are very few ingredients identified to date which can replace molasses in such formulations. (See Perry reference listed) Thus the use of liquid supplements is tied both to the costs of grain and molasses. Other ingredients of liquid feeds include dicalcium phosphate, ammonium sulfate, calcium chloride, ammonium polyphosphate, and phosphoric acid.

Feedstuff Manufacturing

At the introduction of this entry, the broad statistics of the feedstuff industry are given. As with most other industrial activities, the number of feedmill establishments in the United States has diminished during the past decade or two, but the size and sophistication of the remaining mills have increased. Feed mills are particularly well adapted to automation and, during the 1970s, many mill managers turned to instruments, controls, and computers to improve the efficiency of their operations, as well as the quality of their product and customer service. Most new mills and mill expansions are well engineered in these respects.

A short description of a modern, large feed mill,[1] located in Iowa, is included here to convey some concept of the equipment and operations involved in feed manufacture.

Based upon a 10-hour workday, the annual production of this mill will approximate 200,000 (180,000 metric tons) of animal feeds. At this mill, about 90% of the feeds produced are high-protein concentrates which go to local member cooperatives to be mixed with producers' grains. The mill is cooperatively owned by some 60,000 members. The mill uses soybean meal from its soybean processing plant located at the same site.

The tower of the mill (Fig. 4) rises 182 feet (54.6 meters) above ground level and is surrounded by a warehouse, loading and unloading facilities. There are receiving pits—two railroad and one truck—for accepting bulk materials. These pits empty into two separate receiving systems, each of which handles 150 tons (135 metric tons) per hour. When an ingredient arrives, the shipment is entered on a computer terminal which feeds into the batch-weighing computer system. The computer[2] is used mainly for batching, inventory control, and record keeping. See Fig. 5.

From the receiving pits, ingredients are transferred to the tower where 133 bins hold about 4000 tons (3600 metric tons) of ingredients and 1500 tons (1350 metric tons) of finished feed. The mill and bins are constructed

[1] Boone Valley Co-op Processing Association, Eagle Grove, Iowa.

[2] Raven Industries, Inc., Sioux Falls, South Dakota.

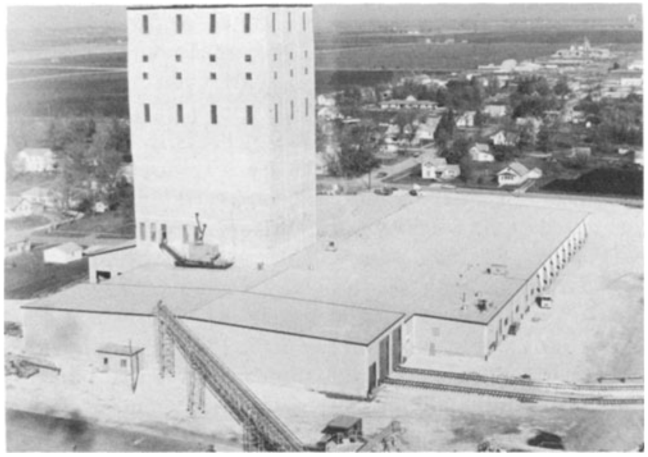


Fig. 4. Overall view of modern feed mill, showing mill tower and rail and truck receiving and shipping connections. (*Boone Valley Co-op Processing Association, Eagle Grove, Iowa*)

of concrete. Hoppers are welded directly to the steel frames at the bottom of the bins to move ingredients smoothly from the bins to the hoppers. Each of the bins has a hopper and conveyor leading from it. The finishing feed bins furnish feed for further processing, blocking, texturizing, crumbling, pelleting, sacking, and bulk loadout. Tanks in the basement of the mill provide storage for 55,000 gallons (2082 hectoliters) of liquid fat and molasses.

There are two separate 4-ton (3.6 metric-ton) batching systems. Flow of ingredients from bins into the batchers is computer-controlled. Dual controls in the computer system permit operation of both systems simultaneously. Each of the two systems is capable of batching formula feed at 40 tons (36 metric tons) per hour. See Figures 6, 7, and 8. Memory banks in the computer allow each half of the system to control and provide information on about 80 ingredients and 150 formulations of 15 ingredients each. Each system can handle four different types of liquids.

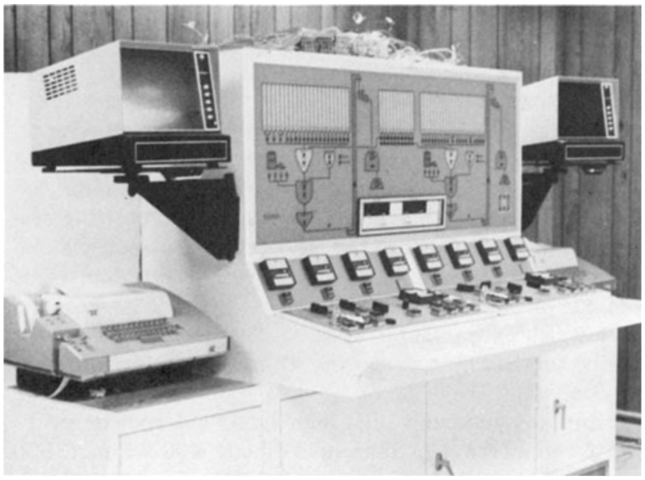


Fig. 5. Feed mill computer allows operator to follow major ingredients from bins into scale, then mixers, where liquid and bag dump ingredients are added. The panel has controls for two independent batching systems. (*Boone Valley Co-op Processing Association, Eagle Grove, Iowa*)

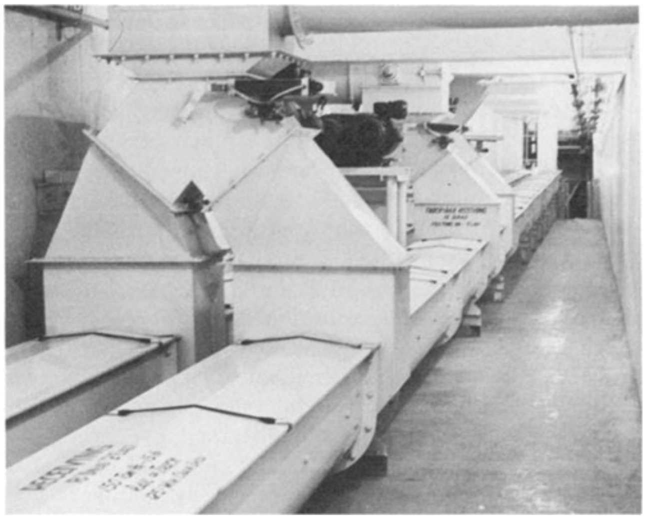


Fig. 6. Each of the plant's conveying systems under the receiving area can accept bulk ingredients at up to 150 tons (135 metric tons) per hour. (*Boone Valley Co-op Processing Association, Eagle Grove, Iowa*)

Formula length is unrestricted, thus allowing the listing of ingredients which are hand-added. In addition to raw ingredient inventory and batch weighing control, the computer gives a printed record of every batch and summarizes each batch run before a formula change. The computer provides a production summary, showing total amount

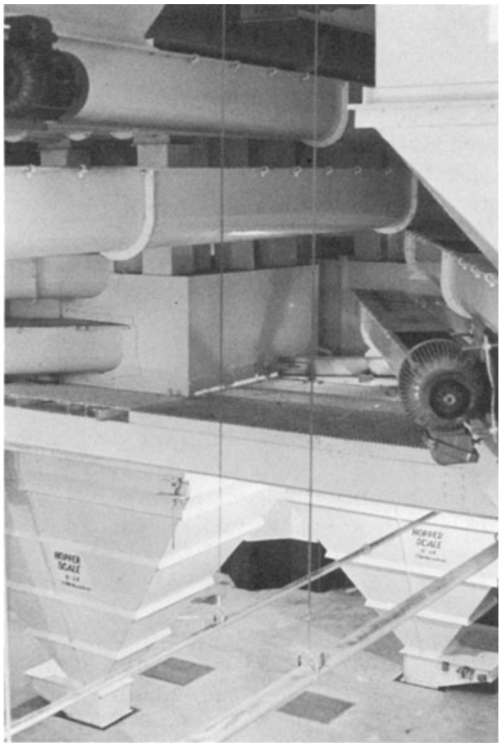


Fig. 7. From the ingredient bins in the mill tower, the system of closed conveyors channels ingredients to the two 4-ton (3.6 metric-ton) hopper scales shown here, which are located on the main floor of the mill. (*Boone Valley Co-op Processing Association, Eagle Grove, Iowa*)

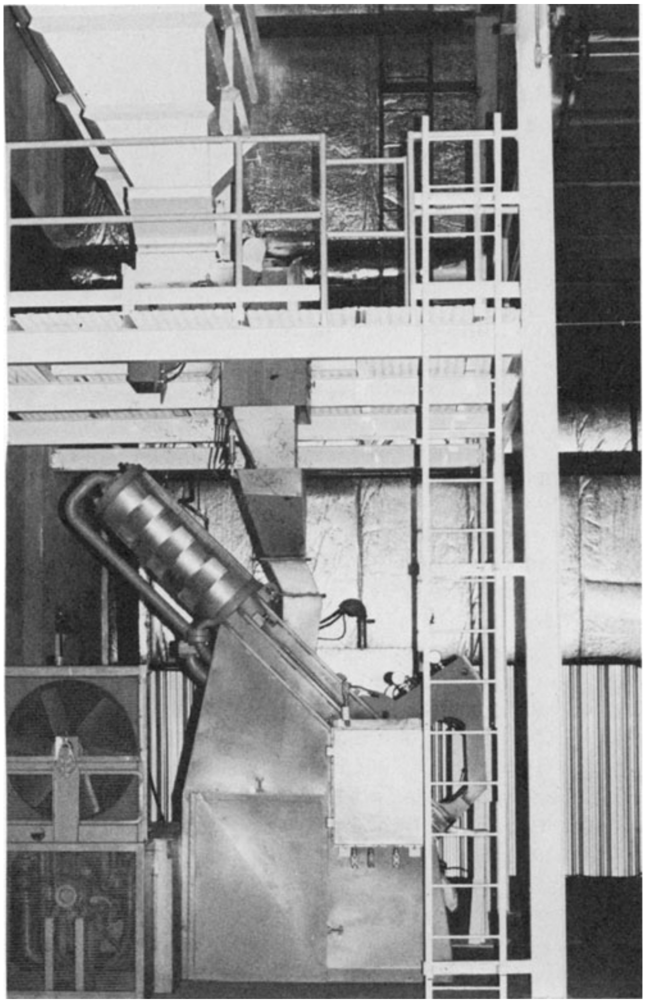


Fig. 8. A 100-ton (90-metric ton), 100-horsepower block press that turns out three blocks per minute. A specialized mixer above the press is designed to carry a high level of molasses. The press is on an outside wall of the mill tower, in the warehouse area. (*Boone Valley Co-op Processing Association, Eagle Grove, Iowa*)

of each ingredient used within a formulation and the total formulation produced over a production cycle (shift, day, month, etc.).

In addition to the terminal in the receiving office, a high-speed printer and a CRT (cathode-ray tube) readout are located in the main feed office and connnected to the batching computer.

All major ingredients are controlled from the control panel. Although drugs are added manually to feeds, the addition of this operation to the computer control system is possible.

The mill has three 200-horsepower pellet mills and one 100-horsepower pellet mill. See Fig. 9. Two baggers each will sack feed at 17 bags per minute. A blocking machine and equipment for texturized feed line and mineral feed line are also part of the mill equipment. For use mostly in the texturized feed line, a grain processor can heat grain to about 350°F (177°C), exploding it like popcorn. The grain processor is situated so that it can feed into either one of the larger batching systems, or into the texturized feed production line.

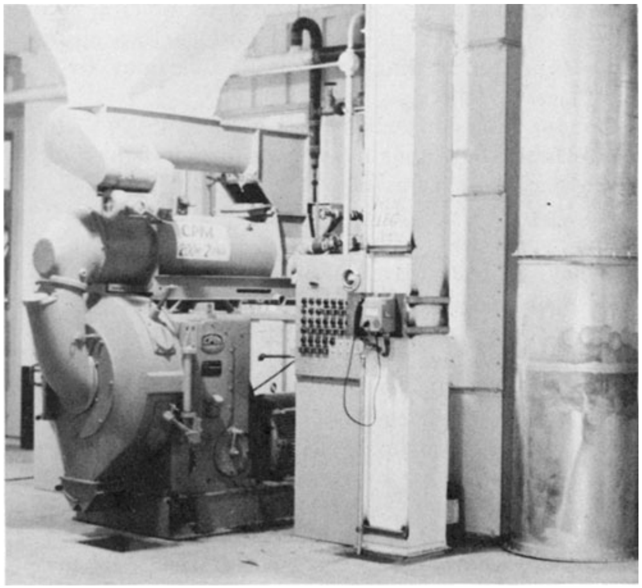


Fig. 9. One of three 200-horsepower pellet mills located at the feed mill. (*Boone Valley Co-op Processing Association, Eagle Grove, Iowa*)

Bulk loadout facilities are also organized on a dual system. A double truck bay with two scales and double feed-out system allows two trucks on individual scales to load different feeds at one time.

Fiberglass explosion vent panels are generously located on the walls of the mill tower, as may be noted from Fig. 4. The panels are mounted on the outside of metal frames to blow out in case of explosion, but the frames keep the panels from blowing in during high winds. All equipment that generates dust is equipped with a negative air pressure dust-collection system. One of the plant's five dust collection systems draws dust from the three receiving hoppers, two receiving drags, and two receiving legs. Other collection systems include one for each of the 40-ton (36 metric-ton) mixing systems, the bagging area, the grinder, and the pellet shakers. Another system provides vacuum clean-up capabilities for all areas of the mill. A sprinkler system for fire control is used throughout.

Pelleting. Significant quantities of feed products are furnished in pellet form. Producing a pellet with sufficient durability at a practical cost requires a balance between the ingredients used, operating practices followed, and the possible addition of a component for its binding qualities. Binding agents sometimes are nutritional, as, for example, urea, sugar, and molasses. In other cases, the binding agents of a secondary or negligible contribution are selected. These include substances, such as the lignin sulfonates and various colloidal binders. Considerable research has been conducted at Kansas State University on pellet binders. (See *Feedstuffs*, page 41, May 16, 1977).

Although increased costs of fuel have added to the cost of pelleting feeds over the recent past, feed efficiencies associated with pelleted rations tend to offset the higher costs in most instances. For example, complete swine feeds can pick up a 5 to 10% improvement in feed efficiency where corn (maize) and soybean meal rations are pelleted. Thus, a producer can pay somewhat more per ton for a pelleted feed versus a meal. As feed mixtures become more complex, with additions of additional trace elements, minerals, vitamins, drugs, chemicals, etc., there are some advantages of pelleting.

Among natural ingredients used as binding agents are:

Molasses. Both cane molasses and hemicellulose extract (wood molasses) increased pellet durability in the Kansas State trials. A 2% dried hemicellulose extract reduced power requirements slightly.

Whey. The ideal level of whey product when used as a pellet binder is believed to range from 1 to 3%. Higher levels are sometimes used for nutritional purposes. Studies conducted by Foremost Foods, showed that pellet durability improved up to the 6% level. Increased levels required more power in the pellet mill. However, it is not unusual for feed manufacturers to use whey product from the 10 to 20% level in pig starter rations because of nutritional benefits.

Sugar. At low levels, pelleting is not a problem, but at the higher levels desired for some feeds, such as baby pig starter, there are some operating difficulties.

Cereal Binders. These materials show a response in reducing fines and in most cases of increasing durability, findings of research done at Far-Mar-Co. The principal application of cereal binders is in pelleting bulky materials, such as a ration with a high percentage of corn cobs, cottonseed hulls, or ground hay.

Fatty Substances. These substances are considered "antibinding agents" by some producers. To achieve a satisfactory pellet when adding fat at high levels, some producers find that spraying the fat onto the finished pellets is the best procedure.

Among chemical materials used as binding agents are:

Lignin Binders. Lignin sulfonate may be used as a pelleting aid in an amount not exceeding 4% of the finished pellet (or as a source of metabolizable energy in an amount not to exceed 4% of the finished feed).

Research at Kansas State found that a lignin binder is effective in increasing pellet durability, with a 1% level actually as effective as a 2% level in turkey starter rations. In a high-fat layer ration, the binding at a 2% level caused a slight increase in durability. Use of this material at any level increases the power required in pelleting. Combinations of lignin sulfonate with aluminum silicate clay for binding are also available.

Colloidal Binders. Sodium bentonite and calcium bentonite, highly colloidal plastic clays, are found widely in some regions. Bentonite, which contains softened hydrated aluminum silicate, has characteristics of water absorption and volumetric expansion, high ion exchange capacity, and high surface area. Bentonite is not hygroscopic and can be stored in bulk. Generally considered inert, the substance may have some slight nutrient values.

Smectite-Vermiculite. This combination is said to produce a hard, firm pellet and increase pelleting speed. Some beef cattle feeds containing high levels of urea are being produced with this combination of material at a level of up to 10% total feed.

Customized Binders. Some manufacturers offer special combinations of materials found effective as pellet lubricating and binding agents. One of these is "Pel-Aid," composed of sodium carboxymethylcellulose, dried fleshings hydrolysate, safrole-free extract of sassafras (Hess & Clark Division of Rhodia).

Tests have indicated that the material can speed up production by over 6% in high-urea cattle feed and up to over 55% in a dairy concentrate. Usually, the material is added at a rate of about 0.5 pound per ton (0.25 kilogram per metric ton) of feed before mixing.

Feed Uniformity. A major concern of feed producer and consumer alike is reliable, consistent feed uniformity. A nonuniform feed tends to defeat many of the benefits of careful nutritional planning and, in fact in some cases, can cause serious problems of dietary imbalance. These observations are essentially self-evident. A. L. Cline observes, "A formula feed is a very complex substance composed of many different particles varying in number, size, shape, density, and electrostatic character. The rather formidable task of the feed manufacturer is to combine and mix these particles of ingredients in such a way that the concentration of, say protein, in one 20-gram sample of broiler ration is the same as in every other 20-gram sample of the feed. If that objective is met, then we can say that the feed is uniform with respect to the protein concentration. But this observation says nothing about variations in concentrations of salt, or calcium, or a coccidiostat. Indeed, this is what makes defining feed uniformity difficult because in a given feed some nutrients, such as protein or fat, might be very uniform, whereas other nutrients can appear to be quite nonuniformly dispersed."

Some ingredients are naturally well distributed. For example, a feed composed of 40% corn (maize), 49% soybean meal and smaller amounts of dehy (alfalfa), fats, vitamins, and minerals has the protein distributed throughout the bulk (90%) of the feed particles. It is apparent that little mixing is required to effect a highly homogeneous distribution of protein. Tests have indicated that mixing of such ingredients for a short span of 3 minutes can accomplish a good distribution of protein, but with large variations in ash, manganese, calcium, and phosphorus.

When adding an antibiotic or other drug to a feed, the drug may be concentrated at the start in just a few kilograms of premix. None occurs as a component of the corn, soybean meal, or other grains. To obtain uniform distribution of a very small number of drug particles relative to the total feed particles, very extensive mixing is required. It follows that a feed, properly mixed with respect to a micro-ingredient added separately, will exhibit uniformity in those nutrient parameters associated with the bulk ingredients. The converse is not true.

Although beyond the scope of this volume, Cline develops a theoretical basis for determining feed uniformity, comments on the statistical evaluation of feed uniformity, and the importance of sample size. (See Cline reference listed)

On-Farm Feed Mills. The extent to which the producer should process and mix feedstuffs at or near the location of consumption versus procuring feeds from commercial suppliers has been a topic of debate for a number of years. E. P. Roy has made a quantitative study of this topic. Full reference to the source article is suggested (See Roy reference listed), but some of the advantages and disadvantages of on-farm operations are summarized by Roy about as follows:

Advantages of on-farm feed mixing include: (1) Medium-to-large-scale producers can save on feed costs (provided a number of conditions are met), but savings are marginal for small-scale producers; (2) fresher feeds are provided to the animals; (3) use of home-grown grain is facilitated; (4) labor requirements are nominal; (5) ration formulation assistance is easily available, but a basic knowledge of nutrition is required; (6) less chance of diseases being carried onto the producing premises; (7) greater convenience; (8) improving availability of on-farm feed milling equipment. **Disadvantages** include: (1) Capital invested in on-farm feed mixing equipment may enjoy a better return from some other investment; (2) purchasing ingredients in small lots increases basic costs; (3) Lowest feed costs per unit weight of product produced should be the critical test of a feed's worth, not just the lowest cost per unit weight of ration procured or mixed; (4) services normally provided by feed dealers may not be available; (5) knowledge of regulations on various drugs and other feed ingredients must be constantly up-to-date; (6) when on-farm equipment breaks down, parts and service may not always be readily available; (7) some materials, such as urea, pelleting and crumbling of feeds, and handling of fats and molasses are complex and burdensome tasks.

Energy and Feedstuffs. As of the early 1980s, studies and actions are just getting underway toward reducing the large energy requirements of the feed producers. A University of New Hampshire study (See Davulis reference listed) indicates that a savings of 37 trillion Btus of energy could be realized if energy-minimizing feed rations were substituted for least-cost rations. The study covered six regions of the United States. Considering all of the species and regions analyzed, the energy-saving ration used about 18% less energy, but cost about 11% more than the weighted least-cost ration. The researchers concluded that, "While considerable energy savings are possible, the cost of such savings would appear to be prohibitive at the present time."

As with other high-energy consuming industries, the incentive to increase research along these lines most likely will occur as energy costs continue to increase, probably with only limited alterations in feeds and methods taking place each year.

References

Allaway, W. H.: "The Effect of Soils and Fertilizers on Human and Animal Nutrition," U.S. Department of Agriculture, Washington, D.C., *Agriculture Information Bulletin No. 378* (1975).

Ammerman, C. B., and P. R. Henry: "Current Status of Selenium for Ruminants," *Feedstuffs*, 25-26 (March 13, 1978).

Austic, R. E.: "Nutritional Interactions of Amino Acids," *Feedstuffs*, 22-23 (July 17, 1978).

Blair, R.: "Faba Beans: An Improved Crop for Animal Feeding," *Feedstuffs*, 15-16 (July 18, 1977).

Blanchard, J., *et al.*: "Potential Feeding Value of Crop Residues in the United States, *Feedstuffs*, 22 (August 15, 1977).

Bowland, J. P.: "The Use of Rapeseed Meal in Pig and Poultry Rations," in *Feed Energy Sources for Livestock* (H. Swan and D. Lewis, editors), Butterworths, London (1976).

Carew, L. B., Jr.: "Metabolizable Energy Determination," *Feedstuffs*, 22, 31 (May 15, 1978).

Cline, A. L.: "Statistical Evaluation of Feed Uniformity," *Feedstuffs*, 39, 41 (June 26, 1978).

Cline, T. R.: "Protein Quality and Amino Acid Balance," *Feedstuffs*, (July 24, 1978).

Conrad, H. R., and J. A. Rogers: "Dried Grains for Dairy Cattle," paper presented at Brewers Feed Conference, St. Louis, Missouri (November 15, 1977).

Cook, L. J., *et al.*: "Production of Polyunsaturated Ruminant Body Fats," *Nature*, **228** 178 (1970).

Coppock, C. E., and J. J. Fettman: "Chloride as a Required Nutrient for Lactating Dairy Cows," *Feedstuffs*, 19, 21-22, 48 (February 20, 1978).

Davis, G. K.: "Magnesium in Animal Nutrition," *Feedstuffs*, 35-36 (June 27, 1977).

Davulis, J. P., and G. E. Frick: "Potential for Energy Conservation in Feeding Livestock and Poultry in the United States," University of New Hampshire, Durham, New Hampshire (1977).

El Boushy, A. R., and R. W. A. Vink: "The Value of Dried Poultry Waste as a Feedstuff in Broiler Diets," *Feedstuffs* 24, 26 (December 12, 1977).

Eng, K. S.: "Protected Fat in Ruminant Diets," *Feedstuffs* 18, 21-22 (November 14, 1977).

Ensminger, M. E.: "Swine Science," 4th edition, Interstate, Danville, Illinois (1970).

Ensminger, M. E.: "Beef Cattle Science," The Interstate, Danville, Illinois (1976).

Esmay, M. L.: "Principles of Animal Environment," Avi, Westport, Connecticut (1978).

Forth, W., and W. Rummel: "Absorption of Iron and Chemically Related Metals *in vitro* and *in vivo*," in *Intestinal Absorption of Metal Ions, Trace Elements and Radionuclides* (S. C. Skoryna, and D. Waldron-Edward, editors), Pergamon, New York (1971).

Forth, W., and W. Rummel: "Iron Absorption," *Physiology Review*, **53**, 724 (1973).

Froseth, J. A.: "Gestating Sows Do Well on High-alfalfa Trial Rations," *Feedstuffs*, 12 (March 14, 1977).

Gillies, M. T.: "Animal Feeds from Waste Materials," Noyes Data Corporation, Park Ridge, New Jersey (1978).

Goihl, J. H.: "Corn Quality and Swine Performance," *Feedstuffs* 25 (August 14, 1978).

Gracey, J. F., and J. R. Todd: "Chronic Copper Poisoning in Sheep following the Use of Copper Sulfate as a Mollukicide," *British Veterinarian Journal*, **116**, 405-408 (1960).

Grandhi, G. H., *et al.*: "Rapeseed Meal May Boost Heavy Hogs' Carcass Quality," *Feedstuffs*, 12 (June 13, 1977).

Grieve D. G.: "Brewers Yeast Compared with Corn, Soybean Meal," *Beef Industry Research Report* (1978).

Grumbles, L. H.: "Cage Layer Fatigue (Cage Paralysis)," *Avian Diseases*, **3**, 122-125 (1969).

Grummer, R. H., *et al.*: "The Role of Manganese in Growth, Reproduction and Lactation of Swine," *J. of Animal Science*, **9**, 170-175 (1950).

Gutcho, M. H.: "Feeds for Livestock, Poultry and Pets," Noyes Data Corporation, Park Ridge, N.J. (1973).

Halloran, H. R.: "Maintenance of Sodium and Chloride Balance," *Feedstuffs*, 16 (July 3, 1978).

Haresign, W., and D. Lewis: "Recent Advances in Animal Nutrition," Butterworth Group, Woburn, Massachusetts (1977).

Harms, R. H., Damron, B. L., and R. D. Miles: "Phosphorus and Laying Hen Nutrition," *Feedstuffs*, 33-34 (June 27, 1977).

Harms, R. H.: "Brewers Dried Grains as an Ingredient in the Formulation of Feeds for Laying and Breeding Hens," paper presented at Brewers Feed Conference, St. Louis, Missouri (November 15, 1977).

Harper, A. E.: "Amino Acid Imbalances, Toxicities, and Antagonisms," *Nutrition Review*, **14**, 225-227 (1956).

Harper, A. E., Benevenga, N. J., and R. M. Wohlheuter: "Effects of

Ingestion of Disproportionate Amounts of Amino Acids," *Physiology Review*, 50, 428-558 (1970).

Hartman, R. H., *et al.*: "Effect of High Dietary Manganese on Hemoglobin Formation," *Journal of Nutrition*, 57, 429-439 (1955).

Hendrix, K. S., *et al.*: "Residue Feeds Can Supply Protein Required by Cows," *Feedstuffs*, 14-15 (January 9, 1978).

Hoelscher, M. A.: "Value of Non-Protein Nitrogen in Beef Rations," *Feedstuffs*, 26, 48 (February 20, 1978).

Hoelscher, M. A.: "Feeding Feedlot Waste to Cattle," *Feedstuffs*, 27 (July 17, 1978).

Hoelscher, M. A.: "Molybdenum Toxicity and Copper Deficiency," *Feedstuffs*, 40, 49 (September 25, 1978).

Hull, J. L.: "Cottonseed Meal Outperforms Urea in Straw Trials," *Feedstuffs*, 48 (May 16, 1977).

Jimenez, A. A.: "Water: A Neglected Nutrient in Most Dairies," *Feedstuffs*, 19 (February 27, 1978).

Kendall, J. D.: "Supplemental Vitamin E, Selenium Effects Studied," *Feedstuffs*, 13-27 (June 20, 1977).

Kendall, J. D.: "Liquid Supplements," *Feedstuffs*, 17-18 (September 5, 1977).

Kendall, J. D.: "Maintenance Needs Rise 1% for Each Degree Drop," *Feedstuffs*, 13-14 (October 31, 1977).

Kershner, R., and V. Headley: "Adding Animal Fat to Pelleted Feeds," *Feedstuffs*, 19-20 (July 27, 1968).

Kienholz, E. W.: "Why Water is So Important to Animals," *Feedstuffs*, 17-18 (January 16, 1978).

Krautmann, B. A., and C. R. Zimmerman: "A New Look at the Vitamins in Layer Feeds," *Feedstuffs*, 22-23 (August 21, 1978).

Layrisse, M., *et al.*: "Food Iron Absorption: A Comparison of Animal and Vegetable Foods," *Blood*, 33, 430 (1969).

Leidahl, R.: "Selenium Ups Hatchability-Cuts Gizzard Myopathy," *Feedstuffs*, 10 (August 22, 1977).

Lincoln, E. P.: "Researchers Study Algae Production from Hog Waste," *Feedstuffs*, 13, 26, (August 1, 1977).

Madsen, F. C., and C. B. Atwater: "Vitamin K Active Compounds Used in Feeds," *Feedstuffs*, 24-25 (November 7, 1977).

Martinez-Torres, C., and M. Layrisse: "Iron Absorption from Veal Muscle, *American Journal of Clinical Nutrition*, 24, 531 (1971).

Maynard, L. A., and J. K. Loosli: "Animal Nutrition," 5th Edition, McGraw-Hill, New York (1962).

McGhee, F., Greger, C. R., and J. R. Couch: "Copper and Iron Toxicity," *Poultry Science*, 44, 310-312 (1965).

McGillivray, J. J.: "Review Underlines the Importance of Phosphorus Availability in Poultry and Animal Feeds," *Feedstuffs*, 32, 34 (June 22, 1977).

Meade, R. J.: "Animal Byproducts in the Formulation of Nutritionally Adequate Diets for Swine," *Feedstuffs*, Part I, 21-22, (September 1, 1975); *Feedstuffs*, Part II, 22-23, (September 8, 1975).

Mehring, A. L., Jr., *et al.*: "The Tolerance of Growing Chickens for Dietary Copper," *Poultry Science*, 39, 310-312 (1960).

Mertz, W., and E. E. Roginski: "Chromium Metabolism: The Glucose Tolerance Factor," in *Newer Trace Elements in Nutrition*, Dekker, New York (1971).

Miller, E. R.: "Biological Availability of Iron in Iron Supplements," *Feedstuffs*, 21-22 (August 21, 1978).

Morrison, F. B.: "Feeds and Feeding," Morrison, Clinton, Iowa (1959).

Moser, B., and R. D. Fritschen: "Adding Tallow to Diet Increases Gain," *Feedstuffs*, 10 (February 20, 1978).

Neathery, M. W., and W. J. Miller: "Tolerance Levels, Toxicity of Essential Trace Elements for Livestock and Poultry," *Feedstuffs*: Part I, 18-20, 34 (August 29, 1977); Part II, 22-23, 28 (September 12, 1977).

Neumann, A. L.: "Beef Cattle," 7th edition, Wiley, New York (1978).

Perry, T. W.: "Hemicellulose Extract in Cattle Supplement Formulation," *Feedstuffs*, 39 (October 3, 1977).

Polin, D., and R. K. Ringer: "25-Hydroxy-D_3 Vitamin D_3 and Graded Levels of Phosphorus: Effect on Egg Production and Shell Quality," *Feedstuffs*, 40, 41 (October 24, 1977).

Preston, R. L.: "Typical Composition of Feeds for Cattle and Sheep, 1977-1978," *Feedstuffs*, A-2-A-4 (October 3, 1977). Also 3A-10A (August 28, 1978).

Ross, I. J.: "Recycled Swine Waste Fed in Growing-finishing Diet," *Feedstuffs*, 14 (July 24, 1978).

Roy, E. P.: "The Economic Feasibility of On-farm Package Feed Centers," *Feedstuffs*, 39-40 (August 22, 1977).

Scott, T. W., *et al.*: "Production of Polyunsaturated Milk Fat in Domestic Ruminants," *Australian Journal of Science*, 32, 291 (1970).

Scott, M. L.: "Renderers' Products in Poultry Nutrition," *Feedstuffs*, 25-26 (March 20, 1978).

Scott, M. L.: "Nutritional and Biochemical Aspects of Selenium in Poultry," *Feedstuffs*, 19-20 (May 30, 1977).

Scott, M. L.: "The Energy Requirements of Laying Hens for Maintenance, Activity and Egg Production," *Feedstuffs*, 18-19 (August 8, 1977).

Schaible, P. J.: "Poultry: Feeds and Nutrition," Avi, Westport, Connecticut (1970).

Sibbald, I. R.: I. R.: "The 'True Metabolizable Energy' System," Part I, *Feedstuffs*, 21-22 (October 10, 1977).

Sibbald, I. R.: Part II of above, ibid 23-24 (October 17, 1977).

Spears, J. W., and E. E. Hatfield: "Role of Nickel in Animal Nutrition," *Feedstuffs*, 24, 26, 28 (June 13, 1977).

Staff: "Feed Manufacturing Technology," American Feed Manufacturers Association, (Miller Publishing Company, Minneapolis, Minnesota) (1976).

Staff: "Protein and Non-Protein Nitrogen for Ruminants," United Nations Economic Commissions for Europe, Pergamon, New York (1977).

Staff: "The Maize Crop as a Basic Feed for Beef Production," Elsevier, Amsterdam (1977).

Staff: "Swine Management Handbook," The Pennsylvania State University College of Agriculture, University Park, Pennsylvania (1978).

Staff: "Liquid Ingredients Handbook," National Feed Ingredients Association, West Des Moines, Iowa (1978).

Staff: "Nutrient Requirements of Domestic Animals," National Academy of Sciences, Washington, D.C., separate publications on beef cattle; dairy cattle; poultry; swine; and sheep (periodically updated).

Stagelman, W. J., and O. M. Cotterill, "Egg Science and Technology," Avi, Westport, Connecticut (1978).

Stake, P. E.: "Trace Element Absorption Factors in Animals," *Feedstuffs*, 20-21, 26 (December 19, 1977).

Sullivan, T. W., and Y. Y. Al-Ubaidi: "Copper and Iron Requirements and Interactions in Young Turkeys," *Feed Processing*, 22, 199 (1963).

Summers, J. D., and S. Leeson: "Poultry Nutrition Handbook," Department of Animal Science, Ontario Agricultural College, University of Guelph, Guelph, Ontario Canada (1977).

Swan, H., and D. Lewis: "Feed Energy Sources for Livestock," Butterworths, London (1976).

Trotter, W. K., Davies, Y., and D. Burdick: "Market Potential of Dehydrated Coastal Bermuda Grass in Swine Feeds," *Feedstuffs*, 13-15 (July 4, 1977).

Tunks, F. E.: "Sunflower's Ascendancy Adds to Meal, Silage Supplies," *Feedstuffs*, 22-23, (July 4, 1977).

Ullrey, D. E.: "Selenium for Ruminants and Swine," *Feedstuffs*, 18-21 (June 6, 1977).

Underwood, E. J.: "Trace Elements in Human and Animal Nutrition," 4th edition, Academic Press, New York (1977).

Vosloh, C. J., Jr.: "Structure of the Feed Manufacturing Industry, 1975," U.S. Department of Agriculture, Washington, D.C. (special publication).

Waldern, D. E.: "Barley Processing Methods Compared in Feeding Trials," *Feedstuffs* (August 8, 1977).

Wallace, H. D., *et al.*: "Influence of High Levels and Sources of Copper on Pigs," *Journal of Animal Science,* **21**, 1016 (1962).

Waterman, R., Romsos, D. R., Miller, E. R., and G. A. Leveille: "Effects of Low Levels of Supplemental Tallow in the Finishing Rations of Meat-type Pigs," *Feedstuffs,* 33-34 (October 29, 1973).

Welch, R. M., and D. R. Van Campen: "Iron Availability to Rats from Soybeans," *J. of Nutrition,* **105**, 253 (1975).

Wiley, W. H.: "Biology and Production of Turkeys," a bibliography, Data Systems Application Division, U.S. Department of Agriculture, National Agricultural Library, Beltsville, Maryland (1977).

FENAMINOSULF FUNGICIDE. A sulfonate type soil fungicide developed in Germany* in the mid-1950s and used on a select grouping of vegetables, such as bean, beet, cucumber, maize (corn), pea, sorghum, spinach, and sugar beet, as well as on cotton, pineapple, and sugar cane, for the control of certain fungus diseases. The compound is available as wettable powder (35 and 70%); granule (5%); and dust (2+ and 10%). Prepared formulations frequently contain a percentage of PCNB fungicide to enhance the spectrum of the compound. Fenaminosulf is not injurious to most plants, but is not indicated for greenhouse production. The compound is injurious to birds and some other forms of wildlife and thus precautions must be taken to avoid contamination of nearby land, lakes, and streams. The compound is applied directly to the soil and also used as a treatment for seed. Target diseases of Fenaminosulf include:

anthracnose
Aphanomyces spp. diseases
Phytophthora
Pythium spp. diseases

It should be noted that the compound is not effective against *Rhizoctonia* spp. diseases.

The chemical name of Fenaminosulf is sodium *p*-(dimethylamino) benzene-diazo sulfonate.

Other designations: DAPA, *Dexon*

See also **Fungicide; Pesticide Application.**

FENBUTATIN-OXIDE ACARICIDE. Developed in the United States in the mid-1970s, this acaricide is an organic tin compound which is effective against mites as encountered in orchard and vegetable crop production. The compound is available as a wettable powder (50%). The acaricide is nontoxic to honeybees and may be mixed with most insecticides. Use of the compound in the United States is essentially confined to apple, citrus, and pear.

The organic chemical name of Fenbutatin-Oxide* is Hexakis (beta, beta-dimethylphenethyl)-distannoxane.

Other Designations: *Bendex, Torque, Vendex*

See also **Acaricide; Insecticide; Pesticide Application.**

FENITROTHION INSECTICIDE. Also rather commonly termed *Methylnitrophos,* this organic phosphate type insecticide was developed in the late 1950s as a control agent against a variety of insects (listed below). Mainly used in the United States for insect control in forests, the compound is widely used in many other regions of the world on a variety of forage, fruit, and vegetable crops. It is also favored in certain European countries for public health measures in controlling fly, mosquito, *et al.* Fenitrothion is available as an emulsifiable concentrate in several strengths; dust (2 to 3%); wettable power (40%); and granules (3%). Care must be taken in the use of the compound because certain plants are damaged, including cotton, some fruit crops, notably some varieties of apple, and cabbage, mustard, and rape. The compound also is injurious to honeybees and possesses some toxicity to fishes. Thus, care must be exercised in avoiding excessive use and pollution of adjacent fields, lakes, and streams. The compound has some tolerance of alkaline materials, but must be applied immediately upon any blending with such materials. Target pests of Fenitrothion include:

aphid
armyworm
bollweevil
bollworm
cockroach
codling moth
fly
gnat
leafhopper
lygus bug
mealy bug
mite
mosquito
pear psylla
plant hopper
rice borer
spruce budworm
stem borer
thrip
whitefly

The organic chemical name of Fenitrothion is O,O-dimethyl O-(-3-methyl-4-nitrophenyl) phosphorothioate.

Other designations: *Accothion, Agrothion, Bay 41831, Cyfen, Cytel, Folithion,* MEP, *Methylnitrophos, Novathion, Nuvanol, Sumithion.*

See also **Insecticide; Pesticide Application.**

FENNEL. Of the family *Umbelliferae* (carrot family), the common fennel plant (*Foeniculum vulgare*) is cultivated as a vegetable in America[1] and Europe. The commercial vegetable has broad leaf stalks which overlap each other at the base of the stem, forming a bulbous enlargement which is firm, white, and sweet. The bulb measures from 3 to 4 inches (7.5 to 10 centimeters) in diameter. The stalks grow to about 2 feet (0.6 meter) in height. Stalks of the plant can be blanched much like celery and eaten directly as a vegetable. Parts of the plant and extracted oils are used as flavoring foods, primarily in confectionaries and liqueurs. In the United States, cultivation occurs mainly in California, New Jersey, and Long Island (New York). A native of Europe, the plant is cultivated in central Europe, Saxony, Franconia and Wurtemburg, in the south of France; in Italy, India, and China.

Fennel was cultivated by the Romans as a garden herb and was much used for seasoning meats and vinegar sauces. Use of fennel is mentioned in records of Spanish agriculture dating back to 961 A.D. The plant was first noted growing in a wild state in South America in the early 1880s.

---

*Bayer AG.

*Shell Chemical Company.

[1] In the United States, fennel is commonly called anise and is not to be confused with *Pimpinella anisum,* which is also called anise in most other countries. See also **Anise.**

Because the vegetable is a minor crop, production statistics are not accurately maintained. It is estimated by the United Fresh Fruit & Vegetable Association (1974) that production in the United States is about 20 million pounds (9 million kilograms) annually.

Fennel is planted in row beds with a lettuce planter, using 2.5 to 3 pounds to the acre (2.8 to 3.4 kilograms per hectare). There are approximately 4500 seeds per ounce (about 160 seeds per gram). Spacing of plants in the row is about 4 inches (10 centimeters), but they are thinned to 10 to 14 inches (25 to 35 centimeters). Fennel has a broad tolerance as to soil acidity, generally preferring a pH of 5 to 6.8. Desirable temperature range is from 70° to 75°F (21.1° to 23.9°C), with a minimum temperature no lower than 45°F (7.2°C). A satisfactory yield is considered to range between 1000 and 1500 pounds/acre (1120 to 1680 kilograms/hectare). A very good yield would be 2000 pounds/acre (2240 kilograms/hectare). In California, the growing period ranges between 110 and 125 days. The two principal marketing seasons in Europe and the Americas are the Christmas and Easter Seasons, when large amounts of fennel are used for flavoring special dishes and pastries associated with these holidays. Fennel must be harvested quickly when mature as it goes to seed readily when left in the field. Fennel is relatively resistant to pests and diseases.

Even in California, where most of the fennel is grown in the United States, the crop continues to be harvested by hand, hauled to a packing shed, cleaned, trimmed, cut to length and packed. The container most frequently used is the "Sturdee" nailed 15-1/2-inch (approximately 39 centimeters) crate, or a wirebound crate holding from 40 to 50 pounds (18 to 22.5 kilograms).

Commercial fennel oil, used by manufacturers of mass-prepared commercial food products, is prepared by steam distillation of the dried ripe fruit of the fennel plant. This is an essential oil, pale yellow in color, with a specific gravity of 0.975. The odor and taste of the oil are somewhat camphorlike, arising from the presence of fenchone ($C_6H_{16}O$), an isomer of camphor. Pinene, camphene, and anethole are also present. Anethole, also known as anise camphor, finds use in dentrifices and pharmaceutical products.

Another fennel plant (*Foeniculum dulce*), also known as Florence fennel, sweet fennel, Italian fennel, and Cretain fennel, is cultivated in southern Europe. Stalks of this plant also can be blanched much like celery and eaten directly as a vegetable. Extracts of the plant also are prepared for use in confectionaries and liqueurs. The plant can be grown successfully in the southern United States. Sweet fennel is planted in the spring, about 1-1/2 feet (0.5 meter) apart, and grows well in good soil under full sun. Mancozeb fungicide (*Dithane, Fore*) is sometimes used on fennel to control fungus diseases.

Other species of fennel grow wild in many areas of the world, up to heights of 12 to 15 feet (3.5 to 4.5 meters). Although some fennels live from one year to the next, they are generally considered to be annuals. Planting may be from seed or cuttings.

Contained in an edible portion of 100 grams (3.5 ounces) of fennel are the following:

Water	90	grams
Food energy	28	Calories
Fat	0.4	gram
Total carbohydrate	5.1	grams
Ash	1.7	grams
Calcium	100	milligrams
Phosphorus	51	milligrams
Iron	2.7	milligrams
Vitamin A	3500	international units
Thiamine	none	
Niacin	none	
Vitamin C (ascorbic acid)	31	milligrams

References

Seeling, R. A.: "Anise (*Foeniculum vulgare*) (Fennel)," Bulletin published by United Fresh Fruit & Vegetable Association, Washington, D.C. 20036 (1974).

Staff: "Composition of Foods Used in Far Eastern Countries," U.S. Department of Agriculture, Washington, D.C., *Agriculture Handbook 34,* (revised periodically).

Staff: "Food Chemicals Codex," 2nd edition, National Academy of Sciences, Washington, D.C. (1972).

FENSULFOTHION INSECTICIDE-NEMATICIDE. One of the early organic phosphate contact pesticides which functions as an insecticide and nematicide. Developed in Germany* in the late 1950s, the compound is most effective against rootworms, maggots, and nematodes (see list below). It is used on a wide variety of crops, notably citrus fruits, groundnut (peanut), sweet potato, sorghum, soybean, and numerous other vegetables and cereals. The compound is available as emulsifiable concentrate in several strengths and granules (5, 10 and 15%). Used properly, the compound is not injurious to plants. Because of toxicity and environmental conditions, the compound is not usually used for greenhouse production. Fensulfothion is toxic to honeybees, fishes and thus precautions must be taken to cover the soil once the compound has been applied and to avoid pollution of nearby fields, lakes, and streams. Some producers apply the compound along with fertilizer, including liquid fertilizers.

Principal insect targets of Fensulfothion include:

cabbage maggot
corn rootworm
nematodes
onion maggot
wireworm

The organic chemical name of Fensulfothion is O,O-diethyl O-(4-(methylsulfonyl)phenyl) phosphorothioate. Other designations: *Dasanit,* DMSP, *Terracur-P.*

See also **Insecticide; Nematicide; Pesticide Application.**

FENTHION ACARICIDE-INSECTICIDE. One of the early organic phosphate pesticides that functions as an acaricide and insecticide. Developed in Germany* in the late 1950s, the compound is directed against a variety of insects. It is used extensively in agricultural structures and households as a control for fly, mosquito, roach, *et al.* and is also widely used, particularly in areas outside the United

---

*Bayer AG.

States, on crops. Main crop usage in the United States is on alfalfa, pasture grasses, and rice. Fenthion is available as emulsifiable concentrate of various strengths, wettable powder (50%); granules (2%); and dust (3%). Generally, the compound is not injurious to plants, but some damage has been evidenced on certain trees (hawthorne, linden, sugar maple) and to certain varieties of apple and cotton. Spraying should be done at temperatures less than 32°C (90°F). The compound is toxic to honeybees, fishes and other aquatic life, including cray fish, crab, and shrimp.

Target pests of Fenthion include:

ant
aphid
armyworm
bollworm
caterpillar
cattle gnat
flea
fly
leafhopper
leaf miner
mealy bug
mite
mosquito
pear psylla
thrip

The organic chemical name of Fenthion is O,O-dimethyl-O-(3-methyl-4-(methylthio)phenyl) phosphorothioate.
Other designations: *Baycid, Baytex, Entex, Lebaycid, Queletox, Spotton, Tiguvon. Queltox,* not marketed in the United States, is sold is some regions for controlling birds.

See also **Acaricide; Insecticide; Pesticide Application.**

FENTIAZON FUNGICIDE. A sulfur-bearing preventive foliar fungicide developed in Japan* in the mid-1960s and used principally in Japan on rice. It is used in some other areas for the control of bacterial leaf blight. The compound is furnished as a wettable powder (50%). The compound is not available in the United States.
Other designation: *Celdion.*

See also **Fungicide; Pesticide Application.**

FENUGREEK. A seasoning prepared from the dried seeds from the long pods of the annual legume *Trigonella foenum* L., a plant native to southern Europe. The seeds, of a brownish-yellow color and of irregular oval shape, range up to 3/16-inch (4-5 millimeters) in length. Flavor of fenugreek has been described as mildly bitter and suggestive of burnt sugar. Aside from the considerable use of fenugreek in various curry powders, it finds application in chutney, and in some artificial maple syrups.

FERBAM FUNGICIDE. One of the earlier carbamate type foliar fungicides developed in the early 1930s in the United States* and used on a wide variety of crops, ranging from numerous fruits through vegetables and tobacco. In addition to its fungicidal properties, Ferbam repels certain varieties of insects. The compound is supplied as wettable powders of various strengths and dusts (0.6 to 25+%). Ferbam is not injurious to plants, although minor damage has been reported in connection with apple (Golden Delicious). After spraying a black residue remains on the crop, when used in excess, the residues should be washed off. When used with copper, mercury, or lime, the fungicidal efficiency is lowered. Target diseases of Ferbam include:

anthracnose
apple scab
blight (celery)
blight (seed)
blotch (sooty)
Botrytis spp. disease
brown rot
damping off
leaf spot (cherry)
leaf spot (tomato)
mildew (downy)
peach leaf curl
rot (cranberry)
shot-hole

Ferbam must not be applied to carrot within 7 days before a harvest if tops are to be used for food. Ferbam must not be applied to blackberry or raspberry within 40 days before a harvest. Ferbam must not be used on potato or sweet potato.

The organic chemical name of Ferbam is ferric dimethyldithiocarbamate.
Other designations and related compounds: *Carbamate, Ferbane, Ferbeck, Fermate, Fermucide, Ferradow, Hexaferb, Hokmate, Karbam Black, Niacide, Tricarbamix Fe* (with maneb and ziram), *Trifungol, Vancide-FE95.*

See also **Cucumber; Fungicide; Pesticide Application; Tomato.**

FERMENTATION. A modern definition of fermentation would be those energy-yielding reactions in which organic compounds act as both oxidizable substrates and oxidizing agents. Anaerobic reactions in which inorganic compounds are utilized as electron acceptors may be termed "anaerobic respirations," whereas reactions in which oxygen serves as a terminal electron acceptor are respirations. Almost any organic compound may be fermented provided it is neither too oxidized nor too reduced, since it must function as both electron donor and electron acceptor. In some fermentations, a compound is degraded via a series of reactions in which intermediates in the sequence act as electron donors and acceptors; in others, one molecule of the substrate may be oxidized while another molecule is reduced; or two different organic compounds may be degraded after a coupled oxidation-reduction reaction. These fermentations provide energy required for the growth of a variety of cells. In addition, many microorganisms can carry out, in appropriate conditions, a number of fermentative reactions (e.g., oxidations, reductions, cleavages) which do not yield useful energy, or do not yield sufficient energy for growth.

From a very practical standpoint, fermentative reactions are related to foods and food production in at least three fundamental ways: (1) They make it possible for foods that are ingested to be metabolized (used for energy and the building of indispensable substances for growth and maintenance); (2) They make it possible for the conversion of chemicals *in nature* (for example, conversion of starches into sugars in the ripening of fruit) and for the conversion of chemicals in *food processing* to create such interesting items as bread, cheese, and wine, among many, many others; and (3) They cause problems in the storage of various food products, not only in economic terms, but also but in terms of a number of foodborne diseases.

Thus, the references to fermentation throughout this

---

*Takeda Chemical Industries, Ltd.

*DuPont.

volume are extensive. Consult alphabetical listings. To avoid duplication, this entry is confined to briefly describing some of the more important categories of fermentation:

Alcoholic Fermentation—first identified by Gay-Lussac in 1810, but at that time, it was thought that the process resulted from contact catalysis and the decay of animal or vegetable materials. This explanation was refuted by the work of Pasteur (1857) on the lactic acid fermentation. Pasteur determined that fermentation was caused by living cells, that different microbial species caused different fermentations, that the nitrogeneous materials present served only to support the growth of the cells, that lactic acid was produced when cells (removed from the fermentation mixture) were added to a sugar solution, and that the natural fermentation yielded both alcohol and lactic acid, but that the amount of each could be altered by changes in pH. In later studies, Pasteur showed that the conversion of glucose to alcohol, $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$, was caused by yeast cells growing under anaerobic conditions, thus leading to the earlier definition that fermentation was "life without air." This has since been displaced by the modern definition given earlier in this entry. In particular, see entries on **Beer and Other Malt Beverages; Carbohydrates; Rum; Whiskey; Wine** (and other entries on specific wines).

Amolytic Fermentation—the fermentation of starch, but specifically it is an incomplete fermentation of starch in which simple sugars are not produced.

Butyric Fermentation—in which butyric acid is produced. The organisms producing this type of fermentation are mainly anaerobic like *Clostridium butyricum.* Some organisms, such as *Clostridium tetani,* the organism causing tetanus, and *Clostridium botulinum,* the organism causing botulism, also produce this type of fermentation. See also **Foodborne Diseases.**

Lactic Fermentation—in which lactic acid is produced. This is an important fermentation for the preservation of food. *Lactobacillus bulgaricus, L. casei,* and *Streptococcus lactis* are used for the manufacture of dairy products, such as sour cream. *Lactobacillus plantarum* is used in the preservation of certain vegetables, such as the production of pickles and kraut. See also **Cabbage; Cucumber; Milk and Dairy Products; Silage and Silage Fermentation.**

Controlled Oxidative Fermentations—by which a number of industrial chemicals are produced. *Citromyces,* for example, can be used for the production of citric acid from sugar. *Aspergillus niger* will yield oxalic acid by partial oxidative fermentation, but if the mold is permitted to remain in contact with the acid, it will convert it to carbon dioxide.

Some sugars such as glucose may be completely oxidized to carbon dioxide by certain bacteria, most molds, and some yeasts. Such microorganisms produce complete oxidation by fermentation. Many bacteria and yeasts are able to produce a gassy fermentation. The gaseous end product in the fermentation of vegetable products with *Leuconostoc mesenteroides* and *Lactobacillus brevis* is carbon dioxide. The gaseous end products of the coliform group are carbon dioxide and hydrogen.

Ropy Fermentation—which causes the spoilage of foods. Ropy milk is caused by *Aerobacter aerogenes, Lactobacillus bulgaricus, L. casei,* and *Alcaligenes viscosus.* Ropy bread is caused by members of the *Bacillus mesentericus* group which are identical with or are strains of *B. subtilis* or *B. pumilus.* Rope in maple syrup is produced by *A. aerogenes.*

See also **Bread and Bakery Products, Milk and Dairy Products.**

A characteristic cultural reaction of *Clostridium perfringens* and many other clostridia is known as a *stormy fermentation.* When the organism is inoculated into milk the lactose is fermented and the casein is coagulated.

See also **Foodborne Diseases; Milk and Dairy Products.**

The anaerobic respiration which takes place in the muscles of higher animals, when insufficient oxygen is available for a complete breakdown of the food, is also called fermentation. Lactic acid and carbon dioxide are the products of this type of fermentation.

See also **Yeasts and Molds.**

References

Note: Numerous references on fermentation are included throughout this volume. Consult reference lists at end of foregoing entries, and others given in alphabetical listing.

FERTILIZER. A substance, but often a combination of substances, of organic and/or inorganic nature, natural and/or manufactured, in solid or liquid or slurry form made available to plants to promote normal, healthy, and often vigorous growth. Most frequently added to soils, fertilizers also are sometimes applied directly to plant parts above ground (foliar sprays) or in the nutrient fluids furnished in hydroponic systems.

Unless poisoned or severely leached, some soils still may retain some of the nutrients required by growing plants and may support plants of a weak, straggly nature, with yields submarginal and quality essentially unacceptable. Some soils may be generally poor, that is, they do not contain any of the primary plant nutrients in adequate concentration; or they may be poor soils because of an imbalance of nutrients. It should be stressed that the proper chemical nutrients must be present along with suitable physical properties of the soil if highest yields and quality of product are to be achieved. The chemical aspects of soils cannot be regarded in isolation from the physical aspects. The concept of soil-plant system is described in entry on **Soil.** A given soil may be classified as generally rich and yet lack the needed concentration of only one or two micronutrients.

Because of the intensity of cultivation in many regions of the world, notably among the large producers of food and other crops, where there is repetitive use of the same tracts of land year after year, the uniformity of nutrient content, as may be present in a tract of virgin soil, cannot be assumed. In fact, experience has shown that the same soil class may vary widely in nutrient content from one field to the next. The ability of soils to provide plant nutrition is a reflection of how the soils have been artificially treated (fertilized and conditioned) over the remote and recent past and upon what kinds of crops have been grown on them. With increasing use of control chemicals, soils require increasing frequency of testing and analysis, not only for required plant nutrients, but also for the possible presence of chemicals that tend to accumulate rather than to dissipate to downward soil levels and even to the groundwater, or that are not biodegradable and hence may be present from one growing season to the next.

Particularly during the last few decades, astute growers in many parts of the world—frequently those concerned with large-scale production operations where investments are very high—have learned to depend increasingly upon reliable scientific analysis of their soils, augmented by tissue analyses of plant parts, and sometimes total plant analyses, as a basis for planning their annual fertilization programs. This scientific approach is to be contrasted with following rule-of-thumb methods and habitually following habits that no longer may be capable of producing maximum yields and product quality. In addition to using various kinds of chemical kits avalable for local application (normally limited to three categories of readings—High, Medium, Low), growers will take advantage of local soil analysis facilities and also programs that have regional or national government support.

Perhaps not sufficiently stressed are problems that can arise from overfertilization as well as those of underfertilization. Crops vary immensely in their ability to tolerate deficiencies and excesses of nutrients (insofar as giving a yield and quality even if not the highest). Over fertilization can cause serious pollution problems, a topic that has been under serious investigation for the last several years in connection with clean water programs. And on a more selfish level, the grower who overfertilizes is simply wasting money as well as running the risk of damage to certain kinds of crops and those crops that may be planted on the same land in following seasons.

Basic Fertilizer Functions. Major reasons for adding fertilizer to soils and plants include: (1) Replenishment of chemical elements that have been reduced or exhausted by the soils to the crops previously grown or leached from the soils as the result of poor tillage practices, overirrigation, natural flooding, and, in some cases, adding nutrients that are naturally deficient in a given soil class; (2) customizing the nutrient content of soils to particular growing objectives, that is, to the chemical needs of specific crops required to achieve highest yields and premium product quality.

Fertilization, in combination with irrigation, has been responsible for converting vast semiarid and arid lands with lean soils into lands useful for production of certain vital food and fiber crops. This effective combination is particularly important to a number of the developing countries that have large holdings of land in these categories. Thus, agricultural and food production planners and technologists with various governments and with international organizations are deeply concerned with the availability of fertilizers in the decades ahead, just as they are also concerned with the availability of adequate water supplies, technology, and with the further development of superior hybrids and new strains of crop plants. See "Green Revolution" described in entries on **Rice**; and **Wheat**.

While self-evident, the fact that crops exhaust the soil of key chemical ingredients is made even clearer by examination of Table 1, which lists the constituents of the ashes of certain crops. In the analysis, nitrogen is lost and does not appear in the ash, but other methods for analyzing for nitrogen confirm its significant content in crops. Carbon, oxygen, and hydrogen, of course, are made available to crops by way of water and the atmosphere.

Principal Categories of Nutrients. The nutrients required by plants are placed into three main categories: (1) *Primary nutrients or elements*—nitrogen, phosphorus, and potassium because they are generally required by plants in larger amounts and are often present in more limited amount in soil; (2) *secondary nutrients or elements*—calcium, magnesium, and sulfur because they generally are not so limited in soils and are required by plants in smaller amounts; and (3) *micronutrient elements,* of which there are several. See Table 2.

TABLE 1. CONSTITUENTS OF ASH OF NORMAL CROPS

	Silica	Potash	Soda	Magnesia	Lime	Ferric Oxide	Chloride	Sulfate	Phosphate
Crop and Part	Pounds of Constituent Removed per Acre of Ground (Kilograms per Hectare given in parentheses)								
Grain	15 (16.8)	14 (15.7)	7 (7.8)	2 (2.2)	8 (9)	1 (1.1)	0 (0)	0 (0)	36 (40.3)
Straw	233 (261)	33 (37)	1 (1.1)	28 (31.4)	12 (13.4)	6 (6.7)	4 (4.5)	13 (14.6)	11 (12.3)
Roots	27 (30.2)	143 (160)	17 (19)	46 (51.5)	18 (20.2)	4 (4.5)	12 (13.4)	46 (5.5)	26 (29.1)
Tops	3 (3.4)	89 (99.7)	17 (19)	72 (80.6)	10 (11.2)	3 (3.4)	50 (56)	39 (43.7)	29 (32.8)
Hay	78 (87.4)	38 (42.6)	12 (13.4)	45 (50.4)	7 (7.8)	1 (1.1)	4 (4.5)	9 (10.1)	15 (16.8)

TABLE 2. PRINCIPAL CATEGORIES OF PLANT NUTRIENTS

PRIMARY NUTRIENTS OR ELEMENTS

Nitrogen (N)
Phosphorus (P)
Potassium (K)

SECONDARY NUTRIENTS OR ELEMENTS

Calcium (Ca)
Magnesium (Mg)
Sulfur (S)

MICRONUTRIENTS

	General Range in Soils	
Element	Pounds/Acre	Kilograms/Hectare
Boron (B)	20–200	22.4-224
Manganese (Mn)	100–10,000	112.0–11,200
Zinc (Zn)	10–600	11.2-672
Copper (Cu)	2–400	2.2-448
Iron (Fe)	10,000–200,000	11,200–224,000
Molybdenum (Mo)	1-7	1.1-7.8

Nitrogen Requirements

Although the requirements for nitrogen and other elements contained in fertilizers are reasonably well understood today, this was far from self-evident just a few centuries ago. It seems reasonably safe to postulate that the early growers of plants of various kinds practiced rudimentary forms of fertilization without understanding any of the details of what they were doing—beyond reasoning along the lines that "something taken from the soil must be returned," in itself a rather profound observation for ancient peoples. This observation plus noting from chance experiences and later followed by some trial and error exercises were the prelude to modern fertilization technology. It remained for the awakenings of chemistry in the 1600s and notably the early scientists of the late 1700s and early 1800s to commence investigations of the technical links between plants and plant nutrients.

Chilean saltpeter, $NaNO_3$, was the first of the chemical nitrogenous fertilizers. Ammonium sulfate, $(NH_4)_2SO_4$, made available as a byproduct of coal-gas produced in large quantities prior to the advent of wide use of natural gas, was also an early fertilizer, but followed Chilean saltpeters by several years. Ammonium sulfate is still an important source of nitrogen, but no longer holds the lead role in most parts of the world. In the early 1900s, attempts to fix atmospheric nitrogen in a compound that could be applied directly to the soil were made. During that period, nitrogen fixation was a much-discussed aspect of industrial chemistry much as synthetic fuels are a timely topic today. For some years, calcium cyanamide, $CaCN_2$, was produced in the United States, largely as the result, at that time, of the new-found hydroelectric energy of the Tennessee Valley region. A large facility was located at Muscle Shoals, Alabama. The last plant for making calcium cyanamide in the United States was closed in June 1971. In Norway, because of low-cost hydroelectric energy then available, production of calcium nitrate by way of first producing nitric acid was pioneered.

The first breakthrough in the large-scale synthesis of ammonia resulted from the work of Fritz Haber (Germany, 1913), who found that ammonia could be produced by the direct combination of 2 elements, nitrogen and hydrogen, in the presence of a catalyst at a relatively high temperature and very high pressure. Largely because of the urgent requirements for ammonia in the manufacture of explosives during World War I, the process was adapted for industrial-quantity production by Karl Bosch, who received one-half of the 1931 Nobel prize for chemistry in recognition of these achievements. Thereafter, many improved ammonia-synthesis systems, based on the Haber -Bosch process, were commercialized, using various operating conditions and synthesis-loop designs. Thus, the production of synthetic ammonia, NH_3, became the most important nitrogen-fixation process.

For many years, the bulk of nitrogen fertilizers has been based upon ammonia, as synthesized from atmospheric nitrogen and reacted with hydrogen drived from natural gas, oil, coal, lignite, or electrolysis of water (the foregoing hydrogen sources listed in decreasing order of use). There has been an increasing trend in some of the major agricultural countries during the last few decades to favor the use of liquid nitrogen fertilizers for some crops. These products include anhydrous ammonia, aqua ammonia, ammonium salts in solution, and numerous combinations, such as formulations also containing phosphate salts. Because of the easy solubility of these materials, some ecologists have expressed concern over so-called *nitrogen runoff.* However, most soils will fix ammonium ions quite rapidly, thus diminishing a pollution threat.

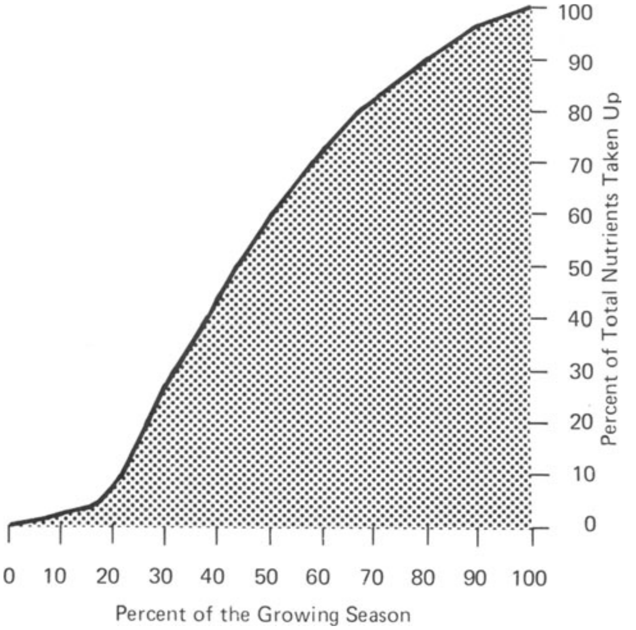
It is interesting to observe that the compound *urea,* NH_2CONH_2, was discovered (in urine) as early as 1773 by Rouelle and first identified as a pure crystalline organic compound by 1822, and first synthesized by Wöhler in 1828. Although there was an obvious connection between urea and life processes, little if any thought was given to its use as a fertilizer (source of nitrogen) until after World War I, when the German firm BASF (Bosch) developed a process for synthesizing urea from carbon dioxide and ammonia. Urea-form fertilizers, now widely used, are the result of reacting urea and formaldehyde to provide a form of controlled release of nitrogen. Urea also can be coated with sulfur (itself required by many soils) to reduce the rate of solution. And, slowly soluble compounds, such as isobutylidene diurea, can be made, but because of high cost, these are marketed only to horticulturists rather than growers of commercial crops.

Although not chemical fertilizers (artificially produced), the importance of natural nitrogenous materials as returned to the soil in various degrees of organic farming are of extreme importance and markedly reduce the total demand for chemical nitrogen fertilizers. Significant nitrogen needs are met by returning *crop residues* to the soil (although there are also negative aspects to this in terms of insect, fungus, bacteria, and weed controls). *Green manure* is a crop purposely grown for plowing under to enrich the soil. See **Green Manure**; **Humus**; and **Compost**. *Animal manure* also is a significant contributor to the soil, not only in terms of nitrogen, but phosphate and potash as well. See **Manure.** Also certain crops, notably legumes, create more nitrogen for the soil than they use—this as a result of bacteria that inhabit the root zones of these plants. See **Legume.** Collectively, these types of materials are sometimes referred to as *organic fertilizer.*

The importance of nitrogen to plant health and vigor is more deeply appreciated when one delves into the biochemical aspects of the element. Nitrogen is, of course, a component of vital tissues in plants and animals. Nitrogen occurs in the amino acids, which combine to form proteins, in enzymes, in pigments, such as chlorophyll and hemoglobin, and in the vitamins of the B group. Nitrogen compounds, necessary for plant growth, are passed along to livestock and humans who consume the plants. The role of nitrogen in plant and animal life is described in several entries of this volume, notably **Amino Acid**; **Chlorophylls**; **Enzyme**; and **Protein**; among others.

In recent years, more stress has been given by some authorities to the fact that, unlike organic nitrogenous fertilizers, commercial chemical fertilizers do not liberate their nutrients at different rates, as required by prevailing conditions so that they do not become available to the plants when they are most needed. Authorities observe that plants fed with inorganic nitrogen tend to be overfed and as a result nitrate is stored in the vascular systems of the plants. Furthermore, often because of the lack of humus in the soil, the nitrates can be washed into the ground water. Another undesirable effect of heavy application of inorganic nitrogen is the accumulation of free amino acids (i.e., not incorporated into proteins) and a decrease in the vital amino acid, methionine. It also has been observed that excessive nitrogen fertilization also leads to a decline in plant quality in terms of taste, to reduced storability, and to an increase of disease and attack by pests, which, in turn, forces the grower to apply more pesticides. Some authorities have observed that nitrates (NO_3 ion) have not always proved to be entirely harmless, especially when converted to nitrites (NO_2 ion), which can be toxic.

But, these same authorities readily agree that there is by no means ample natural nitrogen fertilizers available and that to increase worldwide food production, there must be heavy dependence upon chemical nitrogen fertilizers. This, in turn, has placed heavy stress on the *timing of fertilizer applications.* If chemical nitrogen fertilizers not capable of equilibrating plant requirements with nitrogen release rates, then the times and amounts of fertilizer application by growers must be carefully coordinated. This requires a detailed understanding of the *uptake* (use) of fertilizer by the plant. A very generalized uptake curve for an average of several crops is shown in the accompanying figure. It must be emphasized that each crop has its own uptake curve. Fortunately, the bank of information in this area has expanded much during recent years, such information being relatively easily available from government and private agricultural specialists. The *central scientific staffs* of most fertilizer manufacturers also can furnish reliable information along these lines. The uptakes of a number of crop plants are described in several specific crop entries in this volume. Uptake, of course, is not confined to nitrogenous fertilizers, but refers to other primary and secondary nutrients as well. As will be pointed out later, it is interesting to note that the various nutrients do not accumulate uniformly throughout plants, but tend to be concentrated within certain parts (leaves, stems, etc.) so that when making tissue analyses, it is important to subject the proper plant part to analysis.



Composite nutrient uptake chart representing an average of many plants. Each plant has its own specific nutrient uptake curves. (Source: Leitch reference listed)

Type of Nitrogenous Fertilizers. In terms of world commerce, the main chemical nitrogen fertilizers are anhydrous ammonia, urea, ammonium nitrate, ammonium sulfate, and calcium nitrate. Nitrogen solutions, consisting of an ammonium salt or combination of ammonium salts in water solution, are very popular in several agricultural regions. Also, prilled combinations in the form of calcium ammonium nitrate and ammonium sulfate nitrate are also produced. Mixed fertilizers (nitrogen-phosphorus-potassium) are described later.

Anhydrous Ammonia. This compound, NH_3, is applied directly to the soil from portable pressurized tanks. The manufacture of ammonia has been described earlier.

Urea. This compound contains 46.65% nitrogen by weight. The manufacture of urea involves the noncatalytic, exothermic reaction of ammonia and carbon dioxide to form ammonium carbamate, which is retained at an elevated temperature until water splits out to form urea: (1) $2NH_3 + CO_2 \rightarrow NH_2COONH_4$; (2) $NH_2COONH_4 \rightarrow NH_2COONH_2 + H_2O$. In addition to its use as fertilizer, urea is also incorporated in some animal feedstuffs. See also **Feedstuffs.** Grain size is from 1 to 2.4 millimeters for fertilizers and from 0.2 to 1 millimeter for animal feed.

Ammonium Nitrate. This compound contains approximately 35% nitrogen by weight. Ammonium nitrate is easily produced by reacting ammonia with nitric acid: $NH_3 + HNO_3 \rightarrow NH_4NO_3 - 26$ kcal. Nitric acid of 50 to 60% concentration is neutralized with gaseous ammonia at a slight positive pressure to form ammonium nitrate solution. The heat of reaction released in the process is used to preconcentrate the ammonium nitrate solution to 85 to 95 percent. Concentration to 97 to 99.5% then takes place in steam-heated concentrators. The final product is obtained by prilling or granulating the ammonium nitrate melt. For fertilizer, the product is furnished as high-density prills[1] with a size of 1 to 3 millimeters, or as granules. Final moisture content ranges from 0.2% to 0.4%. Large-scale production also results from reacting calcium nitrate with ammonia and carbon dioxide: $Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \rightarrow 2NH_4NO_3 + CaCO_3$. This product is also prepared as prills or granules, or may be marketed as a solution, either alone or mixed with other nitrogen-containing liquids, such as urea and aqua ammonia. Because of hazards associated with ammonium nitrate (the popular explosive ANFO is a mixture of NH_4NO_3 and fuel oil), danger can be minimized by making nitro chalk, which is a mixture of ammonium nitrate and calcium carbonate, and having a nitrogen content of about 26%.

Ammonium Sulfate. This compound contains approximately 21% nitrogen by weight. The product is prepared in several ways. In the simplest process, ammonia is neutralized with sulfuric acid. In the gypsum process, ammonium sulfate is formed by the chemical conversion of gypsum (calcium sulfate) and ammonium carbonate to ammonium sulfate and calcium carbonate: $CaSO_4 \cdot 2H_2O + (NH_4)_2CO_3 \rightarrow (NH_4)_2SO_4 + H_2O - 3.9$ kcal. The calcium carbonate is separated by filtration, and the ammonium sulfate solution is concentrated with simultaneous precipitation of crystals. In another process, the byproduct aqueous ammonium sulfate solution resulting from scrubbing coal gas with sulfuric acid is the feed material. Following evaporation and crystallization, ammonium sulfate crystals are washed and dried. A major source in the United States and some other industrial countries is ammonium sulfate resulting as a byproduct from caprolactam manufacture (used in nylon production). Ammonium sulfate grain sizes range from 0.5 to 3 millimeters and, when properly prepared and stored, are free-flowing and easy to distribute.

Calcium Nitrate. This compound contains approximately 15% nitrogen by weight. This product can be produced by reacting ground limestone and nitric acid. Ground limestone is digested with nitric acid to form a calcium nitrate solution which s then neutralized with ammonia. The excess of nitric acid, and consequently, the amount of ammonia is adjusted for an ammonium nitrate content of from 5 to 7% in the final product. The neutralized solution is concentrated to a melt of about 87% concentration in multistage concentrators. Calcium nitrate is also a byproduct from nitrophosphate manufacture, described later. Prill size ranges from 1 to 3 millimeters; granules from 2 to 4 millimeters. The product is also available as flakes with edges of 2- to 4-millimeter length.

Calcium Ammonium Nitrate. Depending upon the amount of calcium carbonate added, the nitrogen content of this material ranges between 20.5 and 28% by weight. Raw materials are ammonia, nitric acid, and natural limestone or precipitated calcium carbonate. Ammonia and nitric acid are neutralized to ammonium nitrate, and the ammonium nitrate solution is subsequently concentrated. Concentrated ammonium nitrate melt, powdered limestone, and recycle material are granulated, classified, and powder-coated. The finished product is in the form of round, hard granules of a grain size between 1.5 and 4 millimeters, and a moisture content of about 0.5% maximum. In the prilled product, powdered limestone is added to the ammonium nitrate melt. The mixture is fed into a prilling basket at the top of a tower where the final product is obtained in the form of prills which are subsequently cooled and powder-coated. The hard spherical prills have a diameter of 1 to 3 millimeters and a moisture content of 0.5% maximum.

Ammonium Sulfate Nitrate. This material is produced from nitric acid, ammonia, and sulfuric acid by the Hibernia process. The nitrogen content of the double salt is from 26 to 28% by weight. The nitric acid is neutralized with gaseous ammonia, and the heat released is used for the evaporation of water. The ammonium nitrate solution is fed into a saturator, where sulfuric acid and ammonia are added for neutralization. Simultaneously, phonolite and ferric sulfate are added to improve the hardness and storage properties of the product. In the process, all of the available ammonium nitrate forms a double salt with ammonium sulfate. The finished ammonium-sulfate-nitrate melt is granulated, the grain size being from 2 to 4 millimeters. The granules are extremely hard and have good storage properties.

Phosphorus Requirements

Phosphorus is an essential nutrient for biochemical and physiological functions in life processes, plant and animal. Phosphorus is an ubiquitous element, found throughout the plant and animal worlds and occurring in all tissues and organs. These aspects of the need for phosphorus are described in several entries in this volume, including **Cell (Biology)**; **Phosphatases**; **Phospholipids**; **Phosphorus**; **Phosphorylation (Oxidative)**; **Phosphorylation (Photosynthetic.)** Deficiencies of available phosphorus in soils are a major cause of limited crop production and phosphorus deficiency is regarded by some authorities as the most critical mineral deficiency in grazing livestock. For descriptions of phosphorus requirements of various crop plants, see specific entries on these topics. See also **Feedstuffs.**

Liebig and other investigators in the mid-1800s indicated that the much earlier noted fertilizing properties of bones were derived mainly from their phosphate content and that treatment of bones with sulfuric acid increased their effectiveness on soils. With these advantages proclaimed, a large market for what was then called "chemical manure" resulted in a shortage of bones throughout the European agricultural community. Fortunately, a number of years later a number of guano deposits were located in Peru and quite a bit later, phosphate minerals were located in Florida and other parts of the world. Guano fertilizers today are used mainly for special horticultural products, whereas commercial chemical phosphate fertilizers are derived from phosphate rock.

Types of Phosphate Fertilizers. In formulating phosphate fertilizers, solubility is of particular concern. Good solubility assures availability of phosphorus in the fertilizer to the plants. For example, in water and in alkaline and

[1] Prills are small round or acicular aggregates of a material that are artificially prepared (as contrasted with true crystals).

neutral soils, the apatites, which are $Ca_5(PO_4)_3R$ (where R is usually fluorine, but may be OH, CO_3 or Cl), are quite insoluble and hence of little value to the soil. This is also true of tricalcium phosphate, $Ca_3(PO_4)_2$. On the other hand, these compounds are moderately soluble in acid soils and thus can be used with discretion. Somewhat in contrast, dicalcium phosphate, $CaHPO_4$, is quite soluble in acid soils and moderately soluble in water and alkaline and neutral soils. Thus, it possesses a considerable advantage over the aforementioned compounds. Fortunately, monocalcium phosphate, a $Ca(H_2PO_4)_2$, is soluble in water, and all moist soils. The presence of iron and aluminum phosphates also has an effect on solubility, these compounds being insoluble in water, but soluble in weak acids.

Some countries require total water solubility and thus monocalcium and ammonium phosphates must be used. In other areas, slight solubility in water or appreciable solubility in weak acids is adequate. Some humic soils can assimilate ground phosphate rock even without chemical treatment.

Commonly, in phosphate fertilizer manufacture, phosphorus is recovered from phosphate rock. The rather wide range of phosphate rock composition is shown in Table 3.

Nomenclature. Because the ammonium phosphate fertilizers contain two of the primary plant nutrients, it is pertinent at this point to briefly comment on the manner in which fertilizers are named. A series of three numbers, separated by dashes, is used to indicate the primary-nutrient content of fertilizer mixtures. In order, from left to right, the numbers show the percentage of nitrogen, phosphoric oxide, and potash. Example:

5 — 10 — 5

5% Total Nitrogen	10% Available Phosphoric Oxide	5% Soluble Potash

Single Superphosphate. Produced in large quantities and the oldest of the water-soluble phosphates, this material contains approximately 20% P_2O_5 by weight. Single superphosphate is made by reacting ground phosphate rock with 70% sulfuric acid. This reaction results in a solid mass of monocalcium phosphate and gypsum. The mass is cured for several weeks prior to shipping. The empirical reaction for this preparation is:

$$3Ca_3(PO_4)_2 \cdot CaF_2 + 7H_2SO_4 \rightarrow 3Ca(H_2PO_4)_2 + 7CaSO_4 + 2HF$$

The fluorine and silicon evolved are removed by water scrubbing.

Wet-Process Orthophosphoric Acid. Commercially, this material contains 30–54% P_2O_5 by weight. When sulfuric acid is added to phosphate rocks in a proportion greater than required to make the aforementioned single superphosphate, orthophosphoric acid, H_3PO_4, is produced. While there are several intermediate reactions, in summary form it is:

$$Ca(PO_4)_2 \cdot CaF_2 + H_2SO_4 + H_2O \rightarrow H_3PO_4 + CaSO_4 \cdot H_2O + HF$$

The acid produced is an intermediate.

Triple Superphosphate. By acidulating phosphate rock with phosphoric acid, a concentrated or triple superphosphate is produced. This is essentially monocalcium phosphate containing very little gypsum. The reaction is:

$$Ca(PO_4)_2 \cdot CaF_2 + H_3PO_4 + H_2O \rightarrow Ca(H_2PO_4)_2 \cdot H_2O + HF$$

The principal use of triple superphosphate is in mixed fertilizers to make P_2O_5 available in water-soluble form.

Ammonium Phosphates. Although several ammonium phosphates can be prepared, only the mono- and the dicompounds are produced for fertilizer use. In some processes, anhydrous ammonia is reacted with phosphoric acid, with the resultant slurry converted to solid form by drying. The ratio of ammonia to phosphoric acid, NH_3/H_3PO_4, can be varied between 1 and 2, and consequently several product grades can be made. Diammonium phosphate, for example, results from: $2NH_3 + H_3PO_4 \rightarrow (NH_4)_2HPO_4$.

Nitrophosphates. Phosphate rock is readily dissolved in nitric acid to yield a mixture of calcium nitrate, phosphoric acid, and monocalcium phosphate. When calcium nitrate is

TABLE 3. ANALYSES OF PHOSPHATE ROCK

Source	Phosphorus Pentoxide	Flourine	Calcium Oxide	Carbon Dioxide	Aluminum Oxide	Ferric Oxide	Silicon Oxide
Florida	31-35%	3.6%	46-50%	2-3%	1%	1-2%	5-10%
Tennessee	32-37	3.6	48-50	2	1-2	1-4	2-12
South Carolina	26	3.4	42	4	1	1.5	13
Idaho	34	3.4	48	2	0.7	0.5	4
Montana	29	3.0	40	1	1.7	1.5	22
Wyoming	31	3.5	48	4	0.4	1	5
Quebec	39	3.0	54	1	0.4	0.4	1
Morocco	35	4.0	53	4	0.3	0.3	1
Bone ash	40	0.1	54	1	0.0	0.2	0.5
Steamed bone meal	35		48	–	–	–	–

In making superphosphate about equal weights of Florida phosphate rock and sulfuric acid are used.

converted to solid form, the material is highly hygroscopic and thus not desirable for packaging and storing. This can be overcome by forming calcium nitrate tetrahydrate crystals through chilling and later removal by filtration or centrifuging. Ammoniation of the mother liquor produces a mixture of ammonium phosphate, dicalcium phosphate, and ammonium nitrate. These can be concentrated and prilled or granulated. Thus, in terms of traditional fertilizer nomenclature, that is, %N: %P_2O_5: %K_2O, numerous product grades are possible according to raw-material ratios and process conditions. By adding potash to 20-20-0, a formulation of 15-15-15 can be obtained, as one of numerous examples.

Nitrophosphates are made in extremely high tonnage in Europe where there is less emphasis on total phosphate water solubility. Because of ample availability of sulfur and a preference for rapid-acting, water-soluble phosphate fertilizers in the United States (particularly for corn and grains), interest in nitrophosphates to date has been moderate.

Nonorthophosphates. If 54% orthophosphoric acid is dehydrated to remove the remaining free water, a pyro acid is yielded. Continued heating removes more water and various insoluble compounds are formed. Evaporation by submerged combustion or under vacuum yields a eutectic between ortho and pyro acids with a P_2O_5 content of about 72% by weight. This superphosphoric acid can be ammoniated to yield liquid ammonium polyphosphate (APP) fertilizers, such as 10-34-0. Because of their strong sequestering properties, these liquids keep impurities in solution, as well as the salts of micronutrient metals which are insoluble derivatives of orthophosphoric acid.

APP fertilizers also are produced by reacting ammonia directly with wet-process phosphoric acid and dissolving the melt in ammonia solution to produce 10-34-0. By adding potash and a bit of clay, nitrogen-phosphorus-potassium suspensions, such as 13-13-13, are possible. If the melt is granulated, a solid with proportions 12-57-0 will result. Thus, by adding urea and potash, a wide variety of mixes (28-28-0, 19-19-19, and so on) are possible.

Potassium Requirements

Researchers in the early 1800s found that potassium is an essential plant nutrient although the details of its function were unknown at the time. The potassium in wood ashes was first used in Europe, later to be replaced by sylvite, KCl, and carnalite, $KCl \cdot MgCl_2 \cdot 6H_2O$, found in deposits in Germany. During the interim, billions of tons of these minerals have been located. A number of sites are continuously mined. Large reserves are found in the U.S.S.R., Canada, and east and west Germany. Significant deposits also are found in Israel and Jordan (Dead Sea region), Spain, France, the United Kingdom, and the United States. Deposits are as water-soluble salts, such as sylvite, and minerals with varying content of magnesium.

The physiological role of potassium in the plant and animal life processes is described in entry on **Potassium.** Potassium is a usual but variable constituent of most soils, but available potassium may be depleted through loss arising from leaching by rain water, flooding, and overirrigation or through loss to crops continuously planted on a given tract. Thus, potassium is categorized as a primary nutrient. Some authorities believe that potassium is absorbed by the plant roots from the soil by an active transport mechanism which carries it through the cell wall structure. Potassium differs from most other essential constituents of plant cells in that it is not built into the cell as a part of an organic compound, but is rather an ion from a soluble inorganic or organic salt. Potassium ions may chelate with cellular constituents, such as polyphosphates. The ion is of the correct size to fit into the water lattice adsorbed to the proteins in the cell. In general, potassium ions are attracted to protein or other colloidal or structural units having a negative charge. Mucopolysaccharides within the cell, on the cell surfaces and of the intercellular structures, are of particular importance in holding potassium. Active centers or other configurational features of the proteins in the cell may be affected or altered by the potassium held by electrostatic or covalent binding. There are several enzyme systems which are activated by potassium.

In plants, the meristematic tissues in general are particularly rich in potassium, as are other metabolically active regions, such as buds, young leaves, and root tips. Potassium deficiency may produce both gross and microscopic changes in the structure of plants. Effects of deficiency include leaf damage, high or low water content of leaves, decreased photosynthesis, disturbed carbohydrate metabolism, low protein content, among other abnormalities. The importance of potassium is also reflected by livestock who consume plants and feedstuffs prepared from plant materials. See also **Feedstuffs.**

Potassium Fertilizers. Potassium minerals, as previously mentioned, are the basis for potassium fertilizers. These minerals are mined in Canada, for example, which supplies most of the needs in North America. Mining usually is by underground methods between 1000 and 5000 feet (300 and 1500 meters), although solution mining is also practiced in Canada. At the surface, the ores are crushed, beneficiated, crystallized, and dried to produce commercial *potash* or *muriate,* KCl, in various grades and particles containing from 60 to 62% KCl.

Relatively small amounts of other potassium salts are used as fertilizers, generally for special purposes. Some vegetables and tobacco, for example, are adversely affected by high chloride concentrations and thus some growers prefer to use potassium sulfate, K_2SO_4, or potassium nitrate, KNO_3. Potassium sulfate is made in substantial quantities in Europe by the Mannheim process from potash and sulfuric acid; and in the United States and other countries by various exchange reactions between potassium, sodium, and magnesium salts. Limited amounts of potassium hydroxide, KOH, are sometimes used in liquid fertilizer formulations.

Potash is frequently applied to the soil along with salts containing nitrogen and/or phosphoric oxide, P_2O_5, in amounts varied for different soil and crop requirements. One method used is that of combining crushed muriate with moist nitrogen- and P_2O_5-containing compounds and granulate the mixture. Another method is that of dry-blending materials, such as urea, diammonium phosphate, and potash, and apply the mixture to the soil. The total water solubility of potash results in full initial K_2O availability in moist soils. However, in clays, when rainfall or irrigation is limited, excessive chloride buildup can be harmful.

Calcium Requirements

The role of calcium in plant and animal life systems is described in entry on **Calcium.** Fortunately, as the fifth most abundant element in the earth's crust, calcium is usually available to plants in abundance. Nevertheless large amounts of calcium are added to soils by virtue of the use of lime (calcium oxide, CaO) as a means to adjust the pH of acid soils. Among many reasons why soil pH is so important are the effects of acidic soils on the availability of manganese, a micronutrient, and also of aluminum, more recently identified as toxic to some crops. The use of dolomitic lime, $CaMg(CO_3)_2$, also is an effective way to correct magnesium deficiencies. Agricultural lime is not water soluble and, therefore, it will not correct soil acidity immediately after application. Lime should be applied from 3 to 4 months before planting season. Because of wide variations in the effects of crops as well as fertilizer applications on soil pH, lime should not be applied to the soil indiscriminately, but only after a soil test indicates the need.

Sulfur Requirements

The role of sulfur in plant and animal life systems is described in entry on **Sulfur**. Sulfur, in some form, is required by all living organisms. Among important sulfur-containing compounds are the amino acids (cysteine, cystine, and methionine); the vitamins (thiamine and biotin; certain complex lipids (sulfatides), among many others. In the chain from soils to plants to humans, inorganic sulfur (sulfate ion, SO_4^{-2}) is taken up by plants and converted within the plant to organic compounds (sulfur amino acids). The most important feature of sulfur in the food chain is that plants use inorganic sulfur compounds to make the aforementioned amino acids, whereas animals and humans use the sulfur amino acids for their own processes and excrete inorganic sulfur compounds that result from the metabolism of the sulfur amino acids.

Although sulfur is a widespread element in the earth's country, ranking as the 14th element in abundance, it is obviously less abundant than calcium and is not so evenly distributed and thus some soils show sulfur deficiencies. In fact, in some regions of the world, sulfur-deficient soils are common. In the United States, for example, these soils are found in the Pacific Northwest and in some regions of the Great Lakes states. For many years, sulfur in the form of calcium sulfate was an accessory part of most commercial phosphate fertilizers. This probably helped to prevent development of widespread sulfur deficiency. The trend toward high analysis fertilizers without sulfur can create a need for more deliberate use of sulfur fertilizers.

Sulfur, of course, is present in ammonium sulfate used as a fertilizer, but ammonium sulfate is only one of several nitrogenous fertilizers from which the grower can select. Elemental sulfur and sulfur-containing compounds are also used for controlling various plant pests. Further, considerable sulfur is made available to the soil as the result of air pollution. Nevertheless, soil analysis can provide an accurate diagnosis of whether or not a particular soil may require additional sulfur. The effect of sulfur deficiencies is described in entry on **Sulfur**; and of insufficient intake by livestock, in entry on **Feedstuffs.**

Magnesium Requirements

The role of magnesium in plant and animal life systems is described in entry on **Magnesium**; also some details are given under **Feedstuffs.** Magnesium is generally abundant in the earth's crust, ranking eighth in abundance among the chemical elements. Nevertheless, magnesium deficiencies are quite common. Magnesium is a fairly common cause of poor crop yields, especially among crops produced on sandy soils. Accumulation of magnesium from the soil by plants is strongly affected by the species of plant. Legumes usually contain more magnesium than grasses, tomatoes, maize (corn), regardless of the level of magnesium in the soil where grown (unless, of course, the element is deficient to the extreme). A high level of available potassium in the soil interferes with the uptake of magnesium by plants, and thus magnesium deficiency can occur even though there are adequate amounts of the element in the soil. The role of magnesium highlights the systems aspects of agricultural management, namely, the relationship between magnesium intake from pasture and from feedstuffs—because when animals are fed diets primarily of grains, a proper balance among magnesium, calcium, and phosphorus must be maintained to minimize danger from urinary calculi. Magnesium deficiency among cattle (grass tetany or grass staggers) is observed most frequently when animals are first grazed on lush grass or wheat pastures, indirectly indicating the relatively low uptake of magnesium by certain crops.

Magnesium deficiencies are easily corrected by applying magnesium-containing minerals, such as kieserite or dolomite.

Micronutrients

In this volume, there is a separate entry on each of the micronutrients listed in Table 2. In addition to the traditionally recognized micronutrients, considerable attention is given in this volume to additional elements, particularly with reference to animal feedstuffs, but also in connection with human nutrition. Because of the very small gap between minimum requirements and toxicity of some of these elements, it is unlikely that the soil is the most fitting place to make them available—with the exception that plants also require some of these substances also. Considerable research remains to make these determinations for all important crops, but a good start has been made in connection with animal requirements. See also **Feedstuffs**; as well as separate entries on **Chloride**; **Chromium**, **Cobalt**; **Fluorine**; **Iodine**; and **Nickel.**

Even though the traditional micronutrients may be required only to the extent of ounces or fractions thereof per acre of hectare, deficiencies can lead to diseased crops and stunted livestock. In connection with specific crops described in this volume, several such instances are included. The status of micronutrient deficiencies in the soils of the continental United States is given in Table 4. Emphasis also

TABLE 4. STATUS OF MICRONUTRIENT DEFICIENCIES IN SOILS OF THE UNITED STATES
(Alaska and Hawaii not included)

	Boron			Copper			Iron			Manganese			Molybdenum			Zinc		
State	ND	Mod	Sev	ND	Mod	Sev	ND	Mod	Sev	ND	Mod	Sev	ND	Mod	Sev	ND	Mod	Sev
Alabama		x		x			x				x		x				x	
Arizona	x				x			x			x		x				x	
Arkansas		x		x			x			x			x			x		
California			x			x			x		x			x				x
Colorado	x			x				x		x			x			x		
Connecticut			x	x			x			x				x		x		
Delaware			x	x			x				x				x	x		
Florida			x			x			x			x		x				x
Georgia		x		x			x			x				x			x	
Idaho		x		x				x		x				x			x	
Illinois		x		x			x				x			x		x		
Indiana		x			x			x				x		x		x		
Iowa		x		x				x		x			x			x		
Kansas		x		x					x	x				x			x	
Kentucky		x		x			x			x			x				x	
Louisiana		x		x				x		x			x				x	
Maine			x	x			x			x			x			x		
Maryland			x	x			x			x				x		x		
Massachusetts			x	x			x			x				x		x		
Michigan			x			x	x					x			x		x	
Minnesota		x			x				x		x		x				x	
Mississippi		x		x				x		x			x				x	
Montana			x	x				x			x		x				x	
Nebraska		x		x					x	x				x				x
Nevada	x			x				x		x			x			x		
New Hampshire		x		x			x			x			x			x		
New Jersey			x		x			x				x		x			x	
New Mexico	x			x					x	x			x				x	
New York			x		x		x					x		x			x	
North Carolina			x		x			x				x	x				x	
North Dakota	x			x				x		x			x				x	
Ohio			x	x			x					x	x			x		
Oklahoma		x			x				x	x			x				x	
Oregon			x		x			x			x			x			x	
Pennsylvania			x	x			x				x			x		x		
Rhode Island		x		x			x				x		x			x		
South Carolina			x	x			x				x		x				x	
South Dakota	x			x				x			x		x				x	
Texas		x		x				x			x		x				x	
Utah	x			x				x				x		x				x
Vermont		x		x			x			x			x			x		
Virginia			x		x			x				x	x				x	
Washington		x		x			x			x				x				x
Wisconsin			x			x	x				x			x				x
Wyoming	x			x			x			x			x			x		

Source: University of Wisconsin
ND = no deficiency.
Mod = moderate deficiency.
Sev = severe deficiency.

should be given to the importance of soil pH in connection with plant uptake of certain micronutrients. For example, manganese salts are practically insoluble at a pH of 6.0, whereas they become increasingly soluble at a pH of 4.0. This is also important in terms of preventing manganese (and aluminum) toxicity for crops that are sensitive to a heavy concentration of these elements. The sensitive balance between benefits and toxicity of the micronutrients must always be borne in mind.

Micronutrients are added to the soil in several forms. **Chelates** are synthetic organic compounds that, when combined with certain metals (iron in particular), remain water-soluble, but protect the metal from further chemical and physical changes. They may be used for soil or foliar applications. See also **Sequestering Agents. Frits** comprise a fusion of certain trace elements (boron, iron, etc.) with glass that, when shattered and applied to soils, slowly releases the trace elements as the glass dissolves. The frits are water-soluble and are used for soil applications. Micronutrients are frequently applied as sulfates for soil and foliar application. For slow release, oxides of the trace elements can be used for soil application.

Multinutrient and Single-nutrient Fertilizers

Multinutrient (mixed) fertilizers are designated as to nitrogen, phosphorus, and potassium content as previously illustrated. Since most crops require all of the primary elements in relatively large amounts, it is often advantageous and convenient to apply them together as a multinutrient fertilizer. However, this practice may not always coincide with amounts and timing of application as determined by crop, soil, and past cropping history. An important advantage of applying nitrogen and phosphorus together is the enhanced uptake of phosphorus. It has been shown by a number of studies that the application of these two elements together results in significantly greater uptake of fertilizer phosphorus. Multinutrient fertilizers are particularly adapted to: (1) Preplant applications which are subsequently incorporated into the soil by plowing, disking, or chiseling; (2) starter fertilizers, where maximum response usually requires all three nutrients be readily available to the developing seedlings; (3) top-dress applications for forages (hay and pastures); and (4) sidedressing of row crops where preplant applications are not utilized.

Even though multinutrient fertilizers have their advantages, there are situations where single-nutrient fertilizers are important. For example, nitrogen fertilizers are often used to supplement an application of multinutrient fertilizer. A spring topdressing of nitrogen on wheat frequently increases yields and raises the protein content of the grain. Where adequate moisture is available, and corn (maize) is planted early at a high population level, supplemental sidedress or topdress application of nitrogen can set the stage for excellent yields. Sometimes adverse moisture conditions cause loss of nitrogen through denitrification. A supplemental application of nitrogen can replace this loss.

In sandy soils, where nitrogen is subject to leaching, it is usually advisable to apply the required nitrogen in split applications rather than in a single application. When soil tests indicate a very low level of available phosphorus and/or potassium, single-nutrient fertilizers can be used and thus prevent an overfeeding with nitrogen. The reverse situation also arises, in which nitrogen alone may suffice.

Soil and Tissue Tests

For methodical planning of fertilizing programs, soil analysis that goes well beyond the simple testing for soil pH is required. With modern analytical instrumentation, soil analysis can be conducted expeditiously. Growers should be familiar with recommended procedures for making certain that a sufficient number of samples are obtained, as well as for obtaining samples that are truly representative of field conditions.

In recent years, tissue testing has become quite popular. Tissue testing of plants can help to diagnose difficult problems and is widely used by plant scientists. Tissue testing permits on-the-spot field testing, with kits available which range from a few chemicals and test papers to elaborate supplies of chemicals, vials, and spot plates. Kits, however, usually yield only limited levels of results. Tissue testing in the laboratory can be carried out with much sophistication. In the field, the number of crops that can be tested is limited, but does include corn (maize), sorghum, small grains, some pasture grasses, potatoes, and tomatoes for nitrogen, phosphorus, and potassium content. Soybeans, edible beans, alfalfa, and some clovers can be tested for phosphorus and potassium content. Grapes, sugar beets are usually tested only for nitrogen.

Where particular problems may be present, particular attention must be taken in gathering the right plant component for analysis. For example, for a *tissue test* on corn, the midrib of the leaf opposite and below the ear is taken for phosphorus and potassium tests. The nitrogen test is made on the lower part of the stalk. A *total analysis* on corn requires that the entire leaf be used. Both kinds of analyses call for the samples to be taken at silking time. With citrus, there is a difference in the age and position of leaves taken from lemons compared to those taken from oranges or grapefruits.

Application of Fertilizers

Broadcast-Incorporated Applications. This is a rapid method for fertilizing. Large areas can be covered in relatively short periods. Comparatively large amounts of fertilizer can be applied in a single application without concern over injury to young plants. Both liquid and dry materials can be broadcast with about equal effort. Most broadcast equipment is sufficiently large to carry sufficient product for a fairly large area (several acres; few hectares). Broadcast applications supply nutrients to the entire root zone rather than to a limited number of roots adjacent to a band. The best time to broadcast fertilizer is following harvest, prior to working the field for residue incorporation and soil preparation for the next crop. Soils are generally dry following harvest and compaction is minimized. Each time the field is worked, the fertilizer is mixed more thoroughly with the soil. Deep placement by incorporation increases the likelihood of nutrient uptake by growing crops.

Many plant nutrients do not move appreciably in the soil. These nutrients must be incorporated into the soil where roots can intercept them. Phosphorus forms highly insoluble compounds in the soil which prevents its movement. In acid soils, iron and aluminum phosphates are formed, while in neutral or alkaline soils, calcium phosphate is produced. These compounds have very limited solubility in the soil solution. Other plant nutrients, such as potassium, magnesium, and zinc are held on the surface of clay particles by electrostatic attraction. This prevents their movement into the soil with percolating water. These nutrients thus must be incorporated into the root zone where uptake can occur. Where nitrogen is the only nutrient being applied, placement into the root zone is not so critical because nitrate nitrogen moves readily into soil with percolating water. Many fertilizer materials can be broadcast and left on the surface for an indefinite period prior to incorporation. However, urea and products containing urea should be incorporated immediately following a broadcast application to prevent loss of nitrogen to the atmosphere.

Banding Fertilizers. The practice of fertilizer banding is common in a number of agricultural areas, including the United States. The main benefits resulting from banding are related to increased crop growth and yield performance. A very common placement for banded fertilizer is from 2 to 3 inches (5 to 7.5 centimeters) below the seed. The intention is to provide young, fast-growing roots that will quickly intercept the band and thus take up the nutrients. In corn (maize), pop up fertilizer is placed in the row with the seed. This placement is also used with older grain drills. Newer grain drills are designed to separate the fertilizer and seed about 1 inch (2.5 centimeters) apart.

The amount of fertilizer that can be banded depends upon the sum of nitrogen and K_2O content of the fertilizer. The rate of N plus K_2O permissible varies with the crop and area. For example, with corn pop-up banding, one suggested upper limit for fertilizer in the band is about 10 to 15 pounds/acre (11.2 to 16.8 kilograms/hectare). With wheat starter fertilizer, the upper limit suggested for grain drills on calcareous soils (Montana) is about 15 pounds/acre (16.8 kilograms/hectare) of N with monoammonium phosphate, or only about 10 pounds/acre (11.2 kilograms/hectare) of N with diammonium phosphate. However, in western Oregon, with greater rainfall and acid soils, an upper limit of about 80 pounds/acre (89.6 kilograms/hectare) of N plus K_2O on spring grain has been suggested by some authorities. These examples are given only to stress the variability and planning required to assure a successful fertilization program.

Sidedressing or Topdressing Fertilizers. Previously in this entry, the importance of fertilizing timing has been stressed. *Sidedressing* is the banding of fertilizer in the root zone after emergence of the crop. This method is limited mainly to use of nitrogen, since phosphorus and potassium are normally applied either preplant or as a starter. Sidedressing of nitrogen has advantages where: (1) Sandy soils are subject to nitrogen leaching; and (2) where extremely wet springs prevent preplant nitrogen application.

Topdressing of fertilizer is the process whereby a dry or liquid material is broadcast after the crop has emerged. In most cases this is limited to nitrogen fertilizers. However, in the case of grasses and legumes, a complete fertilizer may be used. Topdressing nitrogen on wheat has been an accepted practice for many years. This is a rapid, comparatively easy method of applying nitrogen, whether it be a corrective application after a deficiency appears, or the basic nitrogen program. When ammonium nitrate is broadcast on some growing crops, there may be some leaf burn, but this does not reduce yields.

Timing is important when applying nitrogen by the sidedress or topdress method. Most crops begin taking up nitrogen at a fairly rapid rate some 30 to 40 days after emergence. This suggests that nitrogen should be applied within the first 30 days after emergence.

Machinery used in the application of fertilizers is described in entries on: **Planting Equipment; Spreading and Spraying Equipment; Tillage Equipment.**

Fertigation. During the past few years, the use of center-pivot sprinkler systems on the sandy soils of the Great Plains region of the United States has increased markedly. Marginal return from field crops, such as corn (maize) in previous years has made it uneconomical to use much irrigation. Combining fertilizing with irrigation (*fertigation*) with giant sprinkler systems has upgraded over 4 million acres (1.6 million hectares) of land in Colorado, Kansas, and Nebraska. The self-propelled center-pivot sprinklers have made it possible to apply fertilizer solutions conveniently and efficiently. Most authorities agree that nitrogen solutions applied with this method perform well because of nitrate movement into the root zone.

In connection with other nutrients, there are some limitations. Hergert (1977) observes that nutrients not absorbed by the soil (anion forms) and which have a tendency to move with the water are best suited for sprinkler applications. These include nitrogen, sulfur, and some of the chelated micronutrients (zinc, iron, copper). Although magnesium, calcium, potassium, and phosphate and inorganic forms of other micronutrient cations are soluble in irrigation water, they tend to accumulate in the top 1 or 2 inches (2.5 to 5 centimeters) of the soil due to soil retention. Thus, the nutrients are not well mixed throughout the root zone.

The application of fertilizer with irrigation water has been subjected to considerable research over the years. Experiments have shown that sprinkler applications of nitrogen solutions on sandy soils are more efficient than preplant broadcast. However, losses of nitrogen increase as the rate of nitrogen applied increases. The greatest problem with nitrogen on sandy soil is overirrigation and leaching losses. During the growing season, nitrate can be leached if excess irrigation is applied, even if nitrogen solutions are used. The leaching potential on heavy soils is less than for sandy textures because water moves more slowly through the soil profile.

Application of sulfur is often beneficial on sandy soils with low organic matter contents. Sprinkler applications of ammonium thiosulfate solutions works well for correction of in-season sulfur deficiency. Sprinkler applications of 5 to 10 pounds/acre (5.6 to 11.2 kilograms/hectare) have corrected sulfur deficiencies on sandy soils in Nebraska. Good results occur because thiosulfatesulfur is a mobile ion that moves with the soil water throughout the root zone.

Ammonium polyphosophate solutions also can be applied in sprinkler irrigation water. Phosphates, however, are slightly mobile in soil. As the result of research by Hergert and Ruess (1976), it was found that the distribution of phosphorus from sprinkler-applied ammonium polyphosphate in a Nunn clay loam was restricted to the upper 1 inch (2.5 centimeters) of soil. Extractable phosphorus in a Haxtun loamy sand was increased to a depth of 7 inches (17.8 centimeters). Phosphorus movement to this depth would be sufficient to supply roots if it moved down early in the growing season. The research showed that broadcast-incorporated or row-applied phosphate produced greater plant uptake of phosphorus and more early season growth. Sprinkler applications of ammonium polyphosphate may be considered as saving a field operation, but phosphate applied in one year will really not be available until worked into the tillage layer. It can then be used by the following crop. When ammonium polyphosphate is applied in irrigation water, quality of water must be considered. The calcium, magnesium, and bicarbonate content of the water is important. Excess precipitation of calcium and magnesium carbonates must be avoided.

Considerable research remains as regards sprinkler application of micronutrients other than the chelates previously mentioned. Iron deficiencies in any case are difficult to correct with any method of application except for foliar sprays.

Research to date indicates that sprinkler application of nutrients is probably not an effective method of foliar fertilization. Increased nutrient uptake from sprinkler-applied nutrients generally results from increased root uptake of the nutrient. Nutrient concentrations in irrigation water are usually so low that foliar feeding as a mechanism for uptake is limited. Irrigators generally apply between 0.5-inch and 1 inch (1.2 and 2.5 centimeters) of water per application. This translates into terms of between 7000 and 9000 gallons/acre (583 to 750 hectoliters/hectare). In contrast, the usual most effective application of micronutrient foliar sprays is at a rate of from 20 to 30 gallons/acre (167 to 250 liters/hectare).

Worldwide Fertilizer Consumption and Production

In terms of attempts to keep up with growing food demands of various world populations, planners make serious efforts to project supply and demand of fertilizers. Global fertilizer consumption will continue growing throughout the remainder of this century while the world's population increases. Not knowing the possible effects of population reductions brought about by various causes, various birth control programs, unknown natural and warlike disasters, it is rather academic to project needs beyond the end of this century, until a more reliable data base is available. World demand for fertilizer through the 1980s is projected to expand at annual compound rates of 6% for nitrogen, 6.3% for phosphate, and 5.1% for potash. By the mid-1980s, nitrogen demand is expected to reach 64 million metric tons/year, while phosphate and potash demand will amount to about 38 million and 31 million metric tons/year, respectively.

The slowest growth in demand for all nutrients is foreseen in the developed market countries. Demand for plant nutrients in the centrally planned economies, particularly if these countries are permitted to expand their sphere of influence in an uncontrolled fashion, is projected to grow faster, especially for phosphates. This strong growth for phosphates is primarily the result of plans announced by the U.S.S.R. to emphasize increased utilization of phosphate fertilizers. Developing market economies are expected to experience the fastest growth for nitrogen and potash and, also, a strong growth for phosphates. Perhaps the most impressive projected increase is the nearly 10% annual growth in use of nitrogen in the Far East. India, for example, expects to more than double its 1976/1977 nitrogen consumption by the mid-1980s when consumption is projected to exceed 5 million metric tons of nutrient. If that proves true, India will account for nearly one-third of the nitrogen consumption in developing countries. Projection summaries for the mid- to late 1980s, as compared with 1976/1977 levels of worldwide supply capability versus consumption for geographic and economic categories are given in Table 5.

TABLE 5. WORLD FERTILIZER SUPPLY CAPABILITIES, DEMAND, AND BALANCES
(Million Metric Tons of Nutrients)

	Nitrogen		Phosphate		Potash	
Region	Actual 1976-1977	Forecast Mid-1980s	Actual 1976-1977	Forecast Mid-1980s	Actual 1976-1977	Forecast Mid-1980s
NORTH AMERICA						
Supply capability	10.75	12.96	7.80	9.05	8.00	10.17
Consumption	10.26	12.40	5.64	6.30	5.54	6.50
Surplus (-deficit)	0.49	0.56	2.16	2.75	2.46	3.67
WESTERN EUROPE						
Supply capability	9.59	11.51	5.69	7.52	4.54	6.54
Consumption	8.42	10.12	5.47	6.35	4.91	6.32
Surplus (-deficit)	1.17	1.39	0.22	1.17	-0.37	0.22
OCEANIA						
Supply capability	0.22	0.26	1.08	1.41	0.00	0.00
Consumption	0.23	0.30	1.13	1.43	0.25	0.38
Surplus (-deficit)	-0.01	-0.04	-0.05	-0.02	-0.25	-0.38
OTHER DEVELOPED MARKET ECONOMIES						
Supply capability	1.53	2.03	1.04	1.87	0.65	0.86
Consumption	1.08	1.32	1.12	1.29	0.84	0.91
Surplus (-deficit)	0.45	0.71	-0.08	0.58	-0.19	-0.05
TOTAL DEVELOPED MARKET ECONOMIES						
Supply capability	22.09	26.76	15.61	19.85	13.19	17.57
Consumption	19.99	24.14	13.36	15.37	11.54	14.11
Surplus (-deficit)	2.10	2.62	2.25	4.48	1.65	3.46

TABLE 5. WORLD FERTILIZER SUPPLY CAPABILITIES, DEMAND, AND BALANCES (cont.)
(Million Metric Tons of Nutrients)

Region	Nitrogen		Phosphate		Potash	
	Actual 1976-1977	Forecast Mid-1980s	Actual 1976-1977	Forecast Mid-1980s	Actual 1976-1977	Forecast Mid-1980s
AFRICA						
Supply capability	0.16	0.37	0.43	2.05	0.27	0.00
Consumption	0.52	0.82	0.42	0.65	0.21	0.39
Surplus (–deficit)	-0.36	-0.45	0.01	1.40	0.06	-0.39
LATIN AMERICA						
Supply capability	1.32	2.28	1.16	2.03	0.02	0.02
Consumption	2.27	3.65	1.89	3.13	1.11	1.89
Surplus (–deficit)	-0.96	-1.37	-0.73	-1.10	-1.09	-1.87
NEAR EAST						
Supply capability	1.04	3.31	0.58	2.05	0.00	0.14
Consumption	1.64	2.66	0.93	1.38	0.05	0.08
Surplus (–deficit)	-0.60	0.65	-0.35	0.67	-0.05	0.06
FAR EAST						
Supply capability	3.21	6.85	0.78	1.64	0.00	0.00
Consumption	4.34	8.04	1.24	2.42	0.76	1.43
Surplus (–deficit)	-1.13	-1.19	-0.46	-0.78	-0.76	-1.43
TOTAL DEVELOPING MARKET ECONOMIES						
Supply capability	5.73	12.81	2.95	7.77	0.29	0.16
Consumption	8.77	15.17	4.48	7.58	2.13	3.79
Surplus (–deficit)	-3.05	-2.36	-1.53	0.19	-1.84	-3.63
COMMUNIST ASIA						
Supply capability	4.12	6.11	1.64	2.44	0.32	0.45
Consumption	5.01	7.43	1.65	2.67	0.49	0.80
Surplus (–deficit)	-0.89	-1.32	-0.01	-0.23	-0.17	-0.35
EASTERN EUROPE						
Supply capability	13.95	22.02	7.08	10.62	11.47	15.80
Consumption	11.28	17.37	7.00	11.90	8.91	12.05
Surplus (–deficit)	2.67	4.65	0.08	-1.28	2.56	3.75
TOTAL CENTRALLY PLANNED ECONOMIES						
Supply capability	18.07	28.13	8.72	13.06	11.79	16.25
Consumption	16.29	24.80	8.65	14.57	9.40	12.85
Surplus (–deficit)	1.78	3.33	0.07	-1.51	2.39	3.40
WORLD TOTAL						
Supply capability	45.89	67.70	27.28	40.68	25.27	33.98
Consumption	45.05	64.11	26.49	37.52	23.07	30.75
Surplus (–deficit)	0.83	3.59	0.79	3.16	2.20	3.23

Adapted from data sources: Food and Agriculture Organization of the United Nations, Rome, Italy.
World Bank Fertilizer Working Group

Fertilizer Consumption. The use of fertilizer is affected by numerous factors, some of which are quite unpredictable. Inclement weather that delays spring planting can affect fertilizer usage markedly. For example, even though fertilizer prices were depressed in the mid-1970s, world fertilizer consumption declined for the first time since the end of World War II, attributable mainly to the late spring of that period in the Northern Hemisphere, as well as lower farm product prices and income of the previous season. During the inflationary period of the late 1970s and early 1980s, still another dimension has been added to the difficulty of forecasting fertilizer utilization. Political factors particularly as these may arise in some of the developing countries, alter plans and can decrease or increase the demand for fertilizer, depending upon the emphasis given to agriculture at any given time. A shortage of farm credit in some countries can substantially affect fertilizer demand. The degree of fertilizer aid given to developing countries also is a contributing factor.

Following a decline in demand, subsequent fertilizer production tends to be lowered, ultimately causing a shortage and higher prices. Not unlike the other economic aspects of food production, total fertilizer consumption is subject to cycling. Each major type of fertilizer, nitrogenous, phosphate, potash, is also affected cyclically, particularly when a large producing facility for a given type of fertilizer comes onstream.

The governments of several of the major countries, as well as the Food and Agriculture Organization (FAO), have been endeavoring for years to overcome the cyclical imbalances in supply and demand which lead to wide fluctuations in fertilizer prices and the adverse effect which limited supply and high prices have on food production programs in developing countries. The value of long-term contracts has been recognized, but these must include effective arrangements for a suitable base price and a price adjustment formula that is fair and equitable to both producers and consumers, as well as suitable enforcement procedures. Much can be gained by a continuing expansion of the fertilizer production capability of the developing countries, thus reducing their dependence upon imports. Some authorities consider the outlook for nitrogen and phosphate fertilizers in this regard as encouraging through the mid-1980s, but the situation as regards potash is less promising because of limited potash deposits in many of the developing countries.

Fertilizer consumption worldwide as of the late-1970s, by continents and countries, is delineated in Table 6. Shown are total tonnage used annually, along with a breakdown for each major type of fertilizer used by each country. It will be noted that the mix of basic fertilizers varies considerably from one country to the next, not surprising in view of the widely varying soil conditions, agricultural methods, and different crops produced (row crops, pasture, orchards, etc.) and, in particular, the effects of local availability of natural nitrogenous wastes, such as animal manure, which escape any statistical summaries. Worldwide statistics tend to be approximations at best because of the wide variance in data collecting capabilities and differences in respect of accurate and complete reporting. The result is information of a nonuniform quality.

In Table 7, fertilizer consumption is broken down by the three major economic classes of countries in the world today. For a sharpening of perspective on fertilizer consumption, Table 8 lists the leading consuming countries with their percentage of total world fertilizer consumption. Probably even more meaningful is the presentation of Table 9, which relates fertilizer use to arable land areas of each country, thus providing some measure of the intensity of use of fertilizer. Again, these figures do not reflect local use of organic residues. After a summation by continents and economic classes, the leading fertilizer using countries are listed in descending order of *fertilization intensity*. The tabulation clearly portrays the rather wide differences in types of fertilizers used by different countries. High fertilizer consumption per unit area in some countries reflects greenhouse operations which provide availability of land units on a year-round basis and thus increase the intensity factor. One of the most intensive users of fertilizer is Iceland, where open arable land for crops is essentially nonexistent. However, there is substantial permanent pasture land (about 2300 hectares. 5060 acres). Iceland is ideal for greenhouse operations because of the availability of geothermally heated waters. In connection with Table 9, it is of interest to note that the largest fertilizer-consuming countries are not the most intensive, with the United States, the U.S.S.R., and China, for example, far down on the list.

TABLE 6. FERTILIZER CONSUMPTION WORLDWIDE[1]

	(1000 Metric Tons Annually)				
Continent	Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2O)	Total	Percent of World Total
Africa	1101	722	357	2180	2.7
North and Central America	9379	4966	4507	18852	23.1
South America	851	1113	688	2652	3.3
Asia	9340	3829	2254	15423	18.8
Europe[2]	17981	11198	11905	41084	50.4
Oceania	208	956	225	1389	1.7
World total	38859	22784	19937	81580	100.0
Percent of World Total by type	47.6%	27.9%	24.5%		
Country					
AFRICA					
Algeria	71.5	54.7	30.1	156.2	
Angola	6.5	3.5	5.1	15.1	
Benin	2.6	1.8	1.4	5.8	
Botswana	1.2	0.8	–	2.0	
Burundi	0.6	0.2	0.1	0.9	
Cameroon	9.8	2.1	4.8	16.7	
Central African Republic	1.8	0.5	0.7	3.0	

TABLE 6. FERTILIZER CONSUMPTION WORLDWIDE[1] (cont.)

	(1000 Metric Tons Annually)				
Continent	Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2O)	Total	Percent of World Total
Chad	4.5	3.2	1.2	8.9	
Egypt	360.0	65.0	5.3	430.3	
Ethiopia	7.9	11.2	–	19.1	
Gabon	0.03	–	–	0.03	
Guinea	0.7	0.5	0.7	1.9	
Ivory Coast	7.8	4.5	18.6	30.9	
Kenya	19.4	29.3	4.0	52.7	
Lesotho	0.1	0.7	–	0.8	
Liberia	1.2	0.8	1.3	3.3	
Libya	10.1	4.0	1.6	15.7	
Madagascar	2.1	1.6	2.4	6.1	
Malawi	7.6	1.2	1.9	10.7	
Mali	2.9	4.1	0.4	7.4	
Mauritania	0.4	0.07	0.06	0.53	
Morocco	72.0	57.4	28.9	158.3	
Mozambique	3.7	1.1	2.2	7.0	
Niger	0.08	0.06	0.01	0.15	
Nigeria	0.08	0.06	0.01	0.15	
Rhodesia	75.0	44.5	35.0	154.5	
Rwanda	0.2	0.1	0.8	1.1	
Senegal	9.0	9.0	13.7	31.7	
Sierra Leone	1.0	1.0	1.3	3.3	
Somalia	1.9	0.5	0.5	2.9	
South Africa	252.3	345.7	136.7	734.7	
Sudan	60.3	–	–	60.3	
Tanzania	11.1	10.8	5.5	27.4	
Togo	0.3	0.3	0.2	0.8	
Tunisia	23.2	21.8	4.9	49.9	
Uganda	1.6	2.5	0.7	4.8	
Upper Volta	0.7	0.4	–	1.1	
Zaire	3.1	1.8	–	1.1	
Zambia	30.0	12.0	11.4	53.4	
NORTH AND CENTRAL AMERICA					
Canada	510.0	481.0	230.0	1222.0	
Costa Rica	40.0	12.0	26.6	78.6	
Cuba	140.0	61.0	102.0	303.0	
Dominican Republic	46.7	25.2	26.2	98.1	
El Salvador	62.5	33.6	8.0	104.1	
Guatemala	42.0	13.9	13.8	69.7	
Haiti	0.9	0.3	0.4	1.6	
Honduras	9.5	2.2	7.0	18.7	
Jamaica	12.3	6.9	9.4	28.6	
Mexico	654.4	222.7	45.1	922.2	
Nicaragua	31.7	12.0	3.4	47.1	
Panama	14.4	7.0	6.2	27.6	
United States	7795.6	4076.9	4004.9	15877.4	
SOUTH AMERICA					
Argentina	55.5	23.6	5.0	84.1	
Bolivia	3.8	2.0	0.7	6.5	
Brazil	389.2	807.3	521.3	1250.8	
Chile	52.1	99.9	15.1	167.1	
Colombia	126.9	86.5	75.0	288.4	
Ecuador	32.9	19.4	14.2	66.5	
Paraguay	0.6	0.5	2.5	3.6	
Peru	113.9	12.9	12.5	139.3	
Uruguay	9.9	18.0	7.1	35.0	
Venezuela	50.2	39.8	31.6	121.6	

TABLE 6. FERTILIZER CONSUMPTION WORLDWIDE[1] (cont.)

	(1000 Metric Tons Annually)				
Continent	Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2O)	Total	Percent of World Total
ASIA					
Afghanistan	24.2	9.6	–	33.8	
Bangladesh	82.8	35.6	10.7	129.1	
Burma	38.1	4.2	2.3	44.6	
Colombia	0.9	–	–	0.9	
China	3922.0	1318.7	556.3	5797.0	
India	1773.8	477.6	339.2	2590.6	
Indonesia	401.8	110.1	33.0	544.9	
Iran	248.5	173.1	5.0	426.6	
Iraq	27.3	6.1	1.1	34.5	
Israel	32.6	16.9	15.1	64.6	
Japan	690.8	692.4	721.8	2105.0	
Jordan	2.0	.08	0.4	3.2	
Korea (North)	251.9	124.0	500.0	875.9	
Korea (South)	477.4	245.6	155.5	848.5	
Lebanon	19.1	20.0	10.4	49.5	
Mongolia	1.6	14.5	0.2	16.3	
Nepal	9.2	2.8	0.8	12.8	
Pakistan	358.9	40.6	1.8	401.3	
Philippines	177.4	47.8	60.1	285.3	
Saudi Arabia	5.0	2.7	3.5	11.2	
Sri Lanka	77.2	13.8	37.6	128.6	
Syria	27.0	13.4	1.6	42.0	
Thailand	79.8	67.1	42.6	189.5	
Turkey	382.7	217.7	16.7	617.1	
Vietnam (North)	21.2	95.0	24.1	140.3	
Vietnam (South)	100.0	33.5	10.0	143.5	
West Malaysia	117.2	38.0	142.0	297.2	
EUROPE					
Albania	36.3	24.0	3.6	63.9	
Austria	125.3	81.7	124.9	331.9	
Belgium	174.8	129.7	171.2	475.7	
Bulgaria	329.5	215.9	21.9	567.3	
Czechoslovakia	428.0	374.0	675.0	1477.0	
Denmark	300.0	114.1	159.5	573.6	
Finland	226.5	199.2	164.8	590.5	
Germany (East)	671.3	453.1	715.9	1840.3	
Germany (West)	1200.9	876.9	1170.4	3248.2	
Greece	251.3	146.9	22.4	420.6	
Hungary	551.3	361.7	423.2	1336.2	
Ireland	133.0	114.3	111.2	358.5	
Italy	672.2	368.5	231.4	1272.1	
Netherlands	432.0	90.8	110.4	633.2	
Norway	96.2	58.7	77.5	232.4	
Poland	1146.4	888.2	1443.6	3478.2	
Portugal	126.8	67.5	27.7	222.0	
Rumania	490.0	375.0	56.1	921.1	
Spain	718.8	535.1	266.4	1520.3	
Sweden	235.3	132.3	116.7	484.3	
Switzerland	37.9	41.1	62.0	141.0	
United Kingdom	918.4	446.0	474.4	1838.0	
U.S.S.R.	6746.0	3226.0	3708.0	13680.0	
Yugoslavia	352.0	167.0	161.0	680.0	
OCEANIA					
Australia	177.0	630.0	80.0	887.0	
New Zealand	17.8	322.7	141.3	481.8	
Papua New Guinea	3.5	0.8	3.0	7.3	

---

[1] For late 1970s. Sources: FAO reference listed, plus individual governments.

[2] Includes U.S.S.R.

TABLE 7. FERTILIZER CONSUMPTION BY ECONOMIC CLASS[1]

Economic Class	Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2O)	Total	Percent of World Total
	(1000 Metric Tons Annually)				
Developed market economies	17058	11847	10188	39093	47.9
North America	8306	4559	4235	17100	20.9
Western Europe	7582	5280	4858	17720	21.7
Oceania	195	953	221	1369	1.7
Other regions	975	1055	874	2904	3.6
Developing market economies	7205	3467	2071	12743	15.6
Africa	418	307	213	938	1.2
Latin America	1924	1520	960	4404	5.4
Near East	1178	516	47	1741	2.1
Far East	3672	1121	847	5640	6.9
Other regions	13	3	4	20	0.02
Centrally planned economies	14596	7470	7678	29744	36.5
Asian regions	4197	1552	631	6380	7.9
European and all of U.S.S.R.	10399	5918	7047	23364	28.6

[1] For late 1970s. Sources: FAO reference listed, plus individual governments.

TABLE 8. FERTILIZER CONSUMPTION–LEADING CONSUMING COUNTRIES

Country	1000 Metric Tons Annually	Percent of World Total
United States	15,877	19.5
U.S.S.R.	13,680	16.8
China	5,797	7.1
Poland	3,478	4.3
Germany (West)	3,248	4.0
India	2,591	3.2
Japan	2,105	2.6
Germany (East)	1,840	2.3
United Kingdom	1,838	2.3
Spain	1,520	1.9
Czechoslovakia	1,477	1.8
Hungary	1,336	1.6
Italy	1,272	1.6
Brazil	1,251	1.5
Canada	1,222	1.5
Mexico	922	1.1
Rumania	921	1.1
Australia	887	1.1
Korea (North)	876	1.0
Korea (South)	849	1.0
South Africa	735	0.9
Yugoslavia	680	0.8
Netherlands	633	0.8
Turkey	617	0.8
Finland	590	0.7
Denmark	573	0.7
Bulgaria	567	0.7
Indonesia	545	0.7
Sweden	484	0.6
New Zealand	482	0.6
Belgium	476	0.6
Egypt	430	0.5
Greece	421	0.5
Pakistan	401	0.5
All others	10,959	13.3
World total	81,580	100.0

Fertilizer Production. An indication of the relative production/consumption situation as related to major economic and geographic regions of the world was given previously in Table 5, including a forecast into the mid-1980s. In Table 10, the production situation worldwide, as of the late 1970s, is detailed by continent and specific countries and by the three primary types of fertilizer; by economic regions in Table 11; and a summary of fertilizer production by leading producing countries in Table 12.

As of the early 1980s, while Western Europe, Japan, and the United States have excess ammonia production capacities, new entrants to the nitrogen export market are experiencing some success in selling increasing amounts of ammonia. Ammonia plant closings not only are affecting the United States. Japan has commenced to rationalize nitrogen industry capacity by reducing ammonia and urea capacities by 20 and 40%, respectively. In contrast, new production facilities in the U.S.S.R., Mexico, Trinidad and Tobago and elsewhere are contributing significantly to increased world nitrogen export supplies. Both Mexico and

TABLE 9. INTENSITY OF FERTILIZER APPLICATION BY COUNTRIES
(Total Fertilizer Applied/Area of Arable Land)

Continent	Fertilization Rate (100 Grams per Hectare)	Percent of Types of Fertilizer Applied		
		Nitrogenous %	Phosphate %	Potash %
Africa	100	51	33	16
North and Central America	652	49.7	26.4	23.9
South America	264	32.2	42.0	25.8
Asia	324	60.5	24.7	14.8
Europe	1913	41.0	29.1	29.9
U.S.S.R.	588	49.3	23.6	27.1
Oceania	295	14.9	68.8	16.3
World (averages)	541	47.6	27.9	24.5
Economic Region				
Developed market economies	947	43.6	30.3	26.1
Developing market economies	187	56.7	27.3	16.0
Centrally planned economies	717	49.1	25.1	25.8
Country				
Netherlands	7565	68.2	14.3	17.5
New Zealand	5779	3.7	66.9	29.4
Belgium	5773	36.7	27.3	36.0
Luxembourg	5161	46.9	26.6	26.5
Martinique	4571	35.9	31.1	32.8
Germany (West)	4020	37.0	27.0	36.0
Japan	3749	32.8	32.9	34.3
Switzerland	3672	26.9	29.1	44.0
Germany (East)	3671	36.5	24.6	38.9
Ireland	3401	37.1	31.9	31.0
Norway	2931	41.4	25.2	33.4
Czechoslovakia	2792	29.0	25.3	45.7
United Kingdom	2570	50.0	24.2	25.8
Mauritius	2539	32.2	13.0	54.8
France	2459	33.6	36.4	30.0
Hungary	2428	41.3	27.1	31.6
Poland	2307	32.9	25.5	41.6
Finland	2225	38.4	33.8	27.8
Denmark	2158	52.3	19.9	27.8
Austria	2059	37.7	24.6	37.7
Reunion	2052	27.7	33.6	38.7
Barbados	1970	23.1	4.6	72.3
Sweden	1600	48.6	27.3	24.1
Costa Rica	1569	50.1	15.3	34.6
El Salvador	1547	60.1	32.3	7.6
Egypt	1507	83.7	15.1	1.2
Israel	1501	50.5	26.1	23.4
Lebanon	1423	38.6	40.4	21.0
Bulgaria	1264	36.7	27.3	36.0
Guadeloupe	1228	35.7	42.8	21.5
Jamaica	1100	43.0	24.1	32.9
Greece	1077	59.8	34.9	5.3
Italy	1035	52.9	29.0	18.1
Malaysia (Peninsular)	1032	39.4	12.8	47.8
Albania	998	56.8	37.6	5.6
Dominican Republic	986	47.6	25.7	26.7
Rumania	880	53.2	40.7	6.1
Yugoslavia	843	51.7	24.6	23.7
Cuba	815	46.1	20.1	33.8
United States	767	49.2	25.7	25.1
Spain	726	47.1	35.3	17.6

TABLE 9. INTENSITY OF FERTILIZER APPLICATION BY COUNTRIES (cont.)
(Total Fertilizer Applied/Area of Arable Land)

Country	Fertilization Rate (100 Grams per Hectare)	Percent of Types of Fertilizer Applied		
		Nitrogenous %	Phosphate %	Potash %
Trinidad	654	53.2	2.2	44.6
Sri Lanka	650	60.0	10.8	29.2
Rhodesia	623	48.5	28.7	22.8
Portugal	610	57.0	30.5	12.5
U.S.S.R.	588	49.3	23.6	27.1
Colombia	567	43.9	30.0	26.1
Swaziland	526	57.6	12.0	30.4
South Africa	508	34.3	47.0	18.7
Nicaragua	491	67.2	25.5	7.3
Peru	483	81.8	9.3	8.9
Brazil	476	22.7	47.1	30.2
China	446	67.7	22.6	9.7
Belize	429	28.4	47.5	24.1
Vietnam	428	69.9	23.4	6.7
Guatemala	410	60.2	20.0	19.8
Mexico	337	70.9	24.0	5.1
Kenya	300	37.0	55.7	7.3
Indonesia	295	73.6	20.3	6.1
Chile	291	31.2	59.8	9.0
Canada	284	41.5	39.4	19.1
Cyprus	283	60.8	29.3	9.9
Philippines	277	62.1	16.6	21.3
Iran	262	58.4	40.5	1.1
Venezuela	235	41.3	32.8	25.9
Turkey	221	62.0	35.3	2.7
Honduras	215	50.7	11.6	37.7
Papua New Guinea	209	47.8	11.0	41.2
Morocco	207	45.4	36.2	18.4
Pakistan	206	89.8	10.0	0.2
Australia	197	19.8	71.1	9.1
Uruguay	188	28.2	51.6	20.2
India	157	68.2	18.5	13.3
Ecuador	154	48.1	29.2	22.7
Saudi Arabia	145	44.8	24.1	31.1
Bangladesh	142	64.1	27.5	8.4
Senegal	138	28.3	28.5	43.2
Thailand	134	42.5	35.8	21.7
Tunisia	115	46.1	43.5	10.4

the U.S.S.R. have elected to make use of abundant natural gas supplies by using that resource as a feedstock for ammonia production. Major production capacity expansions have come on-stream in both countries and additional facilities are under construction. Since both countries produce both gas and ammonia in state-owned facilities, they have priced their gas at rates well below prevailing world market rates. This low-cost gas enables them to offer ammonia on the world market at very competitive prices despite high transportation costs. Mexico, once a net importer of ammonia, is now a net exporter.

As of the 1980s, phosphate supplies are being augmented. In the late 1970s, a major new phosphate rock mine opened in Florida and the Bu Craa mine in the former Spanish Sahara is getting back into production after over a 3-year shutdown because of political problems. Expansions in Morocco, Jordan, and Senegal are expected to be completed during the early 1980s. Faced with rapid phosphate consumption growth, which exceed production expansion, the U.S.S.R. in recent years has sought alternative sources of phosphate materials and has made agreements with suppliers in the United States, these always dependent upon the political climate. An arrangement between a United States firm for exchange of phosphoric acid for Soviet ammonia, urea, and potash (negotiated for a 23-year period) was commenced in 1978. At that time, this represented one of the world's largest trade agreements. Morocco and the U.S.S.R. have agreed jointly to develop a major new phos-

TABLE 10. FERTILIZER PRODUCTION WORLDWIDE[1]

	(1000 Metric Tons Annually)				
Continent	Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2O)	Total	Percent of World Total
Africa	536	996	285	1,817	2.0
North and Central America	9,972	7,043	7,753	24,768	27.1
South America	458	526	14	998	1.1
Asia	8,763	3,254	954	12,971	14.1
Europe[2]	22,319	12,829	14,746	49,894	54.4
Oceania	192	1,029	–	1,221	1.3
World total	42,240	25,677	23,752	91,669	100.0
Percent of World Total by type	46.1%	28.0%	25.9%		
Country					
AFRICA					
Algeria	78.7	103.1	–	181.8	
Congo	–	–	285.0	285.0	
Egypt	100.2	95.0	–	195.2	
Ivory Coast	6.0	7.4	–	13.4	
Morocco	15.2	147.5	–	162.7	
Mozambique	3.0	0.9	–	3.9	
Rhodesia	65.0	44.5	–	109.5	
Senegal	5.0	22.0	–	27.0	
South Africa	253.0	371.2	–	624.2	
Tanzania	6.0	15.0	–	21.0	
Uganda	–	5.0	–	5.0	
NORTH AND CENTRAL AMERICA					
Canada	800.0	734.0	5562.7	7096.7	
Costa Rica	30.0	–	–	30.0	
Cuba	5.0	15.8	–	20.8	
El Salvador	7.0	1.6	–	8.6	
Guatemala	5.0	–	–	5.0	
Jamaica	3.0	–	–	3.0	
Mexico	388.5	242.8	–	631.3	
United States	8621.0	6049.0	2090.0	16760.0	
SOUTH AMERICA					
Argentina	35.0	5.0	–	40.0	
Brazil	150.2	387.3	–	537.5	
Chile	113.3	24.9	13.5	151.7	
Colombia	90.0	65.0	–	155.0	
Ecuador	2.0	4.0	–	6.0	
Peru	20.0	3.0	–	23.0	
Uruguay	–	10.0	–	10.0	
Venezuela	47.7	26.5	–	74.2	
ASIA					
Afghanistan	19.1	–	–	19.1	
Bangladesh	32.7	13.8	–	46.5	
Burma	43.7	–	–	43.7	
China	3,090.0	1,302.7	300.0	4,692.7	
India	1,186.6	331.2	–	1,517.8	
Indonesia	131.0	–	–	131.0	
Iran	130.8	82.8	–	213.6	
Iraq	32.7	–	–	32.7	
Israel	39.1	19.0	653.9	712.0	
Japan	2,340.9	769.4	–	3,110.3	
Korea (North)	250.0	113.0	–	363.0	
Korea (South)	513.8	166.2	–	680.0	
Lebanon	–	127.6	–	127.6	

TABLE 10. FERTILIZER PRODUCTION WORLDWIDE[1] (cont.)

Continent	(1000 Metric Tons Annually) Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2)	Total	Percent of World Total
Country					
Pakistan	310.8	5.7	–	316.5	
Philippines	53.4	42.1	–	95.5	
Saudi Arabia	80.6	–	–	80.6	
Syria	12.5	–	–	12.5	
Thailand	6.0	–	–	6.0	
Turkey	108.2	160.9	–	269.1	
Vietnam (North)	–	95.0	–	95.0	
West Malaysia	50.0	25.0	–	75.0	
EUROPE					
Albania	36.0	24.0	–	60.0	
Austria	226.1	155.9	–	382.0	
Belgium	639.3	602.7	–	1242.0	
Bulgaria	592.9	188.3	–	781.2	
Czechoslovakia	483.3	380.0	–	863.3	
Denmark	83.1	102.3	–	185.4	
Finland	253.8	215.8	–	469.6	
France	1,694.1	1,720.4	2,078.5	5,493.0	
Germany (East)	435.9	410.2	2,864.0	3,710.1	
Germany (West)	1,574.0	900.4	2,658.9	5,133.3	
Greece	265.0	166.1	–	431.1	
Hungary	416.2	198.5	–	614.7	
Ireland	97.0	130.4	–	227.4	
Italy	1,131.6	409.7	165.6	1,706.9	
Netherlands	1,289.0	296.2	–	1,585.2	
Norway	390.2	127.3	–	517.5	
Poland	1,457.4	823.2	–	2,280.6	
Portugal	129.0	60.2	–	189.2	
Rumania	980.0	404.0	–	1,384.0	
Spain	818.9	655.0	380.6	1,854.5	
Sweden	175.6	164.4	–	340.0	
Switzerland	29.4	3.9	–	33.3	
United Kingdom	884.6	429.2	12.0	1,325.8	
U.S.S.R.	7,856.0	3,869.0	6,586.0	18,311.0	
Yugoslavia	370.9	252.5	–	623.4	
OCEANIA					
Australia	192.0	727.9	–	919.9	
New Zealand	–	301.1	–	301.1	

[1] For late 1970s. Source: FAO reference listed, plus individual governments.

[2] Includes U.S.S.R.

phate rock-mining area near Meskala, including building a railroad to the port. The Soviets also have reported discovery of potentially major phosphate rock deposits along a new railroad route in Siberia. Plans to develop some of the Siberian sites have been announced. Poland also has entered into long-term agreements with American firms.

A relatively new development involving phosphate rock is the recent construction of and planning for commercial facilities to reclaim uranium oxide from phosphoric acid. The product is used in the manufacture of fuel for nuclear power plants. The added value of this byproduct may make exploration for lower-grade phosphate rock deposits more attractive, thus increasing available reserves. Production facilities for reclaiming uranium oxide are already under construction or planned in the United States, France, Israel, Canada, and Yugoslavia.

A Canadian firm, through acquisition of several existing mines, has become the largest producer of potash outside of the U.S.S.R. Long the major supplier of potash to the United States, Canada is increasing exports to Brazil, Japan, India, and the People's Republic of China. Plans for additional potash production facilities outside of North America will result in increasing world potash supplies. Brazil, with assistance from France, is planning a potash mine and refinery complex in Sergipe state. Israel is expanding its potash facility on the Dead Sea, while Jordan is building a potash facility on the opposite shore of the Dead Sea.

TABLE 11. FERTILIZER PRODUCTION BY ECONOMIC REGIONS[1]

Economic Region	Nitrogenous (as N)	Phosphate (as P_2O_5)	Potash (as K_2O)	Total	Percent of World Total
	(1000 Metric Tons Annually)				
Developed market economies	22,307	15,504	13,702	51,513	56.2
North America	9,421	6,783	7,753	23,957	26.1
Western Europe	10,061	6,533	5,296	21,890	23.9
Oceania and other	2,825	2,188	653	5,666	6.2
Developing market economies	4,335	2,366	300	7,001	7.6
Africa	183	530	285	998	1.1
Latin America	1,009	786	14+	1,809	1.9
Near East	815	466	–	1,281	1.4
Far East	2,328	584	–	2,912	3.2
Centrally-planned economies	15,598	7,807	9,750	33,155	36.2
Asian regions	3,340	1,511	300	5,151	5.6
European and all of U.S.S.R.	12,258	6,296	9,450	28,004	30.6

[1] For late 1970s. Sources: FAO reference listed, plus individual governments.

TABLE 12. FERTILIZER PRODUCTION–LEADING PRODUCING COUNTRIES

Country	1000 Metric Tons Annually	Percent of World Total
U.S.S.R.	18,311	20.0
United States	16,760	18.3
Canada	7,097	7.7
France	5,493	6.0
Germany (West)	5,133	5.6
China	4,693	5.1
Germany (East)	3,710	4.0
Japan	3,110	3.4
Poland	2,280	2.5
Spain	1,855	2.0
Italy	1,706	1.9
Netherlands	1,585	1.7
India	1,518	1.7
Rumania	1,384	1.5
Switzerland	1,325	1.4
Belgium	1,242	1.4
All others	14,467	15.8
Total	91,699	100.0

References

NOTE: Numerous cross-referenced entries have been named in this immediate entry. References included at the ends of those entries are *not* repeated here.

Bergeaux, P. J.: "Micronutrients," University of Georgia College of Agriculture, Athens, Georgia, *Bulletin 784.*

Dickinson, W. A., Jr.: "Tissue Analysis," in *Ortho Hypa Highlights,* Chevron Chemical Company, San Francisco, California (Revised periodically).

FAO: "Production Yearbook," Food and Agriculture Organization of the United Nations, Rome, Italy (Published annually).

FAO: "Annual Fertilizer Review," Food and Agriculture Organization of the United Nations, Rome, Italy (Published annually).

FAO: "The State of Food and Agriculture," Food and Agriculture Organization of the United Nations, Rome, Italy (Published annually).

Fishbach, P.E.: "Fertigation and the Importance of Anti-pollution Devices," *Fertilizer Solutions,* **21** (2) 8-13 (1977).

Hergert, G. W., and J. O. Reuss: "Sprinkler Application of Phosphorus and Zinc Fertilizers," *Agronomy J.,* **68,** 508 (1976).

Hergert, G. W.: "Sprinkler Application of Fertilizer Nutrients," *Fertilizer Solutions,* **21** (2) 14-20 (1977).

King, S. M., Mitteness, R. M., and I. M. Wofford: "Secondary Nutrients in Fluid Fertilizers," *Fertilizer Solutions,* **13** (2) 66-74 (1969).

Leitch, D.: "Matching Fertilizer Application to Crop Requirements," in *Ortho Hypa Highlights,* Chevron Chemical Company, San Francisco, California (Revised periodically).

Mortvedt, J. J., Wallace, A., and R. D. Curley: "Iron–The Elusive Micronutrient," *Fertilizer Solutions,* **21** (1) 26-36 (1977).

Staff: "Plants for the Fertilizer Industries," Friedrich Uhde GmbH, Dortmund, West Germany (Revised periodically).

Swenson, R. J.: "The Need for Soil Testing," in *Ortho Hypa Highlights,* Chevron Chemical Company, San Francisco, California (Revised periodically).

Trivedi, R. N., Chari, K. S., and V. Pachaiyappan: "Pollution Control in Fertilizer Industry," Fertiliser Assn. of India, New Delhi (1979).

USDA: "Agricultural Statistics," U.S. Department of Agriculture, Washington, D.C. (Published annually).

USDA: "The Fertilizer Situation," U.S. Department of Agriculture, Washington, D.C., *Bulletin FS-9* (Issued annually).

USDA: "The World Food Situation and Prospects for 1985," U.S. Department of Agriculture, Washington, D.C., *Report 98,* (Revised periodically).

FERTILIZING EQUIPMENT. Spreading and Spraying Equipment.

FERTILIZATION (Flower). Flower; Pollination.

FESCUE. Grasses.

FIBER (Dietary). Although fiber in the human diet may have been espoused as early as 400 B.C. by Hippocrates who identified bran as a laxative, serious evaluation of the dietary role of fiber, with few exceptions, was not undertaken by food professionals until the early 1970s. Much of the interest in fibers stemmed from reports by D. P. Burkitt (British medical researcher and surgeon), who observed that rural Africans, whose diets are high in fiber-containing foods, have a lower incidence of appendicitis, hemorrhoids, diverticular disease, cardiovascular disease, and cancer of the colon than persons who live in the western, developed nations. Diets in the latter countries are comparatively low in fiber content (Burkitt, 1973).

As of the early 1980s, research in this interesting and potentially valuable area of nutrition is quite active, but still in a relatively early stage. Claims of potential benefits from more fiber in the diet in some current instances may prove to be overstated—because 30 or more human diseases and disorders have been mentioned as benefitting in some fashion from increased fiber content. But, research to date has provided a trend of evidence that enhances the role of fiber in human metabolism that goes far beyond the alleviation of constipation, the traditionally accepted role of fiber or "roughage" in the diet.

Definitions of Fiber. A search of the literature reveals inconsistencies in the use of the term *fiber*. The early definition of the Association of Official Analytical Chemists (Washington, D.C.) in the publication "Official Methods of Analysis" (AOAC, 1970) defines *crude fiber* as "*the residue remaining after treatment with hot sulfuric acid, alkali, and alcohol. It consists primarily of cellulose, lignin, and trace amounts of other polysaccharides.*"

This definition appears somewhat narrow in terms of present views of the subject. Based upon the writings of a number of investigators, fiber may be defined as "*that part of plant material in the diet which is resistant to digestion by the secretions of the human gastrointestinal tract—consisting of variable proportions of complex carbohydrates, such as celluloses, hemicelluloses, pentosans, and uronic acids, as well as lignin.*" (Trowell, 1972; Van Soest and McQueen, 1973; Spiller and Amen, 1975; Baker, 1975; Leveille, 1976).

From an analytical standpoint, because it is difficult to measure the undigested fractions (may be different from one person to the next), a definition of dietary fiber probably should be amended to include, "*the residue remaining after an analytical procedure, such as the Neutral Detergent Fiber method* (Van Soest and McQueen, 1973); *or the Acid Detergent Fiber method* (Baker, 1975)."

A definition of dietary fiber should include all the components of a food that are not broken down by enzymes in the human digestive tract to produce small molecular compounds which are then absorbed into the blood stream. Thus, dietary fiber includes hemicelluloses, pectic substances, gums, mucilages, as well as certain other carbohydrates in addition to lignin and cellulose. These chemical compounds are found largely in the cell walls of plant tissues.

The term *crude fiber* as traditionally used may represent as little as one-seventh of the total dietary fiber of a given food (IFT Expert Panel, 1979). It is possible that the term fiber in itself may be somewhat misleading, inasmuch as all components of presently regarded "dietary fiber" are not fibrous in the usual physical sense, while, at the same time, some foods that contain recognizable fibers, such as muscle meats, do not yield undigestible residue.

Burkitt's definition of dietary fiber is "*mostly celluloses and lignin and lignin material, varying in different plants according to type and age. Basically, it passes through the small intestine undigested by our enzymes. A kind of natural and necessary laxative.*"

Wide Variations in Nature of Fibers. As pointed out by the IFT Expert Panel (1979), the results of feeding "high-fiber" diets differ from one researcher to the next. One explanation for conflicting results may the result of inadequate analytical methods used for determining fiber data. But even more fundamental is the fact that different fiber components have very different physiological functions and, inasmuch as fiber composition differs with the food source, the physiological effects noted will depend upon the predominant type of fiber present in the experimental diet. Some of these differences are in kind; others are of degree. As an example, the effect of fiber on the level of serum cholesterol has varied widely. Pectin, lignin, guar gum, oat hulls, and barley have been shown to have some cholesterol-lowering effect in human and animal studies, while bran and cellulose have not shown a similar effect.

Digestion of some components of dietary fiber, especially the hemicelluloses, takes place in the colon as a result of bacterial action. White flour, for example, is high in hemicellulose. The volatile fatty acids produced from this soluble fiber in the digestive process attract water from the surrounding tissues by osmosis, and thus may have a cathartic effect. Some fibers, such as bagasse from sugarcane, are very sharp abrasives to the intestinal tract; while others, such as lignin, may actually be constipating. There are such great differences in the physiological effects of the various constituents of dietary fiber that some researchers feel that it is essentially meaningless to consider high-fiber diets in the abstract. They do not deny that needs may exist for components of dietary fiber with specific properties, but rather that these needs may vary with different physiologic states.

Sources of Fibers. A wide variety of foods supply significant amounts of dietary fiber. Fundamental are those foods, such as fruits and vegetables, which provide significant quantities of fiber as the result of their naturally high fiber content. In many other instances, fibrous components (powdered cellulose; rice and soy hulls; soy, corn (maize), rice, wheat brans; coconut residues, citrus byproducts, ground almond skins, groundnut (peanut) hulls, etc.) can be added to processed foods, such as breads and, particularly to fabricated foods which provide excellent opportunities for improving the dietary aspects of many products in this latter category. A number of the fiber-containing components for addition to food products are not strange because for years past some of these materials have been considered additives, but for other purposes, such as thickening and bulking agents.

TABLE 1. DIETARY FIBER AND COMPOSITION OF REPRESENTATIVE FRUITS, VEGETABLES, AND WHEAT PRODUCTS

		Composition of the Dietary Fiber			Composition of the Noncellulosic Fraction		
Food Substance	Total Dietary (Fresh Basis) Weight %	Noncellulosic Polysaccharides %	Cellulose %	Lignin %	Hexoses %	Pentoses %	Uronic Acids %
Apples (flesh only)	1.42	66	33	<1	20	35	40
Banana	1.75	64	21	15	54	19	27
Bran	48.0	74	18	7	19	60	12
Cabbage (cooked)	2.83	37	63	trace	16	55	28
Carrot (cooked)	3.70	60	40	trace	20	35	45
Flour (brown) (90–95%)	8.70	72	18	10	44	45	11
Flour (white) (72%)	3.45	80	19	1	80	11	9
Flour (wholemeal)	11.0	72	20	8	39	48	13
Pear (flesh only)	2.44	54	28	19	20	46	35
Plum (raw–flesh and skin)	1.52	65	15	19	28	46	25
Strawberry (raw)	2.12	46	16	38	22	33	45
Tomato (raw)	1.40	47	32	21	14	42	44

Note: Data from Southgate (see reference list).

In both fresh vegetables and fruits, the *total dietary fiber* may appear to be relatively low because of the high water content of these foods. However in terms of solids content, the fiber portion appears substantial in many instances. For example, potato and starchy vegetables furnish appreciable amounts of fiber when consumed in relatively generous quantities. The lignin content of most vegetables is quite low, while that of fruits is greatest in those species which contain lignified seeds (such as strawberry), or lignified cells in the flesh (such as pear). The noncellulose polysaccharides in these foods are usually rich in pectic substances (uronic acids) and in 5-carbon sugars (pentoses).

Consumer interest in fibers has caused several bakeries to develop breads which contain from 6 to 8% crude fiber. This is approximately four times the amount of fiber present in ordinary whole wheat bread. Frequently, powdered foodgrade cellulose will be the fiber component added. Cellulose, of course, has been recognized for years as a food additive, often used as a thickener or to decrease separation of fat and water in other products, but its use in breads is relatively new. When added to bread, it must be listed on the ingredient label. Since cellulose and the water it holds dilute other nutrients in normal bread, "high-fiber" breads are sometimes promoted as "low-calorie" products.

The cereal brans, such as wheat, soy, and corn (maize) bran, can be added to many foods, such as snacks, cookies, bread and other bakery products, and cereal-based foods where the natural whole-grain flavor and color and texture imparted by the brans is consistent with the previous image of these products. Of the ingredients available to date, powdered cellulose is probably the most versatile (Colmey, 1978). Powdered cellulose is a bland, white, purified plant fiber, usually derived from wood, that can be added in significant amounts without serious adverse product differences. For example, a commercial reduced-calorie, high-fiber bread may contain 2 grams of crude fiber per 1-ounce (28.35 grams) slice.

Tables 1 through 3 provide information on the characteristics of a number of fibers and fibrous materials.

Properties of Fibers. From the standpoint of application in preventive medicine, fiber has two major functional properties: (1) Absorption capacity, and (2) water-binding properties. As pointed out by Scala (1976), the cardiovascular diseases relate to the ability of fiber to absorb materials which reduce blood cholesterol. The intestinal diseases appear to be related to fiber's water-binding properties and are influenced by the physical tone of the large intestine. Obesity is indirectly related to both properties, but mostly to factors in the food itself.

The water-binding properties of fibers, such as wheat bran, which binds twice its weight in water, and pectins, which bind more than 5 times, increase the rate and volume of fecal elimination, producing more frequent and softer elimination. It thus relieves intracolonic pressure and the symptoms of diverticular diseases, which develop from chronic constipation. In theory, a high-fiber diet should also be preventive, since it produces better muscle tone in the large intestine.

The ability of certain types of fiber—proteins, lignins, and some celluloses—to bind bile salts, cholesterol, and

TABLE 2. COMPARISON OF CRUDE FIBER AND DIETARY FIBER IN CERTAIN FOODS

Food Substance	Crude Fiber (Weight %)	Dietary Fiber (Weight %)
Breads and Cereals		
White bread	0.2	2.72
Whole wheat bread	1.6	8.50
All bran cereal	7.8	26.7
Cornflakes	0.7	11.0
Puffed wheat	2.0	15.41
Puffed wheat (sugar coated)	0.9	6.08
Vegetables		
Broccoli tops (boiled)	1.5	4.10
Lettuce (raw)	0.6	1.53
Carrot (boiled)	1.0	3.70
Pea (canned)	2.3	6.28
Sweet corn (cooked)	0.7	4.74
Fruits		
Apples (without skin)	0.6	1.42
Peaches (with skin)	0.6	2.28
Strawberry (raw)	1.3	2.12
Nuts		
Brazil	3.1	7.73
Groundnut (Peanut)	1.9	9.30
Peanut butter	1.9	7.55

Note: Data from Watt/Merrill; Southgate (see reference list).

TABLE 3. FIBER CONTENT OF HIGH-FIBER FOOD INGREDIENTS AND BREADS

Ingredient	Crude Fiber Content %	Dietary Fiber Content %
Corn bran	13–20	50*–90
Wheat bran	9–11	36–41
Soy bran	38–48	74–82
Rice bran	6–8	45
Cellulose	70	99+
Malto rice flour	10	37
Citrus byproducts	12–20	19–29
Triticale bran	5–6	35

* = estimated

Bread made with 18.5% (flour basis) of various fiber products

Fiber Source	Crude Fiber Content % of Solids
Powdered cellulose	11.5
50% rice hulls + 50% soy hulls	7.6
Soy bran	7.6
Corn pericarp	3.3
Corn bran "A"	3.4
Corn bran "B"	4.3

Note: Data from Colmey (see reference list).

other sterols accounts for fiber's role in reducing blood cholesterol. The enhanced elimination of bile acids helps to remove hepatic-produced cholesterol. The absorption of dietary cholesterol achieves a similar end.

Researchers Parrott and Thrall (1978) observe that the physical and chemical properties of a fiber include: (1) Water absorptive capacity; (2) organic compound absorptive capacity; (3) cation exchange capacity; and (4) particle size. These properties, in turn, are determined by the individual properties and structures of the various cell wall components (Van Soest and McQueen, 1973). For example, cellulose and associated hemicelluloses exhibit a marked water absorption capacity (Burkitt, 1977; Kimura, 1977). Pectic substances are hydrophilic, adhesive, and usually form gels with high water contents (Eastwood, 1973). Other notable nonstructural components associated with fiber which contribute to the functional properties include gums, cutin or epicuticular waxes, and mucilages (Trowell, 1972; Spiller and Amen, 1975). See also **Gums and Mucilages.**

In 1977, researchers Parrott and Thrall (Department of Nutritional Sciences and Public Health, Berkeley, California —and Carnation Research Laboratory, Van Nuys, California, respectively) undertook to develop a profile of the physical/chemical properties of several new fiber sources. Among the fiber sources tested were almond skins, fractionated groundnut (peanut) hulls, Nutrisoy fiber soy bran, high-protein defatted rice bran, coconut residues, and a number of cellulosic fibers. In part, the study showed that each fiber was characterized by distinctly different functional or physical properties. In most cases, dry density was directly proportional to hydrated density. However, responses to pH, ionic strength and mono- and divalent cations were highly individualized. Increasing temperatures resulted in enlarged, elongated particles and structural damage. Protein and fat content of some fibers, as well as color and flavor, should also be taken into consideration when selecting a fiber for possible use.

Status of Fiber Beneficiation of Diets. The IFT Expert Panel on Food Safety and Nutrition (1979) observed that physiological claims for fiber fall into 30 categories:

Definite Value—relieving constipation problems by increasing the water content of feces.

Probable Value—treating (or preventing) diverticular disease.

Possible Value—reducing serum cholesterol, prevention of a variety of disorders, such as hemorrhoids, varicose veins, ischemic heart disease, colon-rectal cancer, diabetes, appendicitis, obesity, gallstones, phlebitis, dental caries, irritable bowel, ulcerative colitis, and the harmful effects of some ingested toxic substances.

The evidence underlying these claims varies. Some comes from direct human studies; others from animal experimentation. Some observations have been made on different population groups, and attempts made to correlate various disease statistics with local dietary factors. Still other claims are theoretical hypotheses derived by combining known physical characteristics of foods and physiology.

Constipation. The value of fiber in increasing water content of feces has been mentioned. Fiber tends to effect a transit time in the gastrointestinal tract which is intermediate between being too rapid (diarrhea) and too slow (constipation). Some authorities theorize that the increased volume and softness of the stools, by reducing straining during defecation, is a factor in preventing hemorrhoids and varicose veins.

Diverticulosis. Diverticula are outpouchings that develop in weak areas in the bowel wall. If they are numerous and become inflamed, diverticulitis is the result. Accompanying the condition quite frequently is pain in the lower left side, an alternating diarrhea and constipation, and flatulence. Diverticulitis was essentially unknown prior to the turn of the century, but the incidence of the disorder has increased markedly in industrialized countries. In western countries, as of the early 1980s, it has been estimated that from one-fourth to one-third of the population of older persons may suffer some or all of the symptoms of diverticulitis. Prior to the current recognized treatment with high-fiber diet, it was treated with a low-residue diet, presuming that such a diet would permit healing and cause less irritation to the bowel.

Cardiovascular Diseases. As previously mentioned, a high-fiber diet may lower the blood cholesterol levels by reducing transit time through the gastrointestinal tract. People on certain high-fiber diets excrete more bile acids, sterols, and fat, implying that the fiber compounds "bind" bile acids and thereby prevent absorption of cholesterol and fat and also the reabsorption of bile acid derived from the body's cholesterol (Stanley, 1970). High serum cholesterol levels have been identified as one of the risk factors in atherosclerosis, although there is disagreement as to whether the actual risk can be reduced by lowering cholesterol levels by means of diet or drugs. Complicating any resolution of the role of dietary fiber in cardiovascular disease are the inconsistent effects produced by dietary fiber from different foods. Conflicting findings are indicated by: Cholesterol-lowering effect in humans by rolled oats (deGroot *et al.*, 1963); similar result with pectin (Keys, *et al.*, 1961). Bran does not appear to alter serum lipids, while alfalfa and possibly a lignin component may have a depressing effect (Eastwood, 1977).

Cancer. The hypothesis relating dietary fiber to colon cancer presumes that the slow movement of the feces which occurs with a low-fiber diet allows more time for any carcinogens present in the colon to initiate cancer. Also, the extra water, bile acids, salts, and fat bound by added fibers are assumed to act as solvents to remove a wide variety of chemical factors which may be carcinogenic. A high-fiber diet also may alter the type and number of microorganisms in the colon, which produce compounds convertible to carcinogens (Aries, 1969). Theories based essentially upon correlations of various population characteristics can, of course, be misleading. As just one example, the incidence of colon cancer in different countries and cultures correlates much better with the consumption of fat in the diet than it does with the consumption of fiber (Carroll, 1975; Chan and Cohen, 1975). As of the early 1980s, there has been no proven relationship between bowel transit times and the incidence of colon cancer. Also, there is no proof that constipation leads to cancer, and none that dietary fiber per se has a definable effect on the intestinal flora in humans (Mendeloff, 1975).

Diabetes. Colmey (1978) states that the results from research indicate that high-fiber diets may be beneficial for some persons, such as diabetics. A clinical study involving eight diabetic subjects was conducted by Miranda and Horwitz in 1977. The objective of the study was to determine if fiber would have a significant effect in the normalization of plasma glucose levels as a desirable goal in the diet therapy of the diabetic patient. The lowering of plasma glucose levels by inclusion of fiber could be an additional tool in achieving control of glucose levels in the diabetic patient. In the tests, two diets were used—one diet contained a low crude fiber level, while the other contained a high crude fiber level. Reduced-calorie high-fiber bread containing powdered cellulose to provide 2 grams of crude fiber per 1-ounce (28.35 grams) slice was the main source of fiber in the study. The researchers summarized their findings as follows:

"This research is consistent with the hypothesis that a diabetic diet with a high level of fiber content induces lower plasma glucose levels in diabetic states. A lower level was achieved in 7 out of the 8 patients fed with a high-fiber diet, compared to a low-fiber diet with exactly the same amount of calories. The mechanism by which high-fiber intake decreases mean plasma glucose levels is not known. The investigator suspects that the fiber acts by slowly releasing the absorbed glucose to the bloodstream, as it takes a longer time for bulk foods, compared to refined foods, to be digested. As such, there is no bolus of available glucose in the blood at one time. Instead, slower absorption rates of food with high-fiber levels cause the available glucose to be released more slowly in the blood. Southgate (1973) has suggested a similar result in the ability of fiber to limit diffusion toward the absorptive mucosal surface. One striking feature of this study was the ability of the fiber per se to lower mean plasma glucose levels. Other studies have used bran, guar and pectin, cellulose, bagasse, rolled oats, and other materials with identified fiber components, in bringing about desired experimental results. This study tends to give more credit to fiber as a whole than to its parts. What seems more important is achieving a defined level of fiber intake, regardless of its source, in attaining beneficial results. In summary, high-fiber intakes may well prove to be effective in a diabetic dietary regimen in promoting control of plasma glucose levels, along with insulin therapy."

Excessive Fiber in Diet. With emphasis upon the probable beneficial effects of dietary fiber, the question of the consequences of fiber overdosage so to speak is rightfully brought forward. Much less research on this point has been conducted. It has been suggested that too much pectin may cause decreased vitamin B_{12} absorption. This would be an important concern for certain types of vegetarians whose diets are already low in that vitamin and high in fiber. There may also be a significant loss of minerals, particularly zinc, iron, calcium, copper, and magnesium, due to binding of these minerals by phytic acid, present in certain plant-based foods. The high-fiber diets of Africa and India, for example, are associated with a high incidence of such mineral deficiencies and kidney stones, especially in areas where rice is the major calorie source. The rate of stomach cancer in some of these areas is high, which should lead to cautious interpretation of epidemiological studies. Also, fiber, by its sheer bulk, may reduce the total amount of food consumed, thereby resulting in the deficiency of certain nutrients and, possibly in extreme cases, to reducing calories in areas where malnutrition already exists. The IFT Expert Panel recommends that persons with kidney disease, diabetes, or other diseases should, without question, obtain permission from their physicians prior to consuming bran or making other drastic changes in their diet. Very large amounts of fiber could even cause enlargement and twisting (or "volvulus") of the sigmoid colon (Eastwood, 1976) and aggravate ulcerative colitis. Both conditions occur in Africa, but rarely in Europe.

See also entry on **Lipids**.

References

AOAC: "Official Methods of Analysis," Association of Official Analytical Chemists, Washington, D.C. (1970).

Baker, D.: "Determining Dietary Fiber in Cereals," paper presented at 60th Annual Meeting, American Association of Cereal Chemists, Kansas City, Missouri (October 1975).

Burkitt, D. P.: "Some Diseases Characteristic of Modern Western Civilization," *British Medical J.*, 1, 274 (1973).

Burkitt, D. P., and H. C. Trowell: "Refined Carbohydrate Foods and Disease," Academic Press, New York (1975).

Carroll, K. K.: "Experimental Evidence of Dietary Factors and Hormone-dependent Cancers," *Cancer Research*, 35, 3374 (1975).

Chan, P. C., and L. A. Cohen: "Dietary Fat and Growth Promotion of Rat Mammary Tumors," *Cancer Research*, 35, 3384 (1975).

Colmey, J. C.: "High-fiber Foods in the American Diet," *Food Technology*, 32, (3) 42, 44–47 (1978).

DeGroot, A. P., Lugken, R., and N. A. Pikaar: "Cholesterol-lowering Effects of Rolled Oats," *Lancet*, 2, 303 (1963).

Eastwood, M.: "Volvulus of the Colon," in *Fiber in Human Nutrition*, (G. A. Spillen and R. J. Amen, Editors), Plenum, New York (1976).

Hardin, G. B.: "High Protein and Fiber Diets May Affect Mineral Metabolism," *Agricultural Research*, 27, (9) 6–7 (1979).

Heaton, K. W.: "Dietary Fiber," Food and Nutrition Press, Westport, Connecticut (1979).

IFT Expert Panel: "Dietary Fiber," *Food Technology*, 33, (1) 35–39 (1979).

Keys, A., Grande, F., and J. T. Anderson: "Fiber and Pectin in the Diet and Serum Cholesterol Concentration in Man," *Proceedings of Soc. Exp. Biol. Med.*, 196, 555 (1961).

Leveille, G. A.: "Dietary Fiber," *Cereal Foods World*, 21, (6) 256 (1976).

Mendeloff, A. I.: "Dietary Fiber," *Nutrition Review*, 33, (11) 321 (1975).

Miranda, P. M., and D. Horwitz: (Personal communication as reported in *Food Technology*, 32, (3) 46 [1978]).

Parrott, M. E., and B. E. Thrall: "Functional Properties of Various Fibers: Physical Properties," *J. of Food Science*, 43, (3) 759–763 (1978).

Roth, H. P., and M. A. Mehlman: "Symposium on the Role of Dietary Fiber in Health," *Am. J. Clin. Nutr.*, 31 (1978).

Scala, J.: "Fiber in Preventive Medicine," *Cereal Foods World*, 356–357 (August 1976).

Southgate, D.: "Analysis of Dietary Fiber," in *Fiber in Human Nutrition* (G. A. Spiller and R. J. Amen, Editors), Plenum, New York (1976).

Spiller, G. A., and R. J. Amen: "Fiber in Human Nutrition," Plenum, New York (1976).

Spiller, G. A., Editor: "Topics in Dietary Fiber Research," Plenum, New York (1978).

Staff: "Dietary Fiber," *Food Technology*, 33, (1) 35–39 (1979).

Stanley, M. M.: "Quantification of Intestinal Functions during Fasting: Estimations of Bile Salt Turnover, Fecal Calcium, and Nitrogen Excretions," *Metabolism*, 19, 865 (1970).

Thompson, S. A., and C. W. Weber: "Effect of pH on Minerals in Fibers," *J. of Food Science*, 44, (3) 752–754 (1979).

Trowell, H. C.: "Ischemic Heart Disease and Dietary Fiber," *American J. of Clin. Nutr.*, 25, 926 (1972).

Van Soest, P. J., and R. W. McQueen: "The Chemistry and Estimation of Fiber," *Proceedings of Nutr. Soc.*, 32, 123 (1973).

Watt, B. K., and A. L. Merrill: "Composition of Foods," U.S. Department of Agriculture, Washington, D.C., *Agriculture Handbook 8*, (1975).

Wen-Li, J. J., and M. E. Zabik: "ENDF (Neutral Detergent Fiber Content) Values for Selected Foods," *J. of Food Science*, 44, (3) 924–925 (1979).

FIBRINOGEN. Protein.

FICIN. Fig; Enzyme Preparations.

FIG. The fruit[1] of the tree of the same name. The fig tree is of the genus (*Ficus*) of the large family Moraceae (mulberry family). The genus *Ficus* embraces over 600 species of rather differing characteristics and, in addition to the fig tree, includes the banyan tree and the India rubber plant (*Ficus elastica*). Botanically, of course, there are a number of similarities which account for their classification (such as exudation of latex fluids) and they all share a preference for the warmer regions of the world. The fig tree (*Ficus carica*) is probably native to southwestern Asia. Figs have been cultivated since earliest recorded times, being widely used by the Hebrews, greatly improved by the Greeks, and highly valued by the Romans. The fig tree is now grown in cultivation in numerous tropical countries and in a number of subtropical regions. Well-tended fig trees are found in the United States in gardens from Virginia south and westward in the Gulf states and further westward to California. Although commercial orchards are found in Texas and Louisiana, the center of fig production in the United States is found in California (about 99% of the U.S. fig crop).

Evidence of the figs existence prior to recorded history has been found in fossil remains in France and Italy, dating back to the Stone Age. A diagram showing the harvesting of a fig tree was found with Egyptian artifacts dating back to 2700 B.C. There is evidence that figs arrived in Greece about 800 B.C. Aristotle studied the fig in 340 B.C. As with so many other fruits, the Spanish introduced the fig to North and Central America. It is recorded that Cortez brought figs to Mexico in 1560. Captain John Smith, in 1629, reported on the excellence of locally grown figs (Jamestown, Virginia). It is believed that the fig was first cultivated at the mission at San Diego during the early 1700s. The Mission variety of fig not only was grown at the mission in San Diego, but in the gardens of numerous other Spanish missions throughout California—and the variety remains one of the leading varieties of figs grown in California as of the early 1980s.

Fig trees are deciduous and have alternate leaves which are rather thick and rough-surfaced above, but soft-hairy

---

[1] Although commonly called a fruit, botanically the fig is not a fruit, but rather it is a *syconium*, a form of inflorescence in which the flowers are borne on the inside wall of a hollow peduncle, rather than on the surface of a stalk (Sackett, 1976).

Tree (*Ficus carica*) bearing figs. (*USDA photo*)

beneath. The leaves are deeply lobed in the cultivated varieties. The minute flowers are borne on the inside of the hollow receptacle, which develops into a pear-shaped body with a minute opening at its apex. The fruit developing from this is a syconium, composed of many small fruits inserted in the inner wall of a hollow fleshy receptacle. The narrow passage into this is partly closed by numerous small bracts. A small fig tree is illustrated in the accompanying figure. Range of height of the tree is 15 to 30+ feet (4.5 to 9+ meters).

Flowers of the Fig Tree. Four kinds of flowers occur in fig trees: (2) Staminate flowers, each having four pollen-bearing stamens, occur in the wild "caprifig." A few cultivated forms have staminate flowers. Pollination is brought about by using pollen from caprifigs, and is called *caprification*. (2) Pistillate flowers, each with a single pistil which if pollinated produces a seed. These flowers are short-stalked. (3) The *gall-flower*, so-called because a small wasp, the *fig wasp* or *Blastrophaga grossorum*, lays it eggs in them. The developing larvae cause the ovaries to become swollen galls, incapable of developing seeds. This type of flower occurs only in caprifigs, in the basal portion of the syconium. (4) In varieties of cultivated figs, there are found sterile flowers, which will neither produce seeds nor become galls. These are called *mule flowers*.

Caprifigs contain the first three types of flowers. If pollen is needed to insure fruit development, caprifigs must be planted, since they alone have pollen-bearing flowers. So, caprifigs must be planted, for example, among Smyrna fig trees, the fruits of which fail to develop unless pollinated.

In Mediterranean countries, where figs are grown in abundance, three crops are produced each year. The first fruits, known as *profichi*, are formed in the spring. In the pistillate flowers of these, the female wasp lays her eggs, so that galls are formed in the profichi. When the young wasp emerge, these profichi are gathered and hung among Smyrna figs. Wasps escaping have to crawl past the staminate flowers near the aperture of the synconium and so are dusted with pollen. The wasp then enters and pollinates a flower of the second crop, thus insuring fruit development. The second crop is known as *mammoni*. The third crop, the *mammae*, remain on the trees. It is in these that the wasp passes the winter. The wasp is about the size of a gnat. See also separate entry on **Chalcid Wasp**, which describes the actions of the fig wasp in more detail.

It should be pointed out that the common fig develops its fruits *parthenocarpically*, meaning without the stimulus of pollination and fertilization of the flowers. As a result, the fruitlets inside the syconia contain no viable seeds, although the figs appear to contain seeds. Actually, these are seedless fruitlets. The navel orange and oriental persimmon also develop parthenocarpically.

It should also be pointed out that the four kinds of figs just described from the standpoint of their flowers are *not horticultural varieties* in the usual sense, but rather they are *botanical types*.

Climate. Although rather high summer temperatures favor vegetative growth of the fig tree, optimum temperatures for fruit development are less clearly defined. The parthenocarpic types of figs produce and set figs under a rather wide range of temperatures, but the quality of the fruit is quite temperature-dependent. Figs of this type produce best at daily maximum temperatures between 85° and 100°F (29.4° and 37.8°C). Where daytime temperatures are consistently above the latter temperature, premature ripening occurs, the fruits are tough, and the number of fruits that are deficient of pulp increases. During their dormant season, fig trees can withstand temperatures as low as 10° to 20°F (-12.2° to -6.7°C), but they must be fully dormant. Injury will occur at substantially higher temperatures than those just stated when cold weather develops at a time when the trees are not fully dormant, as may occur during the spring and fall. Young trees and new growth of older trees are the most susceptible to frost damage. Long, unusually warm periods during winter may bring trees out of dormancy and cause damage when cold weather returns.

Soil and Fertilization. Fig trees grow satisfactorily in moderately fertile soils without fertilizer. Nitrogen is usually the principal deficient element. Where fertilizer is indicated, some growers use a fertilizer with an analysis of 8-8-8. For plants that are from 1 to 2 years old, about 1/3-pound (about 150 grams) of fertilizer are applied each month from the beginning of growth through the end of the summer. For larger trees, fertilizer is applied in late winter, early June, and late July, but exact timing depends upon specific region. Some growers use a total of 12 pounds (5.4 kilograms) of 8-8-8 each year for a tree that is from 12 to 15 feet (3.6 to 4.5 meters) in height. For highest yields, figs require watering throughout the summer. The amounts are determined largely by the soil type and drainage situation.

Propagation. This is usually by stem cuttings, but budding or grafting also is used. Although cuttings can be planted in their permanent site, they are usually rooted in a nursery and transplanted when 1 year old. Trees are planted in generously dug holds, allowing plenty of room to accommodate roots and for loose soil at the bottom of the hole. The plants are set 2 to 4 inches (5 to 10 centimeters) deeper than their depth at the nursery and the tops are cut back to a height of about 30 inches (76 centimeters). Commercially, trees are spaced from 12 to 30 feet (3.6 to 9 meters) apart.

Varieties. Principal varieties of fig planted in the United States are given in Table 1.

TABLE 1. VARIETIES OF FIG GROWN IN THE UNITED STATES

Variety	Characteristics
Brown Turkey	Also called *Brunswick*. Medium-size with reddish-brown skin. Produces fruit parthenocarpically. Longest ripening season of major varieties. Harvested in late summer and fall. Although wood is not as cold-tolerant as the wood of *Celeste*, it will produce a fair crop on sucker wood the year following a severe freeze. Fruit is considered of excellent quality. The California-grown variety is used for both canning and the fresh market. The Texas-grown variety is used for canning and making preserves. The variety also does well in the southeastern states. Yield from trees 3 to 4 years of age will be a few hundred pounds/acre, but the yield from trees 5 to 7 years of age will be from 1 to 2.5 tons/acre (2.2 to 5.6 metric tons/hectare).
Calimyrna	Also called *California Smyrna* or *Lob Injir*. The leading variety cultivated in California. Introduced from Turkey about 1880. Requires caprification. First-crop figs are relatively few large, golden brebas. Main crop, harvested in late summer, is comprised of large fruits with a golden-yellow skin and amber pulp. Quality and flavor are excellent. Variety will produce from 1.25 to 1.5 tons/acre (2.8 to 3.4 metric tons/hectare) of dried figs. This is equivalent to 3.75 to 4.5 tons/acre (8.4 to 10.1 metric tons/hectare) of fresh figs.
Celeste	Grown for fresh consumption and possibly the best quality fig grown in the southern states. Fruit is small and light-brown to violet in coloration when ripe. During the dormant season, the wood of *Celeste* is slightly more tolerant of cold than the wood of other varieties. During extremely hot weather, the *Celeste* may drop part of its crop.
Green Ischia	An excellent variety for fresh consumption. Quite seedy and this detracts from use in preserves. Fruit is of medium-size. Variety does well in the southeastern states. Because fruit is of greenish color, it is not so attractive to birds as some varieties.
Hunt	Fruit is of small-to-medium size, a dull bronze with white flecks and has a distinct bloom. Good quality for fresh consumption. A cold-tender variety. Sometimes planted in southern parts of southeastern states.
Kadota	Also called *Dottato*. Introduced into the United States from Italy in 1860s. Produces fruit parthenocarpically. Fruit has a yellowish-green skin, pulp varies from amber to violet. Fruit is of medium to large size. A major variety grown in California. Also suited to the south-eastern states. Produces a limited crop on suckers following a freeze. Excellent for canning and preserving; considered fair for fresh consumption. Harvested in California in late summer or fall. Yield is greater than other varieties with exception of *Brown Turkey*.
Magnolia	This variety produces excellent preserves if picked just prior to full maturity. Not a sturdy grower. Fruit splits badly and sours during wet weather, but these conditions can be avoided by early picking. Produces a fair crop on sucker wood following a severe freeze. Limited plantings in the southeastern states.
Mission	Also called *Black Mission*. Probably the first fig cultivated in the United States, dating back to the early Spanish mission gardens. Produces fruit parthenocarpically. Fruit is purple-black. Size varies with date of harvest: Medium to large (early-summer); medium to small (late summer or fall). A leading variety cultivated in California. Principally for fresh market.

Production. The leading producers of figs worldwide are listed in Table 2. In commercial plantings, bearing of fruit usually commences about the seventh year after planting, but some varieties under good conditions may bear in the fourth year. Yields are given in Table 1 for several varieties.

Harvesting. The schedule of harvesting commercially grown figs in the United States is given in Table 3. When destined for the fresh market, figs must be harvested when soft and fully ripe. Immature figs are firm and, if picked, do not mature to yield the best flavor. Unfortunately, the figs of some varieties do not abscise until they are in an overripe and partially dried-out condition. Whole figs for canning are given about the same care in harvesting as those intended for fresh market. The pickers detach the figs by firmly but gently twisting the fruit. Because of latex which tends to exude when the fruits are separated from the tree, pickers usually wear gloves to avoid possible skin irritation.

Mechanical harvesting is sometimes used when the figs are to be dried. Large quantities of figs go into confectionery and bakery products, such as fig newtons, fig nut squares and fig bars. Figs are also made into pastes and conserves.

For dried figs, the figs must remain on the tree until fully ripe. The gathered figs are dipped in boiling brine and then put on trays and exposed to the sun. Further drying may take place in the shade. Sometimes the figs are then

TABLE 2. LEADING PRODUCERS OF FIGS (DRIED)[1]

Country	Production (1000 Metric Tons)	Percent of Total
Turkey	40.0	46.5
Greece	19.8	23.0
United States	11.4	13.2
Italy	6.4	7.4
Portugal	6.0	7.0
Spain	2.5	2.9
Total	86.1	100.0

[1] 1977. Figure for United States is average of 15-years of production (1963–1977).

Breakdown of Varieties Grown in the United States[2] (Mid-1970s)

Variety	Percent of Total
Calimyrna	52.2
White Adriatic	23.2
Kadota	10.1
Black Mission	9.6
Conadria	4.1
Others	0.8

[2] Based upon area planted (bearing).

TABLE 3. SCHEDULE OF HARVESTING PERIODS FOR FIG (California)

Utilization and Variety	Starts	Most Active	Ends
Fresh and Canning			
Black varieties (*Mission*) (San Joaquin Valley)	June 5	June 10–July 10	Sept. 1
Calimyra (San Joaquin Valley)	July 1	July 25–Aug. 30	Sept. 15
Kadota			
San Joaquin Valley	June 15	June 20–July 15	Sept. 15
Brentwood	Aug. 15	Sept. 1–Oct. 15	Oct. 15
Dried Varieties			
All varieties and areas	June 15	July -Sept. 15	Oct. 15

Source: USDA *Handbook 186.*

put into sweat boxes and mixed so that their moisture content will equalize. After washing in another brine solution, they are drained and ready for final packing. See entry on **Dried-Fruit Insects.**

Nutritional Aspects of Fig. The composition of fig is given in Table 4; the amino acid content in Table 5. The fig is considered a staple food among some major fig-producing countries, such as Greece and Turkey.

TABLE 4. COMPOSITION OF FIG (Per 100 Edible Grams)

	(*Ficus carica*)	
Constitutent	Raw	Dried (Uncooked)
Water (Percent)	77.5	23.0
Food energy (Calories)	80	274
Protein (Grams)	1.2	4.3
Fat (Grams)	0.3	1.3
Carbohydrates (Grams):		
Total	20.3	69.1
Fiber	1.2	5.6
Ash (Grams)	0.7	2.3
Calcium (Milligrams)	35	126
Phosphorus (Milligrams)	22	77
Iron (Milligrams)	0.6	3.0
Sodium (Milligrams)	2	34
Potassium (Milligrams)	194	640
Vitamin A (Intl. Units)	80	80
Thiamine (Milligrams)	0.06	0.10
Riboflavin (Milligrams)	0.05	0.10
Niacin (Milligrams)	0.4	0.7
Vitamin C, ascorbic acid (Milligrams)	2	0*

*Imputed value from a similar food.

Source: Watt/Merrill (see reference listed).

TABLE 5. AMINO ACID CONTENT OF FIG (*Ficus carica*)

Moisture content	81.7 grams/100 grams
Nitrogen	0.19 gram/100 grams
Conversion factor (Nitrogen)	6.25
Protein	1.2 grams/100 grams
Protein calorie (Percent)	6.1

Amino Acid	Milligrams per Gram of Nitrogen	Milligrams per 100 Grams of Food
Isoleucine	190	36
Leucine	270	51
Lysine	250	48
Methionine	52	10
Cystine	100	19
Phenylalanine	150	28
Tyrosine	270	51
Threonine	200	38
Tryptophan	53	10
Valine	240	46
Arginine	140	27
Histidine	88	17
Alanine	380	72
Aspartic acid	1500	285
Glutamic acid	600	114
Glycine	210	40
Proline	410	78
Serine	310	59

Data Source: FAO *Nutritional Study 24* (reference listed).

References

Bailey, L. H.: "Standard Cyclopedia of Horticulture," Macmillan, New York (1963).

Condit, I. J.: "Fig Culture in California," Division of Agricultural Sciences, University of California, Berkeley, California, *California Agricultural Extension Service Circular* 77 (1941).

Condit, I. J.: "Ficus, The Exotic Species," Division of Agricultural Sciences, University of California, Berkeley, California (1969).

Ito, K. A., *et al.*: "Effect of pH on the Growth of *Clostridium botulinum* in Canned Figs," *J. of Food Science*, 43 (5) 1634–1635 (1978).

Janick, W. H.: "Horticultural Science," 2nd Edition, Freeman, San Francisco (1972).

Mortensen and Bullard: "Handbook of Tropical and Sub-Tropical Horticulture," U.S. Department of State, Washington, D.C. (1970).

Sackett, C.: "Figs," United Fresh Fruit & Vegetable Association, Alexandria, Virginia (1976).

Staff: "History of the California Fig Industry," *The Blue Anchor* (September, 1970).

Staff: "World Dried Fruit Output," U.S. Department of Agriculture, Washington, D.C., *Foreign Agriculture Circular*, (Issued periodically).

Staff: "Agricultural Statistics," U.S. Department of Agriculture, Washington, D.C. (Published annually).

Staff: "Amino-Acid Content of Foods," Food and Agriculture Organization of the United Nations, Italy, Rome, *Nutritional Study 24* (1970).

Watt, B. K., and A. L. Merrill: "Composition of Foods," U.S. Department of Agriculture, Washington, D.C., *Agriculture Handbook 8* (1975).

Westcott, C.: "Plant Disease Handbook," 3rd Edition (Fig: pages 568-569), Van Nostrand Reinhold, New York (1971).

FILBERT. This is an important tree nut of worldwide commercial importance, widely used as a table nut and in numerous bakery and confection products. The filbert ranks along with walnuts, chestnuts, pecans, and almonds in terms of worldwide production. As indicated by the accompanying table, the Asian continent dominates production, most of this production coming from Turkey and to a considerably lesser extent from Iran. Europe is also a major producer of filberts, with most of this production coming from southern countries, including Italy, Spain, Greece, Portugal and France. Although the American species (*Corylus americana*) ranges from Maine westward to Alberta and Kansas and southward to Florida, the species is not an important commercial source of filberts. As of the early 1980s, over 98% commercial filbert production in North America comes from the Pacific Northwest, as the result of importing European species of hazelnut trees many years ago. It is now a progressive and expanding industry. During the 1960s, filbert production from Washington and Oregon averaged about 8200 tons per year, whereas in the 1970s, the production averaged about 10,100 tons per year. There are, of course, variations in production of as much as 5,000 tons from year to year. For example, production in 1977 was 11,750 tons as compared with 7,170 tons for 1976.

Although not of commercial significance, the beaked hazelnut (*C. rostrata*) also ranges widely throughout Canada from Quebec westward to the Pacific slopes and south into the United States to Missouri, Michigan, and Ohio and Delaware in the east. It is found in the mountains as far south as Georgia. The fruit is edible and sweet and shaped like other filberts. The nut is enclosed in a bristly cup which has a beaklike termination, hence the name. Species of hazelnut are also used as garden shrubs rather than as nut producers.

WORLDWIDE PRODUCTION OF FILBERTS (Hazelnuts)[1]

Continent	Production (Metric Tons)	Percent of World Total
North and Central America	11,750	2.9
Asia	281,250	69.2
Europe	99,159	24.4
U.S.S.R.	14,400	3.5
Total	406,559	100.0
Country		
Turkey	265,000	65.2
Italy	70,000	17.2
Spain	24,000	6.0
Iran	16,000	4.0
U.S.S.R.	14,400	3.5
United States	11,750	2.9
Greece	3,400	0.8
Portugal	880	0.2
France	560	0.1
All others	569	0.1
Total	406,559	100.0

[1] 1977 statistics (USDA and FAO; see references listed) (unshelled basis).

NOTE: 1 Weight Unit (shelled) = 2.5 Weight Units (unshelled).

Some authorities use the word *filbert* to describe the nut; and the word *hazelnut* when referring to the source tree or shrub. Others reserve the word filbert for the nuts of trees of European species. And still others use the two words interchangeably. There does not appear to be any hard and fast rule regarding this. It is known that *filbert* was first used in France because the holidy known as Saint Philbert's Day (August 22nd) falls at about the same time the nuts ripen in France. The nut of the variety *C. avellana grandis,* because of its larger size, is sometimes called the *cobnut.*

The hazelnut tree is deciduous and is essentially limited to the northern hemisphere. The male flowers are in the form of long, cylindrical catkins. The flowers are tiny, red and not very showy. They usually develop in the year prior to development of fruit. The fruit is the edible and tasty, ovoid-shaped nut which resides in a toothed container. See Figs. 1 and 2. Some authorities claim that the hazelnut has been cultivated for several thousand years, but its early history is unclear. It is generally believed that the tree (or shrub) originated in the Near East. Unlike most other fruiting trees, the hazelnut has the curious habit of blooming and pollinating in midwinter. The tiny red female inflorescence is enclosed within a bud. The male catkins remain over the winter. Wind carries pollen from the catkins to the flower, where it remains dormant until spring, at which time the nut begins to form. Many varieties of hazelnuts are unfruitful unless they receive pollen from another tree of

Fig. 1. Filberts (hazelnuts). Upper left, note nuts in husk; upper right, shell opened to expose kernel. (*USDA photo*)

Fig. 3. Filbert orchard in a valley of the Pacific Northwest. (*Oregon Filbert Commission*)

the same species. Failure to self-pollinate may be due to a difference in time of pollen shedding and female receptivity on the same tree, or of pollen incompatibility. To ensure cross-pollination, two or more varieties need to be present in a planting. Generally, hazelnuts are planted at 25-foot (7.5-meter) centers. Filberts have shallow roots and can be grown on relatively shallow soils.

The nuts mature during the summer months and are harvested in the early fall. The nuts usually grow in clusters of 2 or 3. Each nut is covered with an open-ended husk which extends beyond the nut itself. During the summer months, the maturing nut and husk are green, but turn to shades of brown (Hazel) as fall approaches. Harvesting takes place in early fall. The nuts are swept or raked into windrows and then picked up by a sweeper-type harvesting machine. Filberts can withstand considerable mechanical handling because of their highly protective shell.

The Asian, Chinese, or Turkish hazelnut tree (*Corylus colurna*) definitely can qualify as a tree because it can attain a height of up to 75 feet (22.5 meters), but in most other respects it is reminiscent of the lesser hazelnut shrubs. The primary difference between a very large shrub and small tree, of course, is essentially a matter of pruning.

European species of the hazelnut tree include *Corylus avellana* and *C. maxima*. Trees cultivated in the Pacific Northwest are varieties of these species and include Barcelona, Daviana, and Du Chilly. The Daviana is used mainly to pollenize the Barcelona. Records indicate that the first hazelnut tree was planted in Scottsburg, Oregon in 1858 at a Hudson Bay Company outpost, a tree which, incidentally, as of the early 1980s was still producing nuts. In 1976, a Frenchman (David Garnot) brought 50 hazelnut trees from Europe and planted them along a fence row which was the custom of the Old World. As of this writing, 49 of the original trees are still producing nuts. In the early 1900s, J. Angus, realizing the commercial possibilities of the hazelnut, started the first hazelnut orchard. Mild weather and good soil are the reasons why the hazelnut tree has done so well in the valleys (notably the Willamette) of the Pacific Northwest. East of the Rocky Mountains, varieties grown include Cosford, Medium Long, and Italian Red. Filberts commonly form suckers at the base and naturally grow in bush form. In the Pacific Northwest, suckers are removed to maintain single-stemmed trees. See Fig. 3. Eastern varieties grow best as multistemmed shrubs, but thinning out of suckers is practiced to maintain plant vigor.

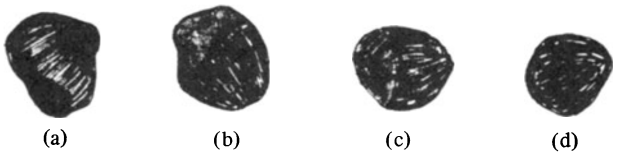


Fig. 2. Comparative size classification of filberts (in-shell): (a) *Giant*—over 23 millimeters (58/64-inch); (b) *Jumbo*—over 22.2 millimeters (55/64-inch); (c) *Large*—from 19.4 to 22.2 millimeters (49/64 to 56/64-inch); (d) *Medium*—17.9 to 19.4 millimeters (45/64 to 49/64-inch).

Research. While the filbert industry in the Pacific Northwest has been quite successful, plant breeders recognize some of the shortcoming of the Barcelona variety and are seeking improvements through development of new strains. Some of the disadvantages of Barcelona include a thick shell (42 to 44% kernel), too much fibrous material on the pellicle (skin), maturity is delayed, and a tendency for alternate bearing.

Prior to the 1960s, most breeding efforts for the filbert crop took place in the eastern states and were directed toward development of cultivars for that region where serious limiting factors exist for the European filbert—these including low winter temperatures and the widespread, natural occurrence of Eastern filbert blight on the native hazel, *Corylus americana*. This disease is tolerated by the wild hazel, but is lethal to most, if not all, selections of European species (*C. avellana*). A search and worldwide collection of cultivars was commenced by Zielinski in 1960 for improvement of Pacific Northwest varieties. A formal breeding program was commenced at Oregon State University in 1968. See Thompson reference.

Work is also going forth in Michigan on development of a new family of filbert hybrids, particularly in connection with hybridizing *Corylus heterophylla* var. *sutchuensis* with *C. avellana*. The former is the Szechuan hazel, a native of western China. See Farris reference.

Nutritional Aspects. A profile of the composition of the filbert is given in Table 1 of entry on **Nut**; the amino acid content of the nut is given in Table 2 of the entry.

References

Ferris, C. W.: "An Introduction to the Stars–A New Family of Filbert Hybrids," in "67th Annual Report of the Northern Nut Growers Association, Inc.," Brownwood, Texas (1976).

Jaynes, R. A., and H. L. Malstrom: "Nut Crops," in *Growing Fruits and Nuts*, in U.S. Department of Agriculture, Washington, D.C., *Agriculture Information Bulletin 408* (1977).

Menninger, E. A.: "Edible Nuts of the World," Horticultural Books, Stuart, Florida (1978).

Staff: "Production Yearbook," Food and Agriculture Organization of the United Nations, Rome, Italy (Published annually).

Staff: "Agricultural Statistics," U.S. Department of Agriculture, Washington, D.C. (Published annually).

Thompson, M. M.: "Breeding for Superior Filberts in Oregon," in *67th Annual Report of the Northern Nut Growers Association, Inc.*, Brownwood, Texas (1976).

Westcott, C.: "Plant Disease Handbook," 3rd Edition (Pests and Diseases of Hazelnut, page 593), Van Nostrand Reinhold, New York (1971).

FILLERS. Binders, Fillers, and Plasticizers; Appendix Table 1.

FILLETING. Seafoods (Processing).

FILM BREAKER. Defoaming Agents.

FILM COATINGS. Coating Agents.

FILM-FORMING AGENTS. Foaming and Whipping Agents.

FILM YEAST. Sherry; Wine.

FILTERING. A principal means used in the food industries (including peripheral operations, such as water treatment) for separating suspended solids from liquids is filtration. Other means include centrifuging, clarifying, and sedimentation. In filtration, the suspension containing the solids is caused to pass through a porous medium. Numerous filtering media, such as diatomaceous earth (DE), are used, such materials often supported by paper, cloth, or wire cloth. Filtration may be conducted under positive pressure or vacuum. Inasmuch as a host of food substances are subject to filtration, this operation can be classified as one of the *unit food processing operations.*[1] See also **Ultrafiltration**.

Filters for processing operations may be broadly classified into two distinct groups: (1) Continuous; and (2) intermittent. There are many operating schemes used. Although not all configurations are included, the principal types are listed in the accompanying table. In addition to food processing, of course, there are numerous applications for these filters throughout other industries. Because of the great range of properties of substances to be filtered, there is no one filtering concept that can be universally applied.

Concept of Electrokinetics Applied to Filtration. Food industry authorities have long regarded filtration as a very efficient and relatively low-cost means for product recovery, clarification, stabilization, and sterilization. A primary component of many filters for decades has been asbestos. Occupational hazards associated with asbestos were reported as early as 1964 and 1968 (Selikoff *et al.*). Just a

CLASSIFICATION OF INDUSTRIAL FILTERS

Class and Type of Filter	
Continuous Filters	Representative Applications in Food Field
Rotary Drum Filters	
Basic Design	Cane mud, calcium carbonate, citrates, dyes, peanut butter
String Filter	Starch, gluten, carbonates
Precoat Filter	Juices, wines,
Cell-less Filter	Adipic acid, fibers, carbonation mud
Traveling-Medium Filter	Gluten, starch
Top-Feed Filter	Salt and similar crystalline materials
Totally Enclosed Filter	Solvent slurries, hazardous materials
Pulp Filter	Fiber washing, pulps
Rotary Disk Filters	Fiber recovery, slurries
Horizontal Filters	
Rotating-Pan	Rapid-settling solids, pulp fibers
Traveling-Belt	Medium and coarse solids, fibers
Filter-Thickener	
Filter Press (Plate and frame)	Pigments,
Leaf Filter	First carbonation juice (beet sugar)
Ultrafilters	
Membrane Types	Enzymes, proteins, fine solids
Intermittent Filters	
Leaf Filters	
Stationary Leaf Filter	Wide variety of applications
Rotating-Leaf Filter	
Traveling-Medium Filter	
Filter Press (Multiple plate and frame)	
Tube Filter	
Nutsche Filter	
Deep-Bed Filters	
Sand or Coal Beds	Process water, process liquors
Pressure Filters	
Cartridge Filters	Wide variety of applications

---

[1] Operations of this type are described in considerably greater detail in Volume 2 of the *Food Science, Technology and Economics Series*, where particular stress is given to advancements and innovations stemming from food engineering and scientific research that have occurred during the past decade.

few of the additional findings were reported by Smith *et al.* (1965); Biles and Emerson, 1968); Schnitzer *et al.*, 1971); and Pontefract and Cunningham, 1973). These developments stimulated the search for substitute filtering media. Authorities indicated in the mid-1970s that glass fibers would not be an acceptable substitute.

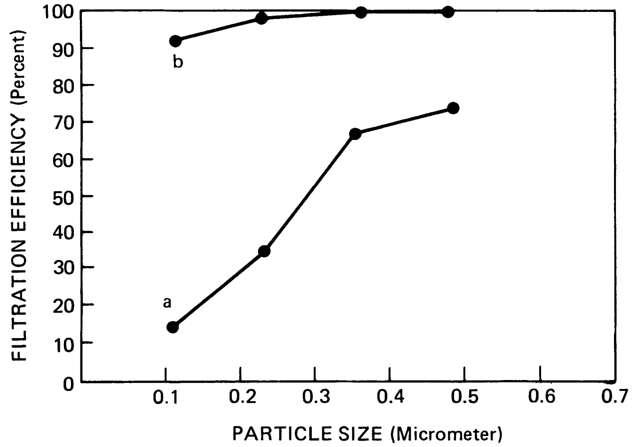
As pointed out by Fiore and Babineau (1979), two mechanisms are involved in the removal of suspended particles from water by filtration: (1) Transport of the particles to the filter surface; and (2) their subsequent attachment, usually referred to as adsorption (adherence to a surface). The physical phenomena of foregoing item (1) predominate for particles larger than the pore size of the medium, whereas the electrochemical phenomena of foregoing item (2) predominate where particles are smaller than the pore size of the medium. Most research leading to development of models of the filtration process (Ives, 1967; 1971) concentrated essentially on the physical mechanisms and provided little, if any, attention to the electrochemical phenomena. However, Smith (1966) demonstrated a resemblance of filtering to coagulation and noted that electrochemical phenomena can be controlling factors. The work of Yao *et al.* (1971) also pointed in this direction. A bit later, Wnek (1974), using theories out of colloid chemistry, made an initial explanation of the various electrokinetic and chemical aspects of filtration.

Researchers essentially agreed that a concentrated study of the asbestos fiber could provide some answers. The research of Yada (1967) demonstrated that chrysotile fibers have (1) a hollow cylindrical form with an average outer diameter of 50 to 80 $\times 10^{-10}$ meter (1 angstrom = 10^{-10} meter); (2) that all such tubes are not simple cylinders, but that some may be spirally wound layers; and (3) that the distance between spiral layers may range between 4 and 7 $\times 10^{-10}$ meter. In short, chrysotile fibers possess an exceptionally large surface area per unit weight.

Riddick (1968) showed that asbestos has an isoelectric or zero point charge at a pH of 8.3 and thus has a positive charge when in neutral, aqueous solutions. It is to be noted that, with few exceptions, the majority of natural substances are negatively charged under these conditions. This observation led to the conclusion that a suitable substitute for asbestos fibers should have an isoelectric point about pH 7 when in neutral, aqueous solutions (Wnek, 1974).

Rose and Rose (1966) defined the zeta or electrokinetic potential as the potential across the diffuse layer of ions surrounding a charged colloidal particle and pointed out that it is essentially responsible for colloid stability. Wnek (1974) explained the operation of a filter bed: "Various physical transport mechanisms convey the particles to the surface of the medium. If the medium and particles are of opposite charge, electrokinetic attraction will deposit particles on the bed. If the medium and particle charges are of the same sign, repulsion will occur and deposition will be hindered, if not prevented. As the particles accumulate, the charge on the medium decreases, diminishing its ability to remove particles. Loss of efficiency starts at the top of the medium bed, and eventually electrokinetic removal of particles ceases, although deposited particles may have sufficiently reduced the pore size of the medium to allow further particle retention by straining. As the top of the medium bed becomes saturated, the lower parts remove more and more particles, until they too become saturated. At this point, if the medium bed has not become mechanically plugged, electrokinetic breakthrough will occur, i.e., charged particles will pass through."

Recent research has been directed toward chemically treating otherwise suitable filter media (sand, perlite, diatomite, etc.) so as to impart a positive charge (as found on chrysotile fibrils) instead of the negative charge of untreated material. Fiore and Babineau (1979) explain the progress of this research in considerable detail. One early example of this modification research is shown in the accompanying figure.



Effect on filtration efficiency of modification of surface charge of diatomite: (a) Untreated diatomite; (b) diatomite treated with melamine-formaldehyde colloid. (*After Fiore/Babineau*)

References

Biles, B., and T. R. Emerson: "Examination of Fibres in Beer," *Nature*, 219, 93 (1968).

Fiore, J. V., and R. A. Babineau: "Filtration," *Food Technology*, 33, (4) 67-72 (1979).

Ives, K. J.: "Deep Filters," *Filt. Separ.*, 4, 125 (1967).

Ives, K. J.: "Filtration. 1. Significance of Theory," *J. of Institute of Water Engineers*, 25, 13 (1971).

Miles, H. V.: "Filtration" in the *Chemical and Process Technology Encyclopedia*, (D. M. Considine, Editor), McGraw-Hill, New York (1974).

Perry, R., and C. Chilton: "Chemical Engineers' Handbook," 5th Edition, McGraw-Hill, New York (1973).

Pontefract, R. D., and H. M. Cunningham: "Penetration of Asbestos through the Digestive Tract of Rats," *Nature*, 243, 352 (1973).

Riddick, T. M.: "Control of Colloid Stability through Zeta Potential," Vol. 1, Zeta-Meter, Inc., Livingston Publishing, Wynnewood, Pennsylvania (1968).

Rose, A., and E. Rose: "The Condensed Chemical Dictionary," 7th Edition, page 1030, Van Nostrand Reinhold, New York (1966).

Schnitzer, R. J., Bunescu, G., and V. Baden: "Interaction of Mineral Fiber Surfaces with Cells *in vitro*," *Ann. New York Academy of Science*, 172, 757 (1971).

Selikoff, I. J., Hammond, E. C., and J. Churg: "Asbestos Exposure, Smoking and Neoplasia," *J. of American Medical Association*, 188, 22 (1964); 204, 106 (1968).

Smith, C. V.: "Electrokinetic Phenomena in Particulate Removal from Water by Rapid Sand Filtration," Ph.D. thesis, Johns Hopkins University, Baltimore, Maryland (1966).

Wnek W.: "Electrokinetic and Chemical Aspects of Water Filtration," *Filt. Separ.*, **11**, 237 (1974).

Yada, K.: "Study of Chrysotile Asbestos by a High Resolution Electron Microscope," *Acta Cryst.*, **23**, 704 (1967).

Yao, Y. M., Habibian, M. T., and C. R. O'Melia: "Water and Waste Water Filtration: Concepts and Applications," *Environ. Sci. Tech.*, **5**, (11) 1105 (1971).

FINING. Wine.

FINISHING (Juice). Citrus Fruits and Processing.

FINISHING PIGS. Feedstuffs.

FINISHING STEERS. Feedstuffs.

FINNAN HADDIE. Seafoods (Nutritional Aspects).

FINO SHERRY. Sherry.

FIORI ALPINI. Liqueurs and Cordials.

FIRE BLIGHT. Apple; Pear.

FIRMING AGENTS. Certain foodstuffs, such as apples, potatoes, and beans, tend to be rather fragile when subjected to processing operations prior to packaging (canning, freezing, *et al.*) and, if not treated in some way to retain their natural firmness to a relatively high degree, the mouthfeel of the final product will be disappointing (mushiness versus slight chewiness or crispness). Certain chemical substances can be added prior or during processing to protect and retain natural firmness. These substances include: Aluminum potassium sulfate; aluminum sodium sulfate; aluminum sulfate, calcium carbonate; calcium chloride; calcium citrate; calcium gluconate; calcium hydroxide; calcium lactobionate; calcium phosphate (monobasic); calcium sulfate; and magnesium chloride, among others. The physical characteristics, sources, and solubilities of these compounds are briefly summarized in Appendix Table 1.

Researchers have found that calcium lactate can be an effective agent for preserving the firmness of apple slices during processing—prior to canning or freezing. Studies have shown that calcium salts participate in firming the tissues of various fruits and vegetables by forming calcium pectates. Calcium citrate is quite useful for firming peppers, potatoes, tomatoes, lima and snap beans prior to and during processing. Soluble calcium salts also are used for firming sweet potatoes. Manufacturers of pet foods have found that from 1 to 2.5% monoglyceride contributes to the firming of pet foods, as well as aiding in the prevention of fat separation. See also **Bodying and Bulking Agents.**

FISH ENGINEERING. Seafoods.

FISHES. Antimicrobial Agents; Aquaculture; Coating Agents; Controlled-Atmosphere and Hypobaric Systems; Crustaceans; Dietary Trends; Foodborne Diseases; Freshwater Fishes; Mollusks; Phosphates; Seafoods; Seafoods (Nutritional Aspects); Seafoods (Processing); Thermal (Heat) Preserving.

FISH FARMING. Aquaculture.

FISH-FINDERS. Seafoods.

FISH LIVER. Seafoods (Nutritional Aspects); Vitamin A.

FISH MEALS, OILS, AND PROTEIN CONCENTRATES. For many years, various species of fish, such as menhaden, tuna, groundfish, herring, sardine (at one time prior to current scarcity), and miscellaneous so-called industrial fish (monkfish, sculpin, sea robins, squirrel hake, sharks, and rays) have been used as a source of nutritional meals and oils for use in feeding livestock, including poultry. When the concept of high-energy diets for livestock became popular in the early 1950s, the feed industry became increasingly aware of various alternative sources in the formulation of balanced feeds. During interim years, the consumption of fish source materials has been essentially one of economics, balancing the costs of fish meals against the costs of other sources. During this period, the base cost of fish has risen largely because of increased labor and overhead costs. Thus, the degree to which fish sources are used in feeds tends to cycle. See also **Feedstuffs.**

Menhaden is the most important species for fish meal. Although tuna are not caught for the primary purpose of reduction, enormous numbers of them are canned and considerable wastes result from processing. The material thus becomes a raw material for reduction. Similarly, the wastes from various groundfish (alewives, salmon, haddock, ocean perch, whiting, cod, pollock, etc.) are used. The herring caught in New England waters is mainly used for canning, whereas the Alaska herring is reduced to meal. Industrial fish, previously mentioned, are mainly used for canned or otherwise preserved pet foods, but some tonnage is used for reduction. Sardines, no longer in generous supply, are principally canned, but wastes are sold for reduction. The various species of fish are described in entry on **Seafoods.**

In the United States, two principal methods of reduction are used: (1) *Wet rendering,* in which the oil is removed before the fish material is dried; and (2) *dry rendering,* in which the oil is removed after drying. Wet rendering is most commonly used and is particularly well adapted to the rapid production of meal and oil from oily fish. In addition to the meal and oil produced, condensed solubles may also result from this method of processing. Dry rendering is well adapted to production on a small scale from fishery materials of low oil content, such as fillet waste from haddock and cod. Continuous dry reduction is used with shrimp and crab scrap.

Wet Rendering. The principal steps of the wet rendering process are: (1) **Cooking,** wherein the oil and water in the fish can be separated from the solid protein easily and economically in subsequent pressing operations. Overcooking and undercooking the fish results in an unsatisfactory product from the pressing operation, and thus cooking must be tailored (temperature and pressure) to the particular species of fish at hand; (2) **Pressing** (frequently the screw-type press) squeezes both oil and water from the fish so that the resulting material has a low oil content and is economical to dry. The solid pressed fish, called *presscake,* is transported to driers for further reduction of moisture; (3) **Centrifuging** is used instead of the formerly used settling tanks for recovery of the oil from the liquid portion. For maximum separation and recovery, two centrifuges are used (a *sludger,* which handles liquor containing oil, water, and some suspended solids, after which fresh hot water is added to the emulsion for processing in a second centrifuge, the *oil purifier,* where last traces of solids and water are removed. The solubles are stored and sold separately, or a portion of them may be added back to the presscake, the resultant product, after drying, being called *full meal* in contrast to regular meal, which has no added solubles. (4) **Drying** in direct-heat driers, steam-tube driers, or air-lift driers, is required to reduce the moisture content of meal down to about 9% to prevent spoilage and to make the product easier to handle and more economical to ship. (5) **Deodorizing** of the moisture-laden gases resulting from the removal of the fine meal particles is required because of objectionable odors present. Generally, the odor components of the gases must be removed before they may be discharged to the atmosphere. The condensable portion of the gases may be removed in scrubbers; the noncondensable portion then can be burned. **Curing.** The dried product, called scrap or unground fish meal, is conveyed to storage sheds where it accumulates in large piles. Some residual oil still remains in the scrap, which is a factor that influences the handling of the scrap. In general, fish oils are highly reactive, being characterized by a high degree of unsaturation, permitting easy combination of the oil with oxygen in the air, releasing considerable heat. This can result in charring; and sometimes in fire. To retard the rate of oxidation and thereby lower the rate of heating, some operators add antioxidants, usually to the dried scrap, but occasionally to the presscake before it is dried. Turning of the scrap, if extensive, may be accomplished by tractors or overhead conveyor mechanisms. The scrap, after being turned and cooled, is left unground or is ground into meal and sold either in bulk or in bags usually weighing 100 pounds (45.3 kilograms).

Dry Rendering. Although many variations in this method of meal production are possible, the fishery material usually is loaded into a large, steam-jacked, cylindrical drier. Inside the drier is a rotating scraper, which brings all material into quick contact with the hot inside wall, yet prevents the material from sticking. The drying is done either under vacuum or at atmospheric pressure. The oil is separated from the dried scrap by batch pressing in hydraulic presses. No product other than oil is produced from this pressing operation. After the oil has been expelled, the remaining solid material is ground into meal (called *whole meal*), or is left unground as cake.

Fish Protein Concentrate

Fish protein concentrate (FPC) has been defined as a stable product suitable for human consumption, prepared from whole fish, or other aquatic animals or parts thereof. Protein concentration is increased by the removal of water and, in certain cases, of oil, bones, and other materials. The traditionally dried or otherwise processed fish meals, etc. do not fall within this definition. This is essentially the definition formulated by the Protein Advisory Group (PAG) of the United Nations in the early 1960s.

Many millions of dollars invested in research and pilot plants have been directed toward the production of fish protein concentrates since the end of World War II. These include investments by various governments as well as by private industry. The objectives, of course, have been the development of an effective protein source, particularly for the less-affluent countries.

The use of minced fish as a basis for food products, such as *kamoboko,* a traditional fish paste, is a practice of long-standing in Japan. Modern methods have been applied to this ancient art, and a major industry has arisen in Japan during the past few decades, producing a varied array of food products from minced fish.

The application of the minced fish technology to western-style products has received active consideration in the last decade or two in North America and Europe and was the subject of government-industry sponsored symposia. A major advantage lies in the significant increase in the yield of fish flesh and protein which can be obtained from raw fish, amounting sometimes to 50% more than is obtained by filleting. Another advantage lies in the divided nature of the material. This not only permits the ready and even inclusion of flavorings, additives, etc., but its properties are readily susceptible to modification, and it presents obvious opportunities for molding or extrusion. Products developed in recent years include minced fish blocks, salted minced fish, intermediate-moisture fish products, and the highly functional fish protein isolates and derivatives. But much remains to be done to fully explore and apply such potentials for better uses of the world's fish. Not only technology, but also economic, institutional, and social hurdles must be overcome. But, with the prospect of using better and more profitably the several millions of tons of fish which are annually converted to fishmeal and oil and the large quantities of species of fish now little used, the incentive is strong for further development (Finch reference).

Classifications of FPC. In 1962, the Food and Agriculture Organization (FAO) of the United Nations proposed consideration of three types of FPC: (1) *Type A*—essentially tasteless, colorless, odorless powder containing a minimum of 67.5% crude protein and a maximum of 0.75% fat. It was observed that this type could be used in most foods at a 5 to 10% level without reducing the acceptability of familiar foods. *Type B*—typified by fishmeal from which most of the fat has been solvent extracted, leaving a fat content of not more than 3%. The product retains a moderate, but distinct flavor which is apparent to some extent in most foods to which it is added. (3) *Type C*—a crude fishmeal that could have a fat content up to 10%, giving it a strong and characteristic odor and flavor. In the United States, principal efforts have been directed toward the Type A product. Numerous regulatory considerations and actions have been taken (Food and Drug Administration, etc.) during the past 2 decades and these are reviewed in detail by Finch.

Fish Protein Derivatives. Groninger (1973) described the preparation of fish protein derivatives. Basically, the derivatives are prepared by reacting the myofibrillar protein with the acid anhydride under slightly alkaline conditions. The reacted proteins are then precipitated from solution with hydrochloric acid and extracted with hot (158°F; 70°C) azeotropic isopropanol to remove residual lipids. The acetylated proteins are then neutralized (pH = 7.0) with sodium hydroxide to solubilize the derivatives, and dried. Klatz and Keresztes-Nagy, 1963, viewed the primary reaction as one that occurs between nucleophilic amino groups of the proteins and the electrophilic groups of the anhydride to form an amide. Other protein side groups, however, can be acylated—these groups including the -OH group of tyrosine, threonone, and serine, and the -SH group of cysteine.

In a further extension of the use for fish protein from underutilized species, Spinelli *et al.* (Pacific Utilization Research Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington) have been developing a process for producing drum-dried fish proteins, with initial experiments concentrating on Pacific hake. Codrying the fish muscle with cereals also has been done and appears to have a number of advantages—facilitates drying, reduces costs, provides a means for increasing the protein content of locally grown grain crops with animal protein. The researchers suggest that in developed countries, a primary outlet for drum-dried fish proteins would be in the meat-replacement (meat extender) market. Stone (1976) forecasts that more than 116 million pounds (52.6 million kilograms) of proteins (dry-weight basis) will be used in the United States alone as meat replacers.

For tonnage of fish oils produced, see entry on **Oilseeds and Related Products**.

References

Creamer, L. K., Roeper, J., and E. H. Lahrey: "Preparation and Evaluation of Some Acid-soluble Casein Derivatives," *New Zealand J. of Dairy Science Technology*, 6, 107 (1971).

Finch, R.: "Whatever Happened to Fish Protein Concentrate?" *Food Technology*, 31 (5) 44-53 (1977).

Groninger, H. S., Jr., and R. Miller: "Acetylated Myofibrillar Protein Binder for Aquaculture Feeds and Fish Bait," *U.S. Patent 3,903,304* (1973).

Hammond, T. M., and D. L. Call: "Utilization of Protein Ingredients in the U.S. Food Industry," Cornell University, Ithaca, New York (1970).

Klatz, I. M., and S. Kerseztes-Nagy: "Hemerythrin: Molecular Weight and Dissociation into Subunits," *Biochem.*, 2, 445 (1963).

Martin, R. E., (Editor): "Second Technical Seminar on Mechanical Recovery and Utilization of Fish Flesh," National Fisheries Institute, Washington, D.C. (1974).

Miller, R., and H. S. Groninger: "Functional Properties of Enzyme-modified Acylated Fish Protein Derivatives," *J. of Food Science*, 41, 268 (1976).

Moorjani, M. N.: "Processing of Protein-enriched Wafers," *Food Technology*, 24, (12) 60 (1970).

Pariser, E. R.: "Fish Protein Concentrate," in *The Encyclopedia of Marine Resources*, (F. E. Firth, Editor), Van Nostrand Reinhold (1969).

Sand, G.: "Twenty Countries try Norse Fish Powder," *Fishing News International*, 38 (1975).

Spinelli, J., *et al.*: "Expanded Uses for Fish Protein from Underutilized Species," *Food Technology*, 31,(5) 184-187 (1977).

Stone, H.: "Novel Proteins—An Alternate Food Source," *Food Prod. Dev.*, 10, 64 (1976).

FISH-SOY CAKE. Seafoods (Processing).

FISH STICKS. Seafoods (Nutritional Aspects).

FISHWAYS. Seafoods.

FLAGELLUM. A long slender hairlike projection from a cell which may be used for a variety of purposes. In many plant and animal sperms, it serves as a means of locomotion. It also serves this purpose in the flagellated bacteria and in the flagellated protozoans. A flagellum differs from a cilium primarily in length and number. Cilia are much shorter and usually are present in greater quantity.

The electron microscope shows that there is a group of mitochondria at the base of each flagellum. The flagellum is made of an outer membrane, beneath which is a cable of 9 protein fibers in a circle and with 2 fibers in the center. See also **Bacteria.**

FLAVIN ADENINE DINUCLEOTIDE (FAD). Amino Acid Metabolism; Coenzyme; Feedstuffs; Riboflavin; Thiamine.

FLAVONES. Citrus Fruits and processing; Hay and Forage Crops.

FLAVONOID. A group of aromatic, oxygen-containing heterocyclic pigments widely distributed among higher plants. They constitute most of the yellow, red, and blue colors in flowers and fruits. Exceptions are the carotenoids. See also **Carotenoids.** The flavonoids include: (1) Catechins; (2) leucoanthocyanidins and flavonones; (3) flavanols, flavones, and anthocyanins; and (4) flavonols. See also **Anthocyanins; Colorants.**

FLAVOR ENHANCERS AND POTENTIATORS. A *flavor enhancer* is a substance which when present in a food accentuates the taste of the food without contributing any flavor of its own. This is reminiscent of the role of a catalyst in a chemical reaction which promotes a reaction without chemically participating in the reaction. Although not usually regarded as a flavor enhancer, common salt, if not used excessively, enhances the taste of food substances. Salt does not fully meet the definition of an enhancer, however, because the salt is detectable as salt.

Monosodium glutamate for many years has been the best known and most widely used of the flavor enhancers. MSG is normally effective in terms of a relatively few parts per thousand, but far less powerful than the newer flavor potentiators. Like enhancers, potentiators do not add any taste of their own to food substances, but intensify the taste response to the flavorings already present in the food. Because a potentiator is more powerful, smaller quantities of the substances are required than in the case of the enhancers, as indicated by Table 1. Generally, the available potentiators are from about 15 to nearly 100 tomes more effective than the enhancers.

TABLE 1. AMOUNTS OF ENHANCERS AND POTENTIATORS REQUIRED FOR FOODS

	(Amounts Required for 10 Kilograms[1] of Material)			
Processed Food	MSG Monosodium Glutamate (grams)	IMP 5′-Inosinic Acid (grams)	I + G[2] Mixture (grams)	GMP 5′-Guanylic Acid (grams)
Dehydrated soups and gravies	600–800	20–26	12–16	9–11
Canned foods				
Poultry, sausage, ham, fish fillets	10–20	1–1.5	0.6–1	0.4–0.7
Soups and gravies	12–18	0.36–0.54	0.22–0.33	0.15–0.23
Crab	10	0.33	0.2	0.13
Fish (boiled, preserved in oil)	20	0.6	0.4	0.26
Sausages (frankfurters, Viennas)	30	1.5	0.9	0.6
Frozen foods (such as hamburger)	11	0.33	0.2	0.13
Ketchup	20	3.3	2.0	1.4
Mayonnaise	40	2.5	1.5	1.1
Snack items				
Potato chips, peanuts (groundnuts), crackers	1000	30	18	13
Soy sauce	10	1.65	1	0.7
Powdered soup for instant ramen (noodle)	1000	33	20	14

[1] 10 kilograms = 22 pounds, 7.36 ounces.

[2] I + G is a 50:50 mixture of 5′-Inosinic acid (IMP) and 5′-Guanylic acid (GMP).

Source: Ajinomoto, Tokyo (1980).

Explanations for the actions of enhancers and potentiators, as of the early 1980s, remain qualitative and rather vague. It is not likely that the actions of these substances will be well understood until there are new theories or refinement of existing theories pertaining to the sensations and perception of taste and odor, as pointed out in the entry on **Flavorings**. Experience does indicate that enhancers and potentiators act more in terms of taste than odors.

Monosodium Glutamate. The chronology of MSG commenced centuries ago when certain seaweeds were used in the Far East to improve the flavor of soups and certain other foods. It was not until 1908, however, when the curiosity of K. Ikeda (University of Tokyo) caused him to study the seaweed *Laminaria japonica,* traditionally used by Japanese cooks to enhance food flavoring. After much research on the seaweed, MSG was isolated and identified as an excellent flavor enhancer, particularly for high-protein foods. As an aside, it is interesting to note that Ritthausen in Germany had isolated glutamic acid as early as 1866 and his associates had prepared the sodium salt of the acid, namely monosodium glutamate. But the path of research in Germany was targeted in other directions and the flavor-enhancing qualities of MSG were left to Ikeda to determine.

Throughout the first half of the century the Japanese produced glutamic acid by extraction from natural materials, a slow and costly method. Nevertheless, the demand for MSG grew rapidly and cost tended to be a secondary factor. It was not until 1956 that Japanese microbiologists succeeded in developing the first industrial production of L-glutamic acid by means of fermentation. See Fig. 1. The problem of producing glutamic acid, as well as a number of other important amino acids, by fermentation was the lack of suitable strains of microorganisms for starting the cultures. Initially, the Japanese researchers were successful in isolating microbial strains from natural sources that possessed good abilities to excrete and accumulate a large amount of the amino acid in the cultural broth, but only under very carefully controlled conditions. For example, S. Kinoshia found that a high yield of glutamate could be attained only when the level of biotin (a vitamin required by glutamate-producing bacteria) was held within certain limits. An excess of biotin killed the microorganisms. Both antibiotics and detergents were used to control the biotin levels. Later, work was conducted with an artificial mutant by way of investigating genetic techniques. Ultimately, large-scale MSG production was achieved by the fermentation route, sugar beets commonly used as a raw material. More detail on the fermentation process can be found in the Oeda (1974) reference listed. MSG also can be produced by chemical synthesis, as shown in Fig. 2.

Although listed as a GRAS substance (generally regarded as safe) for many years, questions concerning its safe usage have arisen from time to time and, as of the early 1980s, MSG still remains somewhat controversial. It is known that overconsumption of MSG can produce an illness in some persons, usually of just a few hours duration. This is com-

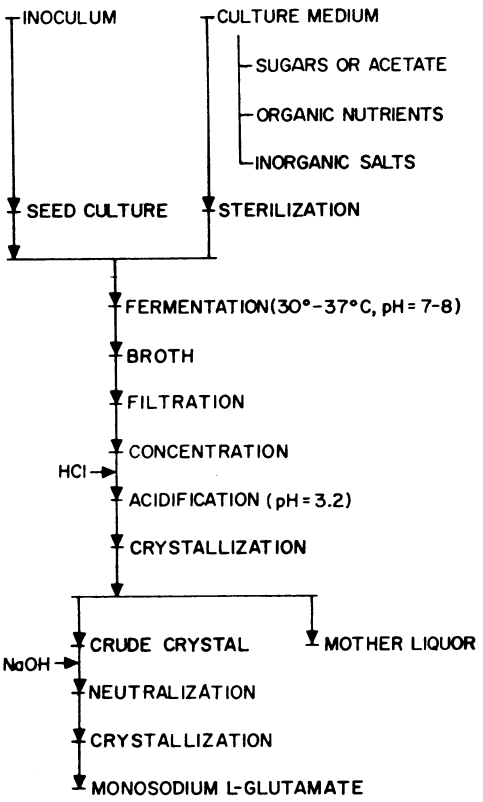


Fig. 1. Preparation of monosidum L-glutamate by fermentation. Sugar beets, corn (maize), and wheat gluten have been used in the process.

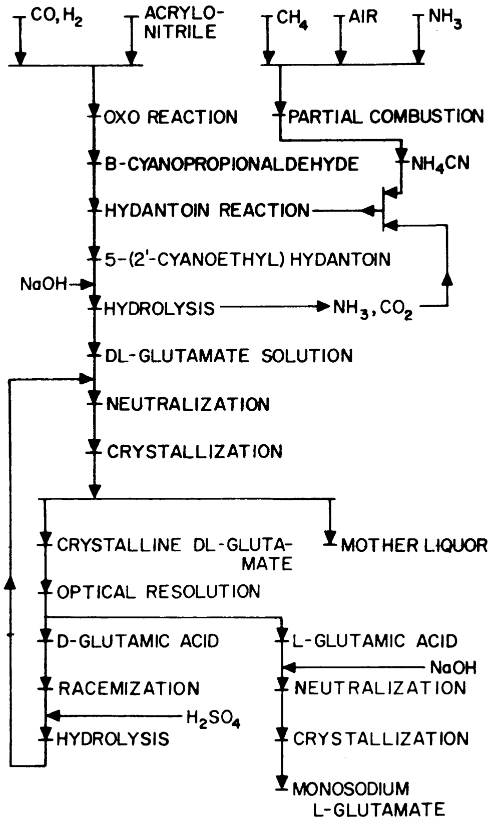


Fig. 2. Preparation of monosodium L-glutamate by chemical synthesis.

monly referred to as the "Chinese Restaurant Syndrome" and is described in the entry on **Foodborne Diseases**. Apparently even when usage is somewhat excessive, only a relatively few people exhibit the symptoms of the syndrome. The possible seriousness of any deleterious effects of MSG tend to be countered by the many years the substance has been used by literally thousands of food processors and many millions of chefs and household food preparers. Some authorities also have a comfortable regard for MSG because of occurrence of the substance in many natural foods, notably mushrooms, tomatoes, and human milk. The topic is summarized by Krueger (1979).

The 5′-Nucleotides. Also dating back many years in the Far East was the knowledge that bonito tuna possesses a substance that very effectively enhances the flavor of foods. However, it was not until 1913 that S. Kodama (Tokyo University) commenced a serious investigation directed toward identifying and isolating the substance from tuna. Initially, Kodama believed that the substance was the histidine salt of 5′-inosinic acid, but later found that the substance was actually 5′-inosinic acid itself. This nucleotide was found to be many more times as effective as MSG. Further research by Kodama and others has shown that these nucleotides are present in many natural foods, as shown by Table 2.

The nucleotides, in addition to their effectiveness at much lower concentrations, have been found to be superior to MSG for certain types of foods (in addition to high-protein foods). It also has been observed that the nucleotides tend to create a sense of increased viscosity, providing more body, for example, to soups. One manufacturer (Takeda) produces a series of the nucleotides by the enzymatic hydrolysis of ribonucleic acid. See formulas of Fig. 3. As of the early 1980s, these compounds are enjoying a high volume of production and usage. It should be pointed out that the nucleotides are commonly used together with MSG. Some researchers point out that while the nucleotides and MSG have a lot in common, there is a considerable difference in their use. The nucleotides are up to 100 times more effective than MSG on a weight basis and whereas MSG has been a favorite of processors for the enhancement of "meaty flavor," the range of the nucleotides is broader, modifying salty or sweet flavors and suppressing many undesirable flavors. The nucleotides are not a replacement for MSG. The substances do have a synergistic effect when used together. Generally, 1 kilogram of nucleotide used with 50 kilograms of MSG will have the same flavor intensifying result as 100 kilograms of MSG alone.

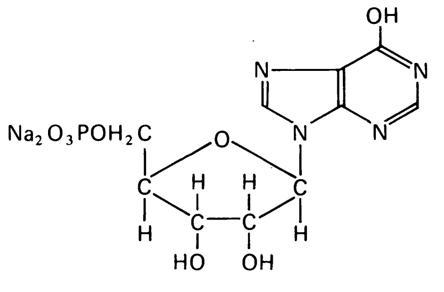
Other Potentiators. Because the market is so large, research continues at a good pace in seeking other potentiators. Established since the early 1940s, **maltol** is effectively used in foods that are high in carbohydrates, such as beverages, jams, and gelatins. Claims have been made that sugar content is reduced by 15% in products using maltol. Other potentiators used or proposed include dioctyl sodium sulfo-

TABLE 2. NATURAL CONTENT OF NUCLEOTIDES IN CERTAIN FOODS

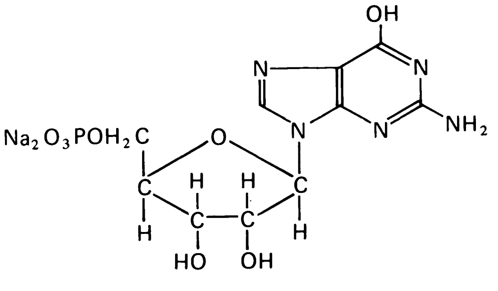
Food	Nucleotides (mg%) 5′-Cytidylic Acid (CMP)	5′-Uridylic Acid (UMP)	5′-Inosinic Acid (IMP)	5′-Guanylic Acid (GMP)	5′-Adenylic Acid (AMP)	ADP + ATP[1]
Sardine	-	-	192.6		6.6	15.4
Bonito			285.2		7.6	15.8
Salmon			154.5	0.0	6.9	
Perch			124.9	0.0	8.4	
Sea bream	-	-	214.8	-	-	30.0
Codfish			43.8		23.9	295.6
Swordfish			19.9	0.0	3.1	
Rainbow trout			117.0		14.6	223.4
Trout			187.0		4.2	27.7
English saurel						
Rested			25		2.8	210.8
Active			73.5		5.9	149
Oyster	+	31	0.0	0.0	21	53
Crab			0.0		10.1	372.5
Prawn (shrimp)			-		11.5	701.5
Beef	1.0	1.6	106.9	2.2	6.6	17.4
Pork	1.9	1.6	122.2	2.5	7.6	12.2
Chicken	2.3	3.6	212	3.6	5.2	30.1
Milk	2.02	-	-	-	0.18	
Asparagus		72			27	77
Corn (maize)			0.0	0.0	6.5	
Lettuce		0.5	±	±	0.9	
Tomato	0.5	2.2	-	-	10.4	
Green beans	0.8	2.6	-	-	1.8	
Cucumber	±	0.6	-	-	0.5	
Onion	±	0.5	±	-	0.8	
Mushroom (dry) (Hot-water extract of dried *shiitake*)	114.2	135.2	-	156.5	131.6	

Source: Takeda, Tokyo (1980).

[1] ADP = Adenosine diphosphate; ATP = Adenosine triphosphate.



Disodium 5′-inosinate
$C_{10}H_{11}N_4Na_2O_8P \cdot H\ O$
Molecular Weight (anhydrous): 392.17



Disodium 5′-guanylate
$C_{10}H_{12}N_5Na_2O_8P \cdot xH_2O$
Molecular Weight (anhydrous): 407.19

Fig. 3. Salts of ribonucleotides. (*Takeda, Tokyo*)

succinate, N,N′-di-*o*-tolyethylenediamine, and cyclamic acid.

See also **Flavorings**; and **Sensory Evaluation.**

References

NOTE: See references at end of entries on **Flavorings; Sensory Evaluation.**

Furia, T. E., and N. Bellanca: "Fenaroli's Handbook of Flavor Ingredients," CRS Press, Cleveland, Ohio (1971).

Furia, T. E.: "Handbook of Food Additives," 2nd Edition, CRC Press, Cleveland, Ohio (1972).

Krueger, J.: "MSG: One of the Food Industry's most Studied Ingredients," *Processed Prepared Foods*, 148(1) 128-140 (1979).

Oeda, H.: "Amino Acids," in *Chemical and Process Technology Encyclopedia*, (D. M. Considine, Editor), McGraw-Hill, New York (1974).

Staff: "An Introduction to Nucleotide Seasonings," Ajinomoto, Tokyo (1980).

Staff: "Ribonucleotide Flavor Enhancers," Takeda, Tokyo (1980).

FLAVORINGS. The *flavor* of a food substance is the combined sensation of *taste* and *odor* as perceived by the eater/drinker of that substance. Although the components (*flavorings*) are present in a food substance, the full aspects of flavor require intimate contact between substance and consumer. The odors emanating from a bakery tend to be richer and more pleasant than the bread itself; the flavor of coffee seldom attains the richness of aroma that one perceives in the vicinity of a coffee roasting plant. Flavor is a unique combination of nerve impulses on the brain centers as the result of actions upon receptors located on the tongue and in the lining of the nose and is thus the result of interaction between the food substance and the consumer.

In terms of total flavor sensation, many authorities agree that odor is usually more important than taste. Experience, of course, demonstrates the marked reduction of flavor sensation when the nasal passages are partially blocked as in the case of a common cold. In such instances, the layman may refer to the flat taste of the food. In actuality, the taste buds are functioning normally; it is the odor component of flavor that is missing.

The odor component of flavor is made up of at least two vectors. Sniffing of a substance without contact with the tongue provides a partial indication of odor—that is, molecular vapors or gases pass directly to the olfactory sensors in the nose via the nasal cavities. This vector might be called the absolute external odor or fundamental odor of a substance. This vector is dependent upon the vapor pressure (volatility) of the food substance itself. The other vector of odor is what some researchers call internal odor because the molecules reach the olfactory sensors by way of the pharynx, a flattened tubular passage that connects the back of the mouth with the nasal cavities. In the mouth, the food substance is wetted by saliva, altering not only the vapor pressure of the flavorings present, but sometimes exposing more and different flavorings, thus affecting flavor intensity and quality. It is well known, of course, that exceedingly dry substances tend to be odorless or nearly so. The odor of a polished metallic surface, for example, is difficult for most persons to detect. The addition of only modest amounts of moisture to most substances significantly increases their fundamental odor—by increasing vapor pressure and by activating the flavoring substances present. The effect of moisture on odor is dramatically illustrated by the dog at the fireside and the dog that has just come in out of the rain.

The Technology of Flavorings

To say that the overall topic of flavorings is intricate and complex is indeed an understatement. Far from exhaustive in its coverage, the "Food Chemicals Codex" describes well over 300 flavoring agents. Feneroli's "Handbook of Flavor Ingredients" (T. E. Furia and N. Bellanca, Editors) describes in detail nearly 200 natural flavorings and nearly 750 synthetic flavorings—and it also does not fully cover the field.

Natural flavorings come from a number of **plant sources** —bushes, herbs, shrubs, trees, weeds, specific parts of which are used as flavoring sources. These include arils, balsams, barks, beans, berries, blossoms, branches, buds, bulbs, calyxes, capsules, catkins, cones, exudates, flowering tops, flowers, fronds, fruits, gums, hips, husks, juices, kernels, leaves, needles, nuts, oils, oleoresins, peels pits, pulps, resins, rhizomes, rinds, roots, seeds, shoots, stalks, stigmas, stolons, thalli, twigs, wood, and wood sawdust—as well as some entire plants. Exploitable plants are found growing throughout the world as reflected by Table 1. The culture of plants as flavoring resources represents an impressive segment of world food production.

Natural flavorings are prepared for commerce in various ways, as will be explained shortly, but it should be pointed out that adding to the complexities of raw natural flavorants are factors of timing and maturity. Some plant parts are only suitable when green (unripe); others must be fully ripe or nearly so. The timing of harvest can be critical. For example, jasmine flowers must be harvested before dawn. The roots of the orris plant must be aged 2 years before they are ready for the commercial market. Several of the natural flavorings in any given category also are obtainable in two or more quality classes. For example, there are at least four classes of crude camphor oil, in addition to the true or distilled camphor oil. There is camphor safrole (Hon-sho variety—Japan; camphor safrole (Taiwan); camphor cineol (Yu-sho variety—China); and camphor linalool (Ho-sho variety—Taiwan). And, there is Ceylon cinnamon bark; Ceylon cinnamon leaf oil; Seychelles cinnamon leaf oil; and Chinese cinnamon bark oil, among several others. There are also several classes of nutmeg essential oil, including the subvarieties of mace oil.

Only a relatively few **animal sources** of fundamental flavoring substances are used. There is the musk deer (*Moschus moschiferus* L.) found in the Himalayan highlands. The reddish-brown secretion of the male is the odorous principle identified as 3-methylcyclopentadecanonone-one, the principal use of which is in perfumery as a fixative, but which has been reported as an additive in certain food products. Levels of usage are low (3 parts per million in some syrups). There is the civet (*Viverra civetta* Schreber), a cat that lives in Africa and southeastern Asia. The glandular secretion is of main interest in perfumery as a fixative, but it has been reported in foodstuffs at low levels (about 4 ppm). There is the beaver (genus *Castor*) of the northern climes of Alaska, Canada, and Siberia, the

TABLE 1. LEADING PRODUCERS OF ESSENTIAL OILS[1]

Almond Oil	France Spain United States
Anise Oil	China Spain France
Bergamot Oil	Italy France China
Camphor Oil	China
Caraway Oil	Poland Netherlands
Cassia Oil	Bahamas China Japan Hong Kong Mexico Israel
Cedar Leaf Oil	Canada
Cedarwood Oil	United States Switzerland Morocco
Cinnamon Oil	Sri Lanka Seychelles
Citronella Oil	China Sri Lanka Indonesia Guatemala
Clove Oil	Madagascar Indonesia Tanzania Singapore Brazil
Mentha arvensis (Cornmint oil)	Brazil Paraguay
Eucalyptus Oil	Portugal Spain China Brazil India
Geranium Oil	France Egypt Comoros and Réunion
Grapefruit Oil	United States Israel
Lavender Oil	France Spain
Lemon Oil	United States Argentina Italy Canada Brazil
Lemongrass Oil	Guatemala China India
Lignaloe Oil (Boise de rose oil)	Paraguay Brazil
Lime Oil	Mexico Haiti Jamaica Spain Bahamas Brazil
Menthol	Brazil Paraguay Japan United States Hong Kong China
Neroli (Orange Flower Oil)	France
Nutmeg Oil	Indonesia
Onion and Garlic Oil	United States Mexico Egypt Italy
Orange Oil	United States Brazil South Africa Belize Israel
Origanum Oil	Germany (West) Spain
Orris Oil	France Switzerland United Kingdom
Palmarosa Oil	India Brazil Madagascar
Patchouli Oil	Indonesia
Peppermint Oil	United States Italy France China Argentina
Pettigrain Oil	Italy Paraguay Uruguay
Pineneedle Oil	Nicaragua Canada France Yugoslavia
Rose Oil (Attar of roses)	France Turkey Netherlands Switzerland Bulgaria Hungary
Rosemary Oil	France Tunisia Spain
Sandalwood Oil	India Indonesia France
Thyme Oil	France Germany (West) Spain
Vetiver Oil	Comoros and Réunion France Haiti Indonesia
Ylang Ylang Oil (Cananga Oil)	Comoros and Réunion France Indonesia Switzerland

[1] Groupings based upon U.S. imports and exports. Producers of finished essential oils may not correspond with countries where raw materials are grown.

dried and ground glandular secretion of which is also used in perfumery, but which has been reported in chewing gum up to concentrations of 400 ppm. The flavoring additive is known as castoreum. And, there is beeswax, a crude yellow wax that represents a secondary secretion of the honeybee. In addition to its use as a modifier in perfumery, the substance is used up to levels of 5 ppm to enhance the flavor and textural qualities of honey. There always has been a close link between the technology of flavorings for the food field and of fragrances used in perfumes, cosmetics, and related products.

Of course, domestic animals and poultry are sources of numerous flavor bases and pastes. Chicken base is made from chicken, slowly deep roasted and blended with seasonings and spices. It is used for preparing broths and as a flavor enhancer in stews, casseroles, salads, vegetables, and pot pies. A chicken-flavored base is available for producing chicken loaf, mashed potatoes, gravies, chop suey, pasta, and stews. A beef flavor base is prepared from roasted beef blended with seasonings for use in meat pies meat loaves, bouillon, stock pots, and noodle dishes. Beef extracts are available for gravies, hashes, stews, chili, croquettes, cooking broth, consommé. Special au jus bases are available for preparing prime and French dip sandwiches, among many other specialty flavorings.

Emphasis is given in this entry on the commercially prepared flavoring substances, rather than the whole and ground spices which are covered separately in the entry on **Spices and Seasonings.** Of course, most of the flavors and essences of spices are available in other forms, including essential oils, extracts, tinctures, oleoresins, and the like. Many sources of spices, herbs, and seasonings are described in separate entries, a list of which is included in the entry on **Spices and Seasonings.** Flavorings are also mentioned in several other parts of this volume, including entries on specific processed foods, such as **Bread and Bakery Products**; **Meat**; and **Milk and Dairy Products.**

Integral flavorings, that is, the flavoring substances that are naturally present in food preparations are sometimes overlooked when one considers the field of additive flavorings. By nature, of course, sugar, salt, specific fruit and vegetable flavors (carrot, orange, bean, melon, etc.) are present and usually perform at their best when a vegetable is fresh, a fruit is ripe, but not overripe, meats and poultry are not overcooked, etc. Salt is a mild flavor enhancer and it alone may suffice to effect a delightful and satisfying flavor experience. Or, the preparer can add more powerful enhancers, such as monosodium glutamate (MSG) to take even better advantage of the natural flavorings present. See entry on **Flavor Enhancers and Potentiators.** Eugenol, the essential oil of cloves, is not limited in occurrence in cloves, but is present in a number of other natural food substances and contributes to their total flavor sensation, even though it may require a gas chromatographic analysis to prove that it is there. Natural flavoring substances, such as sugars, salt, eugenol, among many others, are sometimes called **integers.**

Synthetic flavorings during the past several decades have supplemented the natural flavorings to a substantial degree, but *not* to the point where the natural substances play a minor role. Not including its own production of some natural flavorants, the United States, in 1977, imported 7,816 metric tons of essential oils valued at $82.7 million (1977 dollars); and, in 1978, imported 7,353 metric tons valued at $98.2 million (1978 dollars). The prices paid for over 40 specific essential oils during this period are given in Table 2. An additional approximately 1 million metric tons of menthol were imported annually, with a value of about $20.5 million. A large portion of the essential oils go into food flavorings; the remainder going into perfumery, cosmetics, medicinals, *et al.* During 1978, the United States exported about 8,000 metric tons of essential oils (orange, lemon, peppermint, spearmint, cedarwood oils, among others) at a value of $79 million (1978 dollars). Thus, the United States is a net importer of essential oils by a factor of about $20 million annually.

Synthetic flavorings are frequently prepared from natural raw materials that bear a close relationship to the end-product. Fractions and isolates made from refined essential oils are frequently starting points for synthetic flavorings. On the other hand, a number of synthetic flavorings are made from chemical industry raw materials, such as petrochemicals, via the route of organic synthesis. Major unit operations often part of the synthesis include addition, condensation, cyclization, dehydrogenation, esterification, hydrogenation, oxidation, pyrolysis, reduction, and saponification. Examples of the two approaches include synthetic eucalyptol which commences with purified and concentrated eucalyptol obtained by fractionation of the essential oil. In contrast, cinnamaldehyde ethylene glycol acetate, which possesses a soft, warm, spicy odor reminiscent of cinnamon, is prepared by reacting cinnamaidehyde with ethylene glycol. Cinnamaldehyde is prepared by the condensation of benzaldehyde with acetaldehyde in the presence of sodium or calcium hydroxide.

Although a number of synthetics represent essentially identical replacement of natural flavorings, in many instances the synthetics are an approximation of the natural materials; or represent entirely new flavorings which have significantly broadened the spectrum of available flavorings. The flavorist has many more flavoring substances to call on and many more options than were available several decades ago. Frequently, there are cost advantages for the synthetics, but cost is not always the predominating advantage for synthetics. The flavorist determines the most suited natural or synthetic flavoring, with physical, chemical, and organoleptic qualities considered along with cost.

TABLE 2. RELATIVE VALUES OF ESSENTIAL OILS[1]

Essential Oil	Average Price 1976–1977 (U.S. Dollars per Kilogram)	Price 1978 (U.S. Dollars per Kilogram)
Rose oil (Attar of roses)	1425.98	1501.46
Neroli (Orange flower oil)	283.96	986.63
Orris oil	742.10	942.09
Sandalwood oil	93.15	109.95
Vetiver oil	55.26	67.23
Cassia oil	43.20	66.89
Geranium oil	45.62	60.01
Ylang ylang (Cananga oil)	44.27	52.71
Peppermint oil (Mentha piperita)	24.04	44.62
Cedar leaf oil	26.90	31.41
Bergamot oil	17.03	31.02
Caraway oil	20.87	25.66
Palmarosa oil	19.74	25.26
Origanum oil	21.05	23.97
Lavender oil (including spike oil)	24.05	23.95
Thyme oil	17.52	22.12
Lime oil	16.15	19.54
OTHER ESSENTIAL OILS (average)	10.14	18.07
Patchouli oil	13.30	17.33
Nutmeg oil	11.65	17.13
Onion and garlic oil	*	16.33
Pineneedle oil	8.26	13.75
Lemon oil	11.90	13.23
Citrus oil (other)	*	13.08
Pine oil	*	12.90
Anise oil	14.53	11.79
Lingnaloe (Boise de rose oil)	9.67	10.38
Rosemary oil	7.16	10.04
Pettigrain oil	8.32	9.28
Cornmint oil (*Mentha arvensis*)	7.68	8.73
Lemongrass oil	4.96	6.26
Cinnamon oil	4.59	5.82
Clove oil	4.68	4.96
Almond oil (bitter)	3.63	4.16
Citronella oil	2.96	3.79
Sassafras oil	*	3.50
Eucalyptus oil	3.64	3.10
Camphor oil	1.83	2.88
Cedarwood oil	*	1.92
Grapefruit oil	1.22	1.11
Orange oil	1.14	0.92

[1] Import prices into the United States.

*Previously included with "Other Essential Oils."

The principal natural essential oils imported into the United States are listed in Table 3 and, for comparison, where there is a relatively similar synthetic substitute, it is

TABLE 3. DISPOSITION OF ESSENTIAL OILS IMPORTED INTO THE UNITED STATES

Essential Oil (Synthetic counterparts sometimes included for comparison)	U.S. U.S. IMPORTS %	Usual Maximum Level of Usage (Parts per million)												Comments
		Alcoholic beverages	Bakery products	Beverages (nonalcoholic)	Chewing gum	Condiments	Confections	Ice cream products	Meat	Pickles	Puddings/gelatin desserts	Syrups	Toppings	
NAT. Almond Oil (bitter)	0.9	130	96	80	330		97	66			29			Almondlike, cherry aroma 340 ppm used in maraschino cherries.
SYN. Tolualdehydes (mixture of)	–		28	11	430		25	16			8			100 ppm used in maraschino cherries.
NAT. Anise oil	0.4	45	120	7	3200		500	67	65					Sweet, mellow, mild flavor.
SYN. Anethole	–	1400	150	11	1500		340	26						Sweet anise odor and taste.
NAT. Bergamot oil	0.6	9	29		43		27	130			90			Sweet, fragrant, fruity odor.
NAT. Camphor oil	1.8	Used in limited fashion in foods in Japan. Principally a starting ingredient for other flavorings.												
NAT. Cananga oil	0.7		2	7			2	1						Slightly woody, floral odor.
NAT. Caraway oil	0.2		10000	63		96		63						Warm, biting flavor.
SYN. Carvone	–	130	110	850	2	8	180	120						Odor suggestive of caraway.
NAT. Cardamon seed oil	*	10	57	2	2	8	6	1	36	16				Aromatic, warm odor.
NAT. Cinnamon oil (leaf/bark)	0.6		54	6	600	75	32	18	40	50				Characteristic spicy odor. Also used in spiced fruits (3 ppm).
SYN. Cinnamaldehyde	–		180	9	4900	20	700	8	60					Pungent and spicy.
NAT. Citronella oil	6.4		21	17			25	26						Rose-lemon fragrance.
SYN. Citronellol*	–		18	4	50		16	4		6				Roselike odor.
NAT. Cloves oil	7.7	300	35	3	1800	55	320	13	75	15	5			Characteristic, spicy odor. Used in spiced fruits (830 ppm).
SYN. Eugenol	–		33	2	500	100	32	3	2000		1			Strong, clovelike odor.
NAT. Eucalyptus oil	3.7	1	76	2			130	50						Characteristic odor; astringent taste.
SYN. Ecalyptol	–		4	< 1	190		15	< 1						Camphoraceous odor; pungent taste.

TABLE 3. DISPOSITION OF ESSENTIAL OILS IMPORTED INTO THE UNITED STATES (cont.)

Essential Oil (Synthetic counterparts sometimes included for comparison)	U.S. IMPORTS %	Usual Maximum Level of Usage (Parts per million)												Comments
		Alcoholic beverages	Bakery products	Beverages (nonalcoholic)	Chewing gum	Condiments	Confections	Ice cream products	Meat	Pickles	Puddings/gelatin desserts	Syrups	Toppings	
NAT. Geranium oil	1.1		8	2	210		7	3			2			Strong roselike odor.
SYN. Rhodinol	–		8	2	31		8	2			3			Roselike odor.
NAT. Grapefruit oil	0.6		370	160	1500		630	180			250	400		Sweet, fresh citruslike odor.
SYN. Styralyl acetate	–		17	4	1		12	5					30	Gardenialike odor.
NAT. Lavender and lavender spike oil	1.5		50	10	220		6	40						Characteristic floral odor.
NAT. Lemon oil	6.2		580	230	1900	80	1100	600	40		340	65		Characteristic lemon-leaf odor. Also used in cereals (140 ppm).
SYN. Citronellal	–		5	4	< 1		5	1	4		1			Intense lemon-rose odor.
NAT. Lemongrass oil	2.2		38	4	220		38	9			290			Strong lemonlike odor.
NAT. Lignaloe oil (Boiss de rose oil)	0.8		9	1	35		7	3						Sweet woody-floral odor.
SYN. Isopulegol	–		23	7			23	29						Camphoraceous and mint-like odor.
NAT. Licorice extract	*		84	33	29000		130	39			4	50		Characteristic and intensely sweet taste.
SYN. Methylcyclo-pentenolone	–		13	11	15		18	6			14	30		Sweet, licoricelike taste.
NAT. Lime oil	10.0		370	130	3100	20	680	160			200			Fresh, citrus odor. Sweet-sour taste.
NAT. Mentha arvensis	2.1	Many nonfood uses. Basis for other flavorings.												Strong menthol odor. Cool mint taste.

NAT. Nutmeg oil and mace oil	1.8		75	14	640	21	19	13	150	500	16		Characteristic odor and taste.
NAT. Orange oil (sweet)	18.3		440	130	930	25	690	140					Characteristic odor and aromatic taste.
SYN. Linalyl anthranilate	–		8	2			5	1					Sweet, orangelike flavor.
NAT. Patchouli oil	3.1		10	1	220		6	1					Persistent, slightly camphoraceous odor.
NAT. Peppermint oil	*	240	300	99	8300		1200	110	8	200		650	Strong mint odor; sweet taste.
NAT. Petitgrain oil	1.9		17	2	4	15	5	1		< 1			Harsh, bittersweet odor/taste.
NAT. Pineneedle oil	0.4	Essentially nonfood uses											Pinelike, balsamic odor.
NAT. Rose oil	0.5		1	1	15		3	1		< 1			Warm, rich roselike odor.
NAT. Rosemary oil	1.3		6	4		3	8	1	40				Herbaceous odor; spicy flavor.
NAT. Sandalwood oil	0.5		7	2	47		8	8					Warm, woody odor. Considerable use in Oriental dishes.
NAT. Sassafras oil	5.8		50	290			100	10					Spicy, aromatic odor/flavor.
SYN. *p*-Propyl anisole	–		67	4			64	9					Aniselike odor with sassafras undertone.
NAT. Vetiver oil	2.1	Used mostly for perfumery applications											Woody, earthy odor. Excellent fixative. Sometimes used to reinforce flavor of asparagus.
All other imported essential oils	16.8												
	100.0												

*Also citrinellol derivatives (Ppm figures differ for each)

NAT. = Natural.

SYN. = Synthetic.

also listed in the table. To provide some concept of the levels of usage of both natural and synthetic flavorings by various facets of the food industry, these are detailed for 12 categories of products, those food substances for which flavorings are generally most important.

Spectrum of Flavors. The flavoring field is further complicated by the very large number of flavors that are available from natural and synthetic sources and by the many hundreds of flavors of slightly different emphasis that can be prepared from the materials available. Some concept of the array of material available may be gained by perusal of Table 4, which lists fundamental flavor objectives (apple, citrus, mint, mushroom, et al.) along with an abridged list of optional compounds for the consideration of the professional flavorist. Even with much progress in the technology, there remains a large element of art (experience) along with the science. Sophisticated instruments, such as gas chromatographs, mass spectrometers, among others, are available to assist the professional, but in developing flavorings for new products or in exerting flavor quality control over mass-produced food products, the need frequently arises for a panel of sniffers and tasters, more professionally termed sensory evaluation panels or monitors. The procedure for coffee tasting is briefly described in the entry on **Coffee.** See also entry on **Sensory Evaluation.** It should be stressed that such experienced people also monitor texture, appearance, mouthfeel, and a number of other factors which determine the quality acceptability of a product, in addition to flavor.

As of the early 1980s, the nomenclature of flavorings requires considerably more standardization, not an easy task because of the lack of uniformity in the responses of different people to food substances. This kind of problem is further accentuated in evaluating the flavors of feedstuffs for livestock and of pet foods because of lack of communication—other than observance of eating patterns.

The words and phrases used for describing the partial or total flavor responses to various flavoring ingredients and food situations (Table 5) was assembled from a number of flavor reports and evaluations. This listing, much abridged and not fully representative, does indicate the magnitude of the flavor array. The words feature a large number of analogs (like this; like that), indicative of the early development of a topical language.

Among numerous factors to be considered by the flavorist are flavor yield (total flavor sensation per unit of flavoring substance) and the so-called harmony of flavorings when two or more substances are used. Combinations of flavoring substances can produce synergistic effects, both positive and negative. The use of artificial sweeteners versus natural sugars usually alters the required flavorings quite markedly. The inclusion of a flavor potentiator also must be considered as part of the total flavoring profile. Incidentally, the flavorist uses the term *compound* to describe an intimate mixture of two or more flavoring substances (possibly some natural; some synthetic), as contrasted with the traditional definition of compound, meaning a specific chemical substance made up of specific elements in exact proportions. Commonly, a flavoring compound will be an esoteric, proprietary blend of substances. Traditional

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

Flavor Type and Compound	Taste
Almond	
Totualdehyde (*o, m, p*)	BS
Almond oil (bitter)	*
Ambergis	
Labdanum oil	*
Anise	
Anethol	SW
Anise oil	*
Apple	
Allyl butyrate	BS
Allyl cyclohexylvalerate	BS
Allyl isovalerate	BS
Allyl propionate	BS
Benzyl isovalerate	SW
Butyl isovalerate	SW
Butyl valerate	
Cinnamyl formate	BS
Cinnamyl isobutyrate	SW
Citronellyl isovalerate	SW
Cyclohexyl acetate	BS
Cyclohexyl butyrate	BS
Cyclohexyl isovalerate (white apple)	BS
Cyclohexyl propionate	BS
Ethyl isovalerate	SW
Ethyl valerate	BS
Isopropyl acetate	SW
Isopropyl valerate	BS
2-Methylallyl butyrate	BS
Methyl butyrate	SW
Terpenyl isovalerate	SW
Apricot	
Allyl butyrate	BS
Allyl cyclohexylcaproate	BS
Allyl cyclohexylvalerate	BS
Allyl propionate	BS
Amyl phenylacetate	SW
Benzyl formate	SW
Benzyl propionate	SW
Butyl propionate	SW
Cinnamic acid	SW
Citronellyl acetate	SW
γ-Decalactone	BS
γ-Dodecalactone	BS
Ethyl cinnamate	SW
Geranyl butyrate	SW
Geranyl isobutyrate	SW
Geranyl isovalerate	SW
Heptyl acetate	SW
Heptyl propionate	BS
Methyl ionone	SW
Phenethyl dimethyl carbinol	SW
Phenylpropyl alcohol	SW
Propyl cinnamate	BS

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

Flavor Type and Compound	Taste
Santalyl acetate	BS
Tetrahydrofurfuryl propionate	BS
γ-Undecalactone	SW
Balsamic	
Balsam Peru oil	*
Copaiba oil	*
Fir needle oil	*
Labdanum oil	*
Olibanum oil	*
Banana	
Cyclohexyl acetate	BS
Cyclohexyl butyrate	BS
Cyclohexyl propionate	BS
Ethyl valerate	BS
Basil	
Tarragon oil	*
Butter	
Diacetyl	SW
Camphoraceous	
Basil oil	*
Camphor oil	
Cedar leaf oil	*
Cedarwood oil	
Eucalyptus oil	*
Isopulegol	*
Marjoram oil	*
Patchouli oil	
Sage oil	*
Spike lavender oil	*
Caramel-Butterscotch	
Maltol	*
Caraway	
Caraway oil	*
d-Carvone	*
Dill seed oil	*
Cheese	
Hexanoic acid	*
Isovaleric acid (rancid)	*
Cherry	
Allyl benzoate	BS
Anisyl butyrate	BS
Anisyl propionate	BS
Cyclohexyl cinnamate	BS
Cyclohexyl formate	BS
Methyl anthranilate	BS
Rhodinyl formate	BS
Tetrahydrogeraniol	BS
Tolualdehyde (*o*, *m*, *p*)	BS
Chocolate	
Tetrahydrofurfuryl propionate	BS
Cinnamon	
Cassia oil	*
Cinnamaldehyde	BS*
Cinnamon bark oil	*
Cinnamon leaf oil	*
α-Methylcinnamaldehyde	*
Citrus	
Decanal dimethyl acetal	BT
Lime oil	*
Cloves	
Cinnamon leaf oil	*
Clove oil	*
Clove leaf oil	*
Eugenol (clove buds)	BT
Methyl isoeugenol	BT
Cocoa	
Neryl butyrate	SW
Phenylpropyl cinnamate	SW
Coconut	
Allyl undecylate	BS
Ethyl undecylate	SW
Methyl undecyl ketone	BS
γ-Nonalactone	BS
γ-Octalactone	BS
Cognac	
Allyl pelargonate	BS
Cyclohexyl caproate	BS
Cola	
2-Ethyl-3-furylacrolein	BT
Coriander	
Coriander oil	*
Cumin	
Cumin oil	*
Currant	
Cyclohexyl butyrate	BS
Guaiol acetate (black currant)	SW
Linalyl acetate (black currant)	SW
Linalyl isobutyrate (black currant)	SW
Linalyl propionate (black currant)	SW
Methyl ionone	SW
Methyl propionate (black currant)	SW
Eucalyptus	
Eucalyptol	*
Eucalyptus oil	*

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

Flavor Type and Compound	Taste
Fatty	
Decanal	*
Ethyl nonanoate	*
Heptyl alcohol	*
Lauryl alcohol	*
Lauryl aldehyde	*
Nonanal	*
Octanal	*
1-Octanol	*
Rue oil	*
Undecanal	*
10-Undecenal	*
Fennel	
Fennel oil	*
Flowery	
Anisyl alcohol	*
Benzyl acetate	*
Benzyl phenylacetate	*
Boise de Rose oil	*
Chamomile oil (English)	*
Cinnamic acid	*
Cinnamyl acetate	*
Citronellyl formate	*
Cresyl acetate	*
Cyclamen aldehyde	*
Decanal	*
Dimethyl benzyl carbinol	*
Dimethyl benzyl carbinyl acetate	*
Ethyl anthranilate	*
Geranyl acetate	*
Hydroxycitronellal dimethyl acetate	*
Indole	*
Lavender oil	*
Linaloe wood oil	*
Linalool	*
Linalyl acetate	*
Methyl benzoate	*
Petitgrain oil	*
Phenethyl acetate	*
2-Phenylpropionaldehyde	*
3-Phenylpropionaldehyde	*
Flowery/Fruity	
Anisyl acetate	*
Cananga oil (ylang ylang oil)	*
Cinnamyl isovalerate	*
Citronellyl	*
Ethyl laurate	*
Ethyl octanoate	*
Geranyl butyrate	*
Geranyl propionate	*
Nonyl acetate	*
Fruity	
Benzyl propionate	*
Bergamot oil	*
Butyl acetate	*
Cinnamyl anthranilate	*

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

Flavor Type and Compound	Taste
Cinnamyl formate	*
Citronellyl acetate	*
Citronellyl butyrate	*
Cintronellyl isobutyrate	*
Citronellyl propionate	*
Delta-Decalactone	*
Diethyl malonate	*
Dimethyl benzyl carbinyl acetate	*
Delta-Dodecalactone	*
Ethyl *p*-anisate	*
Ethyl benzoate	*
Ethyl butyrate	*
Ethyl heptanoate	*
Ethyl hexanoate	*
Ethyl maltol	*
Ethyl nonanoate	*
Isoamyl butyrate	*
Isoamyl hexanoate	*
Isoamyl isovalerate	*
Isobutyl cinnamate	*
Linalyl isobutyrate	*
Linalyl propionate	*
Maltol	*
Methyl benzoate	*
Methyl cinnamate	*
2-Methylundecanal	*
Nerolidol	*
Octanol	*
Octyl formate	*
Phenethyl isobutyrate	*
Phenethyl isovalerate	*
γ-Undecalactone	*
Garlic	
Garlic oil	*
Ginger	
Ginger oil	*
Grape	
Allyl salicylate	BS
Cinnamyl anthranilate	BS
Clary oil	*
Cognac oil	*
Guaiol acetate	SW
Isobutyl anthranilate	BS
Isovalerophenone	BS
Octyl isobutyrate	BS
Phenylpropyl acetate	BS
Phenylpropyl ether	BS
Grapefruit	
Grapefruit oil	*
Styralyl acetate	BT
Green Leaves	
Allyl anthranilate	BS
Origanum oil	*
Vetiver oil (earthy)	

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

Flavor Type and Compound	Taste
Hawthorne	
Acetanisole	*
p-Methoxybenzaldehyde	*
Heliotrope	
Piperonal	*
Herblike	
Clary oil	*
Honey	
Allyl phenoxyacetate	BS
Allyl phenylacetate	BT
Benzyl cinnamate	SW
Carvacryl acetate	BS
Cinnamyl butyrate	SW
p-Cresyl acetate	
p-Cresyl ethyl ether	SW
m-Cresyl phenylacetate	SW
p-Cresyl phenylacetate	SW
Cyclohexyl phenylacetate	BS
Ethyl phenoxyacetate	SW
Ethyl phenylacetate	BS
Guaiol phenylacetate	SW
Isobutyl phenylacetate	SW
Linalyl butyrate	SW
Methyl phenylacetate	SW
Phenethyl acetate	BS
Phenethyl butyrate	SW
Phenethyl phenylacetate	SW
Phenylacetic acid	SW
Propyl phenylacetate	SW
Santalyl phenylacetate	SW
Hops	
Hops oil	*
Juniper Berries	
Juniper berries oil	*
Lavender	
Lavender oil	*
Spike lavender oil	*
Lemon	
Citral	*
Citronellal	*
Lemongrass oil	*
Lemon oil	*
Olibanum oil	*
Licorice (Natural is available as Extract)	
Methylcyclopenteneolone	*
Tarragon oil	*
Maple	
Methylcyclopenteneolone	*
Melon	
Cinnamaldehyde	BS
Ethyl hexadienoate	BS
Methyl amyl ketone	
Octyl butyrate	SW
Menthol	
Mentha arvensis (Cornmint oil)	SW
3-*p*-Methanol	*
Mint	
Pennyroyal oil	*
-Phellandrene	*
Spearmint oil	*
Mushroom	
Hexyl furan carboxylate	BT
Musky	
Ambrette seed oil	*
Mustard	
Allyl formate	
Nutmeg	
Mace oil	*
Nutmeg oil	*
Onion	
Onion oil	*
Orange	
Linalyl anthranilate	SW
Mandarin oil	*
Orange oil	*
Tangerine oil	*
Origanum	
Origanum oil	*
Savory oil	*
Peach	
Allyl cyclohexylcaproate	BS
Allyl Cyclohexylvalerate	BS
Allyl undecylate	BS
Amyl phenylacetate	SW
Anisyl alcohol	SW
Anisyl butyrate	BS
l-Citronellol	SW
Cyclohexyl caproate	SW
Cyclohexyl cinnamate	
γ-Dodecalactone	BS
Ethyl cinnamate	SW
Geraniol "palmarosa"	SW
Isopropyl benzyl carbinol	BS
Methyl methylanthranilate	BS
Methyl nonyl ketone	SW
Methyl octine carbonate	SW

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Flavor Type and Compound	Taste
Musk ambrette	SW
γ-Octalactone	BS
Octyl acetate	SW
Phenethyl alcohol	BT
Phenethyl isovalerate	BS
Phenethyl salicylate	SW
Phenylallyl alcohol	BS
Phenylpropyl isobutyrate	BS
Propyl cinnamate	BS
Rhodinyl formate	BS
Terpinwol	BS
γ-Undecalactone	SW
Pear	
Benzyl butyrate	SW
2-Ethylbutyl acetate	BS
Ethyl heptylate	BS
Hexyl acetate	BS
Hexyl furan carboxylate	BS
Isoamyl acetate	BS
2-Methylallyl caproate	BT
Methylheptenone	BT
Propyl acetate	BS
Pepper	
Pepper oil	*
Peppermint	
Menthol	*
Peppermint oil	*
Pineapple	
Allyl caproate	BS
Allyl cyclohexylacetate	BS
Allyl cyclohexylbutyrate	BS
Allyl cyclohexylpropionate	BS
Allyl 2-nonylenate	
Allyl phenoxyacetate	BS
Benzyl formate	SW
Bornyl acetate	SW
n-Butyl acetate	SW
Butyl isobutyrate	SW
Cinnamyl acetate	SW
Decanal dimethyl acetal	SW
Ethyl butyrate	SW
Ethyl hexadienoate	BS
Ethyl phenoxyacetate	BS
Hexyl butyrate	SW
Isoamyl isobutyrate	
2-Methylallyl caproate	BS
Methyl-β-methylpropionate	BS
Methyl undecylate	
Propyl isobutyrate	SW
Plum	
Butyl formate	
Citronellyl butyrate	SW
Citronellyl formate	SW
Citronellyl propionate	BS
γ-Decalactone	BS
Guaiol butyrate	SW
Heptyl formate	
Hexyl formate	SW
Isoamyl formate	SW
Isopropyl formate	SW
Isopropyl propionate	BS
Linalool	SW
Neryl propionate	SW
Phenethyl formate (green plum)	BS
Phenethyl isobutyrate (green plum)	BS
Phenylallyl alcohol	BS
Phenylpropyl butyrate	SW
Propyl formate	BS
Terpenyl butyrate	BS
Raspberry	
Benzyl salicylate	SW
α-Ionone	SW
Isobutyl cinnamate	SW
Methyl ionone	SW
Neryl acetate	SW
Santalol	SW
Roselike	
Citronella oil	
Geranium oil	*
Nerol	SW
Neroli oil	
Palmarosa oil	
Phenethyl alcohol	BT
Phenethyl dimethyl carbinyl isovalerage	BS
Rhodinol	BT
Rose oil (Attar of roses)	*
Rosemary	
Rosemary oil	*
Rum	
Ethyl formate	BT
Isobutyl formate	SW
Sandalwood	
Amyris oil	*
Sandalwood oil	*
Santalol	*
Santalyl acetate	*
Sassafras	
p-Propyl anisole	*
Sassafras oil	
Spearmint	
l-Carvone	*
Spearmint oil	*

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

TABLE 4. REPRESENTATIVE FOOD FLAVORINGS (cont.)

Note: Letters indicate fundamental taste types: BS = bittersweet; BT = bitter; SW = sweet.
An asterisk indicates that compound is described in Appendix Table 1.

Flavor Type and Compound	Taste
Spicy	
Cascarilla oil	*
Cubeb oil	*
Eugenol	*
Isoeugenyl acetate	*
Laurel leaf oil	*
3-Phenylpropyl acetate	*
Pimenta leaf oil	*
Pimenta oil	*
Strawberry	
Anisyl formate	SW
Benzyl isobutyrate	SW
Cuminic alcohol	BS
Ethyl methylphenylglycidate	SW
Ethyl phenylglycidate	SW
Isoamyl salicylate	BS
Isobutyl anthranilate	BS
Methylacetophenone	SW
Methyl cinnamate	SW
Methyl naphthyl ketone	BS
Nerolin	SW
Neryl isobutyrate	BT
Phenylglycidate	SW
Yara yara	SW
Thymol	
Origanum oil	*
Savory oil	*
Thyme oil	*
Vanilla	
Propenyl guaethol	SW
Vanillin	BT
Vanillyidene acetone	BS
Violet	
Costus root oil	*
α-ionone	*
β-ionone	*
Methyl-2-octynoate	*
Walnut	
γ-Octalactone	BS
Wine	
Ethyl acetate	BS
Ethyl heptylate	SW
Wintergreen	
Allyl salicylate	BS
Methyl salicylate	
Wintergreen oil	

Substances with characteristic flavors and essences described in Appendix Table 1: Angelica root oil; angelica seed oil; bay oil; carrot seed oil; celery seed oil; Chamomile oil (Hungarian); Dillweed oil; lavage oil; menthol; myrrh oil; orris root oil; parsley herb oil; pineneedle oil.

strawberry flavoring for soft drinks may include: Amyl acetate, amyl butyrate, butyl isovalerate, ethyl acetoacetate, ethyl butyrate, ethyl caproate, and ethylfuran carbonate—where the beverage is to be sweetened with sugar. On the other hand, if synthetic sweetener is to be used, the formulation will be quite different: Aldehyde C_{16}, diethyl acetal, geraniol, β-ionone, maltol, neroli essential oil, octanal dimethyl acetal, phenethyl alcohol, terpineol, and vanillin. The multiplicity of ingredients to obtain a given flavor is also illustrated by the flavoring substances used in an imitation rose flavor: Aldehyde C_8, citral, citronellol, geraniol, linalool, phenethyl alcohol, and rhodinol. Scores of additional examples of this nature are given and excellently described in the Furia (1971) reference listed.

The flavorist uses terms (reminiscent of sound harmonics) to describe the roles of certain ingredients in a flavor compound: *Top note*—indicates the flavor first perceived by the food monitor or consumer—and is usually a flavoring substance with a volatility relatively higher than the other flavor components present. *Main note* (sometimes called *middle note*)—is the predominating flavor of the food substance, coming on strong so to speak immediately after sensing the top note. *Bottom note* (sometimes called *undertone*)—flavors that are perceived slightly later in the cycle of tasting or smelling a food substance. An optimal blend of the various notes results in what is sometimes called a *full-bodied flavor,* important, for example, in coffees. Although some of the flavors listed in Table 5 appear immensely undesirable (and often are), sometimes, in the proper combination, they contribute to the desired full-bodied flavor effect. For example, in a garlic flavoring, the characterizing flavor, of course, is garlic. However, an expert panel may detect in a satisfactory product a number of flavor notes, some in addition to or desired in garlic flavor. An expert panel has reported the following flavor notes in such a product: Acid, astringent, biting, bitter, boiled, brown, cabbage, earthy, green, heat, iodine, leek, metallic, musty, onion, plastic, potato, rubbery, scallion, sharp, sour, skunky, sulfitic, and toasted.

Physiological Aspects of Flavors

Receptor cells especially sensitive to chemicals are found in virtually all animals. By convention, those receptors normally excited by contact with chemicals in liquid phase at relatively high concentrations are termed taste or gustatory receptors, although the distinctions between taste and smell are not critical at cellular or molecular levels.

Physiologists use the term *papillae* to identify the taste buds so-called on the surface of the tongue. There are several thousand papillae on the human tongue. Because the tongue takes so much abuse when a person is eating a variety, often of very coarse and rough foods, some authorities believe that the papillae are constantly being renewed. Small fibers, almost like tiny hairs, extend from these cells to the surface of the tongue. Some investigators have described the papillae as being of three general shapes—something like tiny mushrooms; those that appear like miniature hills with moats around them; and the tiny threads and cones. Observable differences in shape tend to reinforce earlier theories which embrace the use of differently structured organisms to sense different taste categories, notably

TABLE 5. WORDS AND PHRASES SOMETIMES USED TO DESCRIBE FLAVOR
(Key Flavors and Undertones)

ANIMAL-ASSOCIATED

- Animalic
- Bacony
- Barbequelike
- Barnyardy
- Beefy
- Birdy
- Bird-cagey
- Bloody
- Chickeny
- Clammy
- Cured
- Eggy
- Fatty
- Feathery
- Fishy
- Gluelike
- Guanolike
- Hammy
- Lion cagey
- Meaty
- Muttonlike
- Oily
- Porky
- Salt-airy
- Sea-misty
- Sulfitic

BOTANY-ASSOCIATED

- Barky
- Beanlike
- Grassy
- Green
- Green applelike
- Haylike
- Herby
- Leafy
- Melonish
- Mown-haylike
- Piney
- Seedy
- Stalky
- Tomato-y (many more vegetative terms like this)
- Twiggy
- Unripe
- Vegetabaly
- Viney
- Woody

CHEMICAL-ASSOCIATED

- Acetic
- Aminelike
- Ammoniacal
- Alcoholy
- Aldehydic
- Balsamic
- Camphoraceous
- Chloriney
- Cough mediciny
- Cresylic
- Furniture polishlike
- Fusel oily
- Hydrocarbonlike
- Iodiny
- Medicinal
- Metallic
- Mothbally
- Nicotiny
- Phenolic
- Plasticlike
- Salty
- Shoe polishlike
- Soapy
- Terpeny
- Tobaccolike

DAIRY ASSOCIATED

- Baby biblike
- Buttery
- Butyric
- Cheesy
- Cowy
- Creamy
- Curdled milklike
- Fatty
- Goaty
- Oily
- Sour
- Waxy

DAMP-EARTH ASSOCIATED

- Claylike
- Damp cellarlike
- Dank
- Dirtlike
- Earthy
- Funguslike
- Mildewy
- Moldy
- Mushroomlike
- Musky
- Musty
- Potato skinlike
- Rooty
- Wet haylike
- Woodsy

DEGRADATION ASSOCIATED

- Boiled egglike
- Burnt rubbery
- Dead
- Decayed
- Fried onionlike
- Gym lockerlike
- Limburgy
- Mercaptanlike
- Natural gaslike
- Overripe
- Putrid
- Rancid
- Rotten
- Skunky
- Sulfitic
- Sweat socklike
- Sweaty
- Wet doglike

FERMENTATION ASSOCIATED

- Beery
- Bread doughy
- Cidery
- Moonshiny
- Rummy
- Vinegary
- Whiskey breathlike
- Winey
- Yeasty

FLOWER-FRUIT ASSOCIATED

- Berrylike
- Citrusy
- Estery
- Floral
- Flowery
- Fragrant
- Fruity
- Lemony
- Orangey
- Perfumey
- Rosy (many more flower terms like this)

USUALLY HOTNESS ASSOCIATED

- Acrid
- Astringent
- Biting
- Brown
- Burnt
- Burnt tirelike
- Burnt coffeelike
- Charcoaly
- Chililike
- (Cooling)
- Garlicy
- Hickorylike
- Horseradishy
- Hot
- Mexican
- (Minty)
- Mustardy
- Peppery
- Piquant
- Pungent
- Red peppery
- Sharp
- Smokey
- Spicy (many specific terms in this category)
- Tangy
- Tarlike
- Tart
- Toasty
- Warm

TABLE 5. WORDS AND PHRASES SOMETIMES USED TO DESCRIBE FLAVOR (cont.)
(Key Flavors and Undertones)

NEUTRAL

- Bland
- Cardboardy
- Cereallike
- Chalky
- Characterless
- Crackerlike
- Flat
- Floury
- Light
- Matzolike
- Mellow
- Mild
- Nondescript
- Overcooked
- Papery
- Pasty
- Raw
- Stale
- Starchy
- Strawlike
- Tasteless
- Wallpaper pasty
- Waxy
- Weak

RESINOUS

- Balsamic
- Leathery
- Pruny
- Resinous
- Woody

SWEETNESS ASSOCIATED

- Butterscotchy
- Candylike
- Caramellike
- Chocolaty
- Jammy
- Jellylike
- Malty
- Mapley
- Marshmallowy
- Sacchariny
- Sugary
- Sweet
- Vanillic

MISCELLANEOUS

- Acidy
- Baked
- Bitter
- Boiled
- Broiled
- Characteristic
- Delicate
- Fresh
- Fried
- Full bodied
- Grilled
- Intense
- Lingering
- Overpowering
- Overwhelming
- Peculiar
- Persistent
- Refreshing
- Rich
- Roasted
- Soft
- Strong
- Tenacious

NOTE: Obviously some of the foregoing terms connote dimensions beyond those strictly conveyed by taste and odor, providing credence to the concept that the total experience of eating or drinking goes well beyond two vectors.

the traditional four basic taste sensations—sweet, sour, bitter, salty. As will be noted later, these concepts thus far have been difficult to refine or confirm.

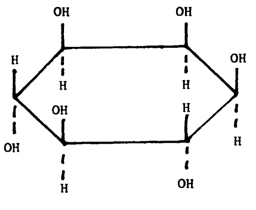
Chemical aspects of taste receptor functions can be studied by recording the patterns of electrical potentials in receptor cells while the cells are being stimulated with pure chemicals of known structures and properties. Since the mid-1950s, when this method was first successfully applied to single taste receptor cells, using receptors on the mouth parts of a fly, many earlier theories of taste stimulation have been revised.

Intracellular recordings from taste cells of rat and hamster show that even primary receptor cells are sensitive to three or four of the so-called basic taste modalities. Consequently, it is generally held that a variety of different receptor *sites* commonly exist on the receptor membrane of any one receptor *cell*. Biochemical characterization of events at receptor sites has progressed in analyzing electrolyte and carbohydrate stimulation.

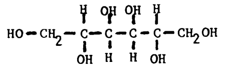
Electrolyte stimulation is chiefly a function of monovalent cations in all animals which have been studied. Consequently, the receptor sites are thought to be anionic. The pH relationships of stimulation also indicate that strongly acidic (e.g., $PO_4^=$ or $SO_4^=$) receptor groups are involved. Calculations of free energy changes of the reaction between salt and receptor site give values between 0 and -1 kcal/mole; and low ΔF values suggest that the reaction involves only weak physical forces. The reaction occurs extremely rapidly, since typical nerve impulses can be recorded within 1 millisecond after stimulating electrolytes are applied. In blow-flies, 0.004M NaCl, which produces 1 impulse per second, represents the threshold for behavior responses. These thresholds appear to be somewhat higher in humans.

No one type of receptor site or reaction can account for the extreme structural specificities. A curious assortment of molecules, can elicit "sweet" sensations. Early studies on a variety of organisms demonstrated that ring structures and D-isomers were more stimulating in polyol compounds than straight-chains and L-isomers. Thus, inositol (Fig. 1), with its ring structure, was found to stimulate. The straight-chain polyhydric alcohols, sorbitol, dulcitol (Fig. 2), and mannitol did not stimulate. Possession of an α-D-glucopyranoside linkage was found to generally increase the stimulating capacity of sugars. Maltose, with a 1,4-linkage, turanose with a 1,3-linkage, and the nonreducing sugars stimulate. Lactose, with its 1,4-linkage, and melibiose, with a 1,6-linkage, both lack the α-link and are relatively nonstimulating.

Conformation, as well as configuration, is important in determining the stimulating power of sugar molecules. Glucose, which exists in solution almost entirely in an aldopyranose "chair" conformation, has derivatives of both 1C and C1 conformations (Figs. 3 and 4). Those of the C1 type are considerably the more stimulating. The hydroxyl groups attached to C3 and C4, and inclined 19° above and 19° below the adjacent plane of the molecule, appear to be necessary for the critical linkage at the receptor site. Lack of effects by metabolic inhibitors (azide, fluoride, iodoacetate, etc.) or of temperature effects upon the initial excitatory process, suggests that this step depends upon specific physical, rather than chemical reactions.

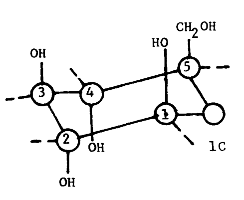


1

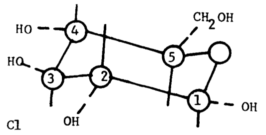


$HO-CH_2-\underset{OH}{\overset{H}{C}}-\underset{H}{\overset{OH}{C}}-\underset{H}{\overset{OH}{C}}-\underset{OH}{\overset{H}{C}}-CH_2OH$

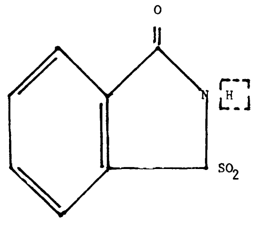
2



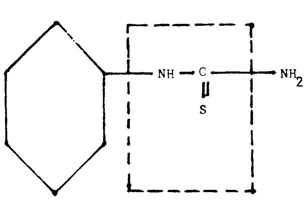
3



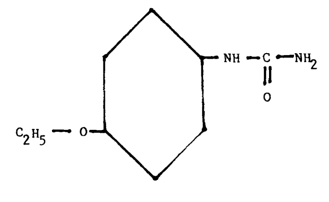
4



5



6



7

Figures 1 through 7. Molecules illustrating relationships between structures and effects on taste receptors. See explanation in text. (After Hodgson)

The nature of other polyol receptor sites and the molecular basis for genetic and species differences in taste capabilities remain largely unknown. Saccharin (*o*-sulfobenzime, Fig. 5) exemplifies both puzzles, since its molecule does not fit any known sugar receptor site, yet it is confused with sugar stimuli by humans and other primates, but probably not by nonprimate animals. The substitution of other groups for 1 hydrogen (dotted lines in Fig. 5) renders saccharin tasteless. The genetic basis of taste has been studied with phenylthiocarbamide (PTC). A strong bitter taste of PTC depends upon the chemical components indicated by dotted lines in Fig. 6, and upon possession of a dominant "taster" gene in humans. Curiously, a small change in the molecule (Fig. 7) yields a product 250 to 300 times sweeter than sugar.

Taste receptors for water have been reported to occur on mouth parts of mammals and invertebrates. Specialized amino acid and amine receptors are found on the legs of various arthropods. The mechanisms by which adequate stimuli initiate nerve impulses in these cells offer a rich field for further investigation. Some stimuli, especially long-chain hydrocarbons, are known to act in an opposing manner, i.e., by decreasing, rather than increasing, the output of receptor impulses. Their effects resemble the actions of narcotics. Some authorities suggest that taste sensations, as ultimately perceived, probably result from a complex coded pattern of augmented or depressed frequencies of nerve impulses, originating in the different cells of a heterogeneous population of taste receptors.

For many years, physiologists have explained that the sense of smell is located in the mucus lining inside the nose. Traditionally, it has been observed that a person with a "dry" nose has little if any sense of smell. Molecules characteristic of certain flavorings must be moistened by the mucus before they can be detected. Traditionally, it also has been observed that these nerve cells (estimated to be a million or more) tend to become blocked (refuse further transmission of signals) upon prolonged exposure to any given odor. This blocking phenomenon can occur within just a few minutes after exposure to certain, usually powerful odors. When all is sorted out concerning the mechanics of tasting and smelling, it is highly likely that operationally the cells in the nose lining and the papillae of the tongue will be highly similar, if not identical—simply because many other interrelationships have been shown to be similar. Of course, over the years, some researchers have approached the phenomena of taste and odor separately. Some of the odor detection theories proposed have included: (1) the *vibrational theory* (Demerdache; Dyson; Wright); (2) the *stereochemical theory* (Amoore, Johnston, Naves); (3) the *theory of interfacial adsorption* (Beck; Davies); and (4) the *profile functional group theory* (Beets).

The aforementioned theories are concerned with the size and shape of odorant molecules, but differ in certain underlying concepts. For example, accommodating for functional groups, electron donor-acceptor characteristics, as well as the sorptive nature of odorants on sensor sites. The vibration theory largely concentrates on the far-infrared and Raman spectral characteristics of odoriferous substances. The remaining theories concentrate on structural and behavior characteristics of odorant molecules, stressing direct interactions physically, chemically, and biologically with the olfactory sensor system.

The vibrational theory stresses so-called osmic frequencies (Wright) as setting up resonances in the sensory organs. In commenting on this concept, Dravnieks observed that spectra are codes describing molecular structures and shapes with emphasis on the distribution of atomic masses, distances, and bond polarities; questions regarding corresponding intramolecular vibrations as direct factors in odor discrimination are independent of the validity of the spectral code.

In connection with the stereochemical theory, Amoore, although emphasizing the importance of molecular shape and size, also gave important emphasis to such chemical factors as electrophilic-nucleophilic characteristics, rotational moment, and the presence of functional groups. In the theory, the functional groups play a more important role in small molecules than in larger ones. Size and shape similarities were analyzed and demonstrated by preparing silhouettes patterned from 3-dimensional molecular models.

Critics of the Amoore theory point out that electrophysiological data do not support the concept that sensors are sensitive to size and shape. Other authorities, however, point out that molecular size and shape, operating with a reactive character, most likely are odor relevant, but that this is not explained satisfactorily by the Amoore theory. Another objection to the theory is that equal weight is given to positive and negative differences in odorant molecules. Further, it is observed that the theory does not account for odor blocking or fatiguing (anosmia).

The profile functional group theory is a relatively complex 2-step concept. First, it is visualized that the functional groups of the odorant molecule interact with the receptor site, thus causing a given orientation of the molecule. This, in turn, determines the final odor-relevant profile. Any similarity in profile at the receptor site causes similar signal transmissions to the brain. Because some odorant molecules will react more strongly at receptor sites than others, stronger signals will be transmitted.

The interfacial adsorption theory proposes that the orientation of odorant molecules is dependent upon their behavior at the hydrophilic-hydrophobic interface, taking into account interaction with the mucus and adjacent olfactory membrane.

Further descriptions of these theories is beyond the scope of this volume.

Formats for Flavorings

In a broad sense, flavorings are available to the food processing industry as solids, liquids, and pastes.

Solid Flavorings. Not many flavorings are obtainable as crystalline solids. These would include coumarin, ethyl vanillin, propenylgluaethol, and vanillin. Dry, powdered flavorings are often desirable because of their relatively easy handling, although hygroscopicity is frequently a problem. Powdered ingredients frequently commence with the drying of an extract, i.e., the full removal of any solvent that may have been used in its preparation. Among the methods used in preparing powders are conventional drying, freeze-drying, spray-drying, and plating. In the case of freeze-dried powders, these often involve the processing of only one flavoring substance, such as citrus juice, coffee, etc. Frequently, the freeze-dried flavorings are quite hygroscopic. Spray-drying offers the flavoring manufacturer considerably more flexibility. Often two or more ingredients will be admixed prior to drying. They may contain other additives, such as colorants, sugar, etc., thus adding to the food processor's convenience. Spray-dried powders are popular for use in various pastries, puddings, and confections. Plating involves the coating of some usually flavor-neutral substances, such as magnesium carbonate or lactose, the latter serving as carriers for the flavoring substance. It is not uncommon to "plate" spice oleoresins onto salt. Flavorings in plated form were once highly favored by the pastry industry. One of the shortcomings of plated flavorings, essentially overcome by encapsulation techniques, was loss of flavoring power through evaporation during storage and handling. Encapsulation of food additives is described in entry on **Additives and Other Food Chemicals.** Ultimately, flavorings also may fall within the sphere of polymeric food additives, as are colorants and antioxidants presently. See also entry on **Polymeric Food Additives.**

Liquid Flavorings. Additives in fluid form offer a number of advantages to the food processor because of their ready diffusability and handling. The liquid format is also desirable from the standpoint of the flavorings manufacturer because so many of the ingredients are available as liquids (essential oils, extracts, etc.). Consequently, liquid flavorings tend to predominate several of the food processing fields. Liquid flavorings are available in numerous liquid formats, ranging from essential oils, oleoresins, extracts, tinctures, infusions, soluble essences, emulsions, fractions and isolates, and concentrated juices.

Paste Flavorings. Many flavorings are available in the form of pastes. For example, fluid extracts of herbs, spices, and fruits can be concentrated to a syrupy consistency. Certain flavorings also are available as resins and resinoids. Highly concentrated cream emulsions of essential oils and absolutes are frequently classified as pastes.

Manufacture of Flavorings

As mentioned earlier, various parts of plants (including trees, shrubs, etc.) are the principal sources of essential oils as well as of spices and seasonings. The production of seven categories of flavorings from aromatic plant raw materials is illustrated by the flowsheet of Fig. 8. As indicated, crude essential oils are the raw material basis for essential oils, rectified essential oils, terpeneless oils, and fractions and isolates.

Essential Oils. An essential oil is a volatile oil derived from plants. Most of these oils, chemically, are principally terpenes (hydrocarbons), but other types also occur. Essential oils, except for those containing esters, are not saponifiable. Some are nearly pure single compounds—for example, wintergreen oil (methyl salicylate). In cases of this type, the synthetic flavoring, depending upon quality control over purity, will be essentially identical with the natural flavoring. Many other essential oils, are mixtures of a number of chemical compounds, but generally in consistent proportional amounts so that, from a flavoring standpoint, the oil is a single substance.

Most essential oils contain relatively sensitive organic compounds from a temperature standpoint. This thermal sensitivity, coupled with relatively high boiling points, makes separation of the oils from the plant raw materials somewhat difficult. Ordinary distillation cannot be used in the majority of cases because of thermal sensitivity. High temperatures required for distillation degrade some and destroy other organic constituents that contribute to the various flavoring notes desired. Of course, prior to distillation, the plant materials are dried in most cases, and some are subject to fermentation. Prior to separation procedures, the dried materials are ground so that a maximum of surface area is exposed.

Direct-heating distillation is a method that dates back

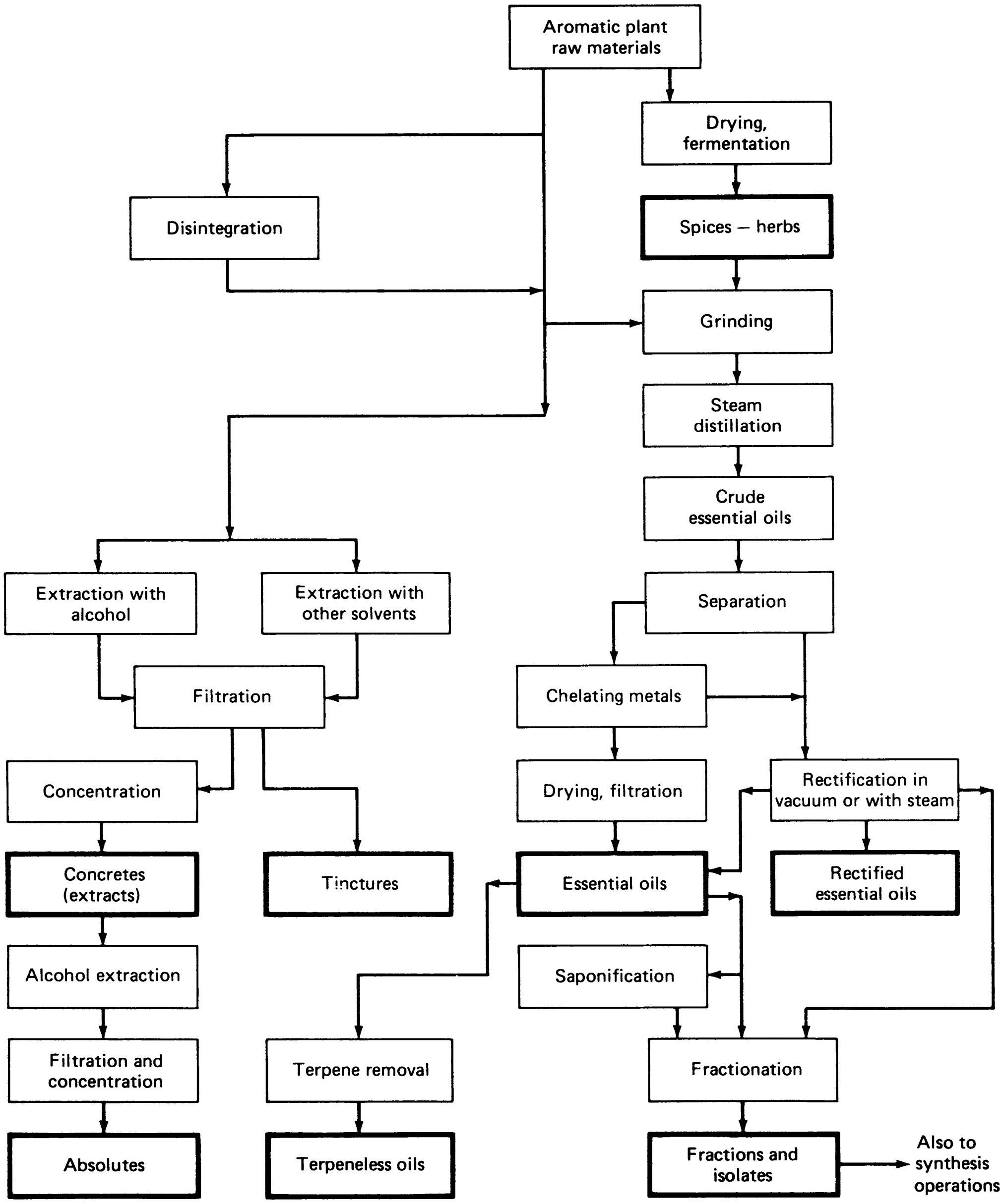


Fig. 8. Production of 7 categories of flavorings from aromatic plant raw materials. These are products prior to final compounding and approval by the manufacturer's flavor quality control center. It will be noted that spices and herbs also serve as a raw material for the production of certain essential oils, rectified essential oils, terpeneless oils, and fractions and isolates. Also, that concretes serve as raw materials for absolutes; and that essential oils serve as raw materials for terpeneless oils, recetified essential oils, and fractions and isolates. All final products are shown in boxes with bold borders. It will be noted that fractions and isolates also are used in synthesis operations as raw materials for synthetic flavorings.

many years and, although still used in less-advanced regions and for some of the minor essential oils, the method has been displaced by steam distillation. However, it is in order to describe briefly the direct-heating distillation procedure. This involves placing the prepared plant materials in a boiler, with water completely covering over these materials. Heat is slowly applied until water commences to distill over. Initially, only steam will be formed and the distillate will be water clear. With continued heating, some of the essential oil will commence to distill over with the water, at which time the distillate becomes milky white. Distillation is continued until the distillate again becomes colorless. Codistillation like this is possible even though the essential oils have relatively high boiling points because, in accordance with Dalton's law, a mixture boils when the sum of the vapor pressures of the individual components equals the atmospheric pressure. This method is slow, requires close manual attention, and separation of the oil from water (usually by decantation) after the distillation is complete.

Steam distillation is widely used because it is somewhat faster, but still requires separation of the oil and water phases of the condensate. Steam under pressure is passed through and around the plant raw materials, volatilizing the oils which condense along with the water condensate. In another configuration, steam can be bled directly into the boiler. Steam distillation is sometimes called hydrodistillation. To avoid any thermal decomposition of flavoring substances, the steam pressure is increased gradually as the substances with the lower boiling points are volatilized. The distillation temperature with water or steam at atmospheric pressure is usually a bit under 100°C (212°F). The distillation temperature can be reduced some by drawing a partial vacuum on the still.

Vacuum distillation is preferred by many flavoring producers because it is more rapid than steam distillation. In this method, the drying and resinification of flavoring constituents is avoided because of the absence of air. The separation of closer-boiling-point materials is more effective under vacuum. Undesirable side reactions between constituents are avoided because of the relatively low temperatures required. Thus, many delicate substances can be handled without thermal degradation.

Rectification (fractional distillation) is used generally in those situations where a higher degree of separation and purity are desired. The products are known as *rectified essential oils*. Traces of water, solid and resinous materials, color bodies, and, depending upon the degree of rectification, terpenes and sesquiterpenes may be removed. Properly designed, a fractional distillation system can effect high purity of final product with only a loss of from 1.5 to 2.5% of the quantity of essential oil input. In deterpenization, the terpenes come off as head fractions. Manufacturers of high-quality flavorings generally prefer the well-defined chemical and physical constants obtainable with a terpeneless essential oil.

In rectification, a part of the vapor is condensed and the resulting liquid contacted with more vapor, usually in a column with plates or packing, by returning (refluxing) some of the condensate back to the column. Greater rectification is accomplished where the reflux ratio is high. In a practical way, this arrangement accomplishes what would otherwise require a series of stills in series. Where several fractions (different boiling points) are desired, these can be taken from different plates or height locations of the column. Heavier components, of course, collect in the lower portions of the column.

Molecular distillation is used for certain flavoring substances, such as fruit juices concentrates. This technique is used where the other methods do not effect the separations desired or cause thermal degradation. In this procedure, distillation is carried out at very low pressures (of the order of 0.001 millimeters). A molecular still is distinguished by the fact that the distance from the surface of the liquid being vaporized and the condenser is less than the mean free path (the average distance traveled by a molecule between collisions) of the vapor at the operating temperature and pressure. This distance is usually of the order of magnitude of a few inches (several centimeters). Close separations are often required in the preparation of fractions and isolates of essential oils that are to be used in the preparation of synthetic flavorings.

It will be noted from flowsheet (Fig. 8) that tinctures, extracts, and absolutes are produced by extraction rather than distillation. Extraction involves the use of alcohol or other solvents. After thorough disintegration of the plant raw materials, the oils are dissolved in the selected solvent, after which the liquid-solid mass remaining is filtered. A tincture is more dilute than a fluid extract and usually less volatile. Some food processors prefer these qualities for certain situations. In other cases, a much more concentrated fluid product (*extract*) or a solid or semisolid (*concrete*) extract is desired. Thus, after filtering, part of the alcohol will be removed by vaporization, leaving a much more concentrated fluid. There are differing degrees of concentration. Most of the familiar extracts found at retailers (almond, lemon, vanilla, etc.) are essential oils dissolved in an alcohol-water mixture. A concrete may be defined as a waxy solid obtained by extraction with a nonpolar solvent after trace quantities of solvent have been removed. When a concrete is dewaxed by a properly selected second solvent, the desired essential oil remains, this latter substance being called an *absolute*.

Oleoresins. To the food processor, an oleoresin represents a flavoring substance midway between the spices and the essential oils. Oleoresins are usually solid and tacky substances at room temperature and soft and sticky at elevated temperatures. Using various spices as starting ingredients, a volatile solvent is percolated through the ground mass, followed by vacuum removal and recovery of the solvent. Generally, oleoresins are uniform and provide a concentrated flavoring power as contrasted with the spices. Oleoresins represent less bulk for the processor to handle (no celluloses as in spices), but they tend to impart less color to a food product (small quantities required because of flavoring concentration) and not all flavor notes may be extracted during their manufacture. Sometimes the manufacturer will add small amounts of essential oils to their oleoresins to provide a more full-bodied flavoring. Oleoresins are also prepared from some spices, such as turmeric and paprika, not for their flavoring, but more for their coloring. Oleoresins of these two spices are commonly used, for example, in French-type salad dressings.

Natural Fruit Flavorings. The production of nine categories of flavorings from citrus fruits is illustrated by the flowsheet of Fig. 9. As pointed out in the section on "Ice Cream" in entry on **Milk and Dairy Products**, the kinds of flavors associated with fruits, including citrus fruits, are extremely popular. The production of essential oils, as shown by Fig. 9, is accomplished by way of steam distillation (as previously described) and also by expression. Almost from antiquity, the juices from fruits have been squeezed out through the application of pressure. Hand presses, for example, date back at least 2 or 3,000 years. Modern presses are hydraulically operated. Worm devices, similar to extruders, are also used and are generally called expellers. Rasping, a form of grating, is also used. See also entries on citrus fruits.

Preparation of fruit flavorings from fruits other than citrus show some variations as indicated by flowsheet (Fig. 10). One major difference is the requirement for depectination.

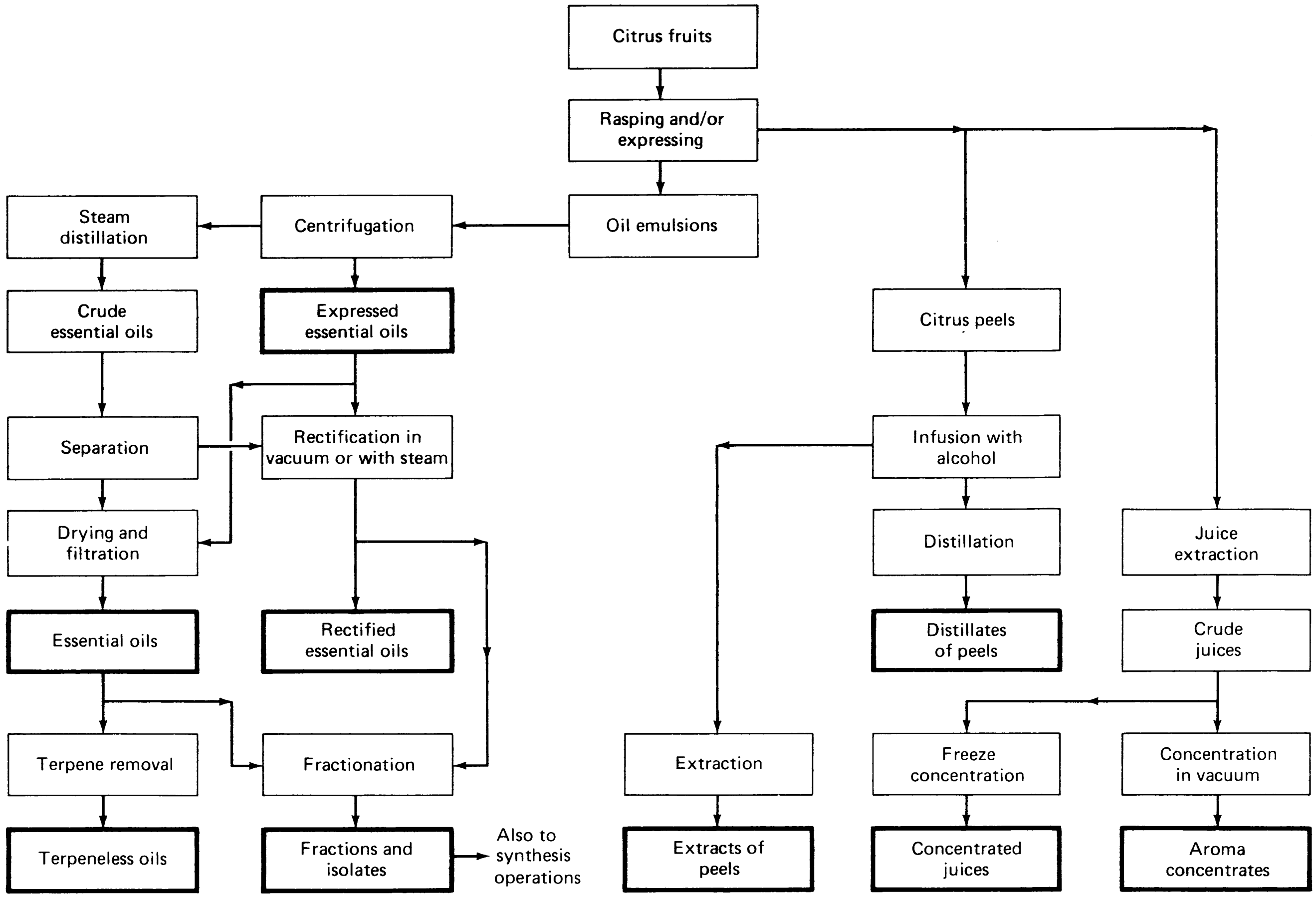


Fig. 9. Production of 9 categories of flavorings from citrus fruits. These are products prior to final compounding and approval by the manufacturer's flavor quality control center. It will be noted that expressed essential oils also serve as a raw material for rectified essential oils as well as fractions and isolates which are also used in synthesis operations as raw materials for synthetic flavorings. All final products are shown in boxes with bold borders.

Flavor Potentiators

Very closely associated with the production and use of flavorings are various flavor enhancers or potentiators. See **Flavor Enhancers and Potentiators.**

References

Amoore, J. E., Johnston, J. W., Jr., and M. Rubin: The Sterochemical Theory of Odor, *Sci. Amer.* (February, 1964).

Beck, L. H.: "A Quantitative Theory of the Olfactory Threshold Based upon the Amount of the Sense Cell Covered by an Adsorbed Film," *Amer. New York Academy of Sciences,* **116,** 448 (1964).

Beets, M. G. J.: "Structure and Odor," in *Molecular Structure and Organoleptic Quality, Society of Chemical Industry* (London) (1961).

Beets, M. G. J.: "Odor and Molecular Constitution," *Amer. Perf.,* 76, 54 (1961).

Beets, M. G. J.: "Some Aspects on the Problems of Odor," *Parf. Cosm. Savons,* 5, 4 (1962).

Davies, J. T., and F. H. Taylor: "Olfactory Thresholds: A Test of a New Theory," *Perfum. Essent. Oil Rec.,* 46 (1) 15 (1955).

Demerdache, A., and R. H. Wright: "Low-frequency Molecular Vibration in Relation to Odor," in *Olfaction and Taste,* (T. Hayaski, Editor), Vol. 2, Pergamon, New York (1967).

Dethmers, A. E.: "Utilizing Sensory Evaluation to Determine Product Shelf Life," *Food Technology,* 33 (9) 40–42 (1979).

Dorland, W. E., and J. A. Rogers, Jr.: "The Fragrance and Flavor Industry," Dorland, Mendham, New Jersey (1977).

Dravnieks, A.: "Comparison of Theories on Relations between Odor Parameters and Other Properties of Odorants," *NATO Advanced Study Institute on Odor Theories and Odor Measurements,* Robert College, Blebes, Istanbul, Turkey (1966).

Dyson, G. M.: "Raman Effect and Concept of Odor," *Perfum. Essent. Oil Rec.,* 28, 13, (1937).

Furia, T. E., and N. Bellanca: "Fenaroli's Handbook of Flavor Ingredients," CRC Press, Cleveland, Ohio (1971).

Furia, T. E.: "Handbook of Food Additives," 2nd Edition, CRC Press, Cleveland, Ohio (1972).

Heath, H. B.: "Flavor Technology," Avi, Westport, Connecticut (1978).

Hodgson, E. S.: "Taste Receptors," in *The Encyclopedia of Biochemistry* (R. J. Williams and E. M. Lansford, Jr., Editors), Van Nostrand Reinhold, New York (1967).

Johnston, J. W., and A. Sandoval: "Organoleptic Qualities and the Stereochemical Theory of Olfaction," *Proc. Sci. Sect. Toilet Goods Assoc,* 34 (1960).

Johnston, J. W.: "Judgments of Odorant Similarity and Dissimilarity," *Proc. Sci. Sect. Toilet Goods Assoc.,* 44, 32 (1965).

Katz, M. H., and G. Jacobson: "Flavor Chemistry," Symposium, *39th Annual Institute of Food Technologists,* Saint Louis, Missouri (1979).

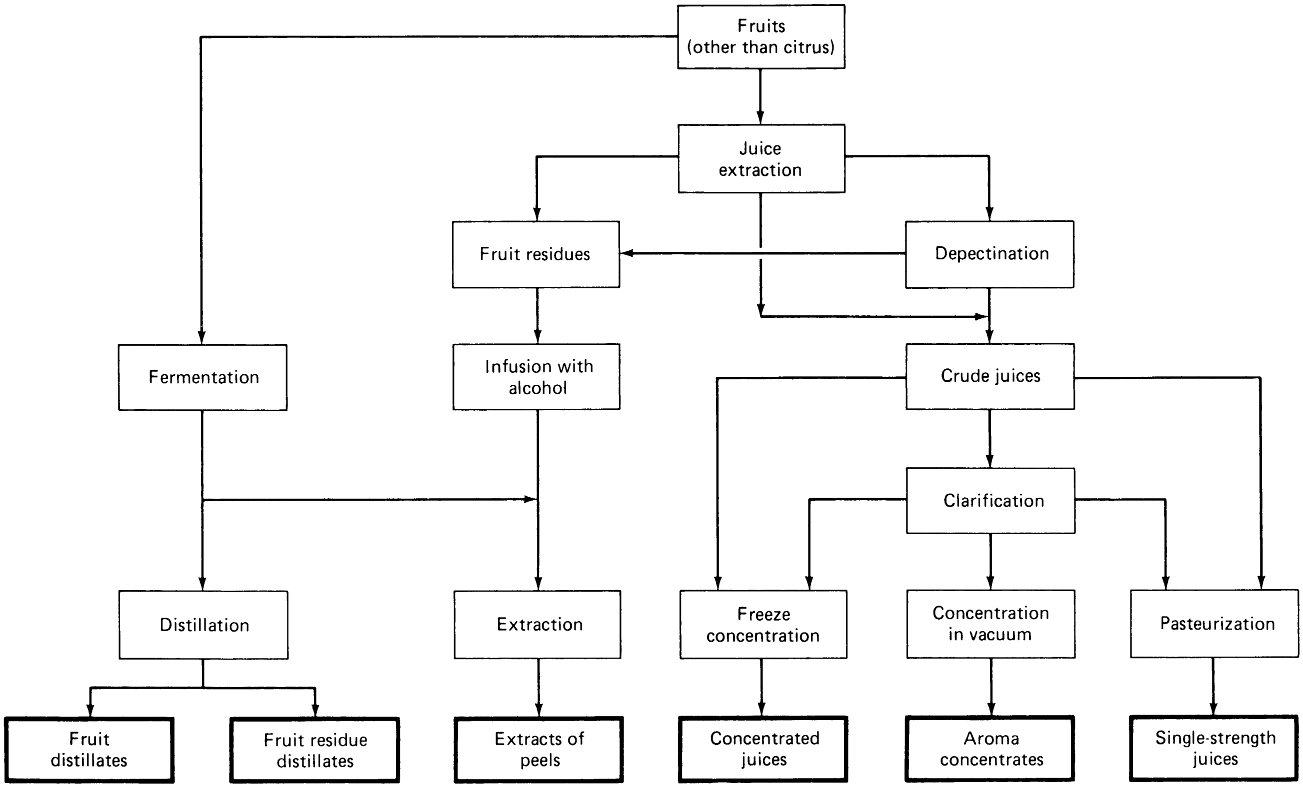


Fig. 10. Production of 6 categories of flavorings from fruits (other than citrus). These are products prior to final compounding and approval by the manufacturer's flavor quality control center. All final products are shown in boxes with bold borders.

Kazeniac, S. J.: "Flavor Trends in New Foods," *Food Technology*, **31** (1) 26-28, (1977).

Nakayama, M., and C. Wessman: "Application of Sensory Evaluation to the Routine Maintenance of Product Quality," *Food Technology*, **33** (9) 38-39, 44 (1979).

Naves, Y. R.: "The Relationship between the Stereochemistry and Odorous Properties of Organic Substances," in *Molecular Structure and Organoleptic Quality*, Society of Chemical Industry (London) (1957).

Reece, R. N.: "A Quality Assurance Perspective of Sensory Evaluation," *Food Technology*, **33** (9) 37 (1979).

Staff: "Food Chemicals Codex," National Academy of Sciences, Washington, D.C. (1972) (Supplements issued periodically).

Staff: "Essential Oils," U.S. Department of Agriculture, Washington, D.C., *Foreign Agriculture Circular* (Issued periodically).

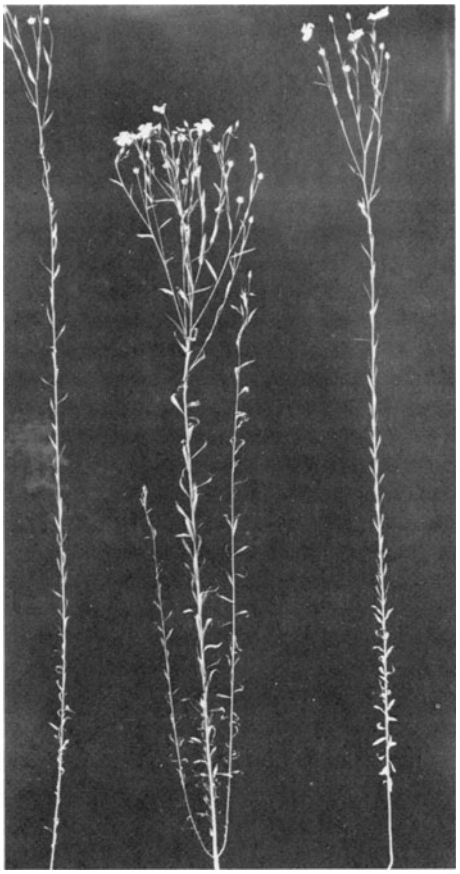
Wolfe, K.: "Use of Reference Standards for Sensory Evaluation of Product Quality," *Food Technology*, **33** (9) 43-44 (1979).

Wright, R. H.: "Odor and Molecular Vibration, 1: Quantum and Thermodynamic Considerations," *J. of Appl. Chem.* (London), **4**, 611 (1954).

Wright, R. H., and K. M. Michels: "Evaluation of Far-infrared Relations to Odor by a Standard Similarity Method," *Amer. New York Academy of Sciences*, **116**, 535 (1964).

FLAVOR PROFILE. Sensory Evaluation.

FLAXSEED. Of the family Linaceae, the flax plant, *Linum usitatissimum,* is grown for both its fibers and seeds. Some authorities believe that the fibers of this plant were among the first vegetable fibers to be used by humans. Picture writings at Thebes not only show the plant, but also give details of the processes used in making cloth from the fibers. Mummy cloths were often made of linen. Of interest



Specimens of flax plant (*Linum usitatissimum*) (USDA photo)

WORLDWIDE PRODUCTION OF FLAXSEED (LINSEED)[1]

Continent	Production (1000 Metric Tons)	Percent of World Total
Africa	78	3.1
North and Central America	492	19.4
South America	706	27.9
Asia	702	27.7
Europe	169	6.7
Oceania	25	1.0
U.S.S.R.	360	14.2
	2532	100.0
Country		
Argentina	630	25.0
India	621	24.6
U.S.S.R.	360	14.2
Canada	297	11.7
United States	187	7.4
Uruguay	62	2.4
Ethiopia	50	2.0
Rumania	43	1.7
China	41	1.6
France	40	1.6
Poland	37	1.5
Egypt	24	0.9
Hungary	20	0.8
Australia	16	0.6
Afghanistan	16	0.6
Brazil	13	0.5
Czechoslovakia	12	0.5
New Zealand	10	0.4
Mexico	8	0.3
Turkey	8	0.3
Bangladesh	7	0.3
Netherlands	6	0.2
Pakistan	4	0.2
Iran	3	0.1
All others	11	0.4

[1] 1976 statistics available in 1979.

to the food field are the seeds, from which a valuable oil, *linseed oil*, can be pressed. The seeds are about 40% oil. The seeds are crushed, heated to about 165°F (74°C), and extracted with a solvent, such as naphtha. In older methods, screw presses operating at very high pressures express the oil from the seeds. Linseed oil is essentially an industrial and technical oil, but the oil cake residuals can be used in livestock feeding diets. See entry on **Feedstuffs**. Worldwide production of flaxseed is given in the accompanying table. From 80 to 85% of the flaxseed produced in the United States comes from Minnesota, North and South Dakota, Montana, and Iowa. The crop needs a generous supply of moisture while growing, but does best in relatively dry weather during ripening. The flax plant, as shown in accompanying figure, is relatively slender and produces few stems with narrow leaves, thus making it a rather poor competitor with weeds. Flax is harvested in the same general manner as the other small grains, that is, with a combine, binder, or header. Direct combining is the most economical method. Principal diseases of the flax plant include wilt, rust, pasmo disease, and anthracnose, all of a fungal nature. Rust is most effectively controlled by planting rust-resistant varieties, crop rotations, and early seedings. Among the fungicides used against the aforementioned diseases are captan, mancozeb, maneb, and zineb. Treatment of seed prior to planting with hexachlorobenzene fungicide or phenyl mercuric acetate can be effective.

Of the major high-protein meals produced worldwide, linseed meal ranks seventh, representing (in 1979) only 1.6% of the world total.

References

Leonard, W. H., and J. H. Martin: "Cereal Crops," Macmillan, New York (1963).

Staff: "Production Yearbook," Food and Agriculture Organization of the United Nations, Rome, Italy (revised annually).

Staff: "Agricultural Statistics," U.S. Department of Agriculture, Washington, D.C. (revised annually).

Note: See also list of references at end of entry on **Oilseeds and Related Products.**

FLEA (***Insecta, Siphonaptera***). Small insects with transversely compressed bodies, sucking mouths, and no wings. They live as bloodsucking ectoparasites in the adult stage on the bodies of mammals and less frequently on birds. They progress chiefly by leaping. They have well-developed legs and possess great jumping ability (13 inches; 32.5 centimeters by some species in a single leap). The adults have short stout antennae and their mandibles are long and saw-toothed. The larvae have biting mouths and eat fragments of organic matter in the debris about the sleeping places of the hosts. The larvae are not parasitic. Stages in the development of the flea are egg, larva, pupa, and adult. The eggs are tiny, with a yellow coloration. An average flea is about 1/8-inch (3 millimeters) long. Although fleas principally affect humans, dogs, cats, and rats, they also can be serious pests to poultry and other animals about the farm. In addition to their severe annoyance, fleas are carriers of serious diseases, the best known of which is the plague. Specific kinds of fleas include:

Human flea (*Pulex irritans*). Frequently bites around the legs and there may be 3 or 4 bites in a line. As contrasted with ticks and lice, fleas move from one host to the next. This flea also is found on hogs and commonly breeds in hog houses, as well as on dogs, cats, goats, domestic rats and some wild animals, such as skunks, coyotes, and badgers. This species is most often found in the Mississippi Valley, in Texas, and westward to the Pacific Coast.

Dog flea (*Ctenocephalides canis*) and **cat flea** (*C. felis*) are probably the most widespread of all fleas and will attack other animals and humans.

Northern rat flea (*Nosopsyllus* or *Ceratophyllus fasciatus*) (Bosc). This insect occurs in the northern United States and it is estimated that fleas of this species on rats in that region will predominate (about 70%).

Sticktight flea (*Echidnophaga gallinacea*). This insect infests poultry and occasionally annoys humans and pets in the southern United States. Young chickens and other poultry are sometimes killed by heavy infestations.

Oriental rat flea (*Xenopsylla cheopis*). Although widely distributed throughout the United States, the insect is most abundant in southern California and the southern United States. In these regions, about half of the fleas found on rats are of this species. The rat flea is capable of transmitting murine or endemic typhus from rats to humans. This disease, known as *Rickettsia typhi,* differs from Old World typhus. A very large percentage of the cases of this disease reported occur in the regions where the oriental rat flea is present. This species also serves as an intermediate for communicating dog tapeworm (*Dipylidium caninum*).

Chigoe flea (*Tunga or Dermatophilus penetrans* [Linne]). A tiny, red-to-brown flea found in the West Indies, Mexico, and some of the southern United States. This insect, about 1/25-inch (1 millimeter) in length, attacks humans, hogs, and domestic animals. Their habits and life cycle parallel those of other fleas, and they depend upon animal blood for their existence. They develop in the soil or in filthy debris. When abundant, the flea can be a severe pest to pigs and dairy animals. In humans, the flea tends to penetrate the body by way of the skin between toes and under fingernails and the wound can be quite painful. The sore produced frequently becomes infected. The body of the flea must be removed with sterile instruments. When the female chigoe flea is full of eggs, she may be as large as a small pea. The chigoe flea must not be confused with the chigger, another small and annoying insect. See **Chigger.**

Control Measures. Malathion, methoxychlor, rotenone, or pyrethrum (pyrethrins) are used for killing fleas on dogs and cats. For destroying fleas in dairy barns and poultry houses, malathion is often used. Other control chemicals useful in combating fleas are given in Table 1 under **Insecticide.**

FLEA-BEETLE (*Insecta, Coleoptra*). These insects are found on several crops and tend to be specialists. The **apple flea-beetle** (*Graptodera foliacea*) is tiny, about 1/5-inch (5 millimeters) in length or less, of a brassy-green color, and is a leaf feeder. The species (*Halticini*) attacks beet, cabbage, horseradish, potato, and tomato. This beetle is small and of the jumping type. The beetle attacks the leaves of the plant, producing large numbers of holes and ultimately destroying the leaves. The **grape-vine flea-beetle** (*Graptodera chalybea*) is about 1/4-inch (6 millimeters) in length, is of a blue metallic color, and feeds on buds and tender shoots of the vine in the spring. Treatment for these beetles is usually the application of chemicals to kill the grubs. Mechanical means of shaking the vine can also be effective, particularly for comparatively small plantings.

Flea.

Several chemical insecticides used for treating flea-beetles are listed in Table 1 in entry on **Insecticide.**

FLINT CORN. Maize (Corn).

FLOOD. Soil Conservation.

FLOODED FIELD. Rice.

FLOOD IRRIGATION. Irrigation.

FLOOR MALTING. Malt.

FLOR. Sherry; Wine.

FLOUNDER. Antioxidants; Aquaculture; Seafoods; (Nutritional Aspects).

FLOUR. Bread and Bakery Products; Fiber (Dietary); Irradiated Food Products; Maize (Corn) Processing; Oat; Protein; Rice; Rye; Sorghums; Wheat.

FLOUR (Soy). Bread and Bakery Products; Soybean; Soybean Processing.

FLOUR MITE. Mite.

FLOW-DIVERSION VALVE. Milk and Dairy Products; Thermal (heat) Preserving.

FLOWER. That part of a plant which is involved in the sexual reproductive process of angiosperms. The formation of the flower is preliminary to the production of fruit with its seeds.

Flowers may be borne at the tip of a stem or a branch, in which case they are said to be terminal flowers. Or they may be borne in the axils of leaf primordia and called axillary. In very many plants the structure which subtends the flower does not develop into a leaf like the other leaves of the plant. Instead, it may remain very small and inconspicuous, or it may grow larger, but be of shape quite unlike that of an ordinary leaf. These structures which subtend flowers are called bracts. In a few plants the bracts are large and brilliantly colored, so that at times they are much more showy than are the flowers. The scarlet bracts of the *Poinsettia* and the white or pink bracts of the flowering dogwood are examples. See Fig. 1. In many monocotyledons, as palms and arums, there is a single large bract which subtends and often more or less surrounds the flowers. Bracts of this kind are called spathes. The striped "pulpit" of the Jack-in-the-Pulpit and the white bract of the calla lily are well-known examples. The bract may surround and protect the flower in the bud.

Flowers may be borne singly or they may be associated in a cluster which is known as an inflorescence. See Fig. 2. A single flower is called a solitary flower, and the stalk which supports it is a peduncle. The stem which supports an inflorescence is also a peduncle, while the individual flowers of the inflorescence are supported on pedicels. When there is a distinct axis extending through an inflorescence it is called a rachis. The arrangement of the flowers of an in-

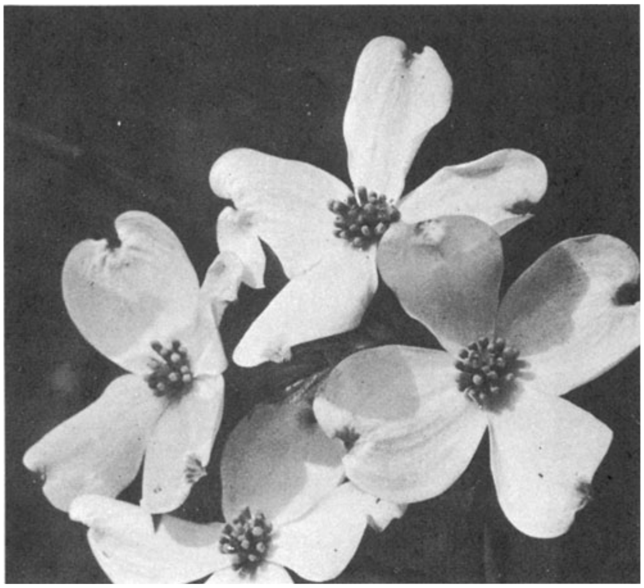


Fig. 1. Blossom of the flowering dogwood tree.

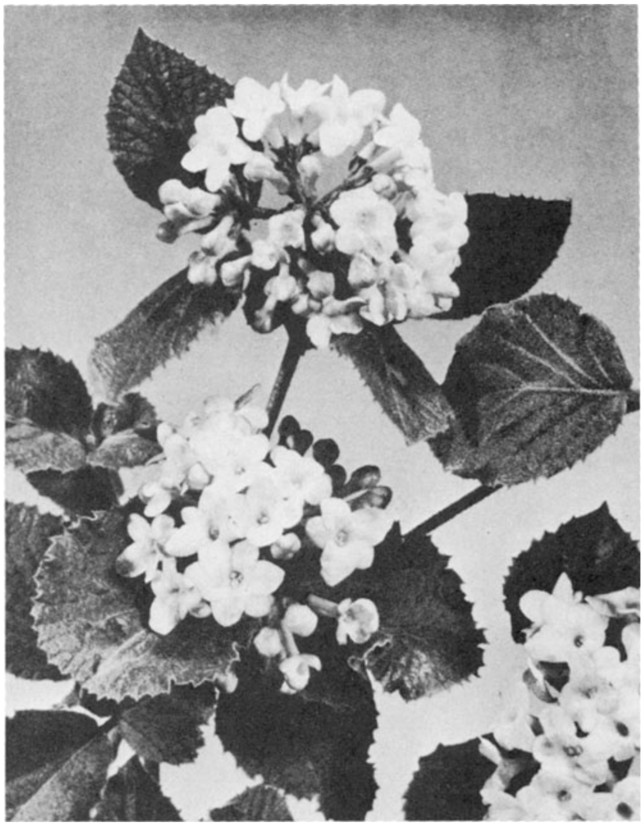


Fig. 2. The fragrant inflorescence of *Viburnum carlesi,* a flowering shrub, is sometimes called the pink snowball. (*Roche*)

florescence varies in different groups. A common, and primitive, form of inflorescence is the raceme, in which the floral shoot grows at the apex and bears many pedicels, each ending in a single flower. The first flowers to open are those at the base at the raceme. If, in an inflorescence of this sort, each branch is a raceme bearing several flowers, it is called a panicle, or a compound raceme. If the flowers of the raceme are borne directly on the main axis, the inflorescence becomes a spike. A secondary spike, common in grasses, is a spikelet. A catkin is a spike which droops. A corymb is a modified raceme in which the lower pedicels of the inflorescence grow faster than the upper ones, so forming a more or less flat-topped cluster. An umbel differs from a corymb in that it has no central rachis, all the pedicels of the inflorescence rising from a common point. More commonly umbels are compound, each of the main stalks of the inflorescence bearing an umbel at its tip. The inflorescence of the onion is an umbel, that of wild carrot a compound umbel. The inflorescence of the composite family is a head, which may be considered as an umbel in which the flowers are all sessile, without pedicels, on the apex of the stem. A cyme is an entirely different type of inflorescence. In the cyme the first flower to open is at the tip of the cluster. Below it on the stem are a number of bracts. From the axils of these bracts branches develop and also end in a flower. This successive branching may be many times repeated, but always the flower terminates the stem and opens. Combinations of these types of inflorescences are found in many plants. A spadix is an inflorescence of the spike form with elongated axis, sessile flowers, and enveloping leaf, the spathe.

A flower consists of an axis, called the receptacle or torus, and, attached thereto, the pistils, the stamens, the petals, and the sepals. See Figures 3 and 4. The pistils and stamens are the essential organs of the flower, the petals and sepals are accessory organs. Any flower which has all four organs is a complete flower, while that which lacks one or more is incomplete. If the organs missing be either stamens or pistils, the flower is imperfect or unisexual. A perfect or bisexual flower has both sets of essential organs. If only the stamens are present the flower is staminate; if only pistils, it is pistillate. If the two kinds of flowers, staminate and pistillate, are found on the same plant, that species of plant is monoecious. When the two unisexual flowers are found on different plants, the species is dioecious. Infrequently flowers are borne which lack both stamens and pistils, and are sterile. When the flower lacks sepals and petals, it is a naked flower.

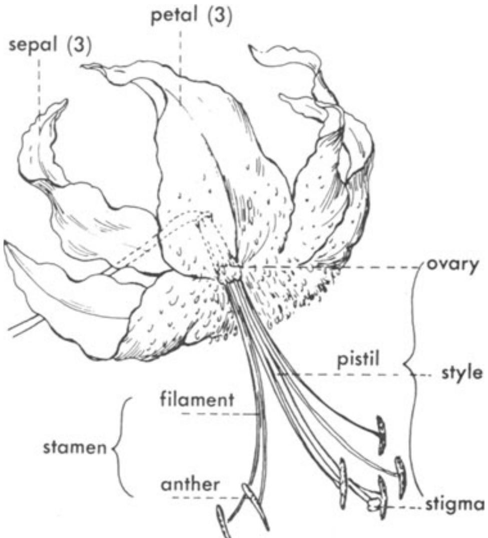


Fig. 3. Reproductive parts of a lily flower.

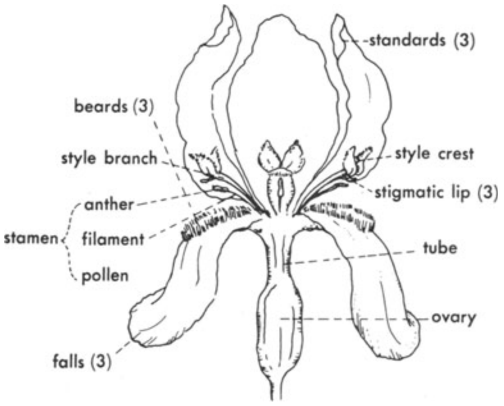


Fig. 4. Reproductive parts of an iris flower.

Flowers may also be distinguished as regular and irregular. Regular flowers are those in which all the members of any set of organs are alike, forming a flower which is radially symmetrical or actinomorphic. Often the organs of one or more sets are not alike, forming an irregular flower. An irregular flower may be bilaterally symmetrical or zygomorphic, one half being a mirror image of the other.

The accessory floral organs, the sepals and petals together, constitute the perianth. In the complete flower, the perianth is composed of a whorl of sepals which is called the calyx and inside the calyx a whorl of petals called the corolla. The sepals are usually green and small. The function of the calyx seems to be to protect the other parts of the flower before the flower bud opens. The petals are usually thin and bright colored or white. The term corolla is applied to all the petals together. The corolla appears in a wide variety of shapes and colors. Its function seems to be to attract animals, especially insects, to the flower and so bring about pollination. The number of sepals and petals is constant for each species of plant. In the flowers of monocotyledons there are usually three of each, while in dicotyledons it varies from four to many, with five a very common number. As a further attraction to insects, many flowers possess special glands called nectaries which secrete a sweet fluid, nectar. Usually these nectaries are situated at the bases of the petals, though they may be found in many other places in the flower. Nectaries known as extrafloral nectaries are found on petioles of leaves or on the stipules.

The stamens, or microsporophylls, taken together constitute the androecium. Usually a stamen consists of two parts, a stalk or filament and an anther. The filament may be short and stout, or more commonly long and slender, raising the anthers well above the base of the flower. The anther when first formed is an undifferentiated mass of cells. As it develops, four groups of cells become set off from the surrounding cells. In these masses, which usually appear as linear strands, certain cells undergo meiosis and become microspores. The sac which contains them is therefore a microsporangium. A microspore develops into a pollen grain. The anther sac, or sporangium, when mature usually opens by two longitudinal slits, or by special pores, and frees the pollen grains. The number of stamens in a flower varies from one to many. Often there are vestigial stamens, or staminodia, present in the flower; in some plants these are large and brightly colored, in others they are small and inconspicuous.

The pistil is the central organ of the flower. See Fig. 5. A single pistil or several pistils, which may be separate or partly, or even completely, united, is called a gynoecium. A pistil is composed of one or more modified leaves called carpels or megasporophylls. When there are two or more somewhat united carpels, the pistil is called compound. A pistil is composed of a basal ovary (ovulary), a terminal stigma, and usually an intermediate style, which is often long and slender. The stigma is a receptive organ, the surface of which is often either sticky or hairy. It is to the surface of the stigma that the pollen grains are carried when pollination takes place.

The style may be very much elongated to lift the stigma above the other parts of the flower and so increase the probability of pollination. The ovary has one or more cavities, or loculi. In these are located the ovules, which will become the seeds. The ovules, are attached to the wall of the ovary or to a central column by a small stalk called the funiculus, through which the developing ovule receives nourishment. That region of the ovary to which the ovules are attached is called the placenta. The number of ovules in a single loculus varies from one to many.

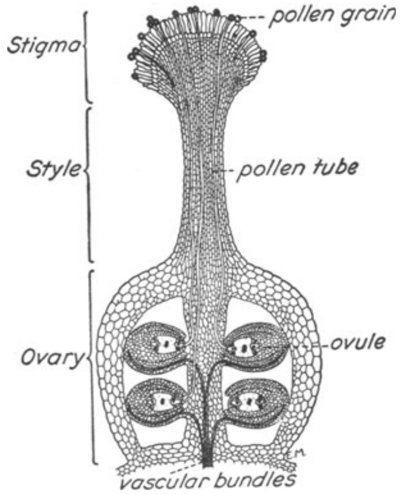


Fig. 5. Longitudinal section of flower pistil showing pollen tubes growing through the style and entering the ovules.

Each ovule first appears as a minute rounded projection on the wall of the ovary or the columella. See Fig. 6. In the early period of its development this projection consists of an undifferentiated mass of cells known as nucellar tissue. One or two layers of cells, known as the integuments, rise from the base of the projection and finally almost completely surround the nucellar tissue. A minute opening through the integuments, called the micropyle, is left connecting the cavity of the ovary to the surface of the nucellar tissue. Within the nucellar tissue a very important series of cell divisions has taken place. While there are many variations of the process as it occurs in different species, the process is essentially as follows. Within the mass of nucellar tissue a single cell has become differentiated from all the others by its larger size and denser cytoplasmic content. This is the megaspore mother cell. It divides twice in rapid succession to form a row of four cells. These two rapidly succeeding cell divisions take place in such a way that the four cells have the haploid or reduced number of chromo-

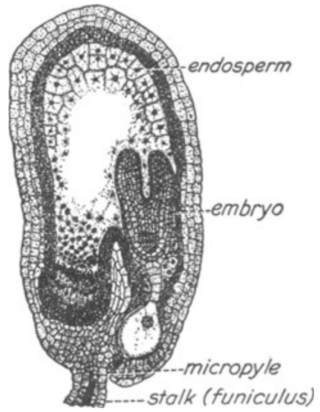


Fig. 6. Ovule of shepherd's purse, containing an embryo and endosperm. (From Chamberlain's *Elements of Plant Science*)

somes. The process is known as meiosis. Three of the four cells disintegrate and are lost. The fourth, or megaspore, is usually the one nearest the micropyle. It enlarges greatly, while by three successive divisions its nucleus divides to form eight nuclei, all contained within the wall of the very much enlarged female gametophyte, commonly called the embryo sac. The arrangement of these eight nuclei is quite uniform. In most plants there are four of them at each end of the embryo sac. See Fig. 7. One from each end moves to the center of the embryo sac, where they form an intimate association and eventually fuse. These two are the polar nuclei. Of the three nuclei which remain at the micropylar end of the embryo sac, one becomes larger than the other two. This is the egg nucleus or megagamete; the other two form cells which are called the synergids. The three nuclei at the opposite end of the embryo sac form cells called the antipodals. The mature embryo sac is thus a seven-celled body, with seven nuclei.

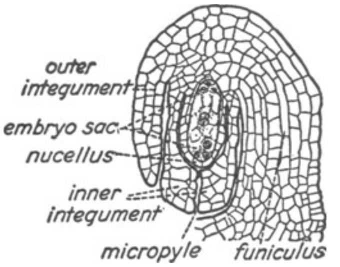


Fig. 7. Mature megagametophyte of lily within an ovule. (From Holman and Robbins *Textbook of General Biology and Botany*)

The pollen grain is carried to the stigma by various agents. The pollen grains of different species of plants are very characteristically shaped, and are often strikingly beautiful because of the many ridges or protuberances with which the outer wall is marked. See Fig. 8. At first a pollen grain contains a single nucleus. This nucleus divides before leaving the anther and gives rise to two nuclei, one of them called the tube nucleus and the other the generative nucleus. The pollen grain germinates when it reaches the stigma, putting out a slender pollen tube which grows down through the tissues of the style and into the ovary. In the pollen tube the generative nucleus divides to produce two sperm nuclei. There is grows towards an ovule, which it enters through the micropyle. The pollen tube continues to grow until its tip reaches the embryo sac. Into this the two sperm nuclei are discharged. One of them fuses with the egg nucleus of the embryo sac, while the other passes to the polar nuclei and fuses with them. The nucleus which is formed by the fusion of these three nuclei is called the primary endosperm nucleus; it contains three times the haploid chromosome complement. The act of fusion of the male nucleus with the egg nucleus is called fertilization. From the endosperm nucleus there is formed by repeated division and subsequent wall formation a mass of triploid tissue known as the endosperm, which surrounds the developing embryo. The endosperm nourishes the embryo during the early stages of its growth. In many plants such as the bean the endosperm is not formed at all or entirely absorbed by the developing embryo, while the seed is still immature; in others the endosperm forms a considerable part of the mature seed. Seeds with endosperm are known as albuminous seeds; those without endosperm as exalbuminous seeds.

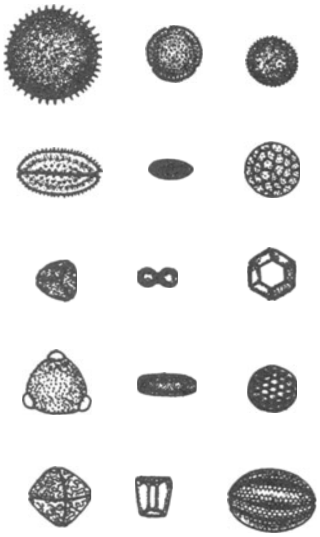


Fig. 8. Pollen grains of various kinds of plants. (*Botanical Gazette*)

The act of fertilization causes the immediate growth of the fertilized egg. In most plants a series of cell divisions takes place, forming a short filament of cells which is called the proembryo. The appearance of the proembryo varies in different plants. The terminal cell of the proembryo becomes by repeated cell divisions a spherical mass of cells which is the beginning of the true embryo. The embryo grows rapidly and becomes differentiated into three regions, a primitive root, or radicle, a primitive shoot, and cotyledons. This embryo is surrounded by the tissues of the nucellus and the integuments, which have grown larger to form seed coats coincident with the growth of the embryo. The mature ovule becomes the seed, and the ovary which contains it becomes the fruit. See **Pollination.**

For related topics, see list of terms in entry on **Botanical and Biological Terms.**

FLUME. Irrigation.

FLUORESCEIN DYES. Colorants.

FLUORIDATION. Fluorine.

FLUORIDES. Meat; Appendix 2, Table 2.

FLUORINE. A member of group 7a (halogens) of the chemical elements and it appears in the periodic table associated with chlorine, bromine, iodine, and astatine. In nature, fluorine is found combined with other elements in compounds called fluorides. Fluorides are not required for plant growth, but in animals, including humans, low levels of fluorides have beneficial effects on teeth and on bone structure. Growth increases in experimental animals have been reported when low levels of fluorides have been added to purified diets.

Excessive levels of certain fluorine compounds are very toxic to both animals and plants. Fluoride substances have been demonstrated to show toxicity in both animals and plants and pose a serious problem when encountered in fumes and dusts from industrial facilities as well as natural emissions from the eruption of volcanoes. Abnormally high levels of fluoride in water also have caused fluorine toxicity in animals and mottled teeth in humans.

Fluorides do not usually move from the soil to plants and on to livestock feedstuffs and human foodstuffs in amounts that are toxic. Injury to plants from fluoride in the soil has been noted in soils that are too acid for satisfactory growth of most plants. On limed soils or soils with sufficient calcium for optimum growth, any fluorine added to the soil reacts with the calcium and other soil constituents to form insoluble compounds, which are not taken up by the plants. Rock phosphate and some kinds of superphosphate fertilizers contain large amounts of calcium fluoride, but the fluorine content of the plants grown on soils that have been heavily fertilized with these phosphates is not appreciably increased. Tea and some other members of the *Theaceae* family are the only plants that take up very much fluorine from the soil.

The soil-to-plant segment of the food chain contains some built-in safeguards against fluorine toxicity. This toxicity has been due to the deposition of airborne fumes and dusts on the aboveground parts of plants, followed by the consumption of these contaminated plants by animals, including humans. Also, fluorine toxicity has been caused by direct inhalation of the fumes and dusts, or by drinking water with high fluorine levels. If the fumes and dusts are mixed into the soil, they will be inactivated and will not find their way into the food chain in toxic amounts.

The safeguards against toxicity provided by the chemistry of fluorine in soils make it unlikely that applying fluorine-containing compounds to soils will be a useful way to insure that plants will contain sufficient fluorine to prevent dental caries. (As pointed out later, tea and mechanically deboned meats may contribute to needs.) When increased fluoride intake is desirable for this purpose, carefully controlled direct additions to drinking water, to dentifrices, or to specific foods are more promising than adding fluorides to soils that produce food crops.

Fluoridation. In a broad sense, this term would signify the addition of fluorine to a substance much as chlorination means the addition of chlorine. In a more specific, but commonly used sense, fluoridation means the addition of very small amounts of a fluoride-containing compound to water supplies for the purpose of preventing dental caries. It has been shown over a number of years that the introduction of about 1 part per million (ppm) of fluoride to drinking water will reduce the incidence of tooth decay in children by as much as 60% as compared with similar groups of children who consume nonfluoridated water. Because of the striking nature of these findings a few cities in the United States commenced experimental treatment of water supplies during the mid-1940s. As of the early 1980s, it is estimated that close to 100 million persons are now supplied with fluoridated water.

The commonly used compound is sodium fluoride or sodium silicofluoride in a dry crystalline or powdered form. Hydrofluosilicic (fluosilicic) acid is also used in the liquid form. Inasmuch as concentrations of fluoride in excess of 1.5 ppm may cause mottling of tooth enamel, it is mandatory to exercise very careful control to maintain the desired 1.0 ppm dosage. Water supply samples are frequently tested by municipal authorities. Fluoride concentrations may be determined by colorimetric or electrometric methods and the latter can be adapted to continuous reporting and controlling purposes.

The concept of fluoridation has created numerous controversies among the populace, a situation that occurs frequently when decisions to install fluoridation systems for the first time are under consideration. Until the mid-1970s, it was believed that such practice was unquestionably safe and that arguments against fluoridation were essentially emotionally motivated. However, some second thoughts are now being taken, particularly with reference to possible reactions of fluorine with certain pollutants, now found in raw water supplies, that once were not present.

Feedstuffs. Excessive amounts of fluoride in the soil can cause tooth and bone damage in livestock. Parts of Arkansas, California, South Carolina, and Texas, in the United States, have soils abnormally high in fluorine content. In serious situations, diarrhea and emaciation will be exhibited by the livestock. The effects depend upon the fluorine source and species. Exceptionally high fluoride levels can be encountered near smelters where pollution safeguards have not been installed or are ineffectively maintained. As compared with other livestock, pigs can tolerate much more fluorine (up to nearly 300 ppm) when it is derived from rock phosphates. See also **Feedstuffs.**

Fluorine in Tea. The majority of foods found in the average diet contain 0.2–0.3 ppm or less fluorine in the food as consumed. Tea and seafoods are notable exceptions (McClure, 1949). Different values are reported for fluorine content of various teas by different investigators (Wang *et al.*, 1949; Fabre and de Campos, 1950; de Campos, 1950; Zimmerman *et al.*, 1957; Quentin *et al.*, 1960; Stankoviansky and Biely, 1965; Okada and Furuya, 1969; Cook, 1970; Venkateswarlu and Sita, 1971). The fluorine content of tea depends upon the origin of the plant, the type of soil and fertilizer, the age of the leaves and the time of harvesting (Wang *et al.*, 1949; Zimmerman *et al.*, 1957; Garber, 1962; Okada and Furuya, 1969).

In 1978, Farsam and Ahmadi (Department of Pharmaceutical Chemistry, University of Teheran, Teheran, Iran) undertook a study to find out the fluorine content of teas consumed in Iran and to evaluate the potentiality of tea as a contributor of fluorine. Tea is an important item in the Iranian diet and it is drunk mostly by laborers and peasants; furthermore, diluted infused tea is used as a supplement in between breast feedings of infants. The investigators concluded that, considering the optimal intake of fluorine of 1 milligram per day suggested for protection from dental caries, the drinking of tea in Iran provides about half of this amount without considering the fluorine content of water and other sources. The habit of tea drinking and feeding infants with diluted tea may account for some dental benefit in Iran.

Fluorine Content of Mechanically Deboned Beef and Pork. One question that has arisen from time to time in connection with mechanically deboned meat (MDM) is its possible fluoride content, because some microscopic bone particles are present. Investigators Kruggel and Field (Division of Biochemstry and Division of Animal Science, University of Wyoming) made a study of this in 1976. Samples were collected from regions where high levels of fluoride occurring in the water and vegetation have been reported. Higher magnesium, iron, and fluoride contents were found in beef MDM from the western and midwestern regions of the United States when compared to the southern region. Higher iron and fluoride contents were found in beef MDM as compared with pork MDM. Among a number of conclusions drawn—the consumption of fluoride from MDM and other foods combined would be far below the 20–80 milligrams or more of fluoride that must be consumed daily to produce toxicity (Food and Nutrition Board, 1974). Mottling of the teeth in children has been observed at fluoride concentrations in the diet and drinking water of 2–8 ppm. A frankfurter containing 10% MDM would contain about 1.7 ppm fluoride. Since the daily fluoride intake in many areas of the United States is not sufficient to afford optimal protection against dental cavities (Food and Nutrition Board, 1974), products which contain MDM should be of value in furnishing needed fluoride and in reducing the incidence of tooth decay (Kruggle/Field, 1977).

References

Allaway, W. H.: "The Effect of Soils and Fertilizers on Human and Animal Nutrition," Cornell University Agricultural Experiment Station and U.S. Department of Agriculture, Washington, D.C., *Agriculture Information Bulletin 378* (1975).

Baker, R. L.: "Determination of Fluoride in Vegetation Using the Specific Ion Electrode," *Analytical Chemistry,* **44,** 1326 (1972).

de Campos, P.: "Fluorine Content of Tea Cultivated in São Paulo," (in *Chem. Abstr.* 1952, **44** (22): 11498).

Cook, H. A.: "Fluoride Intake through Tea by British Children," *Fluoride Quart. Rept.* **3,** 12 (1970).

Fabre, R., and P. de Campos: "Distribution of Fluorine in Plants—Tea Leaves," *Ann. Pharm. Franc.* **8,** 391 (1950).

Farsam, H., and N. Ahmadi: "Fluorine Content of Teas Consumed in Iran," *J. of Food Science,* **43,** (1) 274–275 (1978).

Garber, K.: "Plants and Fluorine" (in German). ("Qualitas Plant, Mater, Vegetables," **9**: 33 (in *Chem. Abstr.* 1962, **57** (2): 2589).

Kirchgessner, M., Editor: "Trace Element Metabolism in Man and Animals-3," Institut für Ernahrungsphysiologie, Technische Universität München, Freising-Weihenstephan, Germany (1978).

Kruggel, W. G., and R. A. Field: "Fluoride Content of Mechanically Deboned Beef and Pork from Commercial Sources in Different Geographical Areas," *J. of Food Science,* **42,** (1) 190–192 (1977).

McClure, F. J.: "Fluoride in Foods," U.S. Public Health *Report 64,* 1061 (1949).

Okada, F., and K. Furuya: "Fluoride Content in Tea" (in Japanese), "Chago Gijutsu Kenkyu" **37**: 32 (in *Chem. Abstr.* 1966, **71** [23]: 245).

Quentin, K. E., *et al.*: "Analytical Determination of Small Amounts of Fluorine in Foods and Waters. 4. Fluorine Studies in Food (in German)," Lebensym-Untersuch. U. -Forsch. **3**: 173 (in *Chem. Abstr.* 1960, **54** [6]: 5967).

Sax, N. I.: "Dangerous Properties of Industrial Materials," Van Nostrand Reinhold, New York (1979).

Staff: "Recommended Dietary Allowances," Food and Nutrition Board, National Academy of Sciences, Washington, D.C. (1974).

Staff: "Effects of Fluoride in Animals," National Academy of Sciences, Washington, D.C. (1974).

Underwood, E. J.: "Trace Elements in Human and Animal Nutrition," 4th Edition, Academic Press, New York (1977).

Venkateswarlu, A., and P. Sita: "A New Approach to the Microdetermination of Fluoride Adsorption-Diffusion Techniques," *Analytical Chemistry,* **43,** 78 (1971).

Waldbott, G. L.: "Fluoride in Food," *American J. Clin. Nutrition,* **12,** 455 (1963).

Wang, T. H., *et al.*: "Fluorine Content of Fukein Teas," *Food Research,* **14,** 98 (1949) (in *Chem. Abstr.* 1950, **44** [7]: 3174).

Zimmerman, P. W., *et al.*: "Fluorine in Food with Special Reference to Tea (in German," Contribs Boyce Thompson Inst. **19**: 49 (1957) (in *Chem. Abstr.* 1958, **52** (1): 610).

FLUOROMETRIC ANALYSIS. Ascorbic Acid (Vitamin C); Pistachio; Riboflavin; Vitamin B_6.

FLURENOL HERBICIDE. A morphactin type postemergence, selective herbicide, developed in Germany* in the late 1960s, for use on various cereal crops. The compound normally is sold mixed with other herbicides, particularly of the phenoxy type. The compound is effective against a number of undesired plants and weeds, including:

charlock
cleave
hemp
lambsquarters
nettle
radish (wild)
shepherd's purse
weed (chick)

The compound is not actively marketed in the United States.

The chemical name of Flurenol is butyl-9-hydroxyfluorene-(9)-carboxylate.

Other designations: *Flurecol.* Representative of blends incorporating *Flurecol* are: *Anitem-M* (*Flurecol* and MCPA); and *Antinen-D* (*Flurecol* and 2, 4-D herbicide).

FLY. A two-winged insect belonging to the order Diptera. See **Diptera.** Flies are probably responsible for the transmission of more infectious diseases than any other insect. Flies are also responsible for tremendous damage to food crops, mainly through the action of their larvae. True flies have only one pair of wings.

FOAM INHIBITOR. Defoaming Agents.

FOAMING AND WHIPPING AGENTS. A foam is a dispersion of a gas in a liquid or solid. The gas globules may be of any size, from colloidal to macroscopic. Bakers' bread is an example of a solid foam. In various food products, such as whipped cream, eggwhite, and ice cream, foams may be

---

*E. Merck, AG.

induced by mechanical incorporation of air into the product. Various chemical substances tend to favor or inhibit the development of a foam. Thus, the frequent requirement for foaming or defoaming agents. Whereas a foam or whipped texture is desirable in some foods, such as those just mentioned, the development of a foam in other cases may have a deterrent effect on processing and the final product. See **Defoaming Agents.** Sometimes the production of a given food product will require consideration of both foaming and defoaming or antifoaming substances. For example, foam control agents are required in the manufacture of sugar from beets. Unless the content of foam control agent in the final sugar product is carefully monitored, the presence of the substance can cause severe problems when later used in breadmaking. Similarly, in brewing, the "head" on beer, when controlled within proper parameters, is a desirable feature of the product. But, brewers during the fermentation operations, usually add defoaming agents to improve fermentation throughput and reduce cleaning operations, among other advantages. A foam control material for use in breweries must have the ability to control foam during fermentation, but it also must be capable of removal by filtration. Thus removed, the agent does not affect the desirable "head" when the beer is ready for consumption.

Although not concerned with a final food product or with food processing, foam formation is also extremely important in the husbandry of milk cows. Formation of foams in the cow's stomach causes a serious condition commonly known as bloat. This is described in entry on **Hay and Forage Crops.**

Since a degree of emulsification is involved in foaming and whipping situations, many substances usually classified as emulsifiers also serve as excellent foaming and whipping agents. Some of these (see list below) are described in more detail in Appendix Table 1:

Calcium stearoyl-2-lactylate
Hydroxypropyl cellulose
Lactylated fatty acid esters of glycerol and propylene glycol
Methylcellulose
Methyl ethylcellulose
Sodium stearoyl-2-lactylate

Frequently, as in the case of ice cream, various toppings, *et al.*, the food product will be mechanically agitated (whipped) to add air into the final product. Sodium caseinate, for example, is used to help whipped topping to peak after being whipped with cold milk. See entry on **Milk and Dairy Products,** particularly section relating to "Ice Cream." In 1970, General Foods Corporation received the IFT (Institute of Food Technologists) Award for developing and commercializing a freeze-thaw-stable, nondairy whipped emulsion resembling whipped cream in appearance, utility, texture, and flavor. In the patented process, a mixture of hydrogenated palm kernel and coconut oil, sodium caseinate, emulsifiers, and stabilizers is whipped, packaged, and frozen. Although there have been numerous interim modifications, this was one of the first substitutes for real whipped cream.

Nature of Foams. A foam is a tightly packed aggregation of gas bubbles, separated from each other by thin films of liquid. If foams were not so common, their existence would cause surprise. None of the obvious properties of a liquid would lead one to suppose that thin liquid films could sustain themselves for any appreciable time against the effect of gravity. The existence and stability of a foam depend upon a surface layer of solute molecules, which form a structure quite different from that of the underlying liquid inside the "interbubble" film. See also **Colloid Systems.**

At the surface of a liquid, molecules are in a state of dynamic equilibrium, in which the net attractive forces exerted by the bulk of the fluid cause molecules to move out of the surface; this motion is counterbalanced by ordinary diffusion back into the diluted surface layer. The equilibrium results in the surface layer being constantly less dense than the bulk fluid, which creates a state of tension at the surface. The tension can be somewhat relieved by adsorption of foreign molecules either out of the bulk solution, or out of the vapor phase. Soluble substances that have a strong tendency to concentrate in the surface layer are collectively known as surface-active agents. Proteins generally fall into this category. The excess concentration of solute at the surface reduces the surface tension of water. The general relation, in the form of a differential equation, was first deduced thermodynamically by Gibbs (known as Gibbs' adsorption theorem), and is:

$$\mu = -\frac{c}{RT} \cdot \frac{d\gamma}{dc}$$

where μ is the excess concentration at the surface; c is the bulk concentration; and $d\gamma/dc$ is the change of surface tension with concentration of solute.

An excess of solute at the surface, as measured by $+\mu$, can be termed *positive adsorption* to be distinguish it from an excess of solvent at the surface ($-\mu$), or *negative adsorption.* According to Gibbs' equation, positive adsorption and the lowering of surface tension always appear simultaneously. When a fresh liquid surface is newly created, however, and before the excess solute molecules have had time to diffuse to the surface, the surface tension must remain high.

Lord Rayleigh showed, by means of his vibrating-jet experiment, that about 5 milliseconds are required for the surface tension of a fresh surface to reach equilibrium; during this time, the tension continuously declines from a high initial value of about 70 dynes/centimeter to a final equilibrium value of about 35 dynes/centimeter. The cause of the stability of a foam resides in this effect.

Should the equilibrium surface layer be disturbed for any reason, fresh surface is created and the tension immediately increases. On a foam film, the stress that creates regions of higher surface tension is always present. The liquid film is flat at one place and curved convexly at another, where liquid accumulates in the interstices between the bubbles. The convex curvature creates a capillary force that sucks liquid out of the connected foam films (Laplace effects), so that internal liquid flows constantly from the flatter to the more curved parts of the films. As the liquid flows, the films are stretched, new surfaces of higher tension are created, and a counterflow across the surface is generated to restore the thinned-out parts of the films (Marangoni effect). In this way, the foam films are in a constant state of flow and counterflow, one effect creating the conditions for its reversal by the other. Pure liquids do not form foams because of the absence of a Marangoni effect.

The Marangoni effect maintains the stability of the foam films even against other disruptive actions, such as hydrodynamic drainage, that, like the Laplace effect, cause stretching of the films. To the Marangoni effect can be traced all the resilient ability of foam films for elastic recovery after external mechanical shock. Foam films sometimes have this property to a remarkable degree, as witnessed by dropping solid objects or passing jets of water through films without causing extensive rupture. In the fragility and brittleness of aged foams, one witnesses the effects of impaired resilience, probably due to the extreme depletion of solution from old films by prolonged drainage.

While the primary stabilizing factor in foam is the resilience of the film, provided by the Marangoni effect, in special cases additional surface-layer phenomena are significant and these include gelatinous surface layers and low gas permeability. Chemical additives contribute to these effects. Such effects can add enormously to the stability of the foam, resulting in such relatively stable structures as are exemplified in meringue, whipped cream, and numerous cosmetic preparations.

Solutions of proteins have surface layers that exhibit plastic viscosity, i.e., the surface does not flow until the shearing stress is greater than a characteristic "yield" value, which may be larger than the small gravitational stress inside a thin film. After the bulk of the liquid has drained away, the thin films remaining are gelatinous and resist rupture for long periods.

Reference

Consult list at end of entries on **Colloid Systems; Defoaming Agents.**

FOAM STABILIZER. Phosphates.

FODDER. A blend of coarse grasses which have been harvested with seeds and leaves and cured for later use as animal feed. Corn (maize) and sorghum are common examples of fodder ingredients. See also **Silage.**

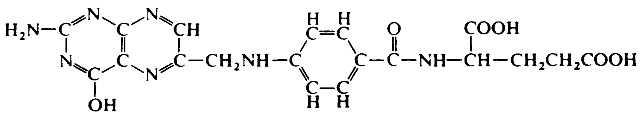
FOLACIN. Folic Acid; Appendix 2, Table 1.

FOLIC ACID. Sometimes referred to as the antianemia factor or folacin, and earlier called vitamin B_c, vitamin M, and the *L. casei* factor, the chemical name for folic acid is pteroylglutamic acid. Most animals require folic acid. The substance is synthesized by bacteria in some vertebrates, including human, rat, dog, pig, and rabbit. Exogenous sources are required by most other vertebrates and invertebrates. In ruminants, synthesis of folic acid occurs in the rumen, but some researchers believe that newborn lambs require a dietary supplement. The most common manifestation of a deficiency in livestock is development of a characteristic macrocytic, hyperchromic anemia (also called megaloblastic anemia). Bone marrow changes, red cells are large and immature, usually with an accompanying reduction of white cell numbers. Folic acid deficiency in poultry retards growth. See **Feedstuffs.** Other disorders include glossitis, diarrhea, gastrointestinal lesions, intestinal malabsorption, and sprue.

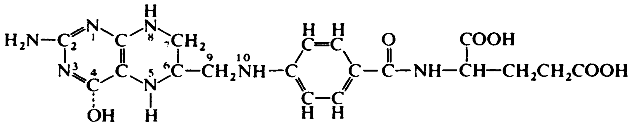
In 1931, Wills demonstrated a factor from yeast active in treating anemia. In 1938, Day *et al.* found yeast or liver extracts active in treating anemia in monkeys. Hogan and Parrot, in 1939, showed how anemia in chicks could be prevented by using liver extract. The *L. casei* growth factor was isolated from liver and yeast by Snell and Peterson in 1940. Hutchings *et al.,* in 1941, found the *L. caesi* factor also essential for chicks. Also, in 1941, Mitchell, Snell, and Williams isolated bacterial growth factor (*S. lactis R*) similar to *L. casei* factor from yeast and named the substance folic acid. Stokstad, in 1943, reported *L. casei* factor from liver more active than that from yeast, and provided evidence of multiple factors. Pterolymonoglutamic acid was finally isolated, the structure proved, and the substance synthesized by Angier *et al.* in 1946. Commercial production of folic acid is either by extraction from yeast or liver, or by synthesis where in 2,3-dibromopropanol, 2,4,5-triamino-6-hydroxypyrimidine, and para-aminobenzoyl glutamic acid are reacted. Folic acid supplement is described briefly in Appendix Table 1.

Folic acid and derivatives are involved biologically in the synthesis of nucleic acid, coenzyme in purine-pyrimidine metabolism, serine-glycine conversion, intermediate in metabolism of purines and pyrimidines, differentiation of embryonic nervous system, one-carbon transfer mechanisms, metabolism of tyrosine and histidine, formation of active formate and methionine, and the synthesis of choline. Antagonists of folic acid include aminopterin (4-amino-pteroylglutamic acid, methotrexate (amethopterin) pyrimethamine, and 4-amino-pteroylaspartic acid. Synergists include biotin, pantothenic acid, niacin, vitamins B_1, B_2, B_6, B_{12} C, and E, somtatotrophin (growth hormone), and testosterone.

Folic acid coenzymes are derivatives of tetrahydrofolic acid. See also **Coenzyme.** Structurally, these are:

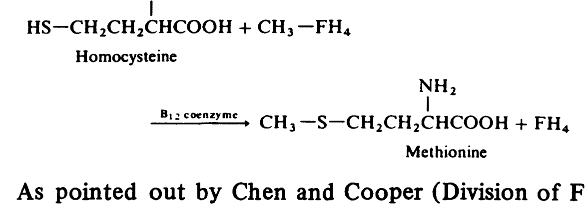


Folic acid



Tetrahydrofolic acid

One-carbon fragments in various oxidation states are: (1) formyl (—CHO); (2) hydroxy-methyl ($—CH_2OH$); and (3) methyl ($—CH_3$). The coenzyme forms of folic acid have one of these groups attached to either the N—5 or N—10 of tetrahydrofolic acid. One folic acid coenzyme, methyltetrahydrofolate ($CH_3—FH_4$) transfers its methyl group to homocysteine to yield methionine, in a reaction which also requires a vitamin B_{12} coenyzme:



$$\mathrm{HS{-}CH_2CH_2\overset{NH_2}{\overset{|}{C}}HCOOH + CH_3{-}FH_4}$$

Homocysteine

$$\xrightarrow{B_{12}\ \mathrm{coenzyme}} \mathrm{CH_3{-}S{-}CH_2CH_2\overset{NH_2}{\overset{|}{C}}HCOOH + FH_4}$$

Methionine

As pointed out by Chen and Cooper (Division of Food

Science and Nutrition, California State University, Northridge, California), the group of compounds denoted by the term *folacin* is a heterogeneous group of derivatives with a similar basic structure and biological function. Folic acid is the basic structural unit in these compounds. Other monoglutamate folates are formed when the pteridine moiety of this basic molecule is reduced or substituted in the 5-nitrogen or 10-nitrogen position. In addition, all of these monoglutamate folates may be transformed into polyglutamates of various length by the addition of glutamic acid residues to the basic molecule.

Distribution and Sources. In the biosynthesis of folic acid, paraminobenzoic acid, glutamic acid, and some substances yet to be identified serve as precursors. Paraminobenzoylglutamic acid is an intermediate in the synthesis. In plants, folic acid is produced within the leaves, seeds, cereal germ. Production also occurs in algae, fungi, and by bacteria, as in the intestines of species previously mentioned. The liver is the primary storage site.

Natural sources of folic acid include the following:

High folic acid content (90–300 micrograms/100 grams)
Asparagus, dry beans (lentils, limas, navy), liver (beef, chicken, lamb, pork), spinach, wheat bran, yeast
Medium folic acid content
Beef kidney
Low folic acid content
Most fruits, nuts, vegetables, grains, and dairy products. See also **Potato**.

Specific requirements for folic acid are given in Appendix Table 2.

Bioavailability of Folic Acid. Factors which cause a decrease in bioavailability include (1) high urinary excretion; (2) destruction by certain intestinal bacteria; (3) increased urinary excretion caused by vitamin C; (4) presence of sulfonamides which block intestinal synthesis; and (5) a decrease in absorption mechanisms. Increase in bioavailability can be provided by stimulating intestinal bacterial synthesis in certain species. No toxicity due to folic acid has been reported in humans.

Some of the unusual features of folic acid noted by investigators include: (1) Folic acid antagonists used in cancer therapy with temporary remissions; (2) folic acid occurs in chromosomes; (3) folic acid is distributed throughout cells; (4) needed for mitotic step metaphase → anaphase; (5) antibody formation decreased in folic acid deficiency; (6) choline-sparing effects; (7) analgesic in humans—pain threshold is increased; (8) antisulfonamide effects; (9) enterohepatic circulation of folate; (10) synthesized by psittacosis virus; (11) concentrated in spinal fluid.

Thermal Destruction of Folacin. Chen and Cooper (1979) have pointed out that the existence of folacin in numerous forms coupled with the lack of differentiation between forms has led to complications in characterizing the substance and in establishing meaningful tables for folacin content of foods. Improved methods have come into use for determining the specific forms of folacin present in foods (Chan *et al.*, 1973). The value derived from separation and quantification of folates has been limited due to lack of information concerning the stability characteristics of various folate forms. These forms have been found to vary over a wide range in their thermal stability (Cooper *et al.*, 1978; Paine-Wilson and Chen, 1979). The presence of oxygen has been implicated as a possible factor in degradation of folates during heating. Heat processing of canned and sealed foods has resulted in markedly higher folacin retention than found in home cooking methods (Huskisson and Retief, 1970). Rolls and Porter (1973) found that the percentage of folacin destroyed during heat processing of milk is affected by the level of residual oxygen in milk. O'Broin *et al.* (1975) found that ascorbic acid has a protective effect on folates, possibly due to its action as a reducing agent. Studies of the effect of temperature on folacin have been less thoroughly documented. Thus Chen and Cooper (1978) undertook a study of the effects of temperature and presence of oxygen and reducing agent on the thermal stability of two naturally occurring labile folates. Their conclusions—loss of 5-methyltetrahydrofolic acid in aqueous solution followed first order kinetics with a low Arrhenius activation energy of 9.5 kcal/mole. Tetrahydrofolic acid was extremely labile during heating and the stability of both forms of folate was increased in the presence of ascorbate and nitrogen atmosphere.

References

Brown, G. M.: "Folic Acid" in *The Encyclopedia of Biochemistry* (R. J. Williams and E. M. Lansford, Jr., Editors), Van Nostrand Reinhold, New York (1967).

Chan, C., Shin, Y. S., and E. L. R. Stokstad: "Studies of Folic Acid Compounds in Nature. 3: Folic Acid Compounds in Cabbage," *Canadian J. of Biochemistry,* 51, 1617 (1973).

Chen, T. S., and R. G. Cooper: "Thermal Destruction of Folacin: Effect of Ascorbic Acid, Oxygen and Temperature," *J. of Food Science,* 44, (3) 713-716. (1979).

Cooper, R. G., Chen, T. S., and M. A. King: "Thermal Destruction of Folacin in Microwave and Conventional Heating," *J. of American Dietet. Association,* 73, 406 (1978).

Jaenicke, L.: "Folic Acid Coenzymes," in *The Encyclopedia of Biochemistry,* (R. J. Williams and E. M. Lansford, Jr., Editors), Van Nostrand Reinhold, New York (1967).

Huskisson, Y. J., and F. P. Retief: "Folate Content of Foods," *South African Medical J.* 44, (12) 362 (1970).

Kutsky, R. J.: "Handbook of Vitamins and Hormones," Van Nostrand Reinhold, New York (1973).

O'Broin, J. D., *et al.*: "Nutritional Stability of Various Naturally Occurring Monoglutamate Derivatives of Folic Acid," *American J. Clin. Nutr.,* 28, (5) 438 (1975).

Paine-Wilson, B., and T. S. Chen: "Thermal Destruction of Folacin: Effect of pH and Buffer Ions," *J. of Food Science,* **44**, (3) 717-722 (1979).

FOLPET FUNGICIDE. A chlorinated hydrocarbon type fungicide developed in the United States* in the early 1950s and used on several fruit and vegetable crops for protection against a number of fungus diseases. The compound is essentially for foliar application. Folpet is furnished as wettable powder (50 and 75%) and dust (10%). Some varieties of fruits evidence damage from application at inappropriate times (close to blooming period; during droughts; *et al.*) and these include cherry (sweet), grape, peach, and pear (D'Anjou). Folpet does not blend with strong alkaline substances and it should not be used with or immediately after

---

*Chevron Chemical Co.

any oil-spray formulations. The compound is injurious to fishes and thus precaution must be taken to prevent pollution of nearby fields, lakes, and streams. The compound is sometimes used after harvesting to protect product during storage and shipping, as in the case of sour cherry. Some of the target diseases of Folipet include:

anthracnose
apple scab
blight (early-late)
cranberry fruit rot
grape black rot
grape dead arm
leaf spot
melanose
mildew (downy)
mildew (powdery)
mold (gray)
rust

The chemical name of Folpet is N-(trichloromethylthio) phthalimide.
Other designations: *Folpan, Phaltan, Thiophal*
See also **Fungicide; Pesticide Application.**

FONOFOS INSECTICIDE. An organic phosphate type soil insecticide developed in the United States* in the late 1960s. The compound is furnished as emulsifiable concentrate in several strengths; and as granules (10 and 20%). Fonofos is effective against a number of specialized insects and is used on a variety of vegetable crops. The compound is injurious to birds, fishes, and other wildlife forms. Consequently, precautions must be taken to prevent excessive usage and pollution of nearby land areas, lakes, and streams. Frequently, the compound is mixed with fertilizer formulations.

Target insects of Fonofos include:

aphid
cabbage maggot
corn rootworm
European corn borer
garden symphylan
onion maggot
wireworm

The organic chemical name of Fonofos is O-ethyl-S-phenyl ethylphosphorodithioate.
Other designation: *Dyfonate.*
See also **Insecticide; Pesticide Application.**

FOOD ADDITIVES AMENDMENT. Risk/Benefit Concept.

FOOD ANALOG. Soybean Processing; Texture.

FOOD AND AGRICULTURE ORGANIZATION. An independent agency of the United Nations family of specialized agencies, the FAO is an agency for international action operating in the general areas of alleviating malnutrition and hunger, with particular emphasis on developing nations worldwide. To professionals in the food field, the FAO is a major collector and publisher of statistics relating to food production and trade worldwide, including:

FAO Production Yearbook, which includes well over 100 tables of production statistics covering nearly 100 categories of crops and commodities. The data are broken down by all producing countries (100+ nations). Data are given for current and recent years, with an average for the prior years dating back approximately 15 years from date of current publication. In addition to production (weight and volume) data, information is given on areas harvested and yields (kilograms per hectare) attained. The publication also includes summaries of land use, population, comparative indices of agricultural production, summaries by continents and by the categories of developed and developing countries, as well as by governments with centrally planned economies. Statistics also are given on means of production (agricultural machinery, pesticides, etc.).

FAO Trade Yearbook, which contains over 180 tables, giving the import/export status, country by country, on approximately 120 commodities of foods traded worldwide. There are similar trade summaries as regards tractors, crude and manufactured fertilizers, and pesticides.

FAO Yearbook of Fishery Statistics, which provides data on sea harvesting and import/export trade worldwide in fish, crustaceans, mollusks, marine oils and fats, country by country. There are approximately 90 tabular summaries.

In addition, the FAO publishes annually *The State of Food and Agriculture,* containing both prose and tables, reviewing progress and problems of the previous year and giving projections into the future. An *Animal Health Yearbook* is published annually. There are various monthly bulletins, including one on *Agricultural Economics and Statistics,* on *Cocoa Statistics,* on the *Coconut Situation,* among others. A *Yearbook of Forest Products,* an annual summary of food and agricultural legislation, and on current food additives legislation are also published. Also, scores of technical books and booklets on a variety of food production topics have been published.

Stated goals of the FAO include: (1) Increasing agricultural productivity worldwide; (2) reducing waste in food systems; (3) stressing agricultural development and fishery planning; (4) education and training of persons, particularly in developing countries, in procedures and techniques for increasing production quantity and quality; (5) assisting developing countries in gaining foreign exchange while improving their total food production status. In matters like these, the FAO ccoperates closely with a number of organizations both inside and outside the United Nations, such as the World Health Organization (WHO), United Nations International Children's Emergency Fund (UNICEF), the World Bank, and similar agencies.

World headquarters of the FAO is in Rome (00100), Italy. The FAO also maintains a number of regional offices, including: Accra, Ghana; Addis Ababa, Ethiopia; Bangkok, Thailand; Santiago, Chile; Cairo, Egypt; Washington, D.C., and New York City (United Nations Headquarters).

FOODBORNE DISEASES. In most countries with well-developed health care systems, foodborne diseases fall within the province of public health authorities as, for example, in the United States, as currently organized, the public health arms of the Department of Health, Education, and Welfare; in the United Kingdom, the Department of Health, etc.; and, on a worldwide basis, the World Health Organization (WHO). Organizational structure varies from one country to the next, but generally the overall concern with foodborne diseases represents an interaction between a number of agencies, bureaus, secretariats, etc. For example, in the United States, among others, the Public Health Service, the Center for Disease Control, and the Food and Drug

---

*Stauffer Chemical Co.

Administration are concerned with various aspects of regulation, education, research, investigation, statistics, etc., as these relate to foodborne diseases as well as other matters that affect the health of the public. In the larger countries, regional and local responsibilities are also participated in by government officials at the state or provincial level, at the town, city, village, and county or parish levels. Thus, there is a vast network of people concerned with prevention and control fo foodborne diseases.

About this Entry. The foodborne diseases as described here represent illnesses caused by substances that are contained in the food substances, either present in the starting material (and not deactivated during processing) or from contamination at almost any point after harvesting, through processing, and through handling in connection with distribution, marketing, and finally cooking and preparing the food for the consumer (commercial establishments—restaurants, fast food chains, takeout establishments, or hotel, cruise ship, rest home, etc. dining rooms) and preparation and handling within the home. The entry is not concerned with what food substances cause nutritional deficiencies. For the latter, see entry on **Nutrition.**

Topics in this entry are discussed in the following order: Classification of foodborne diseases; epidemiology of foodborne diseases; fundamental causes of foodborne diseases; specific foodborne diseases: Salmonellosis, staphylococcal intoxication; botulism, including infant botulism; *Clostridium perfringens; Bacillus cereus* gastroenteritis; shigellosis or bacillary dysentery; yersiniosis; hepatitis A or infectious hepatitis; ciguatera poisoning; scombroid poisoning; paralytic shellfish poisoning, oyster poisoning; abalone poisoning; tetraodon or puffer fish poisoning; mushroom poisoning; mushroom-alcohol intolerance; aflatoxicosis; trichinosis; diphyllobothriasis, anisakiasis; ambeiasis (amebic dysentery); toxoplasmosis; toxicants and toxins from plants; various chemical poisonings. Brief descriptions of other foodborne diseases are included in a series of tabular summaries.

The general absence of catastrophic outbreaks of foodborne diseases testifies to the workability of the system and to the progress that has been made over the past several decades by many countries of the world. Also, an important part of the total system is the food processing and handling industry, with its scores of facets, that over the decades has increasingly cooperated, largely voluntarily, with procedures that are designed to prevent illnesses and fatalities as the result of eating improperly selected and prepared foods. It is not surprising that a significant part of the total foodborne disease problem remaining arises from actions taken by persons at the local level who are less experienced and inadequately aware of foodborne pathogens and poisons—as, for example, the home canner or the gracious host who inadvertently serves slowly warmed-over turkey at a community picnic that has been delayed a day or two because of rain.

It is logical that the first interests in foods as means for transmitting communicable diseases would be concentrated on the main killers of earlier times. In the 1850s and 1860s, Snow and Budd found that water and milk were responsible for the spread of cholera and typhoid fever. Although they could not grow the organisms in the laboratory, they worked on epidemiological evidence. Early interests concentrated on the association of human sewage with drinking water and foods, and other sources of the microorganisms were essentially overlooked or disregarded for a number of years. Savage, as comparatively recently as the 1920s, was one of the few pioneers who insisted that animals were the prime reservoir of salmonellae (except for *S. typhi* and most of the paratyphoid bacilli). Today, it is recognized that there is a high rate of excretion of salmonellae among poultry, swine, and cattle and that not all abattoirs can control the spread of infection from gut contents to meat, and that cross-contamination from raw to cooked foods in food-preparation areas is responsible for a large proportion of foodborne salmonellosis. Thus, it turns out that in the search for the source of an infective agent, animal sewage is far more important than that of humans. Commercial interests for many years militated against the confirmation that the heedless preparation of animal feeds from contaminated raw materials resulted in salmonella excretion in poultry and livestock. Some governments too were unwilling to interfere with trading interests.[1]

During the last 50 years, the number of bacterial agents found to be implicated in foodborne disease has increased. As well as organisms of the Salmonella and Shigella groups, *Staphylococcus aureus, Clostridium perfringens, C. welchii, Bacillus cereus, Vibrio parahaemolyticus, Escherichia coli,* and certain streptococci, among others, have been responsible for outbreaks of food poisoning.

Classification of Foodborne Diseases

Diseases transmitted by foods are frequently classified either as *poisonings* or *infections:*

Poisonings are caused by consuming toxicants which are found in tissues of certain plants and animals, metabolic products (toxins) formed and excreted by microorganisms (bacteria, fungi, algae) while they multiply in foods; or poisonous substances which may be intentionally or incidentally added to foods as a result of producing, processing, transporting, or storing.

Infections are caused by the entrance of pathogenic microorganisms into the body and the reaction of body tissues to their presence or to the toxins that they generate within the body. Intestinal infections may be manifested by *in vivo* enterotoxin production or mucosal penetration. After mucosal penetration, the organisms multiply in the mucosa or pass into other tissues. See Fig. 1.

Diseases transmitted by foods can be placed into seven broad causative categories: (1) Bacterial diseases; (2) viral and rickettsial diseases; (3) parasitic diseases; (4) fungal diseases; (5) plant toxicants and toxins; (6) toxic animals; and (7) poisonous chemicals, including radionuclides. Examples of principal diseases in these categories are given in Table 1.

Although the listings of Table 1 are helpful from the standpoint of classifying principal categories of sources of foodborne diseases, the list tends to give equal weight to

---

[1] Based upon observations made by Betty C. Hobbs, former Director of Food Hygiene Laboratory of the Public Health Service, London, England, in the 14th Underwood Prescott Memorial Lecture (Massachusetts Institute of Technology, 1976).

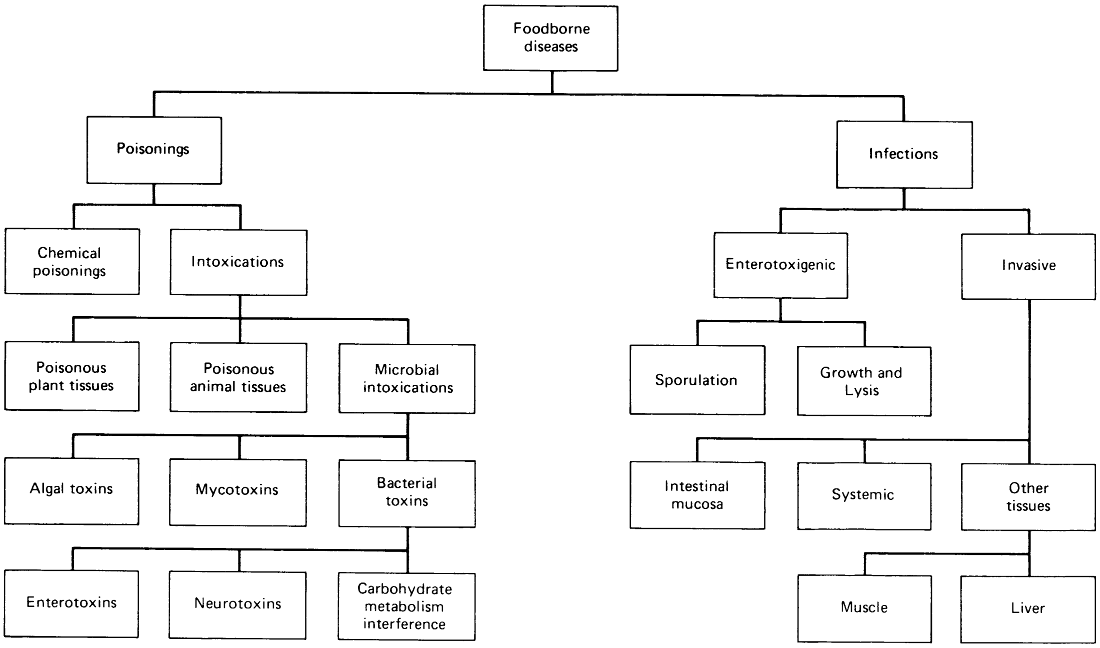


Fig. 1. Classification of foodborne diseases by basic sources and routes of development. (Source: Bryan (1976) reference listed.)

TABLE 1. BROAD CATEGORIZATION OF FOODBORNE DIESEASES

BACTERIAL DISEASES

Salmonelloses
  Salmonellosis
  Enteric fever (typhoid fever)
  Enteric fever (paratyphoid fever)
Staphylococcal Intoxication
Botulism
Clostridium perfringens (*C. welchii*)
  Type A Disease
  Type C–Enteritis Necroticans
Bacillus cereus
  Gastroenteritis
Vibrio parahaemolyticus
  Infection
Arizona hinshawii
  Arizona infection
Pseudomonas cocovenenans (toxins)
  Bongkrek poisoning
Proteus spp. (histaminelike substances)
  Scombroid poisoning (Scombrotoxism; Saurine poisoning; Fish poisoning)

Note: Bacterial diseases usually transmitted by other means, but sometimes foodborne, include: Shigellosis; enteropathogenic *Escherichia coli* infection; beta hemolytic streptococcal infections, such as scarlet fever, septic sore throat; yersiniosis (*Yersinia enterocolitica* infection or pseudotuberculosis); cholera; brucellosis; tuberculosis; diphtheria; tularemia; anthrax; Haverhill fever.

Bacterial diseases in which proof of transmission by foods is inconclusive include: Enterococcal infection; Klebsiella food infection; enterobacter infection; *Pseudomonas aeruginosa* infection; *Bacillus subtilis* infection; listeriosis, among others.

VIRAL AND RICKETTSIAL DISEASES

Hepatitis A (Infectious hepatitis)
Poliomyelitis
Bolivian hemorrhagic fever
Russian spring-summer encephalitis (Diphasic milk fever)

TABLE 1. BROAD CATEGORIZATION OF FOODBORNE DISEASES (cont.)

PARASITIC DISEASES (Helminthic)

Trichinosis
Taeniasis

Note: Other parasitic diseases always or usually transmitted by foods, but less commonly encountered, include: cysticercosis; diphyllobothriasis; spargnosis; angiostrongyliasis; anisakiasis; fasciolopsiasis; echinostomiasis; heterophyid infection; opisthorchiasis; metagonimiasis; fascioliasis; paragonimiasis; dicrocoeliosis; hymenolepiasis diminuta; gnathostomiasis; intestinal myiasis.

Parasitic diseases which are usually transmitted by other means, but which may be foodborne, include: Amebiasis (amebic dysentery); ascariasis; trichuriasis; *Capillaria hepatica* infection; echinococcoses hydatidosis; alveolor hydatid disease; balantidiasis (balantidal dysentery); giardiasis; coccidiosis (Isospora infection); dientamoeba infection; toxoplasmosis; sarcosporidiosis.

FUNGAL DISEASES

Mycotoxicoses reported in humans
  Alimentary toxic aleukia (ATA)
  Urov diseases (Kaschin-Beck disease)
  "Drunken-bread" poisoning
  Akakabi-byo (Red mold disease)
  Ergotism (Saint Anthony's fire)
  Epidemic polyurea
  Toxic moldy rice disease
  Muco-mycotoxic disease
  Aflatoxicosis

Note: Mycotoxicoses of animals that may also potentially affect humans include: Strachybotryotoxicosis; ochratoxicosis; aspergillus toxicosis; moldy corn toxicosis; facial eczema.

Mushroom-associated diseases
  Mushroom poisoning–Cell destruction
  Mushroom poisoning–Neurological effects
  Mushroom poisoning–Enteritis type
  Mushroom-alcohol intolerance
Mycotic infections
  Phycomycosis

TABLE 1. BROAD CATEGORIZATION OF FOODBORNE DISEASES (cont.)

PLANT TOXICANT AND TOXIN DISEASES

Alkaloids
- Jimson weed and nightshade poisoning; senecio poisoning; hemlock poisoning; epidemic dropsy; manchineel poisoning; laburnum poisoning; solanine poisoning; green hellebore poisoning; delphinium and monkshood poisoning; yew poisoning; daffodil bulb poisoning; jessamine poisoning; colchicine poisoning; nicotine poisoning.

Glycosides
- Cyanide poisoning; goiter; baneberry poisoning; buckeye poisoning; oleander, lily-of-the-valley, and black hellebore poisoning; pokeweed, corn cockle, and finger cherry poisoning; tung nut poisoning.

Toxalbumins
- Castor bean and jequirity poisoning; favism.

Resins
- Water hemlock poisoning; mountain laurel poisoning

Other Toxicants, Toxins, and Allergens
- Milk sickness; cocculus poisoning; ackee poisoning; lathyrism; oxalate poisoning; mistletoe poisoning; nutmeg poisoning; *Leucaena glauca* poisoning; djenkol poisoning; carotenemia; esophageal cancer.

Note: There are many other plants and substances that can cause toxic and allergenic illness, including common house and garden plants.

TOXIC ANIMALS (Disease Sources)

Fish
- Ciguatera poisoning; moray eel poisoning; file fish poisoning; tetraodon or puffer fish poisoning; scombroid poisoning; clupeoid poisoning; elastobranch and chonrichytes poisoning; chimaeroid poisoning; cyclostome poisoning; gempylid poisoning; hallucinogenic fish poisoning; ichthyohepatoxism; freshwater fish poisoning; Haff or Yuksov disease; Minamata disease.

Shellfish
- Paralytic shellfish poisoning; oyster poisoning; callistin shellfish poisoning; abalone poisoning; whelk poisoning.

Other Animals
- Cephalopod poisoning; sea urchin poisoning; sea anemone poisoning; sea cucumber poisoning; horseshoe crab poisoning (mimi poisoning); turtle poisoning; hypervitaminosis A; porpoise poisoning; toxic quail poisoning.

POISONOUS CHEMICALS (Disease Sources)

Metallic Containers
- Zinc, cadmium, antimony, copper, lead, tin poisoning.

Intentional Additives
- Nitrite poisoning; niacin poisoning; triorthocresyl phosphate poisoning; diphenylhydatoin intoxication; Oriental (Chinese) restaurant syndrome (excessive monosodium glutamate); potassium bromate poisoning; beer drinkers' cardiomyopathy (cobalt acetate); margarine disease; phenolphthalein poisoning.

Incidental and Accidental Food Additives
- Organic phosphorus poisonings (from insecticides); chlorinated hydrocarbon poisoning (from insecticides); carbamate poisoning (from insecticides); fluoride poisoning (from rodenticides); sodium monofluoroacetate poisoning (from rodenticides); thallium poisoning (from rodenticides); warfarin poisoning (from rodenticides); arsenic poisoning (from insecticides and herbicides); phosphide poisoning (from rodenticides and matches); barium poisoning (from rodenticides); nicotine sulfate poisoning (from insecticides and tobacco products); alkyl-mercury poisoning (from fungicides) epoxy resin poisoning (from contaminated grains);

TABLE 1. BROAD CATEGORIZATION OF FOODBORNE DISEASES (cont.)

POISONOUS CHEMICALS (Disease Sources) (cont.)

- chromium poisoning (from vending machines); calcium chloride poisoning (contaminated popsicles); cyanide poisoning (from fumigants); lye poisoning (from household chemicals); methyl alcohol poisoning (paint solvents and bootleg whiskey); chronic cadmium poisoning (Itai Itai or ouch ouch disease (mining wastes deposited in rice paddies); yusho (rice oil disease—from salad oil); selenium poisoning (home-grown foods with high concentrations of selenium, such as monkey coconut).

Allergens or Enzyme Deficiencies
- Gastrointestinal food allergies
  - Allergens react with antibody and form histamine or histamine-like substances; (Depends upon sensitivity of individual—not general)
    - Milk (protein constituents)
    - Milk products
    - Egg (whites)
    - Cereals (wheat, buckwheat, corn, rice, rye, oats)
    - Fish and seafoods
    - Meats
    - Nuts
    - Spices
    - Vegetables (celery, string beans, lima beans, tomatoes)
    - Fruits (oranges, strawberries, bananas, lemons, watermelon)
    - Preservatives
- Disaccharide intolerance
  - Lactose, sucrose, or isomaltose; (High incidence in blacks and orientals)
    - Milk and other foods containing disaccharides
- Food-drug combinations
  - Amine poisoning
    - Tyramine in cheese can be degraded to p-hydroxyphenylacetic acid by monoamine oxidase inhibitors in certain tranquilizers, causing hypertensive attacks.
  - Mushroom-alcohol intolerance (Specifically inky cap mushroom)
    - Listed under fungal diseases. Disulfiramlike (antabuse) constituents of mushroom interfere with normal metabolism of alcohol. Attacks can occur even if alcohol is consumed 48 hours after eating mushrooms.
- Radionuclides
  - Food contamination may arise from fallout, reactor plant accidents, radioactive wastes, naturally occurring radioactive substances.
    - Strontium^{89} (milk)
    - Strontium^{90} (green leafy vegetables, milk, milk products)
    - Iodine^{131} (milk)
    - Cesium^{137} (green leafy vegetables, milk, milk products, meat, shellfish, fish)
    - Phosphorus^{32} (green leafy vegetables)
    - Barium^{140} (milk)
    - Ruthenium^{106} (laverbread made from seaweed components)

Source: Bryan (1976) reference listed.

all diseases, the intent not being that of conveying seriousness, or frequency of occurrence. Many of the listed diseases occur rarely and, in other instances, diseases may be of a highly regionalized nature.

In those countries with extensive communications networks and where there is advanced epidemiology and microbiological attention given to foodborne diseases, even one case of certain diseases can cause considerable excitement, particularly precipitating dramatic emphasis in the public press when recalls of certain processed foods may be involved. Needless to say, many thousands of cases of food illness are not reported worldwide—so that reliable statistics are available for only a portion of the world's population. Even in advanced countries, only a percentage of foodborne diseases are reported so that they can become part of the formal statistics. For example, the Committee on Salmonella of the National Research Council (United States) estimates that about 2 million cases of salmonellosis occur in the country each year, but that only an average of about 20,000 isolations are made each year. Public health officials observed that before effective control of salmonellosis, as well as other foodborne diseases, can be achieved, improved methods of investigation must be applied to a greater portion of known outbreaks. The goal of a foodborne disease surveillance program is the systematic accumulation of sufficient epidemiologic information to permit a reasoned attack upon the problem. Epidemiology is described a bit later.

Classification by Frequency of Occurrence. A practical and useful classification of the foodborne diseases is by their frequency of occurrence. Such data, of course, will vary considerably from one country to the next, depending upon dietary, technological, climatic, and regulatory differences, among others. For the United States over the mid-1970s (3-year period), this information is detailed in Table 2. A 3-year period helps to average out some of the year-to-year changes, but because of unexpected large outbreaks that may occur at any given time, a longer historical compilation should be used for forecasting.

TABLE 2. PRINCIPAL FOODBORNE DISEASE OUTBREAKS AND CASES (Confirmed) (United States—Cumulative for 3-year Period in Late-1970s)

	Outbreaks		Cases	
Etiology and Specific Disease	(Number)	(Percent of All Diseases)	(Number)	(Percent of All Diseases)
BACTERIAL	337	64.3	16,852	92.1
Salmonella	101	19.3	8241	45.0
Staphylococcus	114	21.8	4770	26.0
Clostridium perfringens	37	7.1	1791	9.8
Shigella	12	2.3	898	4.9
Group A *Streptococcus*	1	<0.2	325	1.8
Yersinia enterocolitica	1	<0.2	286	1.5
Vibrio parahaemolyticus	2	0.3	222	1.2
Bacillus cereus	6	1.1	119	0.7
Clostridium botulinum	58	11.1	91	0.5
Suspect Group D *Streptococcus*	3	0.5	88	0.5
Arizona hinshawii	1	<0.2	15	<0.1
Vibrio cholerae	1	<0.2	6	<0.1
CHEMICAL	128	24.4	586	3.2
Ciguatoxin	51	9.7	237	1.3
Heavy metals	14	2.7	133	0.7
Miscellaneous chemicals	19	3.6	116	0.6
Scombrotoxin	18	3.4	47	0.3
Monodosium glutamate	7	1.3	20	0.1
Mushroom poison	12	2.3	15	<0.1
Paralytic shellfish poison	5	1.0	15	<0.1
Puffer fish tetrodotoxin	1	<0.2	2	<0.1
Neurotoxic shellfish poison	1	<0.2	1	<0.1
VIRAL	12	2.3	572	3.1
Hepatitis A	11	2.1	492	2.7
Echo, Type 4 (Enteric cytopathogenic human orphan viruses)	1	<0.2	80	0.4
PARASITIC	47	9.0	294	1.6
Trichinella spiralis	42	>8.0	278	1.5
Entamoeba histolytica	1	<0.2	9	<0.1
Toxoplasma gondii	1	<0.2	4	<0.1
Anisakis spp.	2	<0.3	2	<0.1
Diphyllobothrium latum	1	<0.2	1	<0.1
TOTAL of all confirmed foodborne diseases	524		18,304	
AVERAGE per year (over 3-year span)	175		6101	

Data base: Bryan (1976) reference listed.

Breakdown by Geographical Areas. A state-by-state breakdown of foodborne diseases in the United States for a 3-year period during the mid-1970s is given in Table 3. The District of Columbia is also included. The tabulation is by descending order of foodborne disease outbreaks. For comparison, the population ranking of the states is given in an adjacent column. In many instances there is a marked absence of correlation between frequency of outbreaks and state population.

Inclusion of similar geographical breakdowns for other developed countries is beyond the scope of this volume. Where available, a source of such statistics would be the World Health Organization.

TABLE 3. FOODBORNE DISEASE OUTBREAKS BY STATES[1] (United States—Cumulative for 3-year Period in Late-1970s)

State	Rank in Descending Order of Outbreaks	Population Rank	Number of Outbreaks	Outbreaks as Percent of All States
New York	1	2	290	21.2
New York City			(241)	(17.6)
Pennsylvania	2	3	148	10.8
Washington	3	22	141	10.3
California	4	1	99	7.2
Hawaii	5	40	59	4.3
Florida	6	9	49	
Minnesota	7	19	46	3.4
Georgia	8	15	35	2.6
Illinois	9	5	32	2.3

TABLE 3. FOODBORNE DISEASE OUTBREAKS BY STATES[1] (United States–Cumulative for 3-year Period in Late-1970s) (cont.)

State	Rank in Descending Order of Outbreaks	Population Rank	Number of Outbreaks	Outbreaks as Percent of All States
Tennessee	10	17	31	2.3
New Jersey	11	8	30	2.1
Wisconsin	12	16	30	2.1
Ohio	13	6	29	2.1
Louisiana	14	20	23	1.7
Connecticut	15	24	22	1.6
Alaska	16	50	20	1.5
Oregon	17	31	20	1.5
Massachusetts	18	10	19	1.4
South Carolina	19	27	18	1.4
Michigan	20	7	17	1.3
Colorado	21	30	15	1.1
Missouri	22	14	15	1.1
Texas	23	4	13	0.9
Nebraska	24	35	12	0.9
Virginia	25	13	12	0.9
Kentucky	26	23	11	0.8
Utah	27	36	11	0.8
Arizona	28	33	9	0.7
New Hampshire	29	42	9	0.7
Oklahoma	30	26	9	0.7
Idaho	31	43	8	0.6
Nevada	32	48	8	0.6
Indiana	33	11	7	0.5
Alabama	34	21	6	<0.5
Arkansas	35	32	6	
Iowa	36	25	6	
Rhode Island	37	39	6	
South Dakota	38	45	6	
West Virginia	39	34	6	
Maryland	40	18	5	
Mississippi	41	29	5	
Montana	42	44	5	
North Carolina	43	12	5	
District of Columbia	44	41	4	
Delaware	45	47	2	
Kansas	46	28	2	
Maine	47	38	2	
New Mexico	48	37	2	
North Dakota	49	46	2	
Vermont	50	49	2	
Wyoming	51	51	1	

[1] Includes District of Columbia.

Data base: Bryan (1976) reference listed.

Epidemiology of Foodborne Diseases

Epidemiology is the study of the patterns of a disease and the factors that cause disease. This is a highly refined tool used by public health authorities in identifying and pinpointing information that is fundamental to taking corrective and controlling actions in connection with all communicable diseases and is a particularly useful tool and concept for controlling foodborne diseases. Whenever possible, reliable information must be developed quickly. Recalls of preserved foods, usually distributed on a nationwide basis, must be initiated as soon as possible for the obvious reason of halting further spread of disease from a particular batch of contaminated food. On the other hand, such recalls are costly, both in terms of money and prestige, to the food processor and thus cannot be ordered without reasonable evidence of cause. Fortunately, since human lives may be at stake in some instances, there is essentially good cooperation among all parties concerned. The communications networks have been very helpful in disseminating information concerning highly suspect or confirmed contaminated foods, of which, in some cases, there may be many thousands of containers still on the store shelves and, of particular vulnerability, unopened containers that may be on the shelves of households. Fortunately, most foodborne disease outbreaks are of a localized or regional character and do not involve nationwide attention, as may be required in the recall of a popular brand of a given contaminated product. Common terms used in epidemiology have been defined as follows:

Epidemiology. The study of the patterns of disease and the factors that cause the disease.

Pattern. The composite of the relationships of time, place, and person within a group of cases of a disease. Time refers to onset of illness; place refers to residence, geography, and food sources; and person refers to age, sex, occupation, ethnic group, social attributes, and food history of persons involved. The patterns of the disease must be studied in terms of possible causal factors.

Causal factors. The agent, reservoir, vector, vehicle, host, and their interrelationships, as well as conditions that permit the agent to survive and/or multiply. Important causal factors for foodborne diseases are given in Table 4. These factors constitute the chain of infection for bacterial foodborne diseases, and the chain of actions in connection with other foodborne disease forms. In an epidemiologic investigation, the outbreak must be de-

TABLE 4. CAUSAL FACTORS FOR TYPES OF FOODBORNE DISEASES

Progressive Chain of Causal Factors Required for Development of Foodborne Diseases	
1. Causative organism (etiologic agent) present	All foodborne diseases
2. Source and reservoir of organism	All foodborne diseases
3. Mode of dissemination of the organism from the source to a food substance	All foodborne diseases
4. Food that has been contaminated must be capable of supporting the growth of the organism	Bacterial origin only
5. Food that has been contaminated must remain in the temperature range suitable for proliferation of the organism long enough for the organism to multiply to sufficient numbers to cause illness or to produce sufficient toxin to cause illness	Bacterial origin only
6. Quantity of food eaten must contain sufficient amounts of the organism or toxin to exceed the susceptibility threshold of the person who has eaten the food	All foodborne diseases

scribed in terms of its distribution and each of the causal factors must be determined.

Epidemic. The occurrence of a group of illnesses of similar nature in a community or region, clearly in excess of normal expectancy and derived from a common or propagated source. The minimum number of cases that indicates an epidemic will vary with the infectious agent, with the size and type of population exposed, with previous experience or lack of exposure to the diseases, and with the time and place of occurrence. Thus, an epidemic is relative to usual frequency of the disease in the same area, among specified populations at the same season of the year. A single case of a communicable disease (as botulism or typhoid fever) long absent from a population or a single case that is the first invasion by a disease (as *Vibrio parahaemolyticus* infection) not previously recognized in an area is also to be considered epidemic. The word epidemic must be defined in contradistinction to the word endemic, which is the habitual presence of a disease or infectious agent within a given geographic area or the usual prevalence of a given disease within such an area. An obvious example of endemic and epidemic can be seen from the graph of pneumonia-influenza deaths (used as example, although not foodborne) over a span of some 3 years. See Fig. 2.

Epidemic curve. is a graphical representation of cases according to the distribution of the time of onsets of cases. It is usually constructed as a histogram (See Fig. 3), but sometimes as a frequency polygon. In both types of graphs, the frequencies or number of cases are plotted on the ordinate axis and the time of onset of illness along the abscissa. The duration of each interval may be in hours, intervals of a few hours, etc. The interval selected depends upon the disease in question and the span of time over which cases occurred. A histogram represents each case or group of cases by a block in a unit of time. If more than one case occurs in a time interval, a block representing each additional case is stacked on the initial block. There are no vertical or horizontal spaces between blocks as in bar graphs.

Common-source or point epidemic. An epidemic that is spread by a vehicle, such as foods, milk, water, or fomites (inanimate objects—dishes, utensils, table tops, etc. that may be contaminated) shared by the victims. In a common-source outbreak, when many persons are exposed simultaneously, the relative uniformity of the incubation period for a specific disease results in a single cluster of cases in time. Cases occur rapidly after the first onset, reach a peak (*point*), and then decline. The duration of the epidemic will be within the range of the incubation period of the disease. The histogram of Fig. 3 indicates a common-source situation of a salmonellosis outbreak.

Common-source, single-event epidemic. This is typi-

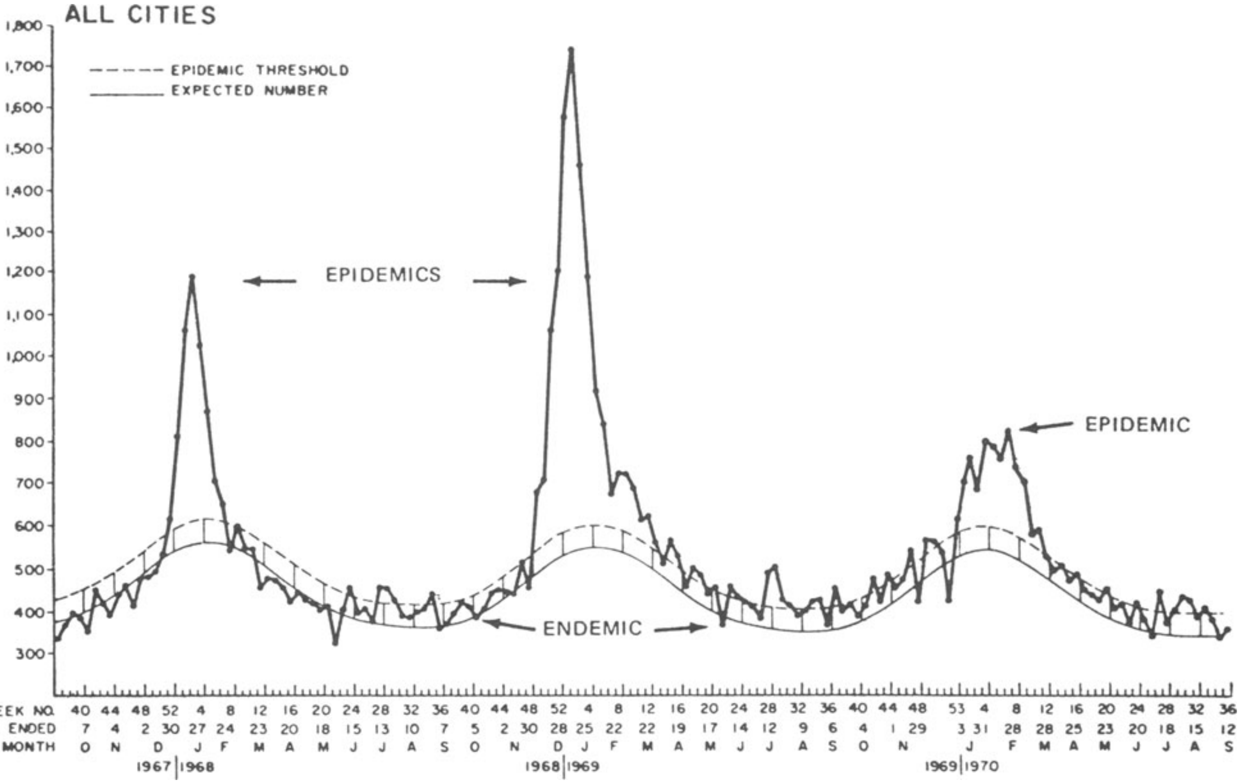


Fig. 2. Illustration of epidemic and endemic. The graph illustrates how an epidemic can be recognized. Epidemics are seen as a significant excess of cases (deaths in this example) over that which is expected on the basis of accumulated experience. The solid endemic line shows the seasonal pattern of the deaths, while the upper, broken line contains the upper level of variations below which 95% of expected observations should fall. When the observed numbers of deaths exceed the broken line for more than 2 successive weeks, an epidemic is indicated. Epidemics are observed during 3 successive years. From past experience of the occurrence of a disease in a community, epidemics can be forecasted. In this illustration, a forecast can be made that epidemics of death caused by pneumonia and influenza will occur again in winter and have higher peaks in the uneven numbered years. Generally, this technique can be used in connection with foodborne diseases, but involving a whole new set of causal factors for each disease being considered. (*Public Health Service, U.S. Department of Health, Education, and Welfare*)

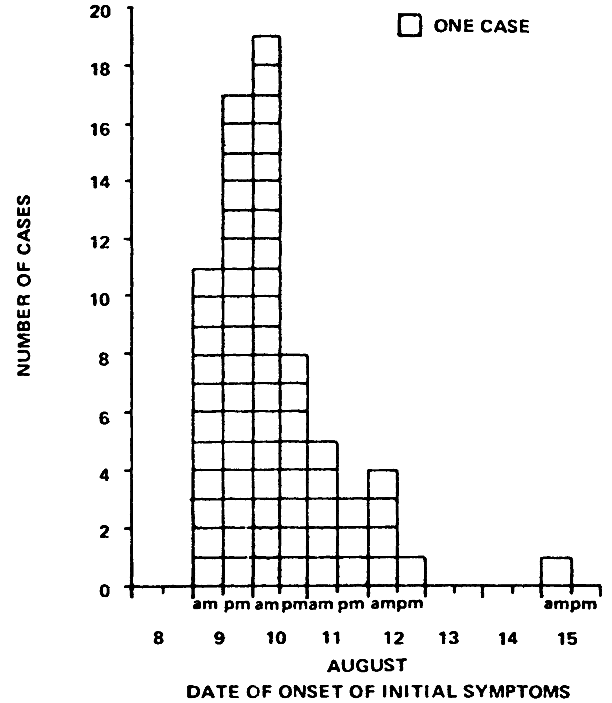


Fig. 3. Histogram (epidemic curve) of a common-source outbreak of Salmonellosis. (*Modified from Goldman,* 1970).

fied by onsets of cases that follow a single situation, as when a group of people eat the same contaminated food (*common source*) at the same place within a short period of time within a short period of time—as during a particular meal (*single event*). Distribution of cases will be stretched out in time when all the cases have not eaten the contaminated food at the same time. Such a situation may be more accurately called a **common-source, multiple-event epidemic.**

Propagated epidemic. An epidemic that is transmitted from a human or animal reservoir by direct or indirect contact with a host. Reservoirs may be in the incubation period of a disease—they may be mild or missed cases, convalescents, or healthy *carriers.* For transmission to occur, the population must have enough susceptibles to give the infection a chance of spreading. As the disease spreads, those infected become immune, and the supply of susceptibles is depleted to a point at which spread tapers off and finally ceases. The rapidity with which contact-spread epidemics reach a peak and the extent of their duration depend upon infectivity of the agent, length of incubation period, initial proportion of susceptibles in the population, and degree of crowding and intimacy of contact. In zoonoses (animal parasites), the change in the proportion of susceptibles among animals and the distribution of the animals are factors that affect time distribution of cases. In vectorborne disease outbreaks, conditions that favor the development of a vector and the length of time that is required for the pathogens to develop in a vector will alter the time distribution of cases. A typical contact-spread epidemic is shown in Fig. 4. Data on two outbreaks of infectious hepatitis are shown in Fig. 5. One set of data defines a common-source outbreak in a city, the other set defines a propagated outbreak in the surrounding county in which the city is located. Bryan (1975) conveniently summarizes the characteristics of common-source and propagated epidemics. See Table 5.

Incubation period. This is the time between exposure

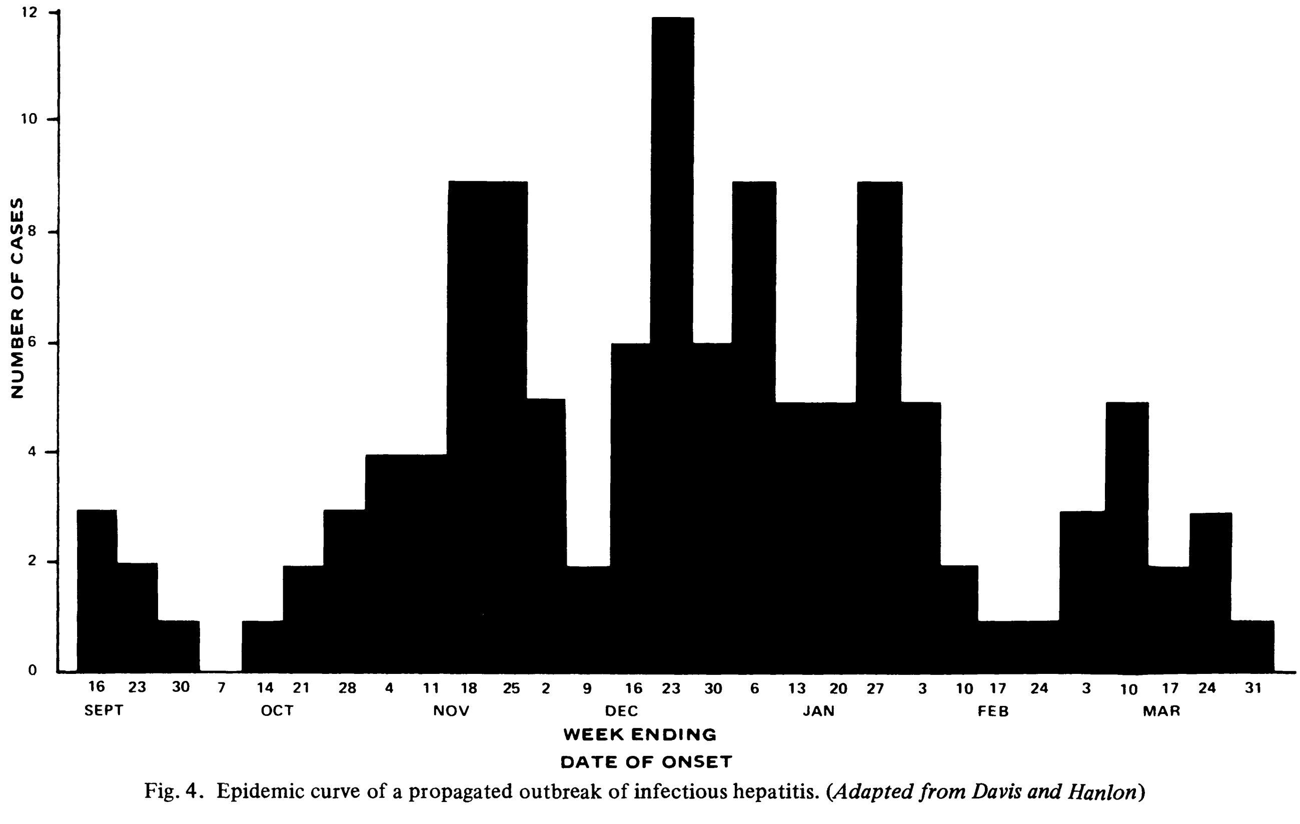


Fig. 4. Epidemic curve of a propagated outbreak of infectious hepatitis. (*Adapted from Davis and Hanlon*)

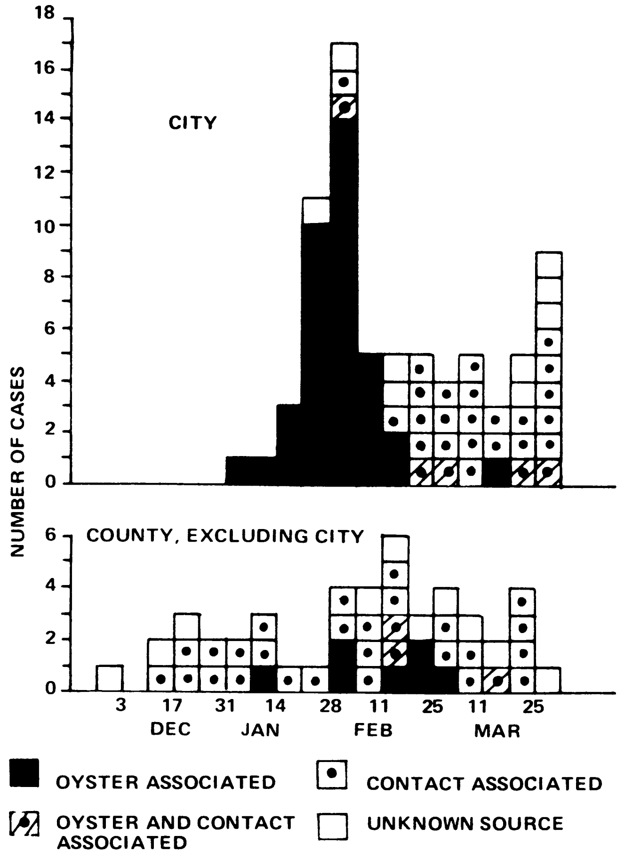


Fig. 5. Epidemic curves of a common-source outbreak with secondary infections and a propagated outbreak of infectious hepatitis. (*Modified from Mason and McLean*)

of a susceptible person to an infection or toxic agent and appearance of the first sign or symptom of the disease. In foodborne outbreaks, it is the time between *ingestion* of contaminated or toxic food and the first symptom. The incubation period may be long or short, depending upon the peculiarities of each specific host-parasite relationship and the ease with which the infecting organism or toxin finds access to the tissue in which its primary multiplication or toxic reaction takes place. When a chemical which is an irritant to the gastrointestinal tract is ingested in sufficient quantity, vomiting follows in a short time, usually within an hour. Infectious hepatitis, which affects the liver, may have an incubation period of 15 to 30 days. The duration of the incubation period is an important characteristic of each disease. During an outbreak investigation, the incubation period cannot be determined until the responsible meal or time of ingestion of the incriminated food has been identified.

Vector. This is a means for transferring organisms from place to place. It is sometimes difficult to determine whether vectors are sources of contamination, or whether they pick up organisms from their environment. They do reflect the contamination of their environment and may transfer such contamination. If the environment of a plant, for example, is contaminated with a particular pathogen, finished products almost inevitably become contaminated.

TABLE 5. COMPARISON OF COMMON-SOURCE AND PROPAGATED EPIDEMICS

Characteristic of Epidemic	Common-source Epidemic	Propagated Epidemic
Onset	Rapid, sharp rise	Insidious, slow rise
Duration	Cases occur within 1 (or a few) incubation period(s) of the disease	Cases occur over several incubation periods
Decline	Rapid. Usually not exceeding 1 incubation period after source is eliminated	Slow, but self-limiting because proportion of nonimmune individuals becomes too small to support spread of agent
Time of episode	Marked localization by time	Not generally localized by time
Period of infectivity of disease agent	Usually brief activity in community (such as food served at 1 meal)	Persists in community
Incubation period of disease	Predominance of cases have shorter-average incubation periods	Predominance of cases have longer-than-average incubation periods
Dose	Large number of organisms are usually transmitted	Fewer organisms are transmitted
Episodes of contamination or infection	Single-event; all victims are infected at 1 time or within a relatively short period of time	Multiple events; victims are infected at various times

Source: Bryan (1976) reference listed.

Outbreak. In the United States, an outbreak of foodborne disease is a situation in which two or more people experience a similar illness, usually gastrointestinal, after ingestion of a common food and where epidemiologic analysis implicates the food as the source of the illness. However, only one case of botulism or chemical poisoning constitutes an outbreak. Outbreaks are divided into two categories:

Laboratory-confirmed outbreak. In which laboratory evidence of a specific etiologic agent is obtained and specified criteria are met.

Outbreak of undetermined etiology. In which epidemiologic evidence implicates a food source, but adequate laboratory confirmation is not obtained. These outbreaks are further subdivided into four subgroups by incubation period of the illness:

Less than 1 hour—probably chemical causative
From 1 to 7 hours—probably *Staphylococcus* infection
From 8 to 14 hours—probably *Clostridium perfringens* infection
More than 14 hours—various other infectious agents.

Much of the information required by public health authorities in developing foodborne disease patterns stems from personal interviews with persons who have suffered (or are still suffering) the illness and other people who appear to possess immediate knowledge of suspected places (household, restaurant, picnic, etc.). where food was probably ingested and where it may have been contaminated prior to ingestion.

Fundamental Causes of Foodborne Diseases

The fundamental causes of foodborne disease outbreaks (United States) are listed in Table 6. This situation will be considerably different, of course, for various countries. Even with advancements in epidemiology and food microbiology, it is interesting to note the rather high percentage of nonconfirmed or unknown causes. Definite etiology was established for 132 out of 306 outbreaks or 30.1% of outbreaks. It will be noted from Table 6 that the most frequent cause of foodborne diseases in the United States stems from improper holding temperature, followed by contaminated equipment, poor personal hygiene, and inadequate cooking. Unsafe food sources are important, but are less-frequent causes of foodborne diseases.

Foods may become contaminated at any stage of production, processing, storage, or preparation. Contamination results when plants or animals possess toxic parts or tissues; when plants or animals become infected or contaminated in the environment of their growing or production area; when infected tissues or feces directly or indirectly contact carcasses; when contaminated raw products are incorporated into a processed food and, if processed, the method of processing fails to destroy the contaminating agents; or when there is postprocess contamination by workers, equipment surfaces, cooling water, ice, aerosols, or vectors (Bryan, 1975).

Animals and Raw Ingredients. Raw products of animal origin are frequently contaminated by pathogens that are associated with animals. Animal tissues that are used for food may become infected within the animal. For example, trichinae in pork from a hog having trichinosis; brucellae in milk from an animal have brucellosis; salmonellae in egg yolks transmitted from the ovary of hens having salmonellosis; and staphylococci in milk from cows having mastitis.

The intestinal tracts of animals and animal feces are a source of enteric organisms (salmonellae, arizonae, entero-

TABLE 6. PRINCIPAL CAUSES OF FOODBORNE DISEASES (United States)

Etiology	Number of Reported Outbreaks	Number of Outbreaks in which Factors Reported	Improper Holding Temperature	Inadequate Cooking	Contaminated Equipment	Unsafe Food Source	Poor Personal Hygiene	Other
BACTERIAL								
B. cereus	2	2	2	–	–	–	–	–
C. botulinum	23	13	3	11	–	–	–	–
C. perfringens	6	6	5	2	1	–	1	1
Salmonella	28	16	10	4	8	3	8	4
Shigella	6	3	1	2	–	–	2	2
Staphylococcus	26	22	20	–	3	1	7	–
Y. enterocolitica	1	–	–	–	–	–	–	–
CHEMICAL								
Heavy metals	6	6	1	–	3	–	–	2
Ciguatoxin	6	2	–	–	–	1	–	1
Scombrotoxin	2	1	–	–	–	–	–	1
Paralytic shellfish poison	4	3	–	–	–	3	–	–
Monosodium glutamate	2	0	–	–	–	–	–	–
Mushroom poison	1	1	–	–	–	1	–	–
Other chemicals	7	5	–	–	–	2	–	3
PARASITIC								
T. spiralis	8	7	–	7	–	–	–	–
E. histolytica	1	–	–	–	–	–	–	–
VIRAL								
Hepatitis A.	2	1	–	–	–	–	1	–
Echo, Type 4	1	–	–	–	–	–	–	–
Confirmed Total	132	88	42	26	15	11	19	14
*Percentage of confirmed total	–	–	47.7%	29.5%	17.0%	12.5%	21.6%	15.9%
Unknown etiology	306	154	118	17	39	6	34	30
*Percentage of all outbreaks reported.	–	–	66.1%	17.8%	22.3%	7.0%	21.9%	18.2%

*Figures in row do not add to 100 because of multiple factors for given etiology.

Data Source: CDC-HEW Publication 78-8185 (1978).

cocci, and *C. perfringens*). If feces or intestinal contents carcasses during processing, enteric organisms will be found on the meat. "Night soil," used in some countries, or sewage-contaminated irrigation water are sources of enteric organisms (salmonellae, shigellae, enteropathogenic *Escherichia coli,* ascaris, and enteroviruses) on vegetables. Sewage-contaminated water is an important factor in the transmission of many parasites to fish, shellfish, or water vegetables and may be involved in the spread of bacterial, parasitic, and viral diseases.

Staphylococci and streptococci may come from the noses and skin of animals and from their abscesses, as well as from humans. These organisms are a common cause of mastitis, and staphylococci are associated with arthritis and bruised tissue in poultry. Saltwater fish may harbor *V. parahaemolyticus* and freshwater fish may be contaminated with *C. botulinum* type E and *Diphyllobothrium latum.* Vegetables and some cereal products are often contaminated by organisms commonly found in soil, such as *C. botulinum, C. perfringens,* and *Bacillus cereus.*

If a contaminated raw food, such as raw eggs containing salmonella, is added to a processed food product, such as milk in the preparation of eggnog, without intervening steps to eliminate the pathogens, these pathogens will remain in the product and may cause problems if the product is stored so as to permit bacterial growth (Bryan, 1975).

Processing Conditions. Where there may be failure of lethal processes (pasteurization, sterilization, etc.), in terms of time and temperature, pathogens may survive and later multiply in substantial numbers. See also **Crustaceans; Milk and Dairy Products; Seafoods (Processing)**; and **Thermal (Heat) Preserving.**

Meat blocks, cutting boards, tables, slicing machines, and knives can easily be contaminated by raw meats and fish and, if used for cooked products, cross-contamination from the raw item to the cooked item can occur. Surfaces of equipment that come into contact with suspect food substances should be frequently swabbed, followed by laboratory tests as part of a consistent quality control program. On a regular basis, samples of scrap material and tailings; materials from vacuum cleaners, dust collectors, and floor sweepings; and swabs from drains and other areas of wet contamination, should be checked. Where an effective quality control program is in force, reports from samples and swabs can be very meaningful in situations where sources of contamination must be traced—as in the case of a foodborne disease outbreak. Such records should be clearly identified with time, processing area, and batch —because, for example, different serotypes of *Salmonella* will be found when different herds or flocks are slaughtered or when meat from different lots is processed (Bryan *et al.* 1968).

Workers who handle raw meat, poultry, or fish can pick up foodborne pathogens and, if they do not cleanse their hands thoroughly after handling raw foods, they can transfer these organisms to cooked and prepared foods. Food workers may be nasal or fecal carriers of foodborne pathogens or they may have lesions (infected cuts, burns, or boils) that contain pathogens. Most people carry *C. perfringens* in their intestinal tract; a third or more of the human population carries coagulase-positive staphylococci in their nares. In some instances, if a food worker has eaten a food that is responsible for an outbreak, the finding of the same organism in the worker's stool or from a rectal swab culture as found in the incriminated food may suggest that the worker was a victim of the outbreak, not the source of the organism. Thus, the importance of obtaining medical and food histories of workers.

Water. In canning and certain other heat-processing operations, cooling water is sometimes responsible for contamination after processing. If heated cans, jars, or bags are placed in cold water, they are stressed and if they leak, the product may become contaminated. Contaminated water may also add pathogens to foods if it is used as an ingredient or to wash or "freshen" the food. Such water, if used to wash equipment, may subsequently contact food and cause contamination.

Failure to preserve food in cans or jars against microbial spoilage can be due to improper process design, failure to deliver the designed process, or postprocess contamination (Pflug and Odlaug, 1977). The latter is usually referred to as leaker spoilage (Everton and Herbert, 1972; Put *et al.,* 1972; Shapton and Hindes, 1962). *Leaker spoilage,* as the name implies, occurs when microorganisms that have leaked into the container through holes or through seams after the product has received the sterilization treatment grow and spoil the product. The occurrence or rate of leaker spoilage is a function of the microbial contamination level in the cooling water; the lower the microbial population in the cooling water, the lower will be the rate of leaker spoilage, other factors being equal (Odlaug and Pflug, 1978).

Food poisoning from postprocess contaminated commercially canned foods involving microorganisms, such as *Salmonella* and *Staphylococcus,* have not been a major public health problem in the United States for a number of years. Both Salmonella and Staphylococcus outbreaks involving canned foods have been reported from the United Kingdom (Put *et al.,* 1972). The outbreaks proved to result from improper chlorination of cooling water, poor quality water used in can cooling, and faulty can seams.

In 1963, there were two deaths (United States) from the consumption of commercially canned tuna fish containing *C. botulinum,* Type E toxin. A large number of cans from the cannery which packed the tuna contained botulinum organisms. Most of these cans had defective seams, indicating that the organisms may have entered after heat processing (Johnston *et al.,* 1963). In 1977, Odlaug and Pflug (Department of Food Science and Nutrition, University of Minnesota, Saint Paul, Minnesota) conducted a study to evaluate the sanitizer and microbiological characteristics of water used to cool containers of food after heat processing in commercial plants in Minnesota and Wisconsin. The detailed fingings (beyond scope of this volume) are wlel reported in the Odlaug/Pflug (1978) reference listed.

Aerosols. Either exterior or interior air sources may be contaminated. Intake air filters should be sampled and, if they are positive, this indicates that the environment of the plant has at some time been contaminated or potentially will become contaminated. Contamination of air filters could be due to animals housed near the plant, neighboring processing plants, birds or rodents nesting near or in the plant, or spillage of delivery or waste materials. In addition to examining air filters and fans, air samplers (jars of liquid media or plates of solid media) are also used to sample air, but they are limited by their location and time of exposure.

Inadequate Food Handling and Storage. Bryan (1972) lists the following factors known to contribute to foodborne disease outbreaks—as these relate to the handling of foodstuffs (after commercial processing):

1. Failure to refrigerate potentially hazardous foods.
2. Allowing foods to remain warm (at bacterial incubating temperatures).
3. Preparing foods several hours or days before intended use; or using leftovers (with inadequate storage after preparation).
4. Failure to thoroughly cook or heat process-contaminated foods.
5. Infected employees (distributors, restaurants, cruise ships, etc.) or household persons who practice poor personal hygiene.
6. Use of a contaminated raw ingredient in a food which is to be served uncooked.
7. Cross-contamination of foods by persons who touch unsafe raw foods while cooking otherwise safe foods; or who use improperly cleaned cooking pots and utensils. Failure to clean equipment after use.
8. Obtaining foods from unsafe sources.
9. Inadequate facilities for dry storage.
10. Incidental or intentional addition of toxic chemicals to foods.

Additionally, attention should be given in all food-preparation areas for the maintenance of an environment that does not promote growth of pathogens—provision for clean, conditioned air; designs that facilitate cleaning and hygienic disposal of all waste materials; frequent removal of grease and soot deposits (also desirable from a fire risk standpoint); inspection of piping and cooking equipment to make certain that no toxic chemicals are present; generous use of approved disinfectants; provision of a safe water source for use in preparing foods and for washing and rinsing equipment, among many others.

Recommended practices, of course, are within the regulatory province of public health officials as regards commercial establishments; but to encourage hygienic practices within the millions of households is essentially a matter of education.

A rather typical situation, resulting from a lack of understanding of food-spoilage organisms, is illustrated in Fig. 6.

Specific Foodborne Diseases

Salmonellosis

Salmonellosis is a foodborne disease that is caused by salmonellae (bacteria) other than *Salmonella typhi* and *Salmonella paratyphi.* Salmonellae are gram-negative (See **Gram-Stain**), nonsporeforming (mostly) motile rod, aerobic, facultatively anaerobic microorganisms. There are over 1600 known serotypes, but only about 50 of these occur commonly. Species involved include *Salmonella choleraesuis* and *S. enteritidis.* Organisms possess O (somatic) and 2 phases of H (flagellar) antigens.

Incubation Period and Symptoms. Commonly, the incubation period ranges from 12 to 36 hours after food ingestion, although it may be as short as 5 and as long as 72 hours. Symptoms are one or more of the following: Diarrhea, abdominal pain, chills, fever, vomiting, dehydration, prostration, anorexia, headache, malaise. Duration of the disease may be several days. Enteritis or focal infection may also occur.

Most Likely Food Sources. Meats, poultry, eggs and their products. Other incriminating foods include: Coconut, cottonseed protein, chocolate candy, dry milk, smoked fish, and yeast. See also **Milk and Dairy Products.**

Typical Sources and Reservoirs of Etiologic Agent. Feces of infected domestic or wild animals and humans.

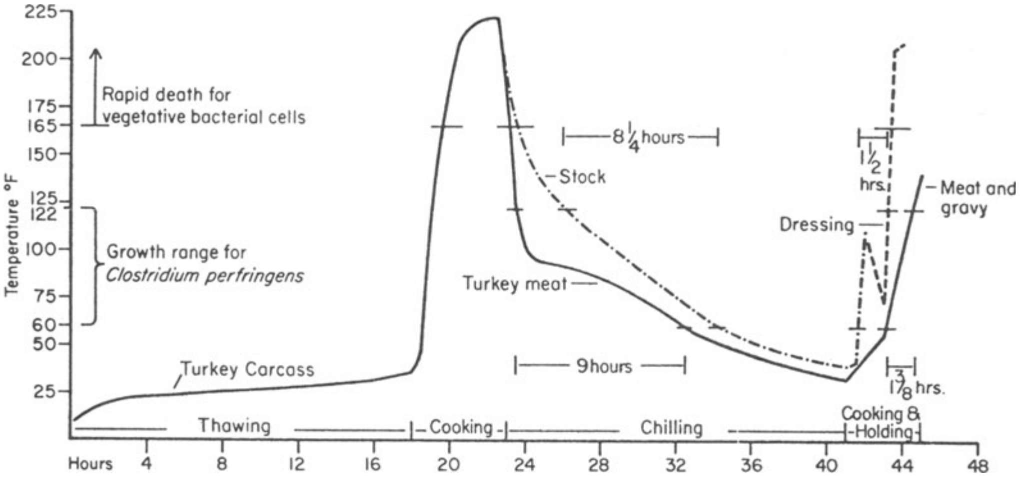


Fig. 6. Time-temperature relationship of a turkey preparation in a school lunch kitchen. In this case, *C. perfringens* could multiply during the 7 to 8 hours in which the meat and stock were in a refrigerator. The organisms present in the meat and gravy would have survived the reheating process. This particular chart was constructed as part of a time-temperature study of the thawing, cooking, chilling, and reheating practices that were used for turkeys which were implicated in a foodborne disease outbreak. (From Bryan et al., 1971)

Susceptibility and Carrier State. Most susceptible persons are infants, the elderly, and malnourished and those with concomitant diseases. However, the disease can affect persons of any age or state of health.

Preventive and Control Measures. Foods should be chilled rapidly in small quantities; foods should be cooked thoroughly. Egg products and milk must be pasteurized. Cross-contamination from raw to cooked foods must be avoided. Strict sanitary measures on the farm and in processing plants must be taken. Feed ingredients for livestock and poultry should be heat-treated. Very importantly, food and feeds must be protected from all excreta.

Some regulatory agencies have suggested the following conditions for egg processing:

Whole Eggs	–Heat to not less than 140°F (60°C) for 3.5 minutes.
Egg Whites	–Neutralize pH, add aluminum to stabilize conalbumin, and heat as stated for whole eggs. –Heat to 125°F (51.7°C) for 1 minute; add 0.75% hydrogen peroxide; hold for 2.5 minutes. –Heat to 125°F (51.7°C); add 0.1% peroxide; hold for 3.5 minutes. –Adjust pH to 9; heat to 134°F (56.6°C); hold for 3.5 minutes.
Dried Egg Whites	–If moisture content is greater than 6%, incubate to 125°–130°F (51.7°–54°C); hold for 7–10 days.
Egg Yolks	–Heat to 144°F (62.2°C) for 3.5 minutes; or to 140°F (60°C) for 7 minutes.
Sugared or Salt Yolks	–Heat to 148°F (64.4°C) for 3.5 minutes; or to 144°F (62.2°C) for 7 minutes.

Processed foods should be chilled as rapidly as practical and held at temperatures no higher than 45°F (7.2°C) for storage periods not exceeding 2 days; and at 40°F (4.4°C) for storage not exceeding 3 days.

Survival of Salmonellae. Several researchers have determined the survival times of salmonellae on different surfaces and substrates:

Contaminated earth and pasture	200 days
Cloth	228 days
Rodent feces	148 days
Roach pellets	199 days
Dried cattle feces	100+ days
Poultry feces	9+ days
Egg shells	21 to 350 days
Dried whole eggs	4+ years
Meat salad	77 days

Although survival is shorter at reduced temperatures, salmonellae remain viable in frozen foods for several months. Reductions of more than 90% have been observed as the result of freezing, but with high starting populations, the surviving population can be potentially dangerous. As pointed out by a number of investigators, cream-filled pastries have a notorious history of being vehicles for foodborne illnesses. Over the years, a number of outbreaks of salmonellosis have resulted from contaminated cream-filled pastries. This product is implicated even more frequently with staphylococcal intoxication.

Rapid Detection of Salmonellae. Recognition of the presence of salmonellae in foods of animal origin has emphasized a need for rapid and simple detection methods that can be used in routine quality control (Swaminathan, *et al.*, 1978). The fluorescent antibody technique, which was granted Official First Action status by the Association of Official Analytical Chemists in 1975, requires the use of an expensive fluorescence microscope, costly fluorescein-labeled antisera, and highly trained personnel to perform the test. The evaluation of fluorescence is subjective and there can be interferences due to nonspecific fluorescence and autofluorescence. Several attempts have been made to devise other rapid and simple methods for detection of salmonellae. Some of these methods involve selective motility media (Stuart and Pivnick, 1965; Chau and Huang, 1974). The use of a semisolid enrichment medium in a column or U-tube leads to isolation of motile salmonellae from a mixture culture. The pure culture is then subjected to a few selected biochemical tests or O and H serology to confirm the presence or absence of salmonellae. Banwart *et al.*, (1968) used such a method to screen and eliminate Salmonella-negative samples of pasteurized dried whole egg.

Most of the selective motility procedures are primarily for the isolation of salmonellae from a mixed culture and require further confirmation through biochemical or serological tests. All methods also required specially designed glassware. Swaminathan, *et al.* (Department of Food Science, University of Georgia, Athens, Gerogia) have developed a method to overcome the aforementioned deficiencies that combines the isolation and reliable detection of motile salmonellae in one step. The method is based upon the disc-immunoimmobilization technique suggested by Mohit *et al.* (1975) and is reported in detail in the listed reference.

Glutaraldehyde. A number of investigators have reported the successful use of glutaraldehyde to disinfect medical, dental and hospital instruments (Stonehill, *et al.*, 1963; Borick, 1968). Varpela *et al.* (1971) reported that glutaraldehyde has low toxicity at low concentrations, retains its potency in the presence of organic matter, is stable during storage in an acid solution, is noncorrosive, and has a low surface tension which provides good penetrating power and rinsability. As of the late 1970s, mutagenicity, carcinogenicity, and teratogenicity, or lack thereof, had not been demonstrated. In 1977, Thomson, Cox, and Bailey made a study of the effectiveness of glutaraldehyde in eliminating inoculated salmonellae from broiler carcases during simulated commercial chilling, and in delaying onset of off-odor and retarding bacterial growth during storage of carcasses. This is reported in detail in listed reference. Glutaraldehyde as of late 1970s has not been approved for general use.

Attempts to destroy *Salmonella* on raw poultry carcasses with chemicals or heat, either during processing or at the ready-to-cook stage, have been ineffective unless the treatment was sufficiently severe to modify the fresh appearance of the product (Juven *et al.,* 1974; Thomson *et al.,* 1976).

Other Salmonellae. **Typhoid fever** or enteric fever can be transmitted by food, *Salmonella typhi* is similar to other salmonellae, but is adapted to the human host. It possesses VI (capsular) antigens as well as O and H antigens. Water is also commonly implicated in outbreaks of typhus. High-protein foods, raw salads, milk, shellfish are the usual categories of foods involved. These are largely foods that have been handled, and then eaten without further heat treatment. **Paratyphoid fever,** also sometimes called enteric fever, can be transmitted by foods. *Salmonella enteritidis* is also similar to other salmonellae, but is more or less adapted to the human host. This microorganism causes a blood stream infection. The disease is of a milder and shorter duration (1 to 3 weeks) than typhoid fever. Foods typically involved are milk, shellfish, raw salads, and eggs.

Staphylococcal Intoxication

Also termed **staphyloenterotoxicosis,** staphylococcal intoxication is caused by *Staphylococcus aureus.* The etiologic agent is enterotoxin A, B, C, D, E, or F of *S. aureus.* This microorganism is gram-positive, nonsporeforming, nonmotile cocci occurring in irregular grapelike groupings. Other properties of the microorganism include—aerobic; facultatively anaerobic; coagulase-positive; ferments mannitol; grows well in 10% salt media; produces lipase and hemolysin; often produces orange or yellow pigments and heat-stable enterotoxin; resistant to antibiotics.

Incubation Period and Symptoms. Commonly, the incubation period ranges from 2 to 4 hours, although it may be as short as 1 and as long as 7 hours after food ingestion. Symptoms are one or more of the following: Sudden onset of nausea, salivation, vomiting, retching; diarrhea; abdominal cramps; dehydration; sweating; weakness; prostration. Fever usually does not occur. Disease is usually of a short duration of about 1 or 2 days.

Most Likely Food Sources. Cooked ham; meat products; poultry and dressings; sauces and gravies; cream-filled pastry; potato, ham, poultry, and fish salads; milk; cheese; hollandaise sauce; bread pudding; and many high-protein leftover foods.

Typical Sources and Reservoirs of Etiologic Agent. Nose and throat discharges; hands and skin, particularly from infected cuts, wounds, and burns; boils, pimples, acne; feces. The anterior nares of humans are the primary reservoir. In cows and ewes, it is the mastitic udder. In poultry, the arthritic and bruised tissue. In most cases, where the disease develops, it will be from food that has been contaminated after cooking or processing.

Preventive and Control Measures. Very similar to the general measures described under "Salmonellosis." In particular, ill persons suffering colds, infected cuts, and diarrhea, should not be permitted to be in the food-preparation area. Thorough cooking, reheating, and pasteurization destroy the microorganisms, but unfortunately, they do not destroy any toxin that may be present. Wherever possible, foods should be prepared on the same day they are served. As previously mentioned, freezing does not fully control the microorganism, with outbreaks occurring from time to time after thawing frozen cream-filled pastries.

Treatment of the illness consists of fluid and electrolyte repletion. Death rarely occurs, except in infants or in elderly or debilitated persons.

Enterotoxin Production in Foams. The production of enterotoxins by *Staphylococcus aureus* appear to be very dependent upon optimum levels of oxygen (Baird-Parker, 1971; Jarvis *et al.,* 1973). From this, one might conclude that enterotoxin production in foods is primarily a surface phenomenon. However, foods often have air entrapped at the interface with the container, in voids between pieces of solids, or in foams. The effect of this limited amount of air has not been investigated even though a number of studies on the effectiveness of rates of continuous aeration in a fermenter or in shaker flasks have been made. In 1978, Woodburn and Morita (Department of Foods and Nutrition, Oregon State University, Corvallis, Oregon) made an initial investigation of this. In these experiments, air was incorporated into culture media by addition of cellulose or nonabsorbent cotton pads to cornstarch pastes and by foam formation in an agar gel. Production of staphylococcal enterotoxin types A, B, and C during incubation at 37°C (98.6°F) was increased both on a per milliliter basis and per 10^6 CFU by such air inroporation, but not in deaerated controls. Nuclease production followed the same trend. Cell numbers were less affected. Conclusions: Even limited inclusion of air within a food system thus increases the rate of staphylococcal production of enterotoxin.

Crisley *et al.* (1964) observed that a synthetic cream pie filling that did not support staphylococcal growth alone did so when put into a pie shell. This may be partially explained by the effect of the layer of adsorbed air between the shell and the filling. The frequent implication of potato and chicken salads, for example, may be related to the air which is incorporated through such mixtures as well as the absence of microbial competition.

A test for staphylococcal enterotoxin is described in *Lancet,* **1,** 472 (1973).

Botulism (Clostridium botulinum)

Botulism is a foodborne disease that is caused by the toxins A, B, E, or F of *Clostridium botulinum.* Toxins C and D cause botulism in animals. Type G, found relatively recently, has not, to date, caused any human cases of the illness. The microorganism is a gram-positive, sporeforming, motile rod. Neurotoxins are formed which interfere with acetylcholine at peripheral nerve endings. The spores are among the most heat-resistant of those found in connection with foodborne diseases. The toxins are heat labile. Fatalities have occurred in cases in which victims have tasted only a very small amount of the toxin-containing food. Despite the potent aspects of botulinus toxin, improvements in respiratory care have helped to reduce the mortality in cases of botulism from 60 to 20%. There is also available a trivalent antitoxin, which when administered promptly, is very effective in most cases in modifying the course of the disease. Cases of botulism also can result from infection of wounds by *C. botulinum,* but the great majority of cases result from ingestion of contaminated food.

Cases and outbreaks of botulism occur in many parts of the world and in all regions of the United States, but the disease is most frequently found in the western United States, notably in Alaska, California, Colorado, Oregon, and Washington. Cases in Alaska, in several instances, have been attributed to toxins released from raw fish that has been aged in plastic bags, from seal meat that has been stored in oil, and from smoked salmon that has been wrapped in seal skins (Eisenger/Bender, 1976).

Incubation Period and Symptoms. Commonly, the incubation period ranges from 12 hours to 36 hours after food ingestion, although it may be as short as 2 hours and as long as 6 days. Symptoms are one or more of the following: Nausea, vomiting, abdominal pain, and diarrhea—signs which may appear early. Headache, vertigo or dizziness, lassitude, double vision, disphagia, dysponia, ataxia, dry mouth, weakness, constipation, respiratory distress, respiratory paralysis may develop. Partial paralysis may persist for 6 to 8 months. Sensorium is usually clear. When the disease is fatal, death usually occurs within 3 to 10 days.

Of paramount importance is the maintenance of ventilation of the patient. The treating physicians will check for impending respiratory failure by taking serial measurements of vital capacity; actual respiratory failure can be recognized by changes in arterial blood gas levels. As lifesaving interventions, endotracheal intubation, eventual tracheostomy, and use of mechanical ventilators are available. The use of guanidine to increase acetylcholine release from nerve terminals remains controversial (Cherrington/Ginsberg, 1970; Faich/Graebner/Sato, 1971).

Infant Botulism. Botulism in infants was first recognized in 1976 and has appeared with surprising frequency since that time. Some authorities now believe that infant botulism may be incriminated in connection with some cases of **sudden infant death** (Pickett *et al.*, 1976; CDC Morbidity and Mortality Weekly Report, 1978).

Some authorities believe that infant botulism may not be caused by ingestion of toxin, but rather by the colonization of the intestine by *C. botulinum,* followed by absorption of the toxin. Honey has been implicated in about one-third of the cases and, consequently, some physicians recommend that honey not be fed to infants under 1 year of age. Onset of the disease (between 5 and 20 weeks) is characterized by constipation, followed by cranial neuropathy which produces muscle weakness. Infants displaying such symptoms have sometimes been described as "floppy." Sudden death may result from hypoventilation and apnea.

Twenty-four-hour consultative and laboratory services are maintained by the Center for Disease Control (CDC) in Atlanta, Georgia, from which polyvalent and monovalent botulinal antitoxins also are obtainable.

Most Likely Food Sources. The sources particularly pertinent to Alaska have been described. Foods generally implicated are improperly canned, low-acid foods (green beans, corn [maize], beets, asparagus, chili peppers, mushrooms, spinach, figs, olives, tuna). Smoked fish and fermented foods also have been implicated.

Preventive and Control Measures. Cans should be heated at high temperatures under pressure for sufficient time. Home-canned foods should be cooked thoroughly, by boiling and stirring for a minimum of 15 minutes. In addition to adequate refrigeration, addition of acidic substances and salt can be helpful. The availability of antitoxins has been mentioned.

Home-canned Tomato Products. Since an outbreak of botulism from home-canned tomato juice in June 1974, changes in procedure for home canning tomatoes have been suggested by a number of scientists (U.S.). Some scientists suggest adding citric acid to produce a definite acid taste and processing to a center temperature of 87.8°C (190°F) for at least 2 minutes. The National Food Safety Committee, composed of many food technologists, met in Saint Louis in 1975. They recommended that tomatoes be hot-packed and pint jars be processed 35 minutes (45 minutes for quarts) in a boiling-water bath, or for 5 minutes at 10 pounds per square inch (0.68 atmosphere) pressure in a steam pressure canner (Johnson, 1975). Many extension specialists have recommended acidification with lemon juice, vinegar, or citric acid in various quantities. Wolf *et al.* (1977) reported the pH of 109 cultivars of tomatoes to be within the acid food range. Officials of the U.S. Department of Agriculture studied 350 cultivars of tomatoes and reported that the fruit normally contains enough natural acid to prevent growth of *C. botulinum* (Sapers, 1977). These conclusions based upon mean pH ignored the considerable variation in pH of individual tomatoes within a given cultivar (Skelton/Craig, 1978). In 1963, Farrow found that 6 to 7% of individual usable tomatoes had a pH of 4.6 or greater.

The pH of tomatoes increases as they ripen from firm-ripe to soft-ripe (Villarreal *et al.*, 1960), increasing the probability of a home canner's having a jar of tomatoes with pH greater than 4.6 (the pH that defines low-acid foods). The Institute of Food Technologists Status Summary (1977) reported that tomatoes can be canned by the boiling water-bath method, but did point out that canning overripe tomatoes can lead to serious problems. In 1978, Skelton and Craig (Department of Foods and Nutrition, Kansas State University, Manhattan, Kansas) undertook a study of the effects of several levels of citric acid, and 4.2 grams (1 tsp) of sugar on the pH, ascorbic acid content, texture and flavor of 2 cultivars of tomatoes canned in a boiling-water bath. The investigators found that adding 0.5 gram of citric acid or 1 gram of citric acid plus 1 tsp of sugar was an acceptable method of decreasing the pH of tomatoes without seriously impairing the flavor or texture.

In a survey by Powers/Godwin (1978), out of 387 jars of tomatoes or tomato juice canned at home in Georgia, 7 containers showed microbial growth indicative of underprocessing or seal failure. Of the remaining 380 jars, the pH of the contents of 1 jar was 4.65. Otherwise all pH values were below 4.6.

In 1978, Nordsiden *et al.* reviewed the effect of a higher process temperature (121°C; 250°F) and the importance of the rate of heat penetration into cans of food during processing, as well as the relative effects of conductive and convective heat transfer. Details are given in reference listed.

Heat Inactivation of Botulinum Toxins. As pointed out by Woolford/Schantz (1978), heat inactivation of botulinum toxins is of current concern as the food industry assesses the use of low-acid foods as ingredients in convenience products, particularly frozen foods which may require or receive only minimal further heating by the consumer. Another concern is the mixing of high-acid and low-acid foods and the effect of this procedure on the stability of any preformed toxin. Previous research by others has indicated that the thermal stability of botulinum toxin is markedly affected by the composition of the food. However, some of the data from those experiments were obtained only from the liquor of canned vegetables (Scott and Stewart, 1950); or meat broths (Prevot and Brygoo, 1953). Othe researchers indicated that factors which increased stability were an acid pH and increased ionic strength of the food. Scott and Stewart also reported that the pH range over which toxin stability was maximum increased in the presence of protein.

Yao *et al.* (1973) reported that type E toxin produced in canned corn (maize) and canned salmon and then frozen and stored at -15°C (5°F) retained its original toxicity level over a period of 264 days. It was noted, however, that after a week or more of cold storage, although toxicity did not change, the heat stability of the toxin began to decrease, i.e., the inactivation rate of the toxin upon heating increased as it remained in cold storage. From this, Woolford/Schantz observed that if this effect is general for all toxin types, then the toxin in frozen convenience foods should be more readily inactivated than toxin in unfrozen foods. The findings of Woolford and Schantz (Food Research Institute, University of Wisconsin, Madison, Wisconsin) proved counter to the foregoing observation. Their conclusions: If foods which contain botulinum toxin are used as ingredients in frozen foods, the toxicity upon frozen storage will not go down nor will the heat stability of type A toxin be decreased. An important factor in the heat stability of the toxin appears to be the pH of the final product. One ingredient may be more acid than the other ingredients, thus lowering the pH and offering greater protection to preformed toxin in the final product.

Para-Hydroxybenzoic Acid Esters. As pointed out by Robach/Pierson (1978), there has been substantial work done on the effect of food additives on the growth and toxin production of *C. botulinum.* Summaries have been prepared by Lechowich (1970) and Rowley and Anellis (1976). Many of the studies on the effect of food additives have centered around the influence of sodium chloride, sodium nitrite, and sodium nitrate as they apply to the preservation of meats (Christiansen, 1975; Collins-Thompson *et al.*, 1974; Tomkin/Christiansen/Shaparis, 1977). Some researchers have studied the effects of sorbic acid and its salts (Ando, 1973), benzoic acid and its salts (Segner *et al.,* 1966), propionic acid and the propionates (Hansen and Appleman, 1955). Segner *et al.* found that 500 parts per million of sodium *para*-hydroxybenzoate had an inhibitory effect on *C. botulinum* type E spores in haddock incubated at 8°C (46.4°F). In 1972, Chichester and Tanner reported that the methyl and propyl esters of parahydroxybenzoic acid are commonly used in the food industry as antimicrobial agents. In 1978, Robach and Pierson (Department of Food Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia) undertook an examination of the effect of the methyl and propyl esters of *p*-hydroxybenzoic acid on the growth and toxin production of *C. botulinum* 10755A. While stressing that further study is required, the researchers found that under experimental conditions (120 hours at 37°C [98.6°F]), growth and toxin production were delayed when 100 parts per million propylparaben was added to a thiotone-yeast extract-glucose medium (TYG). When 1200 parts per million of methylparaben were added to TYG, germination and toxin production were inhibited, while 1000 parts per million delayed growth and toxin production; and 400 parts per million slightly delayed these factors.

Oxidation-reduction Potential and C. botulinum. Smoot and Pierson (1979) point out that a consideration sometimes overlooked in assessing the growth and toxin production of C. botulinum in various media and foodstuffs is the oxidation-reduction potential (Eh) of the system. The Eh is possibly even more critical when growth is being restricted or inhibited by chemicals, such as salt and sucrose. Ando and Iiida (1970) found that the outgrowth of type E spores was significantly affected by the Eh of the growth medium while germination was virtually unaffected. Rowley and Anellis 1976) have pointed out that an Eh of +150 millivolts or greater will inhibit outgrowth of types A, B, and E spores when all other parameters are held optimum. Several studies have been found the Eh of various media to have a significant effect on the chemical inhibition of several clostridial species. Hanke and Bailey (1945) demonstrated that growth-limiting Eh for *C. welchii, C. sporogenes,* and *C. histolycum* was affected by hydrogen ion concentration. Smith and Pierson (1976) showed that differences in medium Eh have an effect on growth-limiting concentrations of chemical inhibitors for type E spores of *C. botulinum.*

In 1979, these investigations were extended by Smoot and Pierson. Their general conclusions: Oxidation-reduction potential of the system should be considered when determining the growth-limiting concentrations of various microbial inhibitors (i.e., sodium chloride, hydrogen ion, sucrose) for *C. botulinum.* Data suggest that the manipulation of the Eh may prove useful in the control of toxic anaerobic microorganisms in food systems. Use of such a phenomenon in a food may depend upon the chemical composition of the food inasmuch as various reducing compounds may be present.

Clostridium Perfringens

During sporulation in the gut, *Clostridium perfringens* (*welchii*) type A microorganisms release a proteinous enterotoxin. However, large numbers of vegetative cells must be ingested. This microorganism is a gram-positive, sporeforming, nonmotile, encapsulated short rod. It is anaerobic and produces lecithinase. There are both heat-resistant (some survive boiling for 1 to 5 hours) and heat-sensitive spores. Heat shock encourages spores to germinate. There are approximately 82 known serotypes.

Incubation Period and Symptoms. Commonly, the incubation period ranges from 8 to 24 hours, with a median of 12 hours. Symptoms include one or more of the following: Acute abdominal pain, diarrhea, occasional dehydration and prostration. Nausea, vomiting, fever, and chills are rare. The disease is of short duration (1 day or less).

Although *C. perfringens* food poisoning is essentially confined to incidences of gastroenteritis, the microorganism when present in severe body wounds can have serious consequences. For infection to occur, a lowered oxidation-reduction potential, which allows spore germination and bacterial multiplication, is required. Tissue necrosis, impairment of blood supply, and introduction of foreign bodies provide such an environment. Major determinants of pathogenicity for invasive clostridia are their potent exotoxins. Once bacterial multiplication and toxin production occur at a site of injury, rapid invasion and destruction of healthy tissue ensue.

Most Likely Food Sources. Cooked meat and poultry that has remained at room temperature for several hours or slowly cooled. Gravy, stew, and meat pies.

Preventive and Control Measures. Foods should be chilled rapidly in small quantities. Excellent personal hygiene by all personnel (including household) should be practiced. Hot foods should be held at 140°F (60°C) or higher. Meats marketed as cured meats should be processed under rigid restrictions. Sewage should be disposed in a sanitary manner. Thorough cooking will destroy vegetative cells, but not the heat-resistant spores. When reheating leftover foods, they should reach a minimum temperature of 165°F (74°C).

Clostridium perfringens Type C. This is a gram-positive, sporeforming, nonmotile rod, anaerobic microorganism. This microorganism was formerly called type F. Lecithinase and necrotoxin are produced. The strains differ in minor antigens. The incubation period ranges from 6 hours to 6 days, but is usually about 24 hours. Symptoms include diarrhea, prolonged abdominal pain, gangrene of small intestine, shock, toxemia. Case fatality rate of this type is about 40%.

Most likely food sources include pork, other meats, and fish. Preventive measures include eating a balanced diet. Foods should be chilled rapidly in small quantities. As with type A, thorough cooking will destroy vegetative cells, but not the heat-resistant spores. Leftovers should be reheated to 160°F (71°C) and hot foods should be held at temperatures greater than 140°F (60°C).

Type C *Clostridium perfringens* disease is sometimes called **enteritis necroticans** or *Pig-Bel*.

Bacillus cereus *Gastroenteritis*

The etiologic agent of this foodborne disease is exoenterotoxin of *B. cereus*. The microorganism is a gram-positive, sporeforming, motile rod, frequently in the form of chains. Lecithinase is produced.

Incubation Period and Symptoms. Commonly, the incubation period ranges from 8 to 16 hours, but may be as short as 1.5 to 5 hours. Symptoms include one or more of the following: Nausea, abdominal cramps, watery diarrhea, some vomiting. Where there is a short incubation period, nausea and vomiting predominate. In many ways, the disease is similar to staphylococcal intoxication. The illness is usually of short duration (1 day or less).

Most Likely Food Sources. Custards, cereal products, puddings, sauces, meat loaf, fried rice. Preventive and control measures are essentially the same as those described for *Clostridium perfringens* type A illness.

Sporulation of C. perfringens and Soy Materials. Craven and Mercuri (1979) observe that soy proteins are increasingly used to supplement meat systems or to simulate meat products. From the standpoint of food safety, the effects on growth or enterotoxin production of food-poisoning bacterial should be compared between these soy products and the meat products they replace. To this end, Craven and Mercuri (U.S. Department of Agriculture, Animal Products Laboratory, Microbiology Research Unit, Richard B. Russell Agricultural Research Center, Athens, Georgia) conducted a study to determine effects of commercially prepared soy materials on sporulation of *C. perfringens* in meat-soy mixtures. In essence, the investigators found that when the initial pH differences were eliminated, the soy materials evidently were good nutrient sources for sporulation. Perhaps the increased sporulation observed with addition of soy products to a liquid medium is due to absorption of compounds, that are inhibitory to sporulation, by the insoluble constituents of soy products. Such an explanation was proposed when *C. perfringens* sporulation increased in media with added activated carbon (Duncan and Strong, 1968) and with added anion exchange resin (Clifford and Anellis, 1971). The investigators summarized by observing that the addition of some commercial soy materials to meats inhibited, and addition of others stimulated sporulation of *C. perfringens*. The data indicated that sporulation was significantly affected when soy proteins that changed the pH of the meat-soy mixtures were used.

Illness from *Clostridum perfringens* in meat products is a major concern in the food industry (Bryan and Kilpatrick, 1971; Hall and Angelotti, 1965). Long-time, low-temperature (LTLT) cookery for beef or other meat in the processing industry, food service establishments and the home creates the potential for substantial growth of *C. perfringens* during cooking. The contamination of raw beef and the potential of *C. perfringens* for rapid growth at relatively high temperatures is also of primary concern. The combination of LTLT cookery and processes, such as mechanical tenderization which contaminate the interior of beef roasts present an ideal situation for excessive growth. However, the increased product yield and final product tenderness support the use of LTLT cookery (Thompson *et al.* 1979).

Mathematical Modeling. A number of researchers have stressed the usefulness of mathematical modeling of physical and biological mechanisms (Pirt, 1975; Wolberg, 1976). Effective mathematical models can be a valuable process design tool and can provide valuable assistance in understanding a system. The mechanisms that are operational during the growth and inactivation of a population of organisms cannot be studied independently. A model facilitates the concurrent study of the mechanisms and their interdependence. When additional experimentation is anticipated, a mathematical model can be used to improve the efficiency of design for future experiments (Thompson, *et al.*, 1979).

Thompson *et al.* (Department of Agricultural Engineering and Department of Food Science and Nutrition, University of Minnesota, Saint Paul, Minnesota) developed and tested a mathematical model of a system as described above. The researchers observe that the model explains over 90% of the experimental variation reported by Willardsen *et al.* (1978) with 156 degrees of freedom for error. Details of the Thompson study are reported in the reference listed.

Vibrio parahaemolyticus Infection

This foodborne illness is produced by *Vibrio parahaemolyticus* microorganisms. The microorganism is gram-negative, straight or curved motile rod and is aerobic and facultatively anaerobic. The microorganism resists 7%, but not 10% sodium chloride media. Possesses O, K., and H antigens.

Incubation Period and Symptoms. Most commonly, the incubation period is 12 hours, although it may be as short as 2 hours and as long as 48 hours. Symptoms include one or more of the following: Abdominal pain, diarrhea (watery stools containing blood and mucus), usually nausea and vomiting, mild fever, chills, headache, prostration. Recovery usually occurs within 2 to 5 days.

Most Likely Food Sources. Raw foods of marine origin. Saltwater fish, shellfish, crustaceans, and various fish products. Cucumbers and other salty foods have been implicated. Reservoirs of the microorganism are sea water and marine life. A large percentage of the illnesses have been reported in Japan, particularly in warmer months. Occurrence is less in the United States and other parts of the world.

Preventive and Control Measures. Foods must be cooked thoroughly. Chilling should be rapid and in small quantities. Cross contamination from saltwater fish must be avoided. Seawater should not be used for rinsing foods to be eaten raw, or for cleaning.

Salt Deprivation and Low-temperature Sensitivity. In furtherance of research in this area, Gray and Muir (Department of Food Science and Nutrition, University of Delaware, Newark, Delaware) examines the effects of low temperature exposure in menstrua containing sodium chloride at concentrations less than 3%. In parallel, the survival of *V. parahaemolyticus* in oysters containing different levels of sodium chloride at 4°C (39.2°F) was determined. The effect of prior growth conditions on the survival of the organism in sodium chloride solutions at 4°C was also examined and morphology of cells grown under different conditions of sodium chloride and temperature were noted. The researchers concluded, in part, that *V. parahaemolyticus* may not be low-temperature sensitive per se, but the sensitivity may, in fact, be one of salt deprivation which is accentuated at low temperature. This loss in viability can, therefore, be offset by maintaining an adequate temperature, or by growth of the organism at a suboptimal temperature of 20°C (68°F). This would explain the relative ease with which the organism is isolated from the natural environment during summer months and contributes further to understanding the reason for the difficulty in isolating the microorganism during winter months when water temperature reaches 10°C (50°F) or lower (Gray/Muir, 1977).

Shigellosis or Bacillary Dysentery

This disease is usually transmitted by interpersonal spread. However, common-source foodborne outbreaks are reported from time to time. The etiologic agents include *Shigella sonnei, S. flexneri, S. dysenteriae,* and *S. boydii.* Shigellae are host specific to humans and thus food substances can be contaminated only by contact with the feces of infected humans. Foods most likely to be contaminated include moist, mixed foods; milk; beans; potato, tuna, shrimp, turkey, and macaroni salads; apple cider; and poi. The incubation period ranges from 1 to 7 days, but usually is less then 4 days. Symptoms are quite variable, ranging from mild to severe, involving abdominal cramps, fever, chills, diarrhea, headache, tenesums, lassitude, prostration, nausea, and dehydration.

Yersiniosis

This sometimes foodborne disease, also known as *pseudotuberculosis,* is caused by *Yersinia pseudo-tuberculosis,* or *Y. enterocolitica,* which are gram-negative, motile rods. Coccoid forms predominate in young cultures. Microorganisms are aerobic, facultatively anaerobic. The incubation period is from 24 to 36 hours or longer. Likely food sources include pork and other meats, raw milk, unpasteurized ingredients of milk products, such as chocolate, and any other contaminated raw or leftover food. Sources and reservoirs include the urine and feces of infected animals, frequently rodents, dogs, and pigs. The microorganisms also are found in soil, dust, and water. Control measures include cooking foods thoroughly and protecting food supplies from contamination by rodents.

Relatively uncommon, yersiniosis occurred in outbreak proportions in central New York (near Utica) in the late 1970s. The ailment affected 218 children and, because the disease mimics appendicitis, 13 needless appendectomies were performed. The disease was first traced to school eating facilities and finally narrowed down to the milk. Upon investigation, it was found that unpasteurized chocolate flavoring had been added to the milk after the milk per se had been pasteurized. Prior to this incident, only about 100 cases had previously been recorded. The first epidemic occurred in the United States in 1973 among four rural North Carolina families, living with poor sanitary facilities. Contaminated milk caused that outbreak.

Foodborne Viral and Rickettsial Diseases

Epidemiological evidence has confirmed the foodborne transmission of several viral diseases, including hepatitis A, poliomyelitis, Bolivian hemorrhagic fever, Russian spring-summer encephalitis, and Q fever. There are also several viral diseases which could possibly be transmitted by foods, but where solid proof is lacking, and these include summer grippe (Coxsackie group A viruses), epidemic myalgia (pleurodynia), echo virus infections (enteric cytopathogenic human orphan viruses), hepatitis B (serum hepatitis), and nonbacterial gastroenteritis (possibly caused by the Norwalk agent).

Hepatitis A (Infectious Hepatitis). Caused by hepatitis virus A, this illness has an incubation period of from 10 to

50 days, but is about 30 days on the average. This is a systemic infection characterized by constitutional and gastrointestinal manifestations and by injury to the liver. Fever, malaise, lassitude, anorexia, nausea, abdominal discomfort, bile in urine, and jaundice all are symptoms. Severity usually increases with the age of the patient. Duration of the illness ranges from a few weeks to several months.

Suspect food sources include shellfish, milk, orange juice, potato salad, frozen strawberries, glazed doughnuts, whipped cream cakes, and a variety of sandwiches. Sources and reservoirs of the virus are the feces, urine, and blood of infected human cases and persons incubating or convalescing from the disease. Although foodborne, the main routes of transmission are person-to-person contact and drinking water. Good preventive measures include cooking foods thoroughly to inactive virus and to avoid pollution of shellfish growing areas. Drinking water must be fully treated, including chlorination. Known cases of hepatitis A should be isolated for 7 to 10 days after jaundice, and all equipment used for parenteral injections should be thoroughly sterilized. Give gamma globulin to contacts.

Charting of hepatitis outbreaks are given earlier in this entry. See Fig. 4.

General Study of Viruses Associated with Food Supply. In 1977, Kostenbader and Cliver (Food Research Institute, Department of Food Microbiology and Toxicology—Department of Bacteriology and World Health Organization Collaborating Centre on Food Virology—University of Wisconsin, Madison, Wisconsin) conducted a study on the association of viruses with food processing and distribution, with emphasis on the food processing plant. Seven plants were selected for examination and the details are well reported in the listed reference. The researchers concluded, in part: No viruses were found in plants processing vegetable products, nor in three of those working with animal products. Incoming swine at one slaughter plant frequently harbored viruses in their intestines; these were apparently not infectious for humans and were not seen in the final product. An agent too elusive to be characterized was found in frozen ground beef patties from another plant; this agent did not appear to be infectious for humans. A further survey of sanitary sewers at nine plants showed that the incidence of intestinal virus infections in processing personnel was below detectable limits. No virus was detected in 60 samples (2 of each of 6 foods from 5 markets). Although the epidemiologic record shows that viruses in foods to be very low.

TOXIC ANIMALS AS SOURCES OF FOODBORNE DISEASES

These diseases include scombroid poisoning, ciguatera poisoning, moray eel poisoning, ichthyohemotoxism (fish serum toxin), file fish poisoning, tetradon or puffer fish poisoning, clupeoid poisoning, elasmobranch and chondrichthyes poisoning, chimaeroid poisoning, cyclostome poisoning, gempylid poisoning, hallucinogenic fish poisoning, ichthyohepatoxism, freshwater fish poisoning, Haff or Yuksov disease, Minamata disease, paralytic shellfish poisoning, oyster poisoning, callistin shellfish poisoning, abalone poisoning, whelk poisoning, horseshoe crab poisoning, turtle poisoning, hypervitaminosis A, porpoise poisoning, and toxic quail poisoning. It will be noted from the names of these diseases that they are, in many instances, quite specific to a given order or species of animal. Also, that the maritime animals predominate. A few of these diseases are described here in some detail; several of the others are briefly described in Table 7.

Ciguatera Poisoning (Ichthyosarco toxism). The exact nature of the etiologic agent of this foodborne disease (one aspect of *seafood poisoning*) has not been definitely established. Some authorities believe that the toxin is accumulated through the food chain in bottom-dwelling large fish (barracuda, red snapper, amberjack, and grouper), which are usually caught near ocean reefs, predominantly in the region between latitudes 35°N and 35°S. Eleven orders, 57 families and over 400 species of marine animals have been incriminated in connection with this poisoning. Some authorities believe that any marine fish may be potential transvector of ciguatoxin. The poison is concentrated in fish gonads, liver, intestines, and muscles. Good prevention is to avoid eating these parts of the suspect fishes. Eating of unusually large reef fishes should be avoided. There is no reliable method of detecting poisonous fishes by their appearance. Neither frying, baking, boiling, broiling, stewing, steaming, drying, salting, nor other ordinary cooking method destroys ciguatoxin.

The first signs of poisoning are usually observed within 3 to 5 hours after food ingestion, but may be as long as 24 hours. Symptoms begin with nausea, vomiting, abdominal cramps, and diarrhea. Paresthesias involving the lips, tongue, mouth, pharynx, and extremities are a prominent feature of the disease. Other symptoms include myalgias, arthralgias, blurred vision, photophobia, transient blindness, and cranial nerve palsies. In severe cases, bradycardia, hypotension, and respiratory paralysis appear early.

Symptoms usually subside after a few days, but weakness and sensory disturbances can persist for quite some time in rare cases. Fatalities are rare. There is no specific treatment for the disease. Where respiratory paralysis develops, mechanical ventilation may be indicated.

Scombroid Poisoning (Scombrotoxism; Saurine poisoning). This foodborne disease comprises another aspect of seafood poisoning. The etiologic agents are histaminelike substances and possibly saurine (*Proteus* app.). Histidine in flesh is broken down by action of *Proteus* spp. or other organisms. It is thermostable and can withstand boiling for at least 1 hour. Histamine is a capillary dilator. Symptoms of the poisoning are evident from a few minutes after ingestion to about 1 hour. There is intense headache, dizziness, nausea, vomiting, metallic or peppery taste, diarrhea, facial swelling and flushing, epigastric pain, throbbing of carotid and temporal vessels, rapid and weak pulse, burning of throat, thirst, difficulty in swallowing, edema, and itching of skin. Although an illness of great discomfort, recovery usually occurs within 12 hours.

Likely sources of this poison are scombroid fishes, such as tuna, bonito, mackerel, and skipjack. Good prevention requires refrigeration of fish immediately after they are killed. The fish should be consumed promptly, if not immediately refrigerated.

Upon noting first symptoms, and if vomiting and diarrhea have not already occurred, ipecac and cathartics can be

TABLE 7. FOODBORNE DISEASES FROM TOXIC ANIMALS (NOT DESCRIBED IN TEXT)

Disease	Etiologic Agent	Nature of Toxin	Possible Food Sources
Ichthyohemotism (Fish Serum Toxin)	Ichthyohematoxin	Destroyed when heated to 60°-65°C (140°-149°F). Drying does not affect toxicity. Hemolytic.	Moray, conger, and anguillid eels.
File fish poisoning	Aluterin	Water soluble. Believed to originate from zonatharian *Polythoa tuberculosa* which grows on coral reefs.	File fish (*Alutera scripto*)
Clupeoid poisoning	Clupeotoxin	Toxin stable to cooking, salting and drying.	Herring, sprat, sardine, tarpon, anchovy, and herringlike fishes of the Pacific and Caribbean.
Elasmobranch and Chondrichytes poisoning	Unknown (possibly ciguatoxin)	Stable to heat and water soluble. Toxin in flesh may be deactivated by drying.	Liver, gonads, and sometimes flesh of sharks, dogfish, rays, skates. Particularly tropical sharks.
Chimaeroid poisoning	Unknown	–	Ratfish, elephantfish, chimaeras
Cyclostome poisoning	Unknown (probably a biogenic amine)	Suspected anticoagulant. Stability to heat not fully established.	Lampreys and hagfishes. Fishlike vertebrates (eellike form).
Gempylid poisoning (Gempylotoxism)	Gempylid oil (*Ruvettus* oil)	Purgative oil	Snake, mackerels, castor oil fish
Hallucinogenic fish poisoning (Ichthyoallyeinotoxism)	Unknown	Heat-stable toxin	Similar to those causing ciguatera poisoning. Mullet, goatfish, rudderfish, surgeonfish. Poison is more concentrated in the head. Occurs in reef fishes, particularly in the tropical Indian and Pacific Oceans.
Ichthyohepatoxism	Ichthyohepatoxin	Hypervitaminosis A believed to be important. Also histaminelike substance considered. Heat-stable toxin.	Sawara (Japanese mackerel); ishingai (sea bass), sandfish. Most outbreaks reported in Japan.
Freshwater fish poisoning (Ichthyo-otoxism)	Ichthyo-otoxin	Some toxins are destroyed by heat; others not. Causes death in severe cases.	Barbel, pike, sturgeons, gars, catfish, minnows, and other freshwater and some salt water fish. Concentrated in roe and ovaries. Sometimes reported in Europe, Asia, and North America.
Haff or Yuksov disease	Unknown. Thiamine inactivative factor suspected. Possible presence of blue-green algae or mercury suspected.	Causes urine to become brownish black in coloration.	Perch, bream, roach, turbot, lake trout. Usually occurs in lakes following luxuriant blooms of green algae.
Minamata disease	Mercuric chloride-vinyl complex.	Central nervous system involvement. Bacterial conversion of mercury to methyl mercury. High case fatility rate.	Crabs, shellfish, marine invertebrates and fish. Occurs in polluted waters.
Whelk poisoning	Tetramine	Curarelike effects. Tetramine (histaminelike). Heat stable. Autonomic ganglionic blocking agent. Duration usually less than 24 hours.	Japanese species of whelk (mollusca): *Neptunea arthritica; N. intereculpta; N. antigua; Babylonia japonica.*

Basic data source: Bryan (1976) reference listed.

used initially. Antihistamines and bronchodilators may provide symptomatic relief. Of several hundred reported cases of scombroid poisoning, no fatalities have occurred.

Paralytic Shellfish Poisoning (Dinoflagellate poisoning). This foodborne disease is still another aspect of seafood poisoning. The etiologic agent is saxitoxin, a neurotoxin that blocks neuromuscular junctions. It is an alkaloid and relatively heat-stable. It is water-soluble. During red tides, cell counts of plankton blooms may reach from 20 to 40 million per milliliter. Onset of the illness usually occurs within less than 1 hour after food ingestion. Symptoms include tingling or burning and numbness around lips, finger tips and extremities. In severe cases, muscle paralysis develops and leads to dysphonia, dysphagia, and ventilatory impairment. Death caused by respiratory paralysis may occur within the first 12 hours.

The gastrointestinal tract must be emptied of any unabsorbed toxin, with care taken to avoid aspiration. Measures designed to support the cardiovascular and respiratory system should be commenced quickly. Use of a mechanical ventilator may be required.

In February 1973, scombroid fish poisoning occurred in 232 persons who had easten from either of two lots of commercially canned tuna. Cases occurred in four states (United States), with no reported hospitalizations or deaths. Patients became ill about 45 minutes after eating the fish. Symptoms lasted about 8 hours. Contaminated fish contained histamine levels of 68 to 280 milligrams/100 grams of fish muscle. This was the first reported outbreak associated with a commercially canned fish product. Numerous outbreaks have occurred in Japan where fresh fish is a substantial part of the diet. One Japanese report described 14 outbreaks involving 1215 persons within a 4-year period (Kawabata, *et al.*, 1967). Some cases of so-called "tuna fish allergy" probably represent scombroid fish poisoning. See also listed references: Hughes/Merson (1976) and Merson *et al.* (1974).

Oyster Poisoning (Asari or Venerupin poisoning). The etiologic agent is venerupin (asaritoxin), which is a heat-stable toxin. Toxicity remains even after 1 hour of boiling. The toxin is organotropic, affecting mainly the liver. Symptoms may be evident within 6 hours, or as long as 7 days after food ingestion. However, onset of the illness usually is apparent within 24 to 48 hours. Symptoms include anorexia, abdominal pain, nausea, vomiting, constipation, headache, malaise, nervousness, halitosis, bleeding of mucus membrane of nose, mouth, and gums, delirium. There is no paralysis. Case fatality rate is as high as 33%.

Food sources are oysters and clams (asari), including *Crassostrea gigae, Dosinea japonica,* and *Tapes semidecussata.* Prevention is essentially control of shellfish harvesting practices.

Abalone Poisoning. The etiologic agent is described as a photodynamic principle that causes photosensitization. The substance is stable to boiling, freezing, and salting. Timing of onset of disease is dependent upon exposure to sunlight. Where accompanied by exposure to sunlight, onset is sudden, with burning and stinging sensation over entire body, prickling sensation, itching, erythema, edema, skin ulceration on parts of body exposed to light. The food source is the Japanese abalone (*Haliotis discus,* or *H. sieboldi*). Best prevention is to make certain that there are no viscera of abalone in food served. It has been suggested that a. seaweed of the genus *Desmarestia* may be the source of the toxin.

Tetraodon or Puffer Fish Poisoning. There are about 90 toxic species of puffer fish (fugu, blowfish, globefish, porcupine fish, molas, burrfish, balloonfish, and toadfish). The etiologic agent is tetrodotoxin (tetraodontoxin). This is a neurotoxin (paralysis of central nervous system and peripheral nerves). The toxin is stable to boiling except in alkaline solution. Toxin is water-soluble. The toxin mainly attacks nerve endings by blocking movements of all monovalent cations. Onset of illness usually occurs within 10 to 45 minutes after ingestion, although it may be delayed up to 3 hours. Symptoms including tingling or prickly seasation of fingers and toes, malaise, dizziness, pallor; numbness of lips, tongue, extremities; ataxia, nausea, vomiting, diarrhea, epigastric pain, dryness of skin, subcutaneous hemorrhages and desquamation; eyes fixed, reflexes lost, respiratory distress; muscular twitching, tremor, incoordination, muscular paralysis, intense cyanosis. Case fatality rate is close to 60%.

Best prevention is complete avoidance of eating puffers. The sale of puffers in Japan is governed by regulation. Puffer cooks and restaurants must be licensed. Proof of experience in preparing puffers is required.

Foodborne Diseases Resulting from Fungus

Possibly, the most publicized of the foodborne diseases of fungal origin is that caused by the mycotoxins present in certain varieties of mushroom. There are however, a number of mycotoxicosis diseases emanating from other fungal sources. Reported in some detail here is mushroom poisoning and aflatoxicosis. Several others are described briefly in Table 8.

Mushroom Poisoning. Some authorities believe that enthusiasm for so-called organic foods and experimentation with natural hallucinogens have probably contributed to the increased incidence of serious and fatal mushroom poisoning that has occurred in the United States during the 1960s and 1970s (Becker, 1976). Warnings ad infinitum pertaining to the danger of foraging for mushrooms have not proved entirely adequate to prevent tragic cases of poisoning by wild mushrooms. These cases especially occur in the fall when the mushrooms, which are in the reproductive part of the fungus, can be easily harvested. Experience has indicated a wide range of susceptibility to mushroom toxins among individuals. Also, the severity of the poisoning may depend upon the season, the degree of maturation of the mushrooms, and logically the number of mushrooms ingested.

The etiologic agents are cytotoxins, the most important of which is amatoxin produced by mushrooms belonging to the genera *Amanita* and *Galerina.* These include those mushrooms commonly referred to as death angel, death cup, destroying angel. The so-called "false morel" mushrooms of the genus *Helvella* are also implicated. Case fatality rate from poisonings by *Amanita* and *Galerina* approach 50%, while with *Helvella* the fatality rate is considerably lower. It must be emphasized that just one or two mushrooms ingested can cause death.

Mushroom toxins are a protoplastic poison that disrupts integrity of cellular membranes. The amatoxin molecule is a complex protein, a cyclic octapeptide (Fig. 7) that, upon ingestion, inhibits ribonucleic acid polymerase II in the victim's cells, thus interfering with protein synthesis. In turn, this results in damage to membranes of cell walls, of organelles, and of nuclei. Lethal hepatic and renal tubule destruction may occur after ingestion of but one cap containing amatoxin. Authorities do not agree as regards the toxicity of phalloidine, a similar substance with a 7-

TABLE 8. FOODBORNE DISEASES FROM FUNGUS (NOT DESCRIBED IN TEXT)

Disease	Etiologic Agent	Nature of Organism	Possible Food Sources
Alimentary toxic aleukia (ATA) (Epidemic panmyelotoxicosis)	Sporofusariogrenin glycoside and other toxins from *Fusarium sporotrichoides* (*F. poae, Cladosporium, Alternaria, Penicillium,* and *Mucor* spp.	Fungi can grow and produce toxin at -2° to -10° C (28.2° to 14° F), with optimum temperature of 24° C (75.2° F). Toxin has destructive action on blood-forming elements of bone marrow. Nonantigenic.	Grains (millet, wheat, oats, barley, rye, buckwheat) that overwinter under snow. Bread
Urov disease (Kaschin-Beck disease)	Toxins from *Fusarium sporotrichiella.*	Mold widespread in soil. Causes chrondo-esteodystrophy (disease of bones and joints of children). Acute and chronic.	Moist grains
Akakabi-byo (Red mold disease)	Scirpene derivatives of *Fusarium nivale* and *F. graminearum.*	Mold causes scab disease of grain. Reported in soil and air (Japan). In humans, causes vomiting, diarrhea and anorexia.	Wheat flour, rice
Ergotism (St. Anthony's Fire)	Ergot alkaloids from *Claviceps purpurea.* Toxic alkaloids: Ergotamine, ergotoxine, and ergometrine groups.	Seed grain of rye and other cereals. Exerts a marked vasoconstrictive effect on arterioles and may be tumorigenic. No longer common.	Rye meal or bread
Toxic moldy rice disease	Toxins from *Penicillium islandicum, P. atrinum, P. citreovirede, Fusarium, Rhizopus, Aspergillus.*	Hepatoxic (rodents) and may induce liver tumors. Reported in soil and air (Japan).	Yellow rice

Basic data source: Bryan (1976) reference listed.

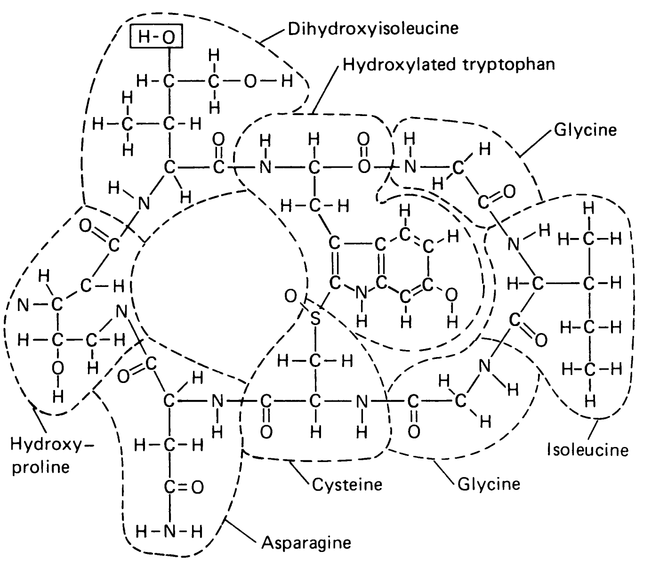


Fig. 7. Amatoxins appear to be made up of 8 amino acids (within the dotted lines). These are joined by peptide bonds and thus a continuous cyclopeptide ring is formed. It will be noted that a sulfur atom serves to link the side chains of 2 of the amino acids and thus a bridge across the ring is created. The OH group contained within the box (for illustration purposes here) is apparently critical to this molecule's toxicity. The specific toxin illustrated here is £-amanitin.

membered cyclopeptide ring structure, which is produced by *Amanita phalloids.*

Early symptoms include abdominal pain, followed by severe vomiting, diarrhea, and fever. Dehydration, hypovolemia, and electrolyte loss may ensue, and hematuria and blood-streaked diarrhea also may occur. After a day or two, the gastionintestinal symptoms abate and the patient may appear to improve. However, by the third or fourth day, hepatic and renal failure become evident. Jaundice, hypoglycemia, oliguria, bleeding, delirium, and coma supervene and, in cases this advanced, 40 to 90% of the patients die. Laboratory confirmation of the presence of amatoxin can be obtained by performing thin-layer chromatographic analysis of samples of mushrooms or of vomitus, gastrointestinal aspirates, or stool speciments (Becker, 1976).

Supportive measures used by treating physicians will include the correction of fluid and electrolyte depletion, important during the initial phase of treatment. Hemodialysis has been used in acute renal failure.

In a number of instances of amatoxin poisoning, thioctic acid (Fig. 8) has been effective in preventing death. Widely used in Europe, the drug is available in the United States on an experimental basis. The principal side effect associated with thioctic acid has been hypoglycemia. Inquiries regarding thioctic acid should be directed to the National Institute of Health, Bethesda, Maryland.

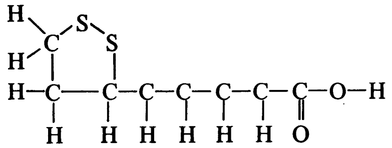


Fig. 8. Thioctic acid, which some authorities have proposed as a possible antidote to the amatoxins found in mushrooms. This is one of several possible isomeric structures.

Toxin ingestion from some mushrooms (or at varying times) may be neurotoxins that are less dangerous than mushroom cytotoxins. Muscarine is one of these neurotoxins. Onset of the illness is rapid. Symptoms include salivation, perspiration, peripheral vasolidation, lacrimation, bradycardia, nausea, vomiting, abdominal cramps, copious watery diarrhea, slow, irregular pulse, pupil constriction, asthmatic breathing, cardiac or respiratory failure (rare). Sensorium is ordinarily clear. Other neurotoxins, with somewhat similar effects, include ibotenic acid, muscimol, uscazone, tricholomic acid, and psilocin. The latter produces psychotomimetic manifestations, causing elevated mood, laughter, hallucinations.

Mushroom-alcohol intolerance is an interesting aspect of certain mushroom reactions. This occurs when alcohol is consumed (ranging from within 24 to 48 hours) after ingesting inky cap mushrooms (*Coprinus attramentarius*). This also occurs in connection with the species *Clitocybe claviceps* when ingested along with, or before beer or sake. Apparently, the disulfiramlike (antabuse) constituents of mushrooms interfere with normal metabolism of alcohol. Normally onset of the illness appears within 1/2 to 2 hours. Symptoms include flushing (purplish-red face), metallic taste, paresthesia of extremities, palpitation, dyspnea, hyperventilation, tachycardia, feeling of swelling hands, nausea, and vomiting. Attacks usually have a duration from 30 minutes to several hours. Prevention is the abstention from alcohol for several days after consuming either of these varieties of mushrooms, and particularly avoiding overheating *C. atramentarius.* Some authorities suggest avoidance of the latter species altogether.

Aflatoxicosis (Aflatoxin Poisoning). The etiologic agents of this foodborne illness are Aflatoxin B_1, B_2, G_1, and G_2 from the *Aspergillus flavus-oryzae* group. These fungi are found worldwide and grow on practically any substrate. They are carcinogenic to rats, ducks, and trout and some authorities implicate them in involvement with human cancers. These toxins are heat-stable. Suspect food sources include cottonseed meal, Brazil nuts, palm kernels, groundnuts (peanuts), corn (maize), other cereals, and animal feeds. Preventive measures include control of moisture during storage of aforementioned materials, preventing of damage during harvesting, insect control, fungicidal mold control, and physical removal of contaminated products, such as groundnuts.

Onset of the illness may require a few weeks. Symptoms include low-grade fever, jaundice, ascites and edema of feet. Fatty infiltration and cirrhosis of liver also may occur. The appearance of aflatoxin is usually random and unpredictable. For example, in Arizona in 1978, about 17,000 tons of cottonseed were stored in a facility that caught fire. The fire was extinguished with water. Subsequent rains and warm weather encouraged the *Aspergillus flavus* mold which produced the aflatoxin. Later tests of milk in grocery stores showed aflatoxin above the 0.5 part per billion (U.S. Food and Drug Administration guidelines) and dairies in the region reacted by dumping some 200,000 gallons of milk. Cases in children with kwashiorkor in India and Africa have been reported. See also entry on **Maize (Corn).**

It is generally accepted that a highly practical approach to control of aflatoxin contamination is controlling storage conditions to prevent growth of *A. flavus* and *A. parasiticus.* However, because of climates in some regions, this is not always a practical approach. Therefore various substances with antifungal or anti-aflatoxigenic activity have been investigated. Gupta and Venkitasubramanian (1975) reported that soybeans are a poor substrate for aflatoxin production and attributed this to phytic acid making the zinc in soybeans biologically unavailable. Bullerman (1974) investigated the antifungal properties of cinnamon, reporting inhibition of *A. parasiticus.* Swaminathan and Koehler (1976) reported that white potatoes inhibited growth and aflatoxin production. In 1978, Buchanan and Fletcher examined the inhibitive properties of 2 methylxanthines (caffeine and theophylline) on growth and aflatoxin production. Positive findings were observed, particularly in the case of caffeine. Findings are reported in detail in the Buchanan/Fletcher (1978) reference listed.

In 1977, Lieu and Bullerman, conducted a very interesting study of the stability of aflatoxins B_1 and G_1, penicillic acid, and patulin in several different food systems (Swiss cheese, bologna, cooked corn mash, bacon, English muffins, etc.) to determine the effects of food substrates and storage temperatures on mycotoxin production. Details are reported in the Lieu/Bullerman (1977) reference listed.

Johnson and Busta (1978) point out that a potential contaminant in some food industry wastes is the mold metabolite, aflatoxin. This substance has been isolated from corn (maize), peanuts (groundnuts), cottonseed and other products (Stoloff, 1976) and has been demonstrated to be a potent hepatocarcinogen in some animals. It is suggested that microbial recovery of waste materials, such as the production of single-cell protein, may reduce the potential hazard of aflatoxin combination. The Johnson/Busta study was directed toward investigating the effect of *B. subtilis* and *L. acidophilus* on aflatoxin in systems for the production of single-cell protein from a protein and starch model waste medium. The investigators selected aflatoxin B_2 as a model toxin for the study. Details are reported in the Johnson/Busta (1978) reference listed.

Hale and Wilson (Coastal Plains Agricultural Experiment Station, Tifton, Georgia) conducted a feeding trial with growing-finishing pigs to study the effect of feeding corn (maize) containing 400 parts per billion of aflatoxin, heated and unheated, with performance of pigs on corn with only a trace of aflatoxin (less than 2 parts per billion), also both heated and unheated. Diets from the unheated aflatoxin-contaminated corn contained an average of 345 parts per billion aflatoxin, while diets made with the similar corn, but heated to an exit temperature from the cooker of about 375°F (196°C), contained only 42 parts per billion aflattoxin. Thus, subjecting the aflatoxin-contaminated corn to a high temperature for only a short period of time reduced the aflatoxin contamination about 8-fold. Pigs fed diets containing the aflatoxin-contaminated corn required about 5% more feed per unit of weight gain than did pigs fed diets containing essentially aflatoxin-free corn. The aflatoxin apparently causes a reduction in feed conversion and reduces digestion and absorption of nutrients.

Foodborne Diseases of Parasitic Origin

Parasitic diseases always or usually transmitted by foods include trichinosis, diphyllobothriasis, and anisakiasis. These are described in some detail here. Other foodborne diseases in this category include taeniasis, cysticercosis, sparagnosis, angiostrongyliasis, fasciolopsias, and several others, briefly described in Table 9. Amebiasis (amebic dysentery) is usually transmitted by other means, but can be foodborne and outbreaks do occur. This is described in some detail here. Toxoplasmosis is also in this category and is described here.

Trichinosis (Trichinelliasis). The etiologic agent is *Trichinella spiralis,* threadlike roundworms (nematodes). The larva excyst in duodenum, females invade mucosa of small intestine, larvae travel via blood and lymph, encyst in muscle. the incubation period varies from 4 to 28 days, but usually requires about 9 days. In the first stage of the disease (intestinal invasion), symptoms include nausea, vomiting, diarrhea, abdominal pain. In the second stage (muscle penetration), there may be an irregular, but persistent fever, edema of the eyes, profuse sweating, muscular pain, thirst, chills, skin lesions, weakness, prostration, labored breathing. In the third stage (tissue repair), there may be generalized toxemia, myocarditis. There will be a high eosinophil blood count.

Because of muscular involvement, there are difficulties with speech, swallowing, and chewing, and usually swelling of the upper eyelids, a characteristic of the disease. Mild cases usually run their course in about 2 weeks; severe cases about 6 weeks. Seldom does any permanent muscle damage result. Contaminated food sources may include pork, bear meat, walrus flesh, and dog meat. Best prevention is by careful control over pork production, making certain that garbage is not fed to pigs. Thorough cooking of all pork also is an excellent safeguard.

Diphyllobothriasis. The etiologic agent is *Diphyllobothrium latum* (broad or fish tapeworm). The flatworm (cestode) attaches to mucosa of small intestine. Length may be 30 feet (0.9 meter) or more. Symptoms are often trivial or absent. Nausea, vomiting, weakness, dizziness, diarrhea or constipation and anemia may occur in serious cases. Deficiency of vitamin B_{12} may occur because of competition of worm for this vitamin. Treatment with one of several antihelminths, such as oleoresin aspidium or quinacrine, is usually successful.

Most common food sources are raw or partly cooked or inadequately pickled freshwater fish, such as pike and pickerel.

Anisakiasis. The etiologic agent is *Anisakis* spp., a roundworm (nematode). The adult worm lives in the intestine of fish-eating sea mammals. Larvae are found in herring. Outbreak reports have been made in the Netherlands, Japan, the United Kingdom, and the United States. Herring is the likely contaminated food source, particularly if raw or partially cooked and pickled or smoked. Best prevention is thorough cooking of herring, or, freshly caught fish can be frozen at -4°F (20°C) and held for 24 hours; or the fish can be preserved with high concentrations of sodium chloride and held for 10 days.

Amebiasis (Amebic Dysentery). Although more frequently associated with the water supply, this disease can also be foodborne. The etiologic agent is *Entamoeba histolytica.* The organism is an amebic protozoan that exhibits four stages (trophozoite, precyst, cyst, and metacyst). Vegetative stage (trophozoite) is very fragile). The cyst stage does not survive drying. After ingestion, intestinal juices render cyst wall permeable and trophozoite emerges. In the vegetative stage it multiplies in mucosa or lumen of colon, and encysts in the lumen of intestine. Most commonly contaminated foods include raw vegetables and fruits, sometimes stemming from use of contaminated washing water. The primary source of the organism is human feces, containing cysts. Main mode of transmission is personal contact. However, flies can transmit organism from feces to water or foodstuffs. Although used in some countries, human excreta should be allowed as fertilizer (night soil).

Incubation period of illness may range from 5 days to several months, but normally is from 3 to 4 weeks. Symptoms are variable, but may include abdominal discomfort, diarrhea, constipation, blood and mucus in stools, distention, headache, drowsiness, ulcers. The illness may spread to blood stream, causing organ infections and abscess of liver, lung, or brain. Most infections are asymptomatic. The disease most often occurs in underdeveloped areas where personal hygiene is inadequate.

Toxoplasmosis. The etiologic agent is *Toxoplasma gondii,* crescent-shaped sporozoa (protozoan). The organism forms cysts. It survives only a short time in an extracellular environment. Incubation period is about 10 to 13 days. Symptoms include fever, lymphocytosis, generalized muscle involvement, headache, myalgia, and rash. Most frequently contaminated food source is rare hamburger. Cysts are found in meat. Best prevention is thorough cooking of meats.

Plant Toxicants and Toxins

Some of the plants that are used as food or sometimes mistaken for food are reviewed here briefly. See Table 10. A number of other food substances may contain poisonous elements, but causes of illness from them are rare. Some of these substances are mentioned in connection with specific commodity and product descriptions found throughout this volume.

Poisonous Chemicals

Because of the importance of certain metals in the metabolic processes of humans and food-source animals, several of these are described in separate entries in this volume. Poisonous aspects, if any, are described in those entries: **Amino Acid; Beef and Dairy Cattle; Bread and Bakery**

TABLE 9. FOODBORNE DISEASES OF PARASITIC ORIGIN (NOT DESCRIBED IN TEXT)

Disease	Etiologic Agent	Nature of organism and Symptoms	Possible Food Sources
Taeniasis	*Taenia saginata* (beef tapeworm)	Flatworm (cestode). Ingested larvae (*Cysticercus* bovis). Larvae develop into adult worms in intestine. Adults attach to mucosa of small intestine by their scolices. Average length is 1.7 feet (3 meters). Eggs may remain viable for 6 months.	Beef. Material from human feces contaminate cattle. Flesh of infected cattle contain agent. Occurs in eastern Africa, South and Central America, Asia, eastern Europe, and southwestern United States.
Sparganosis	Sparganum of *Diphyllobothrium latum* and *Spirometra* spp.	Tapeworm (cestode). Ribbon-like larvae.	Tadpoles, snakes, frogs.
Angiostrongyliasis (Eosinophilic meningoencephalitis)	*Angiostrongylus cantonensis*	Roundworm (nematode). Adult worms live in pulmonary artery of rats and deposit eggs in blood. Larvae hatch from eggs and travel up trachea, are swallowed and pass in feces.	Mollusks–raw crabs, prawns, slugs, land panarian, snails. Raw vegetables sometimes suspected.
Fasciolopsiasis	*Fasciolopsis buski.*	Large intestinal fluke (trematode). Adult attaches to intestinal mucosa. Outbreaks occur in the Orient.	Water chestnuts, water bamboos, water hyacinths, water caltrop, lotus plant root.
Echinostomiasis	*Echinostoma revolutum, E. melis, E. cinetrochis, E. macrorchis, E. recurvatum.*	Intestinal fluke (trematode) Adult attaches to small intestinal wall. Occurs in the Orient and eastern Europe.	Raw snails and clams. Limpets, freshwater fish, tadpoles.
Clonorchiasis	*Clonorchis siensis* (Chinese liver fluke)	Slender hepatic fluke (trematode). Habitat in humans is distal biliary passages and pancreatic duct.	Raw or partly cooked, fresh, dried, salted, or pickled fish. 80 varieties of carp and a number of other species have been incriminated.
Heterophyid infections	*Heterophyes heterophyes, Stellantchasmus talcatus.*	Small intestinal fluke (trematode). Attaches to mucosa of upper levels of small intestine. Similar to *Clonorchis.* Third state of disease may involve cirrhosis, progressive ascites and edema, jaundice. Occurs in Orient, Egypt, and southeastern Europe.	Raw or partially cooked, salted, or dried freshwater or brackish water fish (mullet).
Opisthorchiasis	*Opisthorchis felineus* and O. viverrini.	Hepatic fluke (trematode) resembling *Clonorchis siensis.* Cirrhosis of liver may result. Occurs in central and eastern Europe and the Orient.	Freshwater fish.
Metagonimiasis	*Metagonimum yokogawai.*	Small intestinal fluke (trematode). Attaches to mucosa of upper levels of small intestine. Similar to *Clonorchis.* Occurs in southeastern Europe, and Orient.	
Fascioliasis (Sheep liver infection)	*Fasciola hepatica* and *F. gigantica.*	Large hepatic fluke (trematode). Fluke burrows through intestinal wall to liver. Occurs in South and Central America, southern Europe, Middle East, and Hawaii.	Aquatic vegetation; watercress.
Paragonimiasis	*Paragonimus westermani* (Oriental lung fluke), and *P. skrjabini, P. heterotremus, P. tuanchanensis, P. africanus.*	Plump, oval fluke (trematode). Penetrates intestinal wall and reaches lungs. Occurs mainly in the Orient and Pacific Islands.	Raw or partly cooked crabs and crayfish.

Main data source: Bryan (1976) reference listed.

TABLE 10. REPRESENTATIVE FOOD POISONINGS FROM PLANT TOXICANTS AND TOXINS

Poisoning	Etiologic Agent	Nature of Toxin	Possible Food Sources
Laburnum poisoning	Quinolizidine alkaloid: cystisine.	Similar to nicotine. Stimulation, followed by depression of respiratory system.	Milk from cows feeding on plants, including: Laburnum goldenchain (Cystisus laburnum) and scotch broom.
Delphinium and monkshood poisoning	Polycyclic diterpene alkaloids: Ajacine, ajaconine, delphinine, aconitine.	Hypotensive action affects nervous system (vagus nerve).	Plants sometimes mistaken for horseradish: Larkspur, lark's claw, knight's spur (*Delphinium ajacis*); Monkshood aconite, friar's cap, wolfsbane (*Aconitum napellus*).
Jessamine poisoning	Alkaloids related to strychnine.	Depressant.	Honey made from Carolina jessamine (*Gelsemium sempervirens*).
Colchicine poisoning	Alkaloid: colchicine	Mitotic poison, depression of cell division.	Leaves in salads, tubers mistaken for yams, seed pods, milk of livestock poisoned by such plants as: glory lily (*Gloriosa superba;* autumn crocus (*Colchicum autumnale*).
Cyanide poisoning	Cyanogenetic glycosides: amygdalin, prunasin.	Liberates hydrogen cyanide with odor of bitter almonds. Soaking in water hydrolyzes the cyanogen in cassava.	Seeds and kernels of bitter almond, cassava, choke cherry, cherry pits, peach pits, apple seeds, apricot kernel, lima beans, loquat plum, hydrangea buds. Seeds, kernels, pods, etc. of these plants should not be ingested.
Goiter	Goitrogens: thiooxazolidone derivatives; thiocyanates.	Interferes with uptake of iodine by thyroid gland.	Rutabaga, white turnip, cabbage, soybean, rape seed, peach, pear, strawberry, spinach, carrot. Milk from cows feeding on these plants. (Dietary history to determine specific susceptibility important).
Oleander poisoning	Cardiac glycosides: thevetin, convallarin, steroidal, helleborein, quiabain, digitoxin	Paralyzes sympathetic nerves. Cardiotoxin stimulates heart muscles similarly to digitalis. Produces gastric distress.	Honey made from flowers of oleander (*Nerium oleander, N. indicum*). Also meats roasted on oleander sticks. (Lily-of-the-valley and black hellebore poisoning are similar)
Favism	Vicine, a nucleoside	Susceptibility associated with a sex-linked gene. Allergic reaction. Causes hemolysis of erythrocytes.	Fava or broad bean (*Vicia faba*).
Mountain laurel poisoning.	Resin: Andromedotoxin.	Emetic.	Honey made from flowers of mountain laurel (*Kalmia latifolia*) and also *Rhododendron, Ericaea* spp. plants.
Milk sickness (called trembles in cattle)	Tremetol and resin acid.	Liver poison.	Milk, butter, possibly meat from cows feeding on snakeroot, white snakeroot and Rayless goldenrod.
Leucaena glauca poisoning.	Mimosine, an alpha-aminopropionic acid.	Loss of hair, localized edema, feces are red.	Soup made from Koa haole (*Leucaena glauca*).
Carotenia	High concentration of carotene.	Yellow-orange discolation of skin.	Escessive amounts of yellow vegetables and fruits (carrots, tomato juice, paw paw).
Esophageal cancer	Tannic acid.	Carcinogen causing chronic irritation of the mucous membranes of the throat. May result in throat cancer.	High-tannic sorghum and the grain in Bantu beer and porridge; perhaps in betel nut.

Main data source: Bryan (1976) reference listed.

TABLE 11. REPRESENTATIVE FOOD POISONINGS FROM VARIOUS CHEMICALS

Poisoning	Etiologic Agent	Nature of Poison	Possible Food Sources
Zinc poisoning	Soluble zinc salts.	Astringent, corrosive, and emetic.	Zinc-coated, galvanized containers, pots, cans, tubs. Acids convert zinc into soluble salts. Lemonade, cooked apples, mashed potatoes, spinach, chicken and tomatoes, fruit punch.
Cadmium poisoning	Inorganic salts of cadmium.	Gastrointestinal irritant.	Cadmium (rust-proof) plated utensils, ice-cube trays, pitchers. Foods left in cadmium containers for as little as 1.5 hours have caused poisonings. Main mode of transmission is inhalation of fumes. Lemonade, punch, gelatin dessert, popsicles.
Antimony poisoning	Antimony salts; antimony oxide.	Emetic and irritating to mucous membranes. 18 parts per million can cause symptoms.	Glaze of cheap, gray-enameled cooking utensils containing antimony oxide. Lemonade, punch. fruit gelatin dessert, sauerkraut, popsicles.
Copper poisoning	Copper salts.	Emetic, irritant, and astringent.	Copper pipes, containers, cake decorations. Carbonated beverages, acid foods.
Lead poisoning	Lead–elementary or salts.	Local irritant to alimentary tract in acute poisonings. Organ failure in chronic poisonings.	Lead containers, pipes, putty, pesticides, lead glazes for pottery. Inhalation of lead fumes most common mode of transmission. Acid fruits, maple syrup, beer, cider, vinegar, sardines, ice, bottled whiskey.
Tin poisoning	Tin–elementary or salts	Causes bloating, nausea, abdominal cramps, vomiting, diarrhea, headache.	Tin containers, mostly retinned milk containers. Very few outbreaks reported. Nitrates present cause excessive corrosion of tin linings of cans. Acid foods, cherries, punch, herring, tomato juice.
Nitrite poisoning	Nitrites and nitrates.	Interferes with oxygen-carrying capacity of red blood cells. May form nitrosamines, which are carcinogenic, *in vivo*	Processed meats and fish, beef teas. Nitrites sometimes mistaken and used for salt. Milk formulas; spinach and other plants with excessive fertilization.
Niacin poisoning	Niacin (nicotinic acid), sodium nicotinate.	Causes sudden cutaneous vasodilation.	Color preservative in meat.
Triorthocresyl phosphate poisoning	Triorthocresyl phosphate; triaryl phosphate.	Neurotoxic–paralysis of motor nerve trunks.	Cooking oil substitutes, fluid extract of ginger (Jamaica ginger). Parsley extract, contaminated flour.
Diphenylhydatoin intoxication	Diphenylhydatoin	Normally an epilepsy drug.	Coffee
Oriental (Chinese) restaurant syndrome	Monosodium glutamate (MSG). (Flavor intensifier)	Causes numbness, pressure, tingling sensations in scalp, back of neck, jaw, etc. Headache. Duration usually less than 24 hours.	One teaspoonful of MSG can cause symptoms in persons with susceptibility. Women are more susceptible. Chinese restaurant food (soups, pork with Chinese vegetables, chow mein, egg roll, lobster, boiled rice, etc.)
Potassium bromate poisoning.	Potassium bromate	Caustic and nephrotoxic. Slowly excreted.	Bread, cake, or sugar contamination.
Beer drinkers' cardiomyopathy	Cobalt acetate	Cutaneous vasodilator.	Sometimes used as improver for head of beer. Reported only in habitual, daily consumers of large amounts of beer.
Margarine disease (Planta disease; Blaschenkrankheit)	Emulsifier "ME 18"	Allergic reaction. This emulsifier is used to keep fat from spattering during frying.	Margarine

Other sources of chemical poisoning include: Phenolphthalein, organic phosphorus compounds (insecticides), chlorinated hydrocarbons (insecticides), carbamates (insecticides, such as Carbaryl *Sevin,* fluroine (roach and rat poison), sodium monofluoroacetate (rodenticide), thallium (rodenticide), warfarin (rodenticide) arsenic (pesticide), phosphides, barium, alkyl-mercury, chromium, calcium chloride, lye, methyl alcohol, selenium, among others.

Basic data source: Bryan (1976) reference listed.

Products; Crustaceans; Freeze-Preserving; Meat; Milk and Dairy Products; Mollusks; Poultry; Protein; Protein Quality and Evaluation; Seafoods; Seafoods (Processing); Sheep; Swine; Thermal (Heat) Preserving. See also Table 11. In addition further, and much more detailed attention to microbiology, with stress on modern instrumentation and automation, will be given in Volume 2 of this *Food Sciences, Technology, and Economics Series.*

References

Adams, D. M., Jr., and H. M. Wehr: "Hazardous Anaerobes and Mycotoxins," *Institute of Food Technologists Symposium,* Saint Louis, Missouri (1979).

Ando, Y., and H. Iida: "Factors Affecting the Germination of Spores of *Clostridium botulinum* type E," *Japanese J. of Microbiology,* **14**, 361 (1970).

Ando, Y.: "Studies on Germination of Spores of Clostridial Species Capable of Causing Food Poisoning (2). Effect of Some Chemicals on the Germination of Spores of Clostridium botulinum type A," *J. of Food Hyg. Soc. Japan,* **14**, 462 (1973).

Angel, J. L.: "Porotic Hyperostosis, Anemias, Malarias, and Marhes in the Prehistoric Eastern Mediterranean," in *Population: Dynamics, Ethics, and Policy,* (P. Reining and I. Tinker, Editors), American Association for the Advancement of Science, Washington, D.C. (1975).

Baird-Parker, A.: "Factors Affecting the Production of Bacterial Food Poisoning Toxins," *J. of Appl. Bacteriol.,* **34**, 181 (1971).

Banwart, G. J.: "Glassware Apparatus for Determining Mobile Bacteria. 1. Salmonella," *Poultry Science,* **47**, 1209 (1968).

Becker, C. T., *et al.*: "Diagnosis and Treatment of *Amanita phalloides*-type Mushroom Poisoning," *West J. of Medicine,* **125**, 100 (1976).

Brachfield, B. A.: "Studies on Media Composition and Heat Activation for the Demonstration of Viability of Spores of *Bacillus stearothermophilus,*" Ph.D. thesis, University of Illinois, Urbana, Illinois (1955).

Brenneman, J. C.: "Basics of Food Allergy," Charles C. Thomas, Springfield, Illinois (1978).

Bryan, F. L., and F. G. Kilpatrick: "*Clostridium perfringens* Related to Roast Beef Cooking, Storage, and Contamination in a Fast-food Service Restaurant," *American J. of Public Health,* **61**, 1869 (1971).

Bryan, F. L.: "Guide for Investigating Foodborne Disease Outbreaks and Analyzing Surveillance Data," U.S. Department of Health, Education, and Welfare, Center for Disease Control, Atlanta, Georgia (1975).

Bryan, F. L.: "Diseases Transmitted by Foods," U.S. Department of Health, Education, and Welfare, Center for Disease Control, Atlanta, Georgia (1976).

Buchanan, R. L., and A. M. Fletcher: "Methylxanthine Inhibition of Aflatoxin Production," *J. of Food Sciences,* **43**, (2) 654-655 (1978).

Bullerman, L. B.: "Inhibition of Aflatoxin Production by Cinnamon," *J. of Food Science,* **39**, 1163 (1974).

Busta, F. F. and Z. J. Ordal: "Heat Activation Kinetics of Endospores of *Bacillus subtilis,*" *J. of Food Science,* **29**, 345 (1964).

CDC: "Foodborne and Waterborne Disease Outbreaks," U.S. Department of Health, Education, and Welfare, Center for Disease Control, Atlanta, Georgia (issued annually). (1978 issue: *HEW Publication (CDC) 78-815)*

Chichester, D. F. and F. W. Tanner: "Antimicrobial Food Additives," in *Handbook of Food Additives,* (T. E. Furia, Editor), CRC Press, Cleveland, Ohio (1972).

Clifford, W. J., and A. Anellis: "*Clostridium perfringens* 1. Sporulation in a Biphasic Glucose-ion-exchange Resin Medium," *Appl. Microbiol.,* **22**, 856 (1971).

Chau, P. Y., and C. T. Huang: "A One-day Selective Migration Procedure for Detecting Salmonellae in Feces," *J. of Clin. Pathol.,* **27**, 405 (1974).

Collins-Thompson, D. L. *et al.*: "Effect of Nitrite and Storage Temperature on the Organoleptic Quality and Toxinogenesis by *C. botulinum* in Vacuum-packaged Side Bacon," *J. of Food Science,* **39**, 607 (1974).

Craven, S. E., and A. J. Mercuri: "Sporulation of *Clostridium perfringens* in Meats Supplemented with Soy Materials," *J. of Food Science,* **44**, (3) 755-757 (1979).

Crisley, F. D., Angelotti, R., and M. J. Foter: "Multiplication of *Staphylococcus aureus* in Synthetic Cream Fillings and Pies," U.S. Department of Health, Education, and Welfare, Washington, D.C. *Public Health Report 79,* 369 (1964).

Davis, D. J., and R. C. Hanlon: "Epidemic Infectious Hepatitis in a Small Iowa Community," *American J. of Hygiene,* **43**, 314-325 (1946).

Duncan, C. L., and D. H. Strong: "Improved Medium for Sporulation of *Clostridium* perfringens," *Appl. Microbiol.,* **16**, 82 (1968).

Duncan, C. L., and D. B. Rowley, Co-chairmen: "*Clostridium perfringens* Foodborne Illness," *Institute of Food Technologists Symposium,* Saint Louis, Missouri (1979).

Everton, J. R., and D. A. Herbert: "Post-processing Infections: Cannery Hygiene Control," *1st International Congress of Food Science Technology Proc.* (London), **4**, 197 (1962).

El-Mabsout, Y. E., and K. E. Stevenson: "Activation of *Bacillus stearothermophilus* Spores at Low pH," *J. of Food Science,* **44**, (3) 705-709 (1979).

Farrow, R. P.: "A Survey of pH Variation in Canning Tomatoes," National Canners Association, *Research Report 1-63,* Washington, D.C. (1963).

Fields, M. L., and N. Finely: "The Effect of Selected Carbohydrates and Plant Extracts on the Heat Activation of *Bacillus stearothermophilus* Spores," *J. of Food Science,* **29**, 635 (1964).

Fields, M. L., Zamora, A. F., and M. Bradsher: "Microbiological Analysis of Home-canned Tomatoes and Green Beans," *J. of Food Science,* **42**, (4) 931-934 (1977).

Finely, N., and M. L. Fields: "Heat Activation and Heat Induced Dormancy of *Bacillus stearothermophilus* Spores," *Appl. Microbiol.,* **10**, 231 (1962).

Finley, J. W., *et al.*: "Inhibition of Lysinoalanine Formation in Food Proteins," *J. of Food Science,* **43**, (2) 618-621 (1978).

Goldman, J. J., *et al.*: "Salmonellosis following a Wedding Anniversary Dinner," *Morbidity Mortality Weekly Report,* **19** (33) 324, 332, U.S. Center for Disease Control, Atlanta, Georgia (1970).

Gray, R. J. H., and A. M. Muir: "Salt Deprivation and Low-temperature Sensitivity of Vibrio parahaemolyticus," *J. of Food Science,* **42**, (3) 689-693 (1977).

Gupta, S. L., and Venkitasurbramanian: "Production of Aflatoxin on Soybeans," *Appl. Microbiol.,* **29**, 834 (1975).

Hall, H. E., and R. Angelotti: "*Costridium perfringens* in Meat and Meat Products," *Appl. Microbiol.,* **13**, 352 (1965).

Halmann, M., and A. Keyan: "Stages in Germination of Spores of *Bacillus licheniformis,*" *J. of Bacteriol.,* **84**, 1187 (1962).

Hanke, M. E., and J. H. Bailey: "Oxidation-reduction Potential Requirements of *C. welchii* and Other *Clostrida,*" *Proc. of Soc. Exp. Biol. Med.,* **59**, 163

Hansen, J. D., and M. D. Appleman: "The Effect of Sorbic, Proppionic and Caproic Acids on the Growth of Certain Clostridia," *Food Res.,* **20**, 92 (1955).

Hobbs, B. C.: "Problems and Solutions in Food Microbiology," *Food Technology,* **31**, (1) 90-96 (1977).

Hughes, J. M., and M. H. Merson: "Fish and Shellfish Poisoning," *New England J. of Medicine,* **295**, 1117 (1976).

Hultin, H. O., and M. Milner (Editors): "Postharvest Biology and

Biotechnology," Food and Nutrition Press, Westport, Connecticut (1979).

IFT: "Home Canning," *Food Technology*, 31, 43 (1977).

IFT: "The Risk/Benefit Concept as Applied to Food," *Food Technology*, **32**, (2) 51-56 (1978).

IFT: "The Role of Scientists in Formulating a National (Rational) Policy for Regulating Carcinogens," *Food Technology*, **32**, (8) 30, 48-51 (1978).

Jarvis, A. W., Lawrence, R. C., and G. G. Pritchard: "Production of Staphylococcal Enterotoxins A, B, and C under Conditions of Controlled pH and Aeration," *Infect. Immun.*, 7, 817 (1973).

Jemmali, M. (Editor): "Mycotoxins in Foodstuffs," Pergamon, Elmsford, New York (1976).

Johnson, K. M., and F. F. Busta: "Fate of Aflatoxin B_2 in a Two-step Microbial Recovery System for Food Industry Wastes," *J. of Food Science*, **43**, (4) 1303-1306 (1978).

Johnson, M. G., and R. S. Ittaka (Cochairmen): "Microbial Hazards," *Institute of Food Technologists Symposium*, Saint Louis, Missouri (1979).

Johnston, R. W., Feldman, J., and R. Sullivan: "Botulism from Canned Tuna Fish," *Public Health Reports*, 78, 561, U.S. Public Health Service (1963).

Juven, B. J., Cox, N. A., Mercuri, A. J., and J. E. Thomson: "A Hot Acid Treatment for Eliminating *Salmonella* from Chicken Meat," *J. of Milk and Food Technol.*, 37, 237 (1974).

Kawabata, T., Ishizaka, K., and T. Miura: "Studies on the Food Poisoning Association with Putrification of Marine Products," in *Poisonous and Venomous Marine Animals of the World*, (B. W. Halstead and D. A. Courville, Editors), U.S. Printing Office, Washington, D.C. (1967).

Kim, I., and L. Bjeldanes: "Amine Content of Toxic and Wholesome Canned Tuna Fish," *J. of Food Science*, **44**, (3) 922-923 (1979).

Kostenbader, K. D., Jr., and D. O. Cliver: "Quest for Viruses Associated with Our Food Supply," *J. of Food Science*, 42, (5) 1253-1257 (1977).

Kraft, A. A., and C. R. Rey: "Psychotrophic Bacteria in Foods," *Food Technology*, **33**, (1) 66-71 (1979).

Kramer, A., and J. Farquhar: "Fate of Microorganisms during Frozen Storage of Custard Pies," *J. of Food Science*, 42, (4) 1138-1139 (1977).

Kraybill, H. F.: "Proper Perspectives in Extrapolation of Experimental Carcinogenesis Data to Humans," *Food Technology*, 32, (8) 62-64 (1978).

Latham, M. C.: "Nutrition and Infection in National Development," in *Food: Politics, Economics, Nutrition, and Research*, (P. H. Abelson, Editor), American Academy for the Advancement of Science, Washington, D.C. (1975).

Lechowich, F. V.: "The Effects of Chemicals Upon the Growth of *Clostridium botulinum*," *Proc. of the 1st U.S.-Japan Conference on Toxic Microorganisms*, page 468, U.S. Department of the Interior, Washington, D.C. (1970).

Lieu, F. Y., and L. B. Bullerman: "Production and Stability of Aflatoxins, Penicillic Acid and Patulin in Several Substrates," *J. of Food Science*, 42, (5) 1222-1224 (1977).

Lowrance, W. W.; "Of Acceptable Risk. Science and the Determination of Safety," William Kaufmann, Los Altos, California (1976).

Mason, J. O., and W. R. McLean: "Infectious Hepatitis Traced to the Consumption of Raw Oysters: An Epidemiologic Study," *American J. of Hygiene*, 75, 90-111 (1962).

Merson, M. H., *et al.*: "Scombroid Fish Poisoning," *J. of American Medical Association*, **228**, (10) 1268-1269 (1974).

Miller, M. W.: "Yeasts in Food Spoilage," *Food Technology*, **33**, (1) 76-80 (1979).

Miller, S. A., "Risk/Benefit, No-effect Levels, and Dalaney: Is the Message Getting Through?" *Food Technology*, **32**, (2) 93-96 (1978).

Minor, T. E., and E. H. Marth: "Staphylococci and Their Significance in Foods," Elsevier, Amsterdam (1976).

Mohit, B., Aly, R., and L. D. Bourgeois: "A Simple Single-step Immunoimmobilization Method for the Detection of Salmonella in the Presence of Large Numbers of Other Bacteria," *J. of Med. Microbiol.*, 8, 173 (1975).

Murrell, W. G.: "Spore Formation and Germination as Microbial Reaction to the Environment," *Symposium of Soc. Gen. Microbiol*, 11, 120 (1961).

Nordsiden, K. L., *et al.*: "Home Canning of Food: Effect of a Higher Process Temperature (250°F) on the Safety of Low-acid Foods," *J. of Food Science*, 43, (6) 1734-1737 (1978).

Odlaug, T. E., and I. J. Pflug: "A Review of the *z* and *F*-values Used to Insure the Safety of Low-acid Canned Food," *37th Annual Meeting of Institute of Food Technologists*, Philadelphia, Pennsylvania (June 1977).

Odlaug, T. E., and I. J. Pflug: "Microbiological and Sanitizer Analysis of Water Used for Cooling Containers of Food in Commercial Canning Factories in Minnesota and Wisconsin," *J. of Food Science*, 43, (3) 954-963 (1978).

Pirt, S. J.: "Principles of Microbe and Cell Cultivation," Wiley, New York (1975).

Poelma, P. L., Romero, A., and W. H. Andrews: "Rapid Identification of *Salmonella* and Related Foodborne Bacteria by Five Biochemical Multitest Systems," *J. of Food Science*, 42, (3) 677-680 (1977).

Powers, J. J., and D. R. Godwin: "pH of Tomatoes Canned at Home in Georgia," *J. of Food Science*, 43, (4) 1053-1055 (1978).

Prevot, A. R., and E. R. Brygoo: "Nouvelles Recherches sur le Botulisme et ses cinq Types Toxinques," *Annals of the Pasteur Institute*, 85, 344 (1953).

Put, H. M. C., *et al.*: "The Mechanism of Microbiological Leaker Spoilage of Canned Foods: A Review," *J. of Appl. Bacteriol.*, 35, 7 (1972).

Robach, M. C., and M. D. Pierson: "Influence of Para-Hydroxybenzoic Acid Esters on the Growth and Toxin Production of Clostridium botulinum 10755 A," *J. of Food Science*, 43, (3) 787-789 (1978).

Rodricks, J.V.: "Mytoxins and Other Fungal Related Food Problems," American Chemical Society, Washington, D.C. (1976).

Rowley, D. B., and A. A. Anellis: "Factors Affecting Outgrowth of *C. botulinum* in Foods.," *76th Meeting of American Society for Microbiol.*, Atlantic City, New Jersey (May 1976).

Sapers, G. M.: "News Release," U.S. Department of Agriculture, Philadelphia, Pennsylvania (June 24, 1977).

Scott, W. J., and D. F. Stewart: "The Thermal Destruction of *Clostridium botulinum* Toxin in Canned Vegetables," *Australian J. of Applied Science*, 1, 188 (1950).

Segner, W. P., Schmidty, C. F., and J. K. Boltz: "The Interaction of Selected Chemical Additives with Low Doses of Irradiation Against Spores of *Clostridium botulinum* Type E," *26th Annual Meeting of the Institute of Food Technologists* (1966).

Shapton, D. A., and W. R. Hindes: "Some Aspects of Post-processing Infection," *1st International Congress of Food Science Technology Proceedings* (London), 4, 205 (1962).

Skelton, M. M., and J. A. Craig: "Ascorbic Acid Content, pH and Flavor Characteristics of Acidified Home-canned Tomatoes," *J. of Food Science*, 43, (4) 1043-1045 (1978).

Smoot, L. A. and M. D. Pierson: "Effect of Oxidation-reduction Potential on the Outgrowth and Chemical Inhibition of Clostridium botulinum 10755A Spores," *J. of Food Science*, 44, (3) 700-704 (1979).

Staff: "Procedures to Investigate Foodborne Illness," International Association of Milk, Food, and Environmental Sanitarians, Inc., Ames, Iowa (1976).

Stoloff, L.: "Occurrence of Mycotoxins in Foods and Feeds," in *Mycotoxins and Other Fungal Related Food Problems*, (J. V.

Rodricks, Editor), page 23, American Chemical Society, Washington, D.C. (1976).

Stoloff, L., *et al.*: "Determination of the Potential for Mycotoxin Contamination of Pasta Products," *J. of Food Science,* **43,** (1) 228-230 (1978).

Stuart, P. E., and H. Pivnick: "Isolation of Salmonellae by Selective Motility Systems," *Appl. Microbiol.,* **13,** 365 (1965).

Swaminathan, B., and P. E. Koehler: "Isolation of an Inhibitor of *Aspergillus parasiticus* from White Potatoes (*Solanum tuberosum*)," *J. of Food Science,* **41,** 313 (1976).

Swaminathan, B., Denner, J. M., and J. C. Ayres: "Rapid Detection of Salmonellae in Foods by Membrane Filter-disc Immunoimmobilization Technique," *J. of Food Science,* **43,** (5) 1444-1447 (1978).

Taylor, S. L., and E. R. Lieber: "Specificity and Sensitivity of Seven Histamine Detection Methods," *J. of Food Science,* **42,** (6) 1584-1586 (1977).

Taylor, S. L., Lieber, E. R., and M. Leatherwood: "A Simplified Method for Histamine Analysis of Foods," *J. of Food Science,* **43,** (1) 247-250 (1978).

Tharrington, G., Jr., *et al.*: "Nonspecific Staining of A *Lactobacillus* by *Salmonella* Fluorescent Antibodies," *J. of Food Science,* **43,** (2) 548-552 (1978).

Thompson, D. R., *et al.*: "*Clostridium perfringens* Population Dynamics during Constant and Rising Temperatures in Beef," *J. of Food Science,* **44,** (3) 646-651 (1979).

Thomson, J. E., Cox, N. A., and J. S. Bailey: "Chlorine, Acid and Heat Treatments to Eliminate *Salmonella* on Broiler Carcasses," *Poultry Science,* **55,** 1513 (1976).

Thompson, J. E., Cox, N. A., and J. S. Bailey: "Control of *Salmonella* and Extension of Shelf-life of Broiler Carcasses with a Glutaraldehyde Product," *J. of Food Science,* **42,** (5) 1353-1355 (1977).

Tomkin, R. B., Christiansen, L. N., and A. B. Shaparis: "Variation in Inhibition of *C. botulinum* by Nitrite in Perishable Canned Comminuted Cured Meat," *J. of Food Science,* **42,** (4) 1046-1048 (1977).

Troller, J. A.: "Food Spoilage by Microorganisms Tolerating Low a_w Environments," *Food Technology,* **33,** (1) 72-75 (1979).

Varpela, E., Otterstrom, S., and R. Hackman: "Liberation of Alkalinized Glutaraldehyde by Respirators after Cold Sterilization," *Acta Anaesthesiol. Scand.,* **15,** 291 (1971).

Villarreal, F., Luh, B. S., and S. J. Leonard: "Influence of Ripeness on Organic Acids in Canned Tomato Juice," *Food Technology,* **14,** 176 (1960).

Willardson, R. R, *et al.*: "Growth and Survival of *Clostridium perfringens* during Constantly Rising Temperatures," *J. of Food Science,* **43,** 470, 1358 (1978).

Wolberg, J. R.: "Prediction Analysis," Van Nostrand Reinhold, New York (1967).

Wolf, I. D., *et al.*: "Home Canning of Food: Tomatoes, Tomato Products and Other Acid Foods," *37th Annual Meeting of the Institute of Food Technologists,* Philadelphia, Pennsylvania (June, 1977).

Woodburn, M. J., and T. N. Morita: "Staphylococcal Enterotoxin and Nuclease Production in Foams," *J. of Food Science,* **43,** (5) 1628-1629 (1978).

Woodicka, V. O.: "Food Ingredient Safety Criteria," *Food Technology,* **31,** (1) 84-88 (1977).

Woolford, A. L., and E. J. Schantz: "Heat Inactivation of Botulinum Toxin Type A in Some Convenience Foods after Frozen Storage," *J. of Food Science,* **43,** (2) 622-624 (1978).

Yao, M. G., Denny, C. B., and C. W. Bohrer: "Effect of Frozen Storage Time on Heat Inactivation of Clostridium botulinum type E Toxin," *Appl. Microbiol.,* **25,** 503 (1973).

Zamora, A. F., and M. L. Fields: "Microbiological and Toxicological Evaluation of Fermented Cowpeas (*Vigna sinensis*) and Chickpeas (*Cicer arietinum*)," *J. of Food Science,* **44,** (3) 928-929 (1979).

FOOD CHAIN. The series of events which converts solar energy, initially by way of photosynthesis, to food for plants and animals. The basic work is accomplished by leaves in the case of terrestrial plants and by plankton in the sea. Then, more complex creatures consume plants and/or smaller (usually) organisms and so on in a chain of events involving ever-increasing sizes and appetites of the consumers and ever-decreasing amounts of food available in the chain.

Studies have shown that for a human to gain 1 pound (0.45 kilogram) as the result of consuming sea food, the sea must generate a half-ton (0.45 metric ton) of living matter. At the base of the food pyramid or first link in the chain are the trillions of plankton which create the 1000 pounds (0.45 metric ton) of basic chemical food.

Then, a variety of crustaceans, smaller fishes, and other creatures reduce this 1000 pounds (0.45 metric ton) to 100 pounds (45 kilograms) of available foodstuff. In the next link, the game and food fishes in their feeding reduce the 100 pounds (45 kilograms) to 10 pounds (4.5 kilograms) to gain 1 pound (0.45 kilogram) of weight.

In turn, to gain 1 pound (0.45 kilogram) of weight, the human must consume about 10 pounds (4.5 kilograms) of fish. This may be stated more clearly by indicating that the 10 pounds (4.5 kilograms) of fish may sustain 1 pound (0.45 kilogram) of weight in the human, these latters factors depending, of course, upon a widely ranging metabolism among individuals.

FOOD CHEMICALS. Additives and Other Food Chemicals.

FOOD CHEMICALS CODEX. An indispensable and authoritative compendium on more than 600 food-grade chemicals. Revised editions (2nd edition published in 1972) are scheduled for release at infrequent intervals, but interim changes as well as addition of new substances are handled by means of supplements which are published at approximately 2-year intervals.

As of the early 1980s, in the United States, the *Food Chemicals Codex* is officially recognized and endorsed by the Food and Drug Administration. Preparation of the compendium involved the joint efforts of scientists from the food and chemical industries, from government, and from academic fields. Thus, standards of chemical purity, as described in a series of monographs, are regarded as safe by the government and the scientific community. Most of the substances included in Appendix Table 1 of this encyclopedia are described in considerably more detail in the *Food Chemicals Codex*, which also includes descriptions of all test methods required to determine compliance of food-grade chemicals to *Codex* specifications. The volume is published by the National Academy of Sciences, Washington, D.C.

FOOD-CONDUCTING TISSUE (Plant). Bark; Cambium; Stem (Plant).

FOOD ENERGY CONSUMPTION. Dietary Trends.

FOOD POISONING. Foodborne Diseases; Thermal (Heat) Preserving.

FOOD-PRODUCING SYSTEMS. Introductory.

FOOD STARCH. Binders, Fillers, and Plasticizers; Emulsifiers, Stabilizers, and Thickeners.

FOOD TECHNOLOGY AWARDS. Institute of Food Technology.

FOOT ROT. Beef and Dairy Cattle; Citrus Fruits and Processing; Rhubarb.

FORAGE. A variety of vegetable matter used for feeding animals. This may take the form of hay, pasturage, green feed, fodder, and silage. Forage is comparatively high in total digestible nutrients and low in crude fiber or roughage. See **Hay and Forage Crops**.

FORBIDDEN FRUIT. Liqueurs and Cordials.

FORCED MOLTING. Poultry.

FORCING. Radish; Rhubarb.

FORECASTING (Climate). Climate and Food Production.

FORESHOTS. Whiskey.

FOREST LAND. Land Management.

FORMED MEAT PRODUCTS. Meat.

FORMETANATE ACARICIDE. A combination acaricide-insecticide of the carbamate type developed in the late 1960s in Germany, Formetanate* finds wide application throughout the world on a number of crops. The compound is mainly used in the United States on alfalfa and fruit production. Formetanate should not be used in water with a pH of over 8. The compound is injurious to honeybees and fishes and thus possible contamination of streams, lakes and nearby pastures must be avoided. Damage to some plants has been reported. These include bean, cucumber, eggplant, groundnut (peanut), pea, and soybean. It is important to note that Formetanate does not control aphids. The compound is available as a soluble powder (92%) and wettable powder (50%).

Pests controlled include:

flea beetle
leafhopper
leaf miner
lygus bug
mite
slug
snail
stinkbug
thrip

The organic chemical name of Formetanate is N; N-dimethyl-N'-(s((methylamino)carbonyl)oxy)phenyl) methanimidamide.

Other designations: *Carzol, Dicarzol*

See also **Acaricide; Insecticide, Pesticide Application.**

FORMIC ACID. Flavoring Agents; Silage and Silage Fermentation; Appendix Table 1.

FORMULA FEED. Feedstuffs.

FORTIFICATION OF FOODS. Amino Acid; Banyuls; Bread and Bakery Products; Madeira; Port; Protein; Sherry; Wine.

FORTIFIED FLOUR. Pea; Soybean Processing.

FORTIFIED MILK PRODUCTS. Milk and Dairy Products.

FORWARD-FEED EVAPORATOR. Evaporating.

FOULED. Designation of an area that is normally used for pasture, but that has been made unfit for grazing because of the presence of large amounts of urine or dung, or poisoned by insecticides, herbicides, and other control chemicals. See also **Hay and Forage Crops.**

FOUNDATION STOCK (Poultry).

FOXTAIL MILLET. Millets.

FRACTIONAL DISTILLATION. Flavorings.

FRACTURABILITY. Texture.

FRAGIPAN. Soil.

FRAGRANCE. Flavorings; Flower.

FRANKFURTER ANALOG. Soybean Processing.

FRANKFURTERS. Meat.

FRAPPÉ. Confections.

FREE-CHOICE FEED. Feedstuffs.

FREE RADICAL. An unsaturated molecular fragment in which some of the valence electrons remain free, that is, do not partake in bonding. Examples are methyl $CH_3\cdot$ or $C_6H_5\cdot$ or superoxide or singlet oxygen. The important role of the latter two forms of oxygen in the process of oxygen toxicity of plant and animal tissues and their effect upon enzyme systems is explained briefly in entry on **Oxygen Toxicity (Plant).**

FREE-RUN JUICE. Wine.

FREESTONE PEACH. Peach.

FREEZE AND FREEZE INJURY. Apricot; Cherry; Climate and Food Production. (See **other specific fruits and crops.**)

FREEZE-CONCENTRATING. In lieu of evaporation and other means for concentrating liquid food substances, freeze-concentrating may be used, particularly where it is

---

*Schering AG.

desirable to retain volatile constituents, as in the instances of increasing the alcohol content of wines, and to prepare and preserve flavor, as in the case of orange juice or coffee extract concentrates. From an energy standpoint, the energy required by freeze-concentration is considerably less than that used in evaporating systems.

There are difficulties associated with the achievement of high concentrations by the freeze-concentration process. The liquid viscosity may increase so markedly as concentration increases and freezing point drops that difficulty is experienced in handling the ice-concentrate mixture and separating the concentrate from the ice. Improvements in recent years have been made by the use of ripening-induced growth of large ice crystals through sacrificial melting of small, easily formed, subcritical ice crystals, and the development of wash columns which provide efficient solute recovery from the ice-concentrate mixture (Thijssen, 1974a). Even then, it is estimated that 35–50% dissolved solids represents the maximum concentration that can be practically achieved by freeze-concentration (Thijssen, 1974b). By comparison with two other attractive concentrating methods, the liquid food concentrations are even less: 20–35% by reverse osmosis; and 20–30% by ultrafiltration. See also **Reverse Osmosis**; **Ultrafiltration.** However, these latter processes, when considered in conjunction with (prior to) evaporation may be attractive from an energy-expenditure standpoint. The estimated energy requirements for concentrating a 10% dextrose solution to a 50% concentration by means of freeze-concentrating is given in the accompanying table.

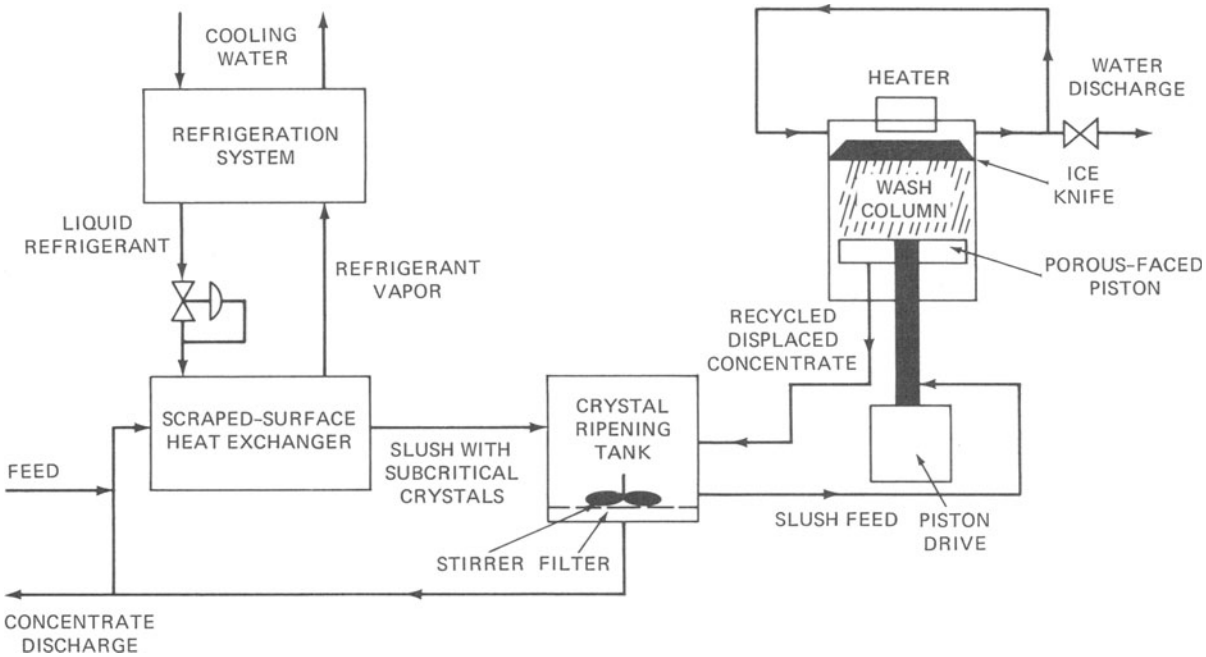
A proprietary freeze-concentrating system is depicted in the accompanying figure.

As described by Schwartzberg (1977), the system illustrated uses crystal ripening, heat removal through subcritical ice crystal formation, and a wash column. Dilute feed, mixed with recycled concentrate, forms subcritical crystals as it passes through a refrigerant-cooled, scraped-surface heat exchanger. Recycling is used to allow

ESTIMATED ENERGY REQUIREMENTS
(Freeze Concentration of 10% Dextrose Solution to 50% Concentration)

	Temperatures					Energy Input (Btu/pound of Water Removed)		
	Condenser		Evaporator					
System	°F	°C	°F	°C	Coefficient of Performance	Compressor Work	Heat Input	Total Steam Equivalent
Ideal (100% compressor efficiency)	70	21.1	10.4	-12	7.03	29.0	–	87.0
Semi-ideal (75% compressor efficiency)	70	21.1	10.4	-12	5.28	38.6	–	115.8
Real (75% compressor efficiency)	88	31.1	-7.6	-22	2.37	86.0	–	258.0
Real + wash dilution effects	88	31.1	-7.6	-22	2.37	94.7	–	184.0
Real + wash + 100% melting	88	31.1	-7.6	-22	2.37	94.7	153.7	437.8
Real + wash + 50% melting	88	31.1	-7.6	-22	2.37	94.7	76.8	360.9

After Schwartzberg (See reference list).



Proprietary freeze-concentrating system. (*After Grenco*) a high rate of ice formation without producing ice concentrations that would block the scraped-surface unit. Part of the concentrate is drawn off as product. In the ripening tank, the unstable subcritical ice crystals melt, and the latent heat they absorb in melting causes freezing on the surface of the large ice crystals (1 millimeter diameter) in the ripening tank (Leninger and Beverloo, 1975; Thijssen, 1974a). Slush from the ripening tank is pumped into a wash column. As the slush advances in the wash column, the concentrate contained in the pores between the ice particles is displaced by water (obtained by melting the ice) and is returned, slightly diluted, to the ripening tank. The wash column operates on a cyclical basis, with slush-admission washing, ice-removal, and melting steps recurring in sequence. Considerably greater detail on this system can be found in the Schwartzberg reference listed.

See also entry on **Orange**.

References

Joslyn, M. A.: "Concentration by Freezing," in *Fruit and Vegetable Juice Processing* (D. K. Tressler and M. A. Joslyn, Editors), page 320, Avi, Westport, Connecticut (1961).

Leninger, H. A., and W. A. Beverloo: "Food Process Engineering," pages 474, 479, 492, 494, D. Reidel, Boston (1975).

Schwartzberg, H. G.: "Energy Requirements for Liquid Food Concentration," *Food Technology*, 31, (3) 67-76 (1977).

Thijssen, H. A. C.: "Freeze Concentration," in *Advances in Preconcentration and Dehydration of Foods*, (A. Spicer, Editor), page 115, Halsted Press, Wiley, New York (1974a).

Thijssen, H. A. C.: "Fundamentals of Concentration Processes," in *Advances in Preconcentration and Dehydration of Foods*, (A. Spicer, Editor), page 35, Halsted Press, Wiley, New York (1974b).

FREEZE-DRIED CULTURES. Milk and Dairy Products.

FREEZE-DRYING. A process for removing moisture from a wet material by bringing the material to the solid state and subsequently subliming it. This process is used for drying and preserving a number of food products, including instant coffee products, vegetables, fruit juices, and meat products. The needs of the food industry, coupled with those of the pharmaceutical manufacturers, accelerated research into this process several years ago and commercial applications of the process are now commonplace in these industries.

The wet material in the form of a wet solid or in the form of a suspension or solution is frozen under vacuum or at atmospheric pressure, followed by transforming the ice into vapor and removing it. In the usual case, the dried material remaining will be a spongy mass of about the same size and shape as the original frozen mass and frequently will be found to have excellent stability, convenient reconstitution when placed in cold water, and will maintain flavor and texture sometimes indistinguishable from the original materials. These properties differ markedly with various materials. Some products are much better adapted to the process than others.

Usually materials to be freeze-dried are complex mixtures of water and several other substances. When such materials are cooled below 32°F (0°C), pure ice crystals will separate out first. With further cooling, the mass will become rigid as the result of formation of eutectics[1]. See Fig. 1. Most food products and biologicals solidify completely at a temperature in the range of -5° to -100°F (-15° to -73°C). At solidification of the entire mass, all of the free water has been transformed into ice. Only a small quantity of the original water, the bound water, remains fixed in the internal structure of the material.

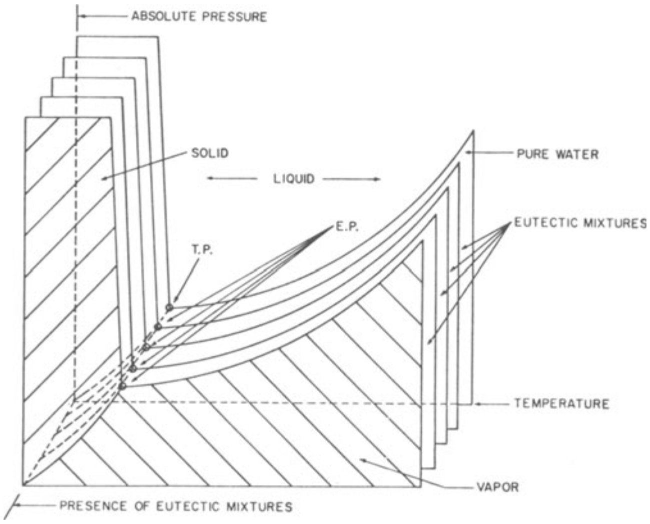


Fig. 1. Eutectic phase diagram in freeze-drying process.

The quality of the finished product as well as the rate of drying will be affected by the size, shape, and size distribution of the ice crystals which form during freezing. These properties also will be affected by the homogeneity of the frozen mass. Thus, freezing must be effected under carefully controlled conditions (time, pressure, and temperature). Large ice crystals result from slow freezing rates. These may be injurious to certain substances. On the other hand, too-rapid freezing results in small ice crystals, which may cause undesirable color and texture changes.

Sublimation (or Primary Drying). For the sublimation phase of the process, the frozen material usually is subjected to a vacuum of about 4.6 millimeters of mercury. The ice-crystal sublimation process can be regarded as comprised of two basic processes: (1) Heat transfer, and (2) mass transfer. In essence, heat is furnished to the ice crystals to sublime them; the generated water vapor resulting is transferred out of the sublimation interface. Thus, it is evident that sublimation will be rate-limited by both resistances to heat and mass transfer as they occur within the material.

As the sublimation interface recedes in the material (See Fig. 2), the dry layer presents a resistance to the flow of water vapor and a pressure difference must exist between the ice interface and the surface of the dry layer. A large pressure difference will facilitate high mass-transfer rates; however, the maximum allowable sublimation temperature at which no melting will occur and the cost of the vacuum equipment restrict this driving force to a limited range. In practice, the maximum allowable temperature and corresponding pressure at the sublimation interface is in the

---

[1] An eutectic is that particular mixture out of a possible combination of two or more mixtures of materials that has the lowest melting point.

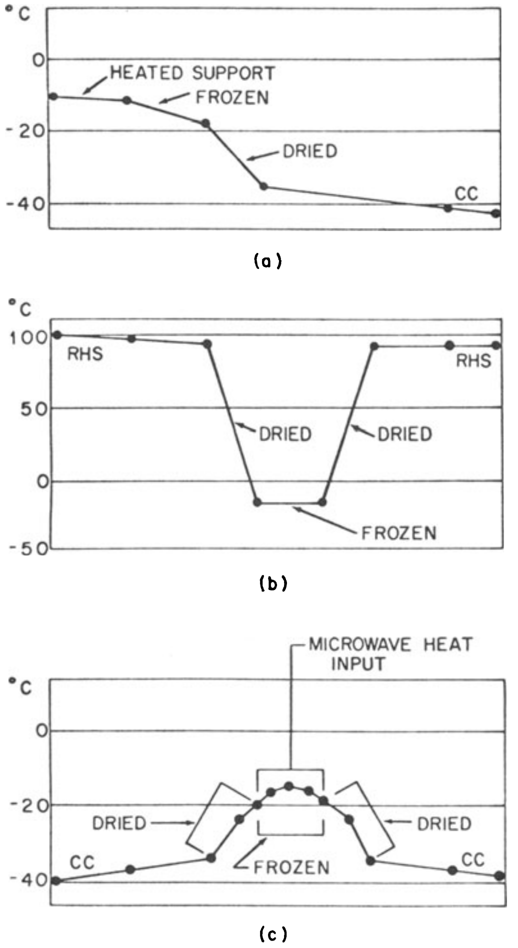


Fig. 2. Heat-input methods for freeze-drying processes: (a) Conduction; (b) radiation; (c) microwave. Note: CC = Cold condenser; RHS = Radiant-heat source. (*Struthers Scientific and International Corporation*)

range of +15° to −40°F (−9.4° to −40°C) and 2000 to 100 micrometers, respectively.

The rate of heat input to the frozen material is a function of the operating vacuum method of heat transfer and the properties of the dried product. The operating vacuum determines the pressure difference and, in turn, the rate of mass transfer, which must be in balance with the rate of heat input. Otherwise, either melting will occur at the sublimation interface and the purpose of freeze-drying will be defeated; or the sublimation temperature will decrease and the cost of processing will increase.

The heat required for sublimation (1200 Btu per pound of ice; 664 kilogramcalories per kilogram of ice) can be supplied by conduction, radiation, electric resistance, microwave, or infrared heating. Three methods of heat input that have been investigated extensively are shown in Fig. 2. Depending on the method of heat transfer, the temperature gradient between the sublimation interface and the heat source is limited by the maximum temperature which can be tolerated on the surface of the dry layer or frozen mass. For radiation, the dry layer should not be heated to the point where charring or decomposition occur. For conduction, melting of the frozen mass in contact with the heating element should be avoided.

In most commercial applications, conditions are such that the rate of sublimation is controlled by heat transfer. The developing techniques for improving the heat-input rate is the objective of many investigations.

Desorption (or Secondary Drying). Upon completion of sublimation of the ice crystals, final dehydration is carried out to remove the bound water which did not crystallize out during freezing and is bound by adsorption phenomena to the dried product. The product temperature is increased to 80° to 120°F (26.7° to 49°C), and under high vacuum, the bound water and oxygen are removed from the dried product. The rate of desorption is considerably slower than sublimation. Although the bound water is only 5 to 10% of the total water in many substances, the secondary drying may require up to 35% of the total drying time.

Drying Rates. Drying a frozen material proceeds initially at a constant rate with rapid evolution of water vapor. As the sublimation interface recedes within the product, water-vapor evolution decreases. This is the start of the falling-rate period. When only bound water remains within the cellular structure of the product, the desorption period begins. During the constant-rate period, the sublimation rate can be expressed in terms of the heat of sublimation of ice and the heat-rate equation:

$$\text{Rate of sublimation} = \frac{UA\ \Delta T}{\Delta H_{\text{ice}}}$$

The overall heat-transfer coefficient U depends upon the properties of the dry product and the method of heat transfer. The heat-transfer rate A is influenced by the mechanical design of the heating elements and the conditioning of the frozen mass. The temperature gradient ΔT is limited by the maximum allowable temperatures at the sublimation interface and dry-layer surface. In the constant-rate period, the first 1/2 to 2/3 of the drying cycle, about 80% of the water is removed.

Processes and Equipment. In addition to the three fundamental operations just described, the freeze-drying process involves several other operations necessary to achieve an economically feasible system for large-scale production. The general commercial process comprises: (1) Preparation of the material; (2) freezing; (3) conditioning of the frozen mass; (4) drying, that is, sublimation and desorption; and (5) conditioning the product. See Fig. 3.

Preparation of the Material. It is not always economically practical to subject a product in its original state to freeze-drying. One or more operations may be required to prepare the product. Wet solids, such as fruits and meats, are usually ground or sliced to facilitate drying by increasing the surface and reducing the thickness. Coffee extract and fruit juices are preconcentrated in order to minimize the water to be removed by sublimation and, in turn, to reduce the processing cost or to ensure that the final product will not be fragile.

Freezing. (1) **Vacuum cooling**: The material freezes itself by the evaporation of water as it is subjected quickly to high vacuum. (2) **Direct contact**: The material is immersed in a cold liquid or in a stream of cold air or inert

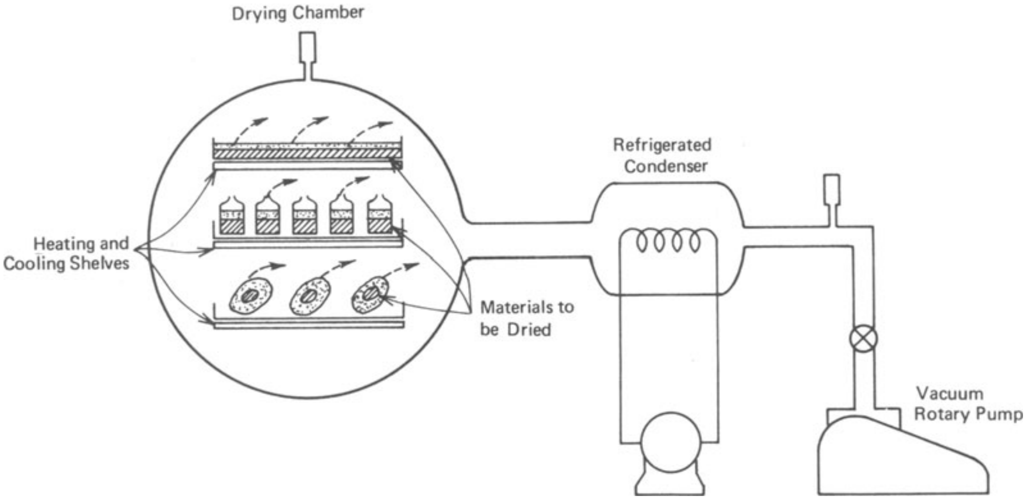


Fig. 3. Schematic diagram of freeze-drying process.

gases. (3) **Indirect contact**: The material is frozen on cold surfaces.

Freezing the material is accomplished in the vacuum chamber where drying takes place in a separate piece of equipment, or if the frozen mass requires some conditioning prior to drying.

Vacuum cooling is normally accomplished in the drying chamber. Its advantage is that large quantities of water are removed rapidly and no prior refrigeration is required. On the other hand, volatile flavor components are removed which may affect the quality of the final product. Also, removing water from the outer layer prior to complete freezing makes the cellular structure of certain materials collapse and subsequent drying and reconstitution may be inhibited. Therefore, this freezing technique has limited application.

In direct-contact freezing, wet solid materials are placed in cold chambers and sprayed directly or immersed in cold air, inert gases, or liquid refrigerants. Solutions or slurries may be frozen by spraying them in a cold stream of gas or liquid. Poor control of the rate of freezing limits these techniques to cases where quick freezing is desirable. Indirect-contact freezing is generally carried out in trays placed on refrigerated shelves inside the vacuum chamber.

A combination of indirect- and direct-contact equipment is commonly used. Trays containing the material to be dried may be placed on refrigerated shelves in a cold chamber and blasted with cold air, or inert gas or freezing belts may be used. Freezing belts in cold rooms are excellent for continuous operations. By controlling the temperature of the surrounding air and the refrigerant temperature along the length of the belt, good control of the freezing rate can be maintained.

Conditioning of the Frozen Mass. Materials frozen in a bulky or block form, meat, and solutions frozen on a belt or trays require further processing before drying. Granulation or slicing of such materials increases the available surface and minimizes the resistance to heat and mass transfer during drying. Standard size-reduction devices operating in cold chambers at about -50°F (-46°C) are somtimes used.

Substances which do not freeze into a rigid solid at low temperatures, such as fruit juices, may be subjected to a devitrification treatment to avoid the soft-glass structure detrimental to optimum drying.

Drying. The conditioned frozen material to be dried is placed in a vacuum chamber, where sublimation and desorption of water occur. As soon as the chamber has been evacuated and the optimum vacuum has been reached (0.5 to 0.05 millimeter of mercury), heating is applied so that the ice sublimes. For large-scale production of food products, the combination of conduction and radiation that results from circulating a hot fluid through coils or plates has proved quite satisfactory for heating.

A number of vacuum-chamber designs have been used. For large installations, custom engineering and fabrication are dictated to assure optimum performance for a given product. The three vacuum chambers commonly used may be classified as batch, semicontinuous, and continuous.

Batch units are frequently cylindrical shelf-type driers equipped with heating and cooling coils or plates. Designs for better heat input, that is, spikes or expanded metal sheet that penetrate the frozen mass or movable heated shelves compressing the frozen materials, have met with some success.

Semicontinuous units are usually long, cylindrical tunnels. Trays with the frozen material are continuously conveyed through a series of heated zones. Interlocks are used in both ends for proper vacuum control. The frozen material is heated along the length of the tunnel with each zone maintained at a different temperature and is removed as a fully dried product.

Continuous units are designed to move the frozen material continuously on the heated surface and transfer it through a series of zones in which the temperature and vacuum are maintained at different levels. The frozen material is fed via interlocks in the chamber. Vibrators or other mechanical means are used to maintain the product in continuous motion.

During the constant-rate drying period, the temperature of the heat source (radiation) is from 200° to 300°F (93° to 149°C) for many food products. Thus, high heat-input rates are achieved. This temperature is reduced to 125° to 150°F (51° to 66°C) in the falling-rate and desorption periods to avoid charring and decomposition of the dried products.

The drying process is discontinued when the residual moisture content is sufficiently low to ensure good preservation of the specific product. This may range from a residual moisture of 1 to 3%.

Water Removal. The three common methods for removing water vapor are condensers, direct- and indirect-contact; desiccants, such as calcium chloride and zeolites; and vacuum pumps. The indirect-contact refrigerated condenser offers a good arrangement for large-scale operations. The condensing surface can be located in the drying chamber, or in a separate chamber. The water vapor condenses and forms an ice layer on the cold surface and subsequently is removed by intermittent melting or scraping.

Vacuum Pumps. The function of these pumps is to evacuate the drying chamber quickly without allowing the prefrozen material to melt—and thereafter to reduce the pressure progressively to the desired vacuum and maintain it at this level by removing the noncondensable gases. The vacuum equipment can be either an oil-sealed rotary vacuum pump, or a multistage steam-ejector system.

Conditioning of the Product. The high porosity and low moisture content of the freeze-dried product requires that the vacuum be broken and packaging be done under a dried inert-gas blanket, in many cases, to prevent oxidation during storage and maintain the low moisture content. Carbon dioxide or nitrogen are commonly used.

Variety of Problems. Each type of food product presents specific problems that affect the design and operation of freeze-drying processes. For some products, such as freeze-dried coffee (annual production of 50 million pounds [22.5 million kilograms]), the process has reached a mature and sophisticated stage. In this process, coffee extract with 20 to 25% solids is the raw material. Major steps in the process include: (1) Clarification of the extract; (2) freeze concentration of the extract to 30 to 40% solids; (3) freezing extract to a completely frozen mass at -13° to -45°F (-25° to -43°C); (4) granulation of the frozen mass; (5) sublimation of the ice at a vacuum of approximately 200 micrometers of mercury absolute; and (6) drying the final product to a moisture content of 1 to 3%. For batch driers, the overall drying cycle is on the order of 6 to 8 hours.

Intensive research continues in the interest of improving the freeze-drying process for certain foods and for expanding the use of this process to a broader spectrum of food products. The Sharma reference (listed at end of this entry) provides a good summary of work in this area being done in connection with freeze-dried meat patties. In another reference, Schmidt describes a comparison of vacuum and atmospheric freeze-drying of carrots. As pointed out by James M. Flink (Massachusetts Institute of Technology), "Specific information on the costs of producing processed foods is generally not available in the scientific literature, it presumably being considered propietary information by those having the best data, the food processing industry." In the Flink reference, based upon available data, a cost comparison is made of three food-preserving processes—canned, frozen, freeze-dried, and freeze-dried compressed.

Increasing attention in the late 1970s is being given to leafy vegetables, such as spinach. The large surface area of spinach seems well adapted for freeze-drying and compression. Foods produced by freeze-drying have less weight and a preserved flavor and structure, but the volume, in terms of packaging, transportation, and storage, is not changed. In an effort to alleviate this problem, different methods of compressing the freeze-dried products have been developed to eliminate most of the void spaces. Many fruits and vegetables have been compressed and then reconstituted to a normal appearance and texture. Most of the research has been directed toward vegetables. When properly preconditioned, freeze-dried foods can be compressed with little to no fragmentation. Freeze-dried foods have an average bulk density of 0.3 gram per cubic centimeter. With existing technology, it may be possible to compress most foods to a bulk density of 0.9 gram per cubic centimeter without interfering with reconstitution. This concept has been studied in some depth at Texas A & M University. See Wisakowsky reference at end of the entry.

Energy Considerations in Freeze-drying. This is one of the highest energy users of the various food substance drying operations. As pointed out by Flink (1977), two quite sizable energy-loss areas which should lend themselves to energy reclamation are: (1) Heat dissipated in the vacuum pumps; and (2) heat rejected to the environment by the refrigeration system condensers. The magnitude of this latter loss is almost equal to the energy required to remove 1 kilogram of water. Most current designs of high-capacity mechanical vacuum pumps generally have water cooling to remove excess heat. This energy is about 10% of that required to remove 1 kilogram of water. Because of vacuum pump design, specification of the maximum outlet temperature for a medium exchanging heat with the vacuum pump is about 45°C (113°F). In any case, this source of heat could serve as a preheater to a flow stream.

The largest energy loss is from the condenser of the freeze-drier refrigeration system, where 1062 kcal/kilogram of water sublimed must be dissipated—to cooling water or ambient air. Assuming a situation where freezing occurs at 0°C (32°F) and freeze-drying at an ice temperature of -20°C (-4°F), most of the aforementioned heat is available at a temperature of 38°C (100.4°F), a fact which limits its usefulness. However, refrigeration systems could be designed which would make this energy available at a higher temperature, but at the cost of requiring more energy input at the compressor. Presumably, there would be some optimum specifications for the refrigeration system. While the savings would be greatest for the freeze-drier system, reclamation of heat from the freezer condenser would also be significant. Loss of energy due to radiant heat transfer from the heating plates to the drier walls and loss of energy with the exiting product appear to be negligible, being less than 0.1% of the energy required to remove 1 kilogram of water.

Microwave Freeze-drying. Because microwave energy penetrates very well into ice, it would appear to offer an excellent solution to the heat-transfer problems of conventional freeze-drying. Because the microwave process has a much shorter drying cycle, decreased equipment capacity can be an economic result. Researchers have found that microwave energy utilization efficiencies range from 65 to 90% over much of the drying cycle. But, microwave heating is dependent upon relatively high-cost electrical energy. Regardless of the economics, a major problem remaining with microwave heating is the melt-back of the frozen core and/or overheating in the dried layer. This situation occurs when microwave energy is put into the food faster than the sublimation-diffusion process can remove it, causing the pressure at the ice interface to rise above the triple point, usually resulting in melting of the ice. When melt-back occurs, the microwaves couple selectively into the water rather than the ice, thus causing intense local heating, accelerated melting, and a "runaway" condition (first reported by Gunn in 1967). Also for certain products, such as meat, a maximum allowable dried layer temperature of 140°F (60°C) should be observed during the process so that thermal degradation of the dried product can be prevented. This requires a matching of the electric heating rate with the mass flow rate in order to optimize the process. In early 1977, researchers at the University of Waterloo–Ontario, Canada) prepared a mathematical analysis of this problem (see Ang references at end of this entry).

References

Ang, T. K., Ford, J. D., and D. C. T. Pei: "Microwave Freeze-drying of Food–A Theoretical Investigation," *International J. of Heat and Mass Transfer*, 20, 517 (1977).

Ang, T. K., Ford, J. D., and D. C. T. Pei: "Optimal Modes of Operation for Microwave Freeze-drying of Food," *J. of Food Science*, 43, (2) 648–649 (1978).

Flink, J. M.: "Energy Analysis in Dehydration Processes," *Food Technology*, 31, (3) 77–84 (1977).

Flink, J. J.: "A Simplified Cost Comparison of Freeze-dried Food with Its Canned and Frozen Counterparts," *Food Technology*, 31, (4) 50–56 (1977).

Gejl-Hanse, F., and J. M. Flink: "Freeze-dried Carbohydate Containing Oil-in-water Emulsions: Microstructure and Fat Distribution," *J. of Food Science*, 42, (4) 1049–1055 (1977).

Gunn, R. D.: Ph.D. Thesis, University of California, Berkeley, California (1967).

Morgan, J. P., and D. F. Farkas: "Some Effects of Selected Plasticizing Agents on the Reversible Compression of Freeze-dried Cooked Beef Cubes," *J. of Food Science*, 43, (4) 1133–1136 (1978).

Noyes, R.: "Freeze-drying of Foods and Biologicals," Noyes Development Corporation, Park Ridge, New Jersey (1968).

Pintauro, N.: "Soluble Coffee Manufacturing Processes," Noyes Development Corporation, Park Ridge, New Jersey (1969).

Porter, W. L., Levasseur, L. A., and A. S. Henick: "Evaluation of Some Natural and Synthetic Phenolic Antioxidants in Linoleic Acid Monolayers on Silica" (related to rancidity of whole tissue, freeze-dried foods), *J. of Food Science*, 42, 1533–1535 (1977).

Schmidt, F. W., Chen, Y. S., Kirby-Smith, M., and J. H. MacNeil: "Low Temperature Air Drying of Carrot Cubes," *J. of Food Science*, 42, (5) 1294–1298 (1977).

Sharma, S. C., and E. Seltzer: "Development of Procedures to Minimize Mechanical Damage in Freeze-dried Meat Patties," *J. of Food Science*, 42, (5) 1336–1343 (1977).

Sivetz, M.: "Overview: Freeze-drying Coffee," *World Coffee and Tea* (August 1971).

Steinhart, J. S., and C. E. Steinhart: "Energy Use in the U.S. Food System," *Science*, 184, 397 (1974).

Stone, H.: "Food Products and Processes," Stanford Research Institute, Menlo Park, California (1972).

Tuomy, J. M.: "Freeze-drying of Foods for Armed Services," U.S. Army Food Laboratory, Natick, Massachusetts, *Technical Report 70-43-FL* (February 1970).

Van Pelt, W. H.: "Dutch Process Cuts Cost of Freeze Concentration," *Food Engineering*, 47, (11) 77–79 (1975).

Wisakowsky, E. E., Burns, E. E., and M. C. Smith: "Factors Affecting the Quality of Freeze-dried Compressed Spinach," *J. of Food Science*, 42, (3) 782–789 (1977).

Zarkarian, J. A., and C. J. King: "Asymmetry in Freeze-drying," *J. of Food Science*, 43, (3) 992–997 (1978); "Acceleration of Limited Freeze-drying in Conventional Dryers," ibid, pages 998–1001.

FREEZE-PRESERVING. Knowledge of the fact that food substances remain edible for longer periods of time when cooled probably dates back to antiquity, centuries before the process for making ice was developed. The latter led to cold storage, a practice that persisted for several decades and which, of course, remains useful for a number of products in current times. Cold storage was first limited by the minimum achievable temperature dictated by the melting point of ice. Chemicals to depress the freezing point were an additional step toward cold-preservation. Generally credited with the initial breakthrough from cold-storage practices to present freezing technology was the step to quick-frozen foods, pioneered by Clarence Birdseye, among others, in the late 1920s. Consumers began to accept the fact that fresh, high-quality food when frozen quickly and when retained at a temperature of about 0°F (-17.8°C), was a good substitute for fresh produce when out of season. Frozen and stored in this way, these foods represented a marked improvement over the earlier available, slowly cooled, frozen fish, poultry, and meat products.

Freeze-preserving is an across-the-board operation in the food industry of countries with advanced technology. Although there are several differences in the engineering principles involved and many design configurations, freeze-preserving can be considered a *unit food processing operation.*[1] Various aspects of freezing technology, as they may applied to specific foods, are described throughout this volume–where such information is closely coupled with the particular vegetable, type of meat, etc. that is being described. There is also a separate entry on **Freeze-Drying.**

Fundamentals of Freezing. In food materials, water is the major component.[2] Thus, when foods are cooled below 0°C, ice formation occurs, starting at a temperature between 0° and -3°C (32° and 26.6°F), which depends upon the molar concentration of soluble cell components. As the temperature is progressively reduced, more and more water is turned into ice and the latent heat of ice formation adds to the sensible heat involved in cooling both ice and the unfrozen portion. This leads to large variations in heat capacities while thermal conductivities also change considerably, mainly because the thermal conductivity coefficient of ice is nearly 4 times greater than that of water. For most biological materials, the largest part of the freezing process takes place in a temperature interval between -1° and -8°C (30.2° and 17.6°F), while the largest variations

---

[1] A processing operation that occurs over and over in the processing of hundreds of different food products.

[2] Paragraph summary prepared by L. Rebellato, S. Del Giudice, and G. Comini (See reference list).

of heat capacity occur between -1° and -3°C (30.2° and 26.6°F). Only at temperatures ranging from -20° to -40°C (-4° to -40°F) and below, there is no more measurable change with temperature in the amount of ice present, and the remaining water, if any, can be considered as nonfreezable. However, for practical purposes, a lower limit to the phase-change interval can be defined on the basis of a ratio of ice to total water content of, say, 90%. This choice, in addition to providing an easily applicable criterion, allows one to approximate heat capacity and thermal conductivity curves, above and below the phase-change zone, by means of constant values. These techniques are described by Bonacina *et al.* (1974).

Rebellato *et al.* (1978) have developed a finite element analysis approach to freezing processes in foodstuffs and apply this method to the computation of temperature distributions in foodstuffs of irregular shape during freezing in an air-blast tunnel. A number of other researchers, including Cleland and Earle (1977, 1979), also have been tackling the very important and mathematically complex problem of predicting the freezing times of various foodstuffs—fundamental to the design and operation of freezing equipment and to the scheduling of production. Cleland and Earle carried out a set of experiments to determine the freezing time of cylindrical and spherical blocks of a widely used food analogue material (Karlsruhe test substance, a defined 23% methylcellulose gel and the thermal properties of which closely model those of real food materials (Riedel, 1960).

Wide Range of Freezing Configurations. The food processor has several options available when selecting the best freezing format for a given set of product characteristics and marketing objectives. Methods can be classified in several ways, as for example the media used to contact and extract heat from the food substance—air or other gases, liquids, or mechanical contact.

Air-blast systems commonly take the form of large rooms, tunnels, or cells. In a room, the air velocity may be low or range up to 1500 feet (457 meters) per minute. The temperature for air-blast freezing usually ranges from -29° to -40°C (-20° to -40°F). Blast freezing requires longer than other available methods and product quality cannot be assured unless efficiently insulated. Insulation can be improved by using cold storage doors and air curtains. Where insulation is inadequate, frosting will occur on the coils, lowering the refrigerating capabilities. Air-blast freezing also can be effected in a tunnel on a fluidized bed, or on a belt. For individually quick frozen (IQF) products, fluidized-bed, air-blast systems are frequently used. An advantage of the fluidized bed is that it keeps the product in motion and separated during the freezing process. As pointed out by Shyette (1979), small products are moved along through a tunnel on a belt while they are frozen. The process is fast and accepted as a standard freezing method for IQF products.

Plate Freezers generally are limited in application to prepackaged products. In this system, the food substance is placed in direct contact with refrigerated metal plates (usually steel or aluminum). Cooling coils are located within the interior of the metal plates. The required contact refrigeration time ranges from about 30 to 90 minutes, depending upon size and nature of food substance.

Liquid-immersion freezing has grown in acceptance during the past few years. This system requires placing the product in a bath of cooling liquid, which must be nontoxic, noncorrosive, have a low freezing point, low viscosity, and high thermal conductivity. Wrapping of the product is required in many cases. Salt solutions and propylene glycol are frequently used. Advantages over air-blast freezing include operational energy savings that result from the high heat-transfer coefficients and high heat capacities.

Aqueous freezants, composed of a single solute species, such as an inorganic salt, acid, or base, or an organic compound, such as sucrose, have been proposed and used for freezing fruits, vegetables, and fish (Ottesen, 1915; Noyes, 1942, 1949; Robertson *et al.*, 1976). Freezants containing more than one solute also have been suggested, including sodium chloride with minor amounts of calcium chloride or potassium chloride added to water or sea water for freezing fish (Holston and Pottinger, 1954), glucose with sucrose (Bartlett, 1941), glycerin with ethyl alcohol (Bland, 1936), and glucose with sodium chloride (Butler and Slavin, 1959). As recently as 1936, a sodium chloride or sodium chloride-sugar mixture was utilized in a prototype "hydrofreeze" aqueous system developed by Marco (Seattle). Flavor impact of aqueous freezants was viewed as an important factor in limiting commercialization of aqueous freezing methods. More recently, Cipolletti *et al.* (1977) have investigated freezant composition as a means of minimizing flavor impact, as well as considering operational characteristics, such as freezing point and viscosity.

In considering a ternary system (15% sodium chloride, 15% ethanol, and 70% water), among other observations, Cipolletti *et al.* noted that: (1) Freezing times to 0°F (-17.8°C) as fast as 2 minutes were achievable for carrots and peas; (2) photomicrographs showed greatly reduced cell damage as compared with air-blast frozen samples; (3) sodium chloride uptake in products after freezing varied from a minimum of 0.89% for peas to a maximum of 2.06% for carrots; (4) ethanol uptake in products after freezing was small (0.05% to 0.27%); and (5) no significant organoleptic preference differences were indicated for peas, snap beans, and corn, frozen either by immersion with the salt-ethanol-water medium—with or without blotting, or air blast. Preference for air-blast frozen carrot samples was indicated by a panel, due to the absence of salt. Panels evaluating mixed vegetable samples containing carrots, peas, beans, and corn indicated no exclusive preference between immersion-frozen and air-blast frozen vegetables.

Cryogenic freezing has gained wide acceptance during recent years. Some of the advantages of this method over blast freezing are immediately obvious from the accompanying table. Because cryogenic freezing is very fast and accomplished at extremely low temperatures (down to -196°C; -320°F), less dehydration occurs. Problems of cell damage, caused by sharp ice crystals formed during slower freezing processes, are largely overcome with short freezing times. Also, the sooner a product is deeply frozen, the sooner will be the halting of bacterial and enzyme degradation. (See observations of Kraft *et al.* later in this entry)

For cryogenic freezing, nitrogen is used in several forms—as a shower of liquid droplets, as a liquid bath for direct immersion, or as a cold gas. Carbon dioxide is used

COMPARATIVE PERFORMANCE OF FREEZING METHODS FOR SELECTED SUBSTANCES

Commodity	Cryogenic Freezing Liquid Freon	Liquid Nitrogen	Blast-Freezing
Strawberry			
Freezing time	3 minutes	5 minutes	900 minutes
Temperature after freeze	-25°C (-13°F)	-28°C (-18°F)	-20°C (-4°F)
Percent weight loss	0.0	1.4	2.7
Mushroom			
Freezing time	3 minutes	5 minutes	180 minutes
Temperature after freeze	-30°C (-22°F)	-26°C (-15°F)	-20°C (-4°F)
Percent weight loss	0.0	1.9	2.5
Beef			
Freezing time	4 minutes	8 minutes	180 minutes
Temperature after freeze	-28°C (-18°F)	-50°C (-58°F)	-20°C (-4°F)
Percent weight loss	0.1	1.4	1.3

After: "Freezing Equipment Influence on Weight Losses," Sture Astrom, Helsingborg, Sweden.

as a liquid or in solid "snow" form. When used in a tunnel for IQF applications, liquid carbon dioxide can freeze product at a temperature from -62° to -78°C (-80° to -109°F). Fluorocarbons and halocarbons also have been used in conjunction with tunnel and spiral-type freezers that are used in IQF methods. The advantages of rapid freezing by cryogenic systems, including reduced tissue damage and improved quality, have been summarized many times, including reports by Meryman (1956) and Sills (1969).

Because of large amounts of ground beef used in frozen meat items, particularly as hamburger for fast-food chains (Harr and Minard, 1977), numerous studies have been conducted on the microbiology of the product and its ingredients (Chestnut *et al.*, 1977). Centralized processing with cryogenic freezing of ground beef may provide increased sanitation in handling than traditional processing methods. When Duitschaever *et al.* (1977) examined frozen ground beef patties from retail markets, the investigators found that the microbiological quality was better than that of fresh ground beef. But, Kraft *et al.* (1979) observed that cryogenic freezing is a commonly accepted method for preserving bacterial cells, and any system involving cryogenic food freezing must consider effects on microorganisms in the foods. Thus, Kraft *et al.* undertook a study designed to evaluate effects of meat composition and freezing by conventional or cryogenic methods on microbial numbers and types in beef patties. Beef patties of different fat content or containing soy protein were frozen by liquid nitrogen, liquid carbon dioxide, or by mechanical freezing and stored at -18°C (-27.8°F) for 5 months. Cryogenic freezing produced significantly greater reduction in total viable mesophiles and psychotrophs than did mechanical freezing. Patties containing 30% fat provided greater survival than observed with 20% fat or added soy protein. After frozen storage, predominant flora consisted of species of *Moraxella Acinetobacter* (42%) and *Pseudomonas* (32%). The former group was favored by mechanical freezing, but a greater proportion of *Pseudomonas* spp. survived cryogenic freezing than mechanical freezing.

In connection with means for chilling poultry, Arafa and Chen (1978) found chilling of broilers by liquid nitrogen exposure resulted in lower Warner-Bratzler shear values and longer sarcomere lengths, indicating more tender meat when compared with immersion-chilled broilers. Liquid nitrogen chilling also resulted in higher cooking yields. Experienced panelists showed a preference for the liquid-nitrogen chilled product. It was also observed that liquid-nitrogen chilling of poultry resulted in a product with a longer shelf-life when compared with that of immersion-chilled broilers.

Related topics in this volume include **Freeze-Concentrating**; **Freeze-Drying**; **Hypobaric Transportation and Storage**; **Meat**; and **Poultry**. Hydrocooling is described in connection with a number of vegetables.

References

Arafa, A. S., and T. C. Chen: "Liquid Nitrogen Exposure as an Alternative Means of Chilling Poultry," *J. of Food Science*, 43, (3) 1036-1037 (1978).

Bartlett, L. H.: "Quick Freezing of Foodstuffs," *U.S. Patent 2,418, 745* (1941).

Bland, O. S. H.: "Improvements Relating to the Preservation of Perishable Articles by Freezing," *B. P. 454,200* (1936).

Bonacina, C., *et al.*: "On the Estimation of Thermophysical Properties in Nonlinear Heat-conduction Problems with Special Reference to Phase Change," *International J. of Heat Mass Transfer*, 17, 861 (1974).

Butler, C., and J. W. Slavin: "Fisher Products," *ASRE Data Book:* Refrigeration Applications, Vol. 1, No. 1, page 1406 (1959).

Chestnut, C. M., *et al.*: "Bacteriological Quality of Ingredients Used in Ground Beef Manufacture," *J. of Animal Science*, 44, 213 (1977).

Ciobanu, A., *et al.*: "Cooling Technology in the Food Industry," International Scholarly Book Services, Forest Grove, Oregon (1976).

Cipolletti, J. C., Robertson, G. H., and D. F. Farkas: "Freezing of Vegetables by Direct Contact with Aqueous Solutions of Ethanol and Sodium Chloride," *J. of Food Science*, 42, (4) 911-916 (1977).

Cleland, A. C., and R. L. Earle: "A Comparison of Analytical and Numerical Methods of Predicting the Freezing Times of Foods," *J. of Food Science*, 42, (5) 1390-1395 (1977).

Cleland, A. C., and R. L. Earle: "A Comparison of Methods for

Predicting the Freezing Times of Cylindrical and Spherical Foodstuffs," *J. of Food Science*, **44**, (4) 958-963 (1979).
Desrosier, N. W., and D. K. Tressler: "Fundamentals of Food Freezing," Avi, Westport, Connecticut (1977).
Duitschaever, C. L., Bullock, D. H., and D. R. Arnott: "Bacteriological Evaluation of Retail Ground Beef, Frozen Beef Patties, and Cooked Hamburger," *J. of Food Protection*, **40**, 378 (1977).
Fennema, O.: "Loss of Vitamins in Fresh and Frozen Foods," *Food Technology*, **31**, (12) 32-35 (1977).
Harr, J. W., and M. E. Minard: "Cryogenic Meat Processing–Cost and Quality," *Proceedings of Meat Industry Research Conference*, page 25, Chicago, Illinois (1977).
Holston, J., and S. R. Pottinger: "Some Factors Affecting the Sodium Chloride Content of Haddock during Brine Freezing and Water Thawing," *Food Technology*, **8**, (9) 409 (1954).
IIF/IIR: "Recommendations for the Processing and Handling of Frozen Foods," *Annexe au Bull. IIF/IIR*, Paris (1972).
Kraft, A. A., *et al.*: "Effect of Composition and Method of Freezing on Microbial Flora of Ground Beef Patties," *J. of Food Science*, **44**, (2) 350-353 (1979).
McHale, T.: "Freezing at Stayton," *Processed Prepared Foods*, **147**, (9) 5962 (1978).
Meryman, H. T.: "Mechanics of Freezing in Living Cells and Tissues," *Science*, **124**, 515 (1956).
Noyes, H. A.: "Freezing Process," *U.S. Patent 2,286,225* (1942).
Noyes, H. A.: "Freezing Comestibles with Compatible Solutions," *U.S. Patent 2,482,202* (1949).
Ottesen, A. J. A.: "Method of Preserving Comestibles," *U.S. Patent 1,129,716* (1915).
Rebellato, L., Del Giudice, S., and G. Comini: "Finite Element Analysis of Freezing Processes in Foodstuffs," *J. of Food Science*, **43**, (1) 239-243 (1978).
Riedel, L.: "Eine Prufsubstanz für Gefrierversuche," *Kaltechnik*, **12**, 222 (1960).
Robertson, G. H., *et al.*: Methodology for Direct-contact Freezing of Vegetables in Aqueous Freezing Media," *J. of Food Science*, **41**, 845 (1976).
Shyette, B.: "Options Open to Freezers," *Processed Prepared Food*, **148**, (4) 46-48 (1979).
Sills, J. T.: "The Role of Cryogenic Freezing," *Meats*, **35**, 26 (1969).
Tressler, D. K., Van Arsdel, W. B., and M. J. Copley: "The Freezing Preservation of Foods," 4th Edition, Avi, Westport, Connecticut (1968).
Woolrich, W. R., and E. R. Hallowell: "Cold and Freezer Storage Manual," Avi, Westport, Connecticut (1970).

FREEZING (Ice Cream). Milk and Dairy Processing.

FREEZING-TIME PREDICTION. Freeze-Preserving.

FREISA. An Italian red wine usually of high quality and made from grape of the same name. Vineyards are located in the hills of Piedmont between Turin and Castle Monferrato. Limited plantings of the Freisa grape have been made in California, where it is sometimes incorrectly spelled Fresia. See also **Wine**.

FRESHWATER FISHES. Some species of fish tolerate and sometimes migrate back and forth between saline and fresh waters. Most of the commercial food fishes that are essentially marine in character and habit are described in the entry on **Seafoods**. Fishes that are predominantly or fully inhabitants of fresh water are described in separate entries and include **Bass**; **Perch**; **Pike**; **Smelt**; **Sturgeon**; **Trout**; and **Whitefishes**. The culture of a number of freshwater fishes, including carp and trout, are also described in entry on **Aquaculture**.

FRIJOLE. Bean.

FROST CONTROL AND DAMAGE. Cranberry; Grape; Grapefruit; Lemon; Lime; Mandarin; Orange. (See many other fruits and vegetables.)

FROZEN CONCENTRATE CITRUS JUICE. Citrus Fruits and Processing.

FROZEN DESSERTS. Bodying and Bulking Agents; Milk and Dairy Products.

FROZEN FOODS. Freeze-Concentrating; Freeze-Drying; Freeze-Preserving. (See numerous specific fruits and vegetables.)

FRUCTOSE. Carbohydrates; Citrus Fruits and Processing; Confections; Fruit; Sweeteners.

FRUIT. As commonly used in the food industry, the word *fruit* signifies tree fruits–apple, apricot, cherry, peach, pear, plum, of deciduous trees; or the important family of citrus fruits; or the bushberries, blackberry, raspberry, and strawberry, among others.

Botanically, a fruit is the ripened ovary of the flower, with or without other associated parts and, thus, this definition greatly broadens the number of food commodities that fall under the umbrella of fruits. There are many kinds of fruits. Usually, they are separated into two classes–dry fruits and fleshy fruits.

Growth of Ovary into a Fruit. The fruit begins its existence as the ovary of the flower. After pollination and fertilization have occurred, embryos begin to develop in one or many ovules inside the ovary. As this growth continues, the ovule gradually becomes a seed, and the ovary wall or *pericarp* may grow larger or thicker, may store relatively large amounts of food, or may undergo other changes. Eventually the seeds reach maturity, and about the same time, the fruit ripens. The final form of the fruit is characteristic of the particular species of plant.

Three layers of cell tissue are sometimes recognizable as the ovary matures. The outermost layer is the *exocarp,* which is usually a thin layer, often an epidermis only one cell thick. The innermost layer is the *endocarp.* Between these two is the *mesocarp,* in which the vascular tissues ordinarily occur. The relative thickness and appearance of these layers vary greatly in different fruits.

During the growth of the ovary into a fruit, other flower parts or adjacent stem tissue may also change and become an integral part of the fruit. In a strawberry, for example, the red pulp is not the ovary, but a very much enlarged and modified stem tip, the receptacle of the flower. A large part of the pineapple is stem, not ovary.

Basic Forms of Fruit

Berry. A true berry consists of a fleshy fruit, derived entirely from the ovary of a flower and its contents. Usually many seeds are embedded in the flesh. Common examples are tomato, grape, gooseberry, and currant. See Fig. 1.

Hesperidium. The hesperidium is a berrylike fruit which is represented by citrus fruits (orange, lemon, grapefruit, mandarin). It differs from a true berry in having a leathery rind of ovary tissue containing oil ducts, and many membraneous, juice-filled sacs in place of solid flesh. See Fig. 2.

Pepo. A pepo is represented by the cucumber, squash, and pumpkin. These fruits resemble berries to a certain extent. The hard outer covering originates from the receptacle of the flower. (In the case of the hesperidium, the rind arises from ovary tissue). See Fig. 3.

Drupe. A fleshy fruit with a thin, edible, outer skin derived from the ovary, is called a drupe. A layer of edible flesh of varying thickness lies beneath the skin. Within this is the stone or pit, which is actually a hard inner wall of the ovary. Enclosed within the pit is the seed. The cherry, peach, and plum are typical drupes. They are also called *stone fruits.* The raspberry consists of a cluster of small, individual drupes, or druplets. Botanically speaking, the raspberry is *not* a berry. See Fig. 4.

Aggregate. An aggregate fruit is one which is formed from numerous carpels of one flower. The fruit, therefore, consists of a cluster of small, individual fruitlets. Examples are blackberry, raspberry, and strawberry. The fruitlets of the blackberry and raspberry are actually small drupes. In the strawberry, the seedlike achenes are fruitlets, embedded in a fleshy, edible floral receptacle. See Fig. 5.

Multiple Fruit. A multiple fruit is formed from individual ovaries of several flowers. Fruits of mulberry, fig, and pineapple constitute common examples. In the pineapple, portions of the flower stalk, sepals, petals, and ovaries of many flowers are fleshy and edible, and all are so tightly compressed together that they appear fused to each other.

Pome. The pomes are fleshy fruits consisting of a thin skin and outer zone of edible flesh. Common examples are the apple and pear. The fleshy portion beneath the skin is ovary tissue. The core in the center consists of a number of seed-containing, leathery little compartments called carpels. These are derived from the inner ovary wall. See Fig. 6.

Legume. The main characteristic of a legume is the shell-like pod containing a number of relatively large seeds. Peas and lima beans are typical legumes. The pod which has developed from a single ovary dries out as it matures, splits into two halves, and releases the seeds. See Fig. 7.

Capsule. A capsule is somewhat like a legume, but differs in that it consists of more than one seed compartment and splits along more than two lines when ripe. The fruit of okra is a familiar example.

Caryopsis. The kernel of sweet corn is a kind of fruit called a *caryopsis.* The more or less horny outer coat is the ovary wall. This is firmly attached to the seed coat of a single seed. The remaining portions (endosperm and embryo) comprises the seed in this case.

Nut. A nut is defined as a hard, dry, single-seeded fruit, partly or entirely enclosed in a husk, which remains with the fruit as it ripens. Common examples are chestnuts and filberts. Although the term "nut" is popularly applied to many hardshelled fruits that may be stored dry, many of these are *not* true nuts. The groundnut (peanut), for example, is not a nut, but it is a legume. The almond is actually the pit of a drupelike fruit and the Brazil nut is actually a seed. See also **Nut.**

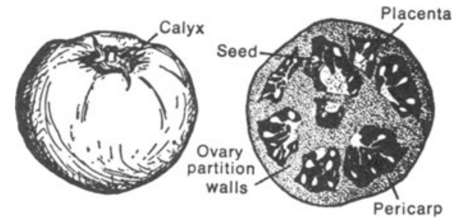


Fig. 1. A berry-type fruit, the tomato (*Lycoperscion esculentum*). (Left), surface view; (Right), cross section.

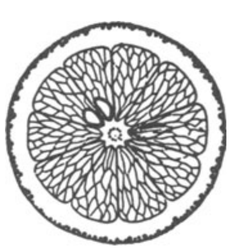


Fig. 2. A hesperidium, the orange (*Citrus sinensis*) shown in cross section.

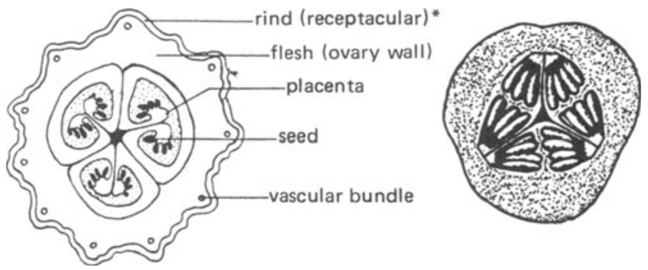


Fig. 3. A pepo, the cucumber (*Cucumis sativus*). Cross sectional views.

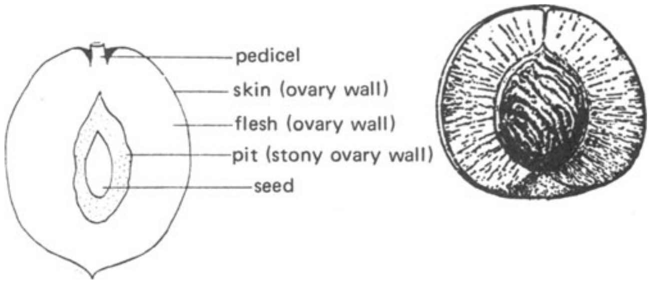
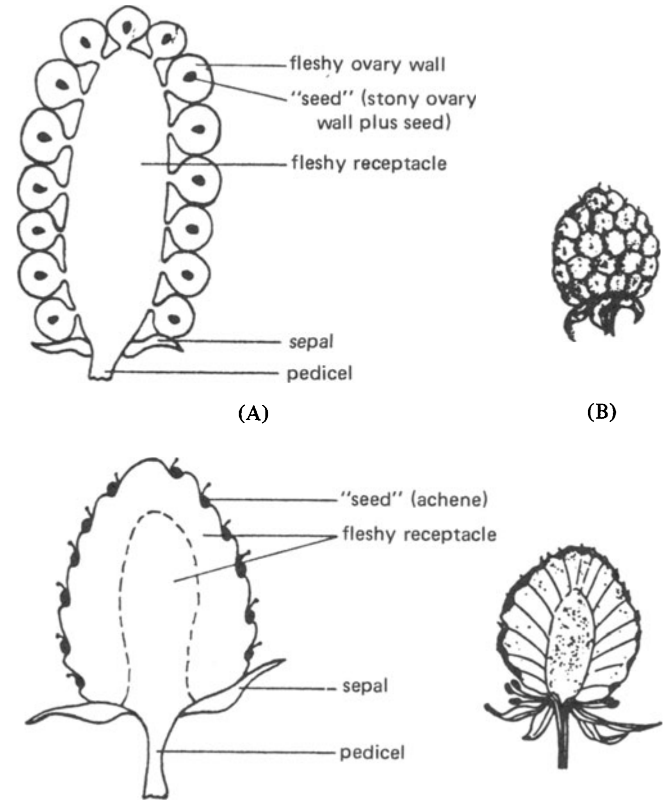


Fig. 4. A drupe, the peach (*Prunus persica*). Cross sectional views.

Dry Fruits. The dry fruits are separated into *dehiscent* fruits, those which split open when ripe, and indehiscent fruits, which do not do so. Common dehiscent fruits are the legume, the follicle, and the capsule; dry indehiscent fruits are the achene, the caryopsis or grain, the samara, and the nut. A follicle is similar to a legume, but splits along one side only. Milkweed pods are follicles. The fruits of the columbine and larkspur are also follicles. A capsule is a dehiscent fruit which develops from a compound ovary. The fruit of a lily or an iris is a capsule. The achene is a single-seed indehiscent fruit which when mature has the seed from the ovary wall except at the point of attachment. Fruits of the buttercup are achenes; also the fruits of the strawberry,



(A) (B)

(C)

Fig. 5. Aggregate fruits. (A) Blackberry (*Rubus*); (B) raspberry (*Rubus*); (C) strawberry (*Fragaria*). (From "Fruits, Vegetables and Flowers," G. M. Kessler, Burgess Publishing Co., with permission)

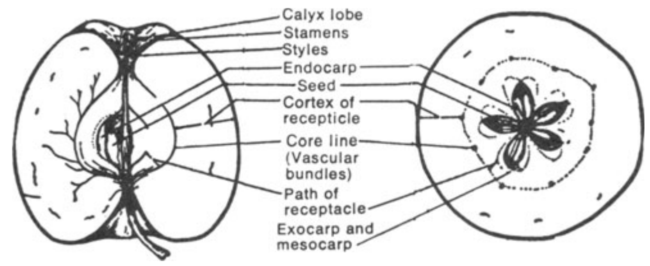


Fig. 6. A pome, the apple (*Malus domesticus*).

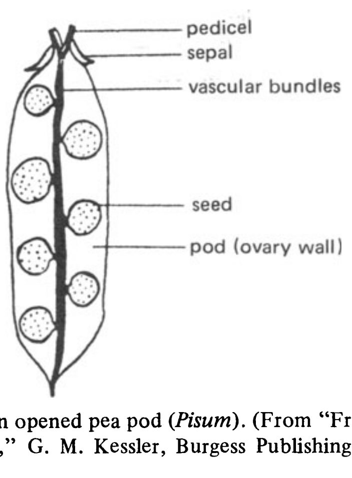


Fig. 7. A legume, an opened pea pod (*Pisum*). (From "Fruits, Vegetables and Flowers," G. M. Kessler, Burgess Publishing Co., with permission)

which are the small hard bodies borne on the surface of the "berry." The achene of the Compositae family differs from the others in having the calyx tube coalesced with the ovary wall. A caryopsis or grain is very similar to an achene, but has the seed coat fused with the pericarp so that the seed cannot be removed from the ovary wall. The fruits of all cereal grasses are caryopses. The samara is an indehiscent fruit which has a wing. The fruits of the maple and elm tree are samaras.

Dissemination of Seeds. Often the structure of the fruit is directly correlated with the dissemination of the seeds. The principal agencies for fruit dispersal are the wind, water, and animals. Many fruits are provided with wings, thin, bladelike structures which enable the fruits to drift slowly downward and generally away from the parent plants. The fruits of the maple are provided with wings. The fruits of the dandelion and thistle are familiar to all, though usually they are called "seeds." In them, a group of slender hairs forms a parachute which enables the fruit to drift far away from its parent plant into new regions. Sometimes, the fruit lacks any special structures which will aid in its dissemination, but is itself very easily blown about. Many fruits, especially those of plants which grow along the shores of streams, are carried about by the water. The large fruits of the coconut are often carried far from the parent plant in this manner.

Animals are an important means of dispersal of fruits and seeds. There are two ways in which fruit may be thus carried. Very commonly, hooks or barbs are formed on the surface of the fruit and are easily caught on the fur of a passing animal, and stay there until some mechanical action breaks off the hooks or barbed bristles and allows the fruit to fall. Some fruits are covered with a sticky coating which causes them to adhere to the coats of passing animals, to be rubbed off later at some other location. Still other "seeds" have a soft, often tasty, outer wall, or edible mesocarp, and are eaten by animals. The hard inner wall of the fruit resists action of the animal's digestive juices so that the seed passes uninjured through the digestive tract and is voided in a region often far distant from the place where it was eaten. Partial digestion of the endocarp may even aid the liberation of the seed for germination. Tomato seeds are particularly resistant to attack by the digestive juices of humans and often will be capable of germination even after passing through extensive sewage treating processes.

The explosive splitting of the walls of many fruits ejects the seeds violently, hurling them away from the parent plant. In some rare species, seeds may be hurled as far as 50 yards (45 meters). See Fig. 8.

Carbohydrate Patterns of Fruits

Soluble carbohydrates are synthesized in the chloroplasts of green plants and those not utilized immediately in respiration are translocated to other parts of the plant. These translocated carbohydrates may be utilized in respiration and growth, or may be stored as reserve foods. In many plants, the most conspicuous site of stored foods is to be found in the fruit.

All fruits undergo four stages of development: (1) Following fertilization, a fruit grows by cell division; (2) there

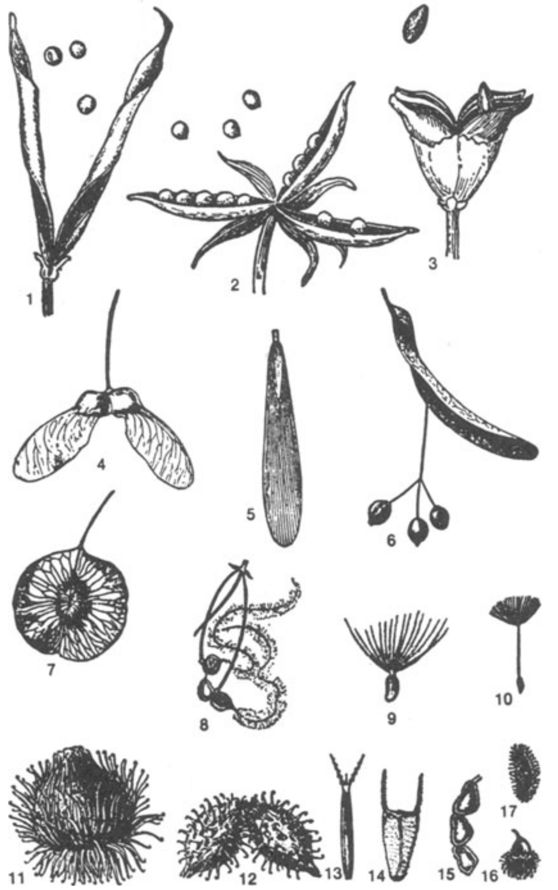


Fig. 8. Dry fruits with devices for dispersal of their seeds. (1 to 3) By sudden dehiscence; (4 to 10) by wind; (11 to 17) by animals. (1) Wild bean; (2) violet; (3) witch hazel; (4) maple; (5) ash; (6) basswood; (7) elm; (8) *Clematis;* (9) thistle; (10) dandelion; (11) burdock; (12) cocklebur; (13) Spanish needle; (14) beggar's trick; (15) beggar's lice; (16) agrimony; (17) carrot.

follows a period of cell enlargement, during which time sap-filled vacuoles are formed. Sugars accumulate in the vacuoles; the cytoplasm which, up to this stage, consisted chiefly of proteins, now contains starch. When a fruit has attained full growth, it may be considered *mature,* but not necessarily *ripe.* (3) Ripening ensues during the third stage of development, during which period substances responsible for flavor and aroma are formed, acidity is reduced, sugars increase, and a certain amount of softening occurs. Softening is the result of conversion of pectic substances in the cell wall from the insoluble to the soluble form. (4) The fourth stage of development, called *senescence,* begins when ripening is essentially complete.

Fruits can be divided into two groups: (1) Those with a starch reserve; and (2) those without a starch reserve, although there are some fruits that fall midway between these classes.

Fruits with a Starch Reserve. Typical of fruits with a *starch reserve* are apple, banana, and pear. It has been shown, for example, that invert sugar and sucrose increase throughout the growing period of the apple fruit, but starch reaches its maximum when ripening processes begin. During the course of ripening, therefore, the starch is hydrolyzed to sugar. During the early stages of ripening, the soluble pectin substances also develop. The sugars in a ripe apple consist mainly of glucose, fructose, and sucrose.

Fruits like the apple, pear, and banana, with their carbohydrate reserve, can be harvested in the *mature green* and permitted to finish their ripening process during storage. Other fruits, like citrus, raspberries, cherries, among others, do not develop a carbohydrate reserve and must, therefore, be ripened on the tree if they are to ripen at all.

Rather pronounced carbohydrate transformations take place in the banana during ripening. It has been shown that when the fruit changes from the green to the ripe stage, total carbohydrates drop from 26.6 to 19%, soluble carbohydrates increase from 1.3 to 17%, and insoluble carbohydrates decrease from 25.3 to 2%. In general, reducing sugars show a gradual increase during post-harvest ripening. The behavior of nonreducing sugars is determined by the variety of fruit.

Another group of substances, known as *tannins,* is sometimes classified as compound carbohydrates. These substances accumulate during the growth of certain fruits, accounting for astringency in the unripe stage. Unripe persimmons, olives, bananas, and dates are characterized by high tannin content. This is true to a lesser extent of certain varieties of pear. During the ripening of these fruits, astringency is reduced as tannins are converted into insoluble forms.

Fruits without a Starch Reserve. Fruits which do not accumulate a large carbohydrate reserve are typified by citrus fruits, blackberries, and raspberries, cherries, peaches, plums, strawberries, and others. During ripening on the tree or bush, these fruits show an increase in sugars and a decrease in acids. Following harvest, fruits without a starch reserve may develop a characteristic color, soften (in some types), and lose a slight amount of acid through respiration, but they will not show any increase in sugar. A good variety of orange has been shown to contain 10.6% soluble solids (mainly sugars) and 0.85% acids when acceptable to consumers.

Several exceptions or variations from the general rule can be found in this second group. Lemons, for example, do not undergo the same changes during ripening as those in oranges and grapefruit. The lemon fruit, during growth and maturation, does not increase in sugar. Free acids in the juice increase during ripening and predominate over sugars in the ripe fruit.

In the avocado, total sugar content decreases during maturation. With the loss of sugar, there is a concomitant increase in oil. Dates are unique not only because of the high sugar content in ripe fruits, but also because different varieties accumulate different kinds of sugar. *Barhee,* for example, accumulates mostly glucose and fructose and is, therefore, classed as an invert-sugar variety. *Deglet Noor,* in contrast, contains mainly sucrose when ripe.

Vegetable-type Fruits. Although a popular distinction is made between fruits and vegetables, technically there is no valid distinction provided that the commodity in question meets the basic definition of fruit as previously given. Thus, if the edible portion of the plant is a leaf, petiole, stem, or root, it is definitely a vegetable. From the popular standpoint, a fruit is more frequently eaten raw as a dessert, and it possesses a characteristic aroma and flavor due to the presence of various organic esters. A vegetable is ordinarily eaten cooked, or when raw, as a salad or relish. It is the product of a herbaceous plant, rarely of a shrub or tree.

Fruits borne on succulent vines, if of economic importance, may be called vegetables, although botanically they may be true fruits. In this category are included tomato, muskmelon, watermelon, and pumpkin.

Mature green tomatoes contain a very slight amount of starch which disappears upon ripening. Reducing sugars increase with ripening, but only traces of sucrose have been found in these fruits in various stages of ripening.

Muskmelons, honeydew and casaba melons undergo an increase in total solids, total sugar and sucrose during ripening and a decrease in invert sugar. The same general changes occur in the watermelon. Both pumpkin and squash differ from related species in that immature fruits contain as much sugar as ripe ones.

Carbohydrate Accumulation in Seeds. Seeds may be grouped into three categories: (1) Those in which carbohydrates represent the main food reserve. The cereal grains are typical of this group. (2) Seeds that accumulate large quantities of proteins. Many of the legumes (peas, beans, etc.) are in this group. (3) Seeds in which large quantities of oil are stored. Sunflower, almond, macadamia, and castor bean seeds belong to this group.

Starch and hemicellulose predominate in seeds in which large quantities of carbohydrates are stored. During the early stages of development of this type of seed, there occurs a gradual increase in sugar up to a maximum. Subsequently, sugars decrease and starch and other polysaccharides increase. Some seeds are used as foods when the seeds are still rather succulent. Sweet corn is an example of this type. Four stages in the development of sweet corn have been described: (1) The *premilk stage,* in which the exudate (when skin is broken) is opalescent. The ratio of sugar to starch at this stage is about 1.9. (2) Next is the *milk stage* when the sugar/starch ratio is about 0.750. (3) In the *early dough stage,* the sugar/starch ratio is about 0.2. (4) In the *final dough stage,* the sugar/starch ratio is about 0.15.

Although some seeds, like peas, are rich in protein, they also accumulate carbohydrates, although to a lesser extent than do the carbohydrate-rich seeds, and the changes from sugar to polysaccharides proceed in the same order during ripening.

Seeds of the coconut possess two rather different features—their large size and the presence of liquid endosperm (milk) during the maturing stages. Ripening stages of coconut have been divided into three parts: (1) Before the formation of the endosperm, when invert sugar and amino acids accumulate in the milk; (2) when the loss of water from the nut takes place and sucrose appears in the milk; and (3) when a sudden rise in the oil content of the endosperm and a loss of nutrients in the milk occur.

Some seeds have the carbohydrate reserves stored as hemicellulose in the tertiary, much thickened cell walls of the endosperm of the cotyledons, instead of in the interior of the cells as in the case with stored starch. The most striking seed of this kind is the seed of the ivory nut palm (*Phytelephas macrocarpa*) from South America. Seeds of the date palm also store carbohydrate in the form of hemicelluloses. Hydrolysis of this seed yields glucose, fructose, mannose, galactose, arabinose, and xylose.

Tree Characteristics

There is a wide variation in the basic growth habits of the various fruit-producing trees and plants. Some of the terms used in describing the botanical features of trees are illustrated in Figures 9, 10, and 11.

Economic Importance of Fruits

Returning at this juncture to the more conventional designation of fruits as commodities, the deciduous fruits, citrus fruits, bush fruits, etc., comprise a very important segment of the total food production spectrum. Worldwide production of deciduous and citrus fruits is delineated in Table 1; and for the United States in Table 2.

There are separate entries on the major and for nearly all of the minor fruits, some of which have been described only briefly in this entry. In addition to entries on specific types and species, see also entries on **Berry**; and **Nut.**

Trends in Shaking and Catching Technology. Pioneered

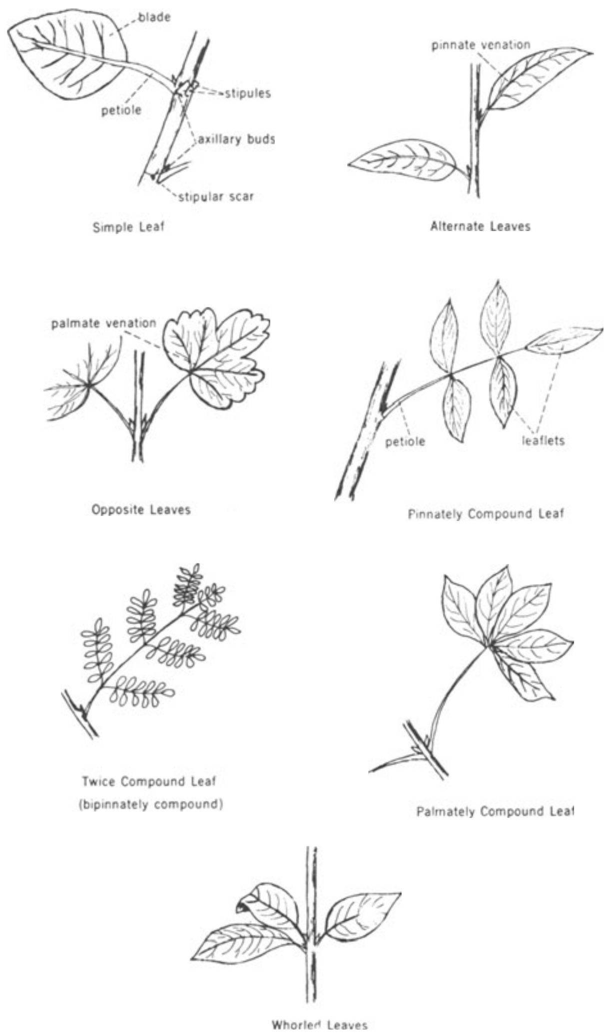


Fig. 9. Various configurations of leaves (University of Georgia College of Agriculture diagrams)

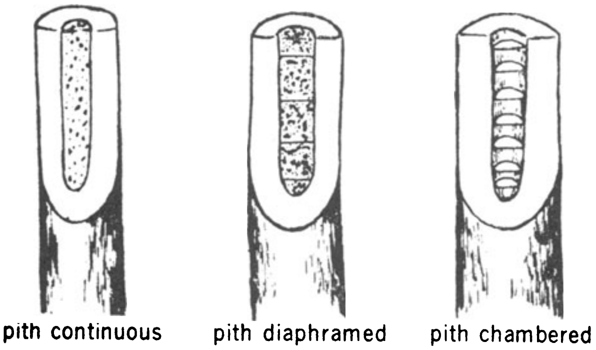


Fig. 10. Pith is the soft central part of a twig. Where the pith is continuous, it is a solid, homogeneous material, not divided into compartments. In diaphragmed pith, cross membranes of denser material extend across the pith. In chambered pith, the central portion of the twig is divided into empty horizontal chambers by cross partitions. (University of Georgia College of Agriculture diagrams)

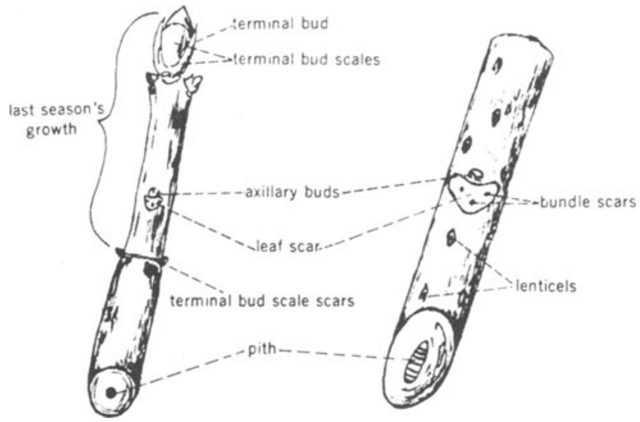


Fig. 11. Illustration of several terms used in describing trees. (University of Georgia College of Agriculture diagrams)

in connection with walnuts and some other kinds of nuts, the concept of shaking the tree to release the fruit has been well established for many years. In early models of equipment, designers concentrated mainly on the shaking part of the system. Since 1942, intensive study of mechanical harvesting of nuts and fruits has been underway in such states as California, Michigan, and New York. Methods of shaking have included: (a) Pole-shaking by hand, wherein secondary limbs were shaken with an oak or aluminum pole having a hook; (b) shaking of secondary limbs with a hand-carried pneumatic power shaker, with reciprocating action supplied by a double-acting air piston; (c) cable-shaking, in which a cable connected a tractor-mounted eccentric to a hook placed over the limb; and (d) boom-shaking, similar to cable-shaking except that the cable is replaced by a rigid member supported by a tractor-mounted or self-propelled boom. An excellent summary of tree-shaking methodology as of the mid-1960s was prepared by R. B. Fridley and P. A. Adrian (*Bulletin 825,* California Agricultural Experiment Station). Although considerably more information is available as of the early-1980s, the fundamentals of the problem are covered by Fridley and Adrian.

Shaking and catching of fruits and nuts in connection with specific commodities, where such operations are partially or fully successful, are described in this volume in entries on specific commodities. One of the latest shaking and catching machines is illustrated in Figures 12 and 13.

TABLE 1. FRUIT PRODUCTION WORLDWIDE[1]

Fruit	Production (1000 Metric Tons)	Percent of Total
DECIDUOUS		
Apple	19 846	47.8
Pear	7 686	18.5
Peach/Nectarine	6 451	15.5
Plum/Prune	4 689	11.3
Apricot	1 502	3.6
Cherry	1 376	3.3
Total	41 550	100.0
CITRUS		
Orange	34 100	67.0
Mandarin/Tangerine	7 300	14.3
Lemon/Lime	4 600	9.0
Grapefruit/Pomelo	4 000	7.9
Other	900	1.8
Total	50 900	100.0

[1] Quantities averaged for years of the late 1970s.

NOTE: For bushberry production, see entries on: **Blackberry and Dewberry; Blueberry; Cranberry; Currant; Elderberry; Gooseberry; Raspberry;** and **Strawberry.**

TABLE 2. FRUIT PRODUCTION IN THE UNITED STATES[1]

Fruit	Production (1000 Metric Tons)	Percent of World Total
DECIDUOUS		
Apple	3 053	15.4
Peach/Nectarine	1 375	21.3
Pear	714	9.4
Plum/Prune	653	13.9
Cherry	231	16.8
Apricot	130	8.7
Total	6 156	–
CITRUS		
Orange	9 506	27.9
Grapefruit/Pomelo	2 585	64.5
Mandarin/Tangerine	666	9.1
Lemon/Lime	653	14.5
Total	13 410	–

[1] Quantities averaged for years of the late 1970s.

NOTE: For bushberry production, see entries on: **Blackberry and Dewberry; Blueberry; Cranberry; Currant; Elderberry; Gooseberry; Raspberry;** and **Strawberry.**

Fig. 12. Operator lining up mechanical shaking and catching machine in fruit orchard. A machine of this type can be used on apples, cherries, peaches, and various nuts. This machine was developed in the late-1970s. (FMC Corporation)

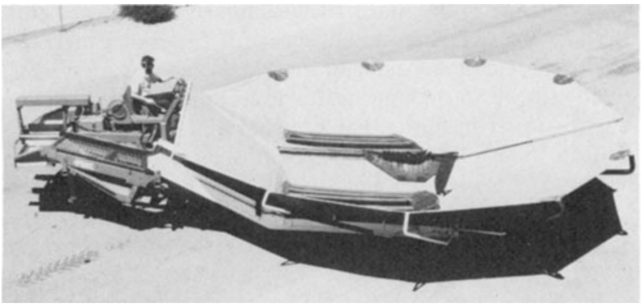


Fig. 13. Another view of machine shown in Fig. 12, looking down on the catching portion which, by way of the split catcher, can be centered under a fruit or nut tree. (FMC Corporation)

References

NOTE: Each specific entry on fruits, nuts, oilseeds, etc., incorporates a listing of references.

FRUIT FLY (***Insecta, Diptera***). Of the family *Trypetidae,* the fruit fly can be quite damaging to several fruit crops. The adult female usually lays her eggs in plant tissue. Larvae of several species are borers, working their way into stems, mining into leaves, and, most damaging, boring into and moving about in the fleshy portions of fruits and vegetables. They also produce galls. The fruit fly tends to specialize as indicated by the following descriptions:

Apple maggot (*Rhagoletis promnella*). Described in entry on **Maggot**.

Cherry fruit fly (*Rhagoletis cingulata* [Loew]). See Fig. 1. A primary cause of deformed and wormy cherries. Often, one side of the fruit will be decayed and shrunken, while the other side is healthy. The maggots of this fly are yellow-white and footless and range up to 1/4-inch (6 millimeters) in length. The head is pointed and is used for boring into the fleshy fruit. Sometimes, the very small maggots are difficult to find, but traces of their burrows will be apparent. Sometimes, the damage is not fully detected until the fruit is processed. In addition to the cherry, this insect damages pear and plum. A closely related species is the **black cherry fruit fly** (*R. fausta* [Osten Sacken]) whose primary target is sour cherry. These insects winter in the pupa stage. The pupa is brown and shaped something like a capsule. Time in this stage is long, ranging up to 150 days. The adults usually emerge when the outside temperature has risen to 40°F (4.5°C), but this habit varies considerably, depending upon locale. The adult fly leaves the soil in late spring. The females puncture cherry leaves and fruits with their ovipositor, each female laying nearly 400 eggs over a laying period of about 25 days. Chemical sprays and trapping are used as control measures.

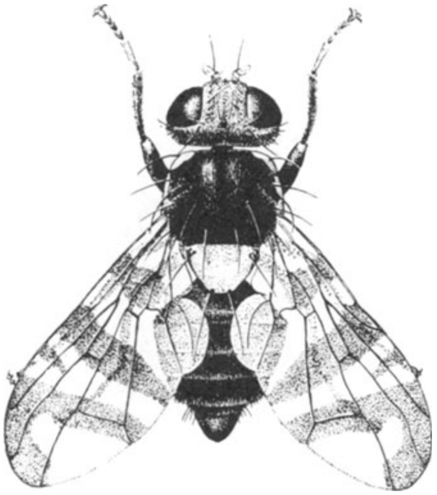


Fig. 1. Cherry fruit fly. (*USDA diagram*)

After larvae development is completed within the cherries, larvae drop to the ground and change to pupae in the soil. Cherry varieties that are harvested early are likely to contain larvae. Therefore, to control the pest, infested fruit must be destroyed and an area around the tree should be cultivated. All cherries that appear damaged on the trees should be picked and immediately burned. Traps reduce the number of adult flies before they lay their eggs in the fruit. Traps may be made by coating a small piece of wood, about 6 X 8 inches, (15 X 20 centimeters) with a sticky substance, such as *Tanglefoot* or *TacTrap.* At the bottom of the board, a small jar or bottle filled with ammonium carbonate is attached. A few holes are punched in the jar lid so that the fumes of the bait can get into the air. Several of these traps are suspended from the lower limbs of the tree. For full effectiveness, the "sticky" board should be cleaned of flies and other debris at periodic intervals. The sticky substance should be renewed periodically as indicated.

Currant fruit fly (*Epochra canadensis*).

Mediterranean fruit fly (*Ceratitis capitata* [Wiedeman]). See Fig. 2. The insect occurs widely in Bermuda, Hawaii and in most subtropical countries. There have been several invasions of the fly into Florida. Several million dollars were invested in clearing an area of 10 million acres after an invasion of the fly in 1929. The fly had been found in scattered locations within this area. Later, in 1956, additional large funds were invested in eradicating the insect from 28 counties in Florida. The fly attacks citrus and deciduous fruits, notably apple, grapefruit, nectarine, orange, peach, pear, plum, quince, as well as coffee.

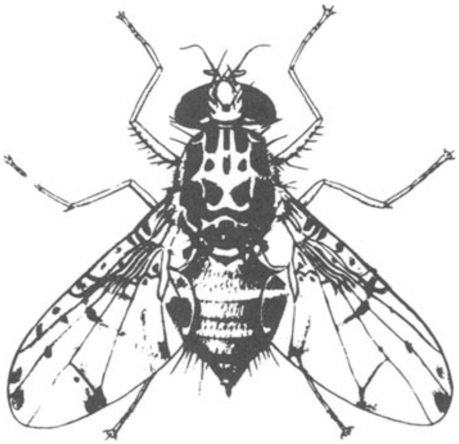


Fig. 2. Mediterranean fruit fly. (*USDA diagram*)

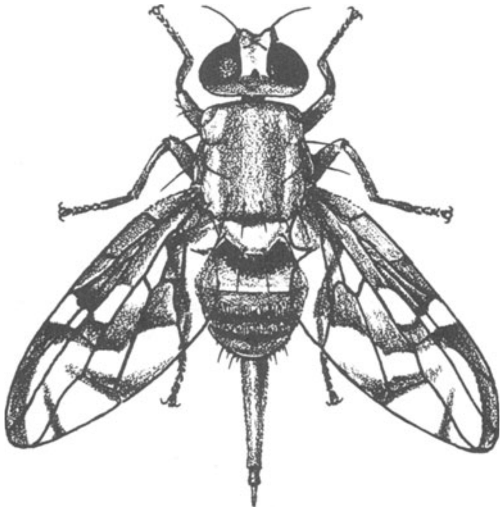


Fig. 3. Mexican fruit fly. (*USDA diagram*)

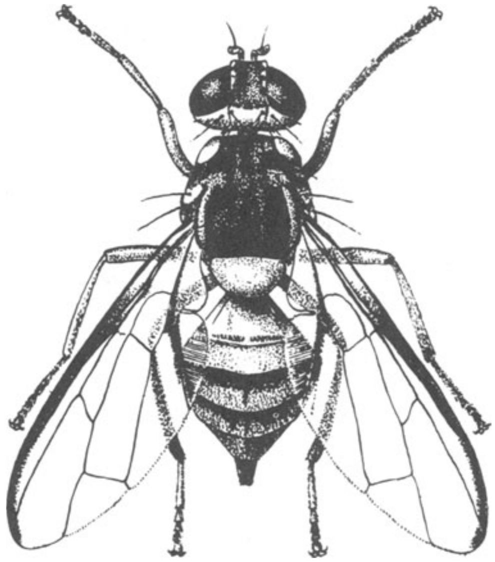


Fig. 4. Oriental fruit fly. (*USDA diagram*)

Mexican fruit fly (*Anastrepha ludens* [Loew]). See Fig. 3. This insect is principally a pest on citrus and mango. The fly is an important economic pest in Mexico and Central America. From time to time, members of this species have been trapped in California.

Olive fruit fly (*Dacus oleae*).

Oriental fruit fly (*Dacus dorsalis* [Hendel]). See Fig. 4. This insect injures all varieties of citrus and most deciduous fruits, as well as avocado, banana, melon, tomato, and many other plants. In 1946, the oriental fruit fly was introduced into Hawaii from the Marianas Islands. The fly is also found in Burma, India, the Philippines, and Taiwan. Extensive eradication programs were carried out in California in mid-1981 and, to a lesser extent, in Florida.

Walnut husk fly or maggot (*Rhagoletis completa* [Cresson]). The adult fly is pale yellow with brown eyes, stiff brown hairs on abdomen, and with transparent wings that have dark stripes. The larva is white or pale-beige and up to 1/2-inch (12 millimeters) in length. The maggot feeds in the husk of maturing nuts and reduces the quality of the kernels. Distribution is throughout the United States. Natural circumstances often assist the nut grower by causing the fly to emerge early or late in the season. The female cannot lay its eggs successfully until the walnut husk becomes soft. During July and August, unsuccessful egg-laying attempts have been observed on eastern black walnuts that were sound and without blemish. However, eggs have been found in mid-August in husks that have naturally or mechanically induced abrasions. Husk maggot problems on the eastern black walnut can be greatly reduced by selecting late-maturing varieties. Larvae which hatch from eggs laid after September 20 in the latitude of Maryland are no problem because they will not mature.

See also **Drosophila.**

FRUIT PACKAGING FUNGICIDE. Fresh fruits are particularly prone to attack by various strains of fungi, which sometimes cause minor discoloration or off odor and also cause more severe damage that makes the product fully unfit for the market. Several fungicide compounds have been developed to effectively control fungicidal development while fruit is in storage and transit.

Biphenyl Fungicide. This is a well-established organic fungicide used mainly to protect citrus fruit. The full organic chemical name is diphenyl or phenylbenzene. It is widely used in many areas of the world and is manufactured by a number of firms. Rather than using the raw chemical, most citrus packagers procure liners, pads, and wrappers that have been impregnated with the compound. The compound is particularly effective in controlling blue and green mold and *Diplodia* stem end rot. The wrappers contain close to 2% active ingredient; box liners about 16.6%; and the pads range from 10 to 25%. There is one liner per box and, only two pads are used. These impregnated articles impart sufficient vapor throughout the fruit container to provide protection. Wherever possible, it is desirable to pack fruit in entirely new containers and this is commonly done where corrugated boxboard containers are used. Where wooden containers are used, they may be reused in some areas. Often zinc petroleum sulfonate (15% solution) will be used to disinfect baskets, crates, and boxes. Where fruit is to be held for awhile in storage, or in degreening rooms, methylene chloride may be used to control mold formation. Trade names of similar or related products include: *Lemonene, Phenador-X.*

Dowcide A Fruit Dip.* Protection of fruit for storage and shipping also can be achieved by using a solution in which the fruit is dipped. Dowcide is available as a wettable powder (97%); solutions of various concentrations; a wax emulsion (0.5 to 5%), as a paste (0.2%), thus providing much flexibility in the manner in which the fungicide may be applied. This compound is particularly effective against blue and gray molds, damping off, brown rot, fruit rot, soft rot, and powdery mildew. If a dip is used, the item of fruit is allowed to remain in the solution for a few minutes, after which it is dried and packed. Or, a packer may prefer to use a spray formulation.

This compound has a number of other uses, including application dressings for tree wounds, overall food processing plant disinfection, and as a general cleanup compound for agricultural structures. Dowcide A also is used as a soil drench in greenhouse operations. In the case of sweet potato, the compound is used as a preplanting dip. Trade names of similar or related products include: *Sopp, Topane.*

Dowcide 1 Fungicide**. This is orthophenyl phenol and is available as a liquid (5 to 18%); wettable powder (98%); and in flake form. The compound is used for waxing a number of fruits and in the disinfection of fruit containers—crates, field boxes, hampers, lugs, *et al.* As previously described, the compound is also impregnated into paper container parts. The compound also is used in a general way for disinfection of agricultural structures. Trade names of similar or related products include: *Orthoxenol, Torsite.*

Frucote Dip or Spray†. This compound, 2-aminobutane, is available as a liquid (25 and 98%) for dipping fruit prior to packaging. It is particularly effective against green and blue molds (*Penicillium* spp) and *Diplodia* stem end rot. The fruit is dipped for 1 to 5 minutes, or the fungicide can be applied in spray form, whichever method may be preferred by a particular packer. Where the spray form is used, a wetting agent often is required. If the dipping solution becomes diluted to below 1% Frucote, the effectiveness is greatly lowered. Trade names of similar or related products include: 2-AB, *Butafume, Deccotane, Tutane.*

See also **Fungicide; Pesticide Application.**

FRUIT PROCESSING. Antimicrobial Agents; Citrus; Fruits and Processing; Coating Agents; Drying. (See specific fruits.)

FRUIT SUGAR. Sweeteners.

FRUITWORM (*Insecta*). The tomato budworm and the corn earworm may be classified as fruitworms. These are described under **Corn Earworm**; and **Tomato.**

The **western raspberry fruitworm** (*Byturus bakeri* [Barber]) and the **eastern raspberry fruitworm** (*Byturus rubi* [Barber]) are among the most destructive insects on loganberry and raspberry. Both the adult and larva forms are destructive. The adult beetles range from 1/8- to 1/6-inch (3 to 4 millimeters) in length and are of a light-brown color. The beetles eat buds, blossoms, and leaves. Eggs are laid on the blossoms and small fruits just getting started. Shortly thereafter, thin, whitish grubs are hatched. They are about 1/3-inch (8 millimeters) in length. The grubs bore into the fruit, fully damaging it. When fully grown, they drop to the ground, where they pupate until early spring. Rotenone is an effective control chemical.

The **gooseberry fruitworm** (*Zophodia convolutella* [Hübner]) eats the pulp of the fruit, causing the berries to dry up, to prematurely color, and become brownish in appearance. Rotenone is an effective control chemical.

Apple fruitworms, sometimes called green fruitworms, are green to green-white caterpillars that look like climbing cutworms. They are up to 1.25 inches (about 3 centimeters) long. The larvae have white or yellow striping on each side. These worms eat leaves and make large holes in fruit. Generally, they are found in the northern United States. Green fruitworms do most of their damage to young fruit in May. However, some fruitworms continue to damage fruit until mid-June. During the first week of June, most of the caterpillars attain their full growth. At this time, they burrow into the soil beneath the trees to a depth up to 3 inches (7.5 centimeters) and construct an earthen cell. About mid-September, the moths emerge and go into hibernation in sheltered nooks. Some pupae, however, do not become moths until early the following spring. When the insect reaches the caterpillar stage, it can be handpicked from small trees and destroyed. Because of its large size, the caterpillar is easily identified. To prevent further damage to the fruit, the ground under the trees should be thoroughly cultivated to a depth of about 4 inches (10 centimeters). This destroys the caterpillars in their earthen cells. Cultivation reduces the number of adult moths that will emerge and lay eggs in subsequent generations.

Pear trees are also affected by the green fruitworm.

Cherry fruitworms are found in the northwestern United States. The adult is a small grayish-black moth with a wingspan of about 1/4-inch (6 millimeters). The larva is a whitish-pink worm with a black head and up to 3/8-inch (9 millimeters) long. The larva bores into fruit and feeds on pulp, causing rough, brownish areas in the pulp and on the skin. The cherry fruitworm winters as a fully-grown larva in a silken cocoon, tunneled inside the pruned stub of a dead twig, under bark, or debris on the ground. The larva pupates in May and the adult emerges about 1 month later.

Controlling the pest involves pruning away all dead branches and twigs and burning them to kill overwintering larvae. Cleaning up bark and debris on the ground also reduces populations in the spring. Damaged and prematurely dropped fruit should be picked up and destroyed. Placing bands around the tree, as in the case of controlling the codling moth, is also effective. Whenever silken cocoons are found, they should be destroyed immediately. See also **Codling Moth.**

FRYING OILS. Oilseeds and Related Products; Palm Oil; Safflower Oil.

FUDGE. Cacao and Chocolate; Confections.

---

*The Dow Chemical Co.

**The Dow Chemical Co.

†University of California.

FUKUHARA ORANGE. Orange.

FULL BODY. Flavorings.

FUMARIC ACID. Acidifiers, Alkalizers, Buffers, and Neutralizers; Amino Acid Metabolism; Flavoring Agents; Appendix Table 1.

FUMIGANT. A chemical substance, applied in gaseous or vapor state and within a confined space, for eradicating all but the most resistant forms of animal life. Thus, fumigants and the procedures of fumigation represent a severe hazard to the lives of humans and domestic and farm animals if they are not treated in the most professional and expert manner. Because fumigation requires an airtight enclosure, permitting of no leakage of the poisonous gases and vapors to the surrounding atmosphere, it is a technique used only when absolutely necessary. Fumigants, in most instances, are universal rather than selective killers, thus eradicating the beneficial forms of life if present, along with the target pests.

In connection with food production and distribution, fumigation finds most frequent use: (1) On citrus trees and other plantings around which portable tents or boxes can be constructed—for reaching pests, such as scale insects, which cannot be controlled by the normal use of spray or dust insecticides; (2) in greenhouses in which, after awhile, pest populations build up to a point where normal control methods no longer suffice; (3) on nursery stock to eradicate scale insects, and to destroy any pests which may be present on stock brought in from other countries or regions and, in particular, of subterranean pests which are not readily visible; (4) in food-packing and processing plants, warehouses, and consumer outlets, again where pest populations have a tendency to build up and where total eradication is periodically required to minimize pest damage; (5) in all manner of food-storage facilities, notably those concerned with various grains and dried fruits, in which extremely resistant species of beetles, weevils, and other insects tend to habituate and increase their populations unless destroyed with fumigation power periodically; (6) in a variety of transportation facilities, such as trucks, railway cars, ship holds, where the problem is similar to that of the warehouse—and very important to avoid shipping (or receiving) damaging pest species from one region to the next; (7) of seeds prior to planting; (8) of soil that may be infested with ants, grubs, nematodes, wireworms and other soil-inhabiting pests; and (9) occasionally in food-serving facilities, where long neglect and lack of cleanliness and normal pest controls have been lacking. Open field fumigation to control cinch bugs and grasshoppers no longer is common.

Several factors must be considered in selecting and applying fumigants. The fumigant, if not a gas at room temperature, must be relatively easily volatilized. While most fumigants are harmful to all forms of animal life, there is some degree of specificity, a factor which affects both the time of treatment and the concentration of the fumigant. There is a rather wide range of costs among fumigants. Some fumigants are flammable; others are not. Reactivity with and absorption by the product being treated is extremely important. Usually these factors increase with the temperature prevailing at the time of fumigation. Living plants also are affected by some fumigants, the extent of injury increasing with temperature and time of fumigation. The penetrating capability of fumigants differs from one compound to the next. This factor also must be considered when selecting suitable coverings, such as plastic sheeting, for making fumigation enclosures.

Briefly, fumigants commonly used include:

Carbon Bisulfide. Liquid with a putrid, sulfurous odor, boiling point (b.p.) 114.8°F (46°C), flammable and explosive. Excellent penetrating power and superior to hydrogen cyanide in this respect. Very toxic to plants and cannot be used in greenhouses. Widely used to control various pests in stored-grain and seed facilities. Most seeds can be exposed to carbon bisulfide without damaging their germinating ability. Emulsion formulations are used against soil insects. The very bad odor at low concentration is an advantage in warning workers of the presence of the fumigant.

Carbon Tetrachloride. Liquid with chloroform-like odor, b.p. 170+°F (77°C), not flammable or explosive. Relatively low toxicity and slow-acting. Most frequently used in combination with other fumigants, such as carbon bisulfide and ethylene dibromide. Useful as a diluent for a number of other fumigants as a means of lowering fire and explosion hazard.

Chloropicrin. A tear gas, b.p. 235°F (112+°C). Frequently mixed with other fumigants, such as carbon tetrachloride and ethylene dichloride as a way to increase volatility of the chloropicrin. Causes injury to germinating ability of seeds and damages live plants. Mainly used against grain-storage pests as found in grain elevators and flour mills.

β, β′-Dichloroethyl Ether. Liquid, b.p. 352°F (178°C), flammable. Used mainly as a soil fumigant against sod webworms and wireworms. Some uses in greenhouses, but compound is phytotoxic. Fumigated soil must be aerated before it is used for new plantings.

1,3-Dichloropropene. Soluble in organic solvents, liquid, b.p. about 230°F (110°C), depending upon combination of isomers used. Particularly effective as a soil fumigant against centipedes, nematodes, and wireworms. Injection rates range from 200 to 400 pounds per acre (about 220 to 440 kilograms per hectare).

Ethylene Dibromide. Liquid, b.p. 269°F (131+°C), not flammable. Widely used on fresh fruits and vegetables for destroying fruit fly larvae and other insects to permit shipment into quarantined areas. Also used extensively as a soil fumigant against nematodes, white grubs, and wireworms, for which applications it is frequently mixed with a petroleum naphtha diluent. The compound is phytotoxic to numerous plants.

Ethylene Dichloride. Liquid, b.p. 183°F (84°C), flammable, of moderate toxicity. Emulsions with water commonly used against peach tree borer in orchard operations and as a soil fumigant against Japanese beetle larvae. Flammability is reduced by mixture with carbon tetrachloride. Compound acts rather slowly, sometimes requiring up to 3 days to kill certain insect pests. The germinating ability of exposed seed is not usually adversely affected, but upon extended periods of exposure, food substances of a fatty nature will absorb some of the fumigant.

Ethylene Oxide. Gas, b.p. -11.5°F (10.7°C), flammable, of moderate toxicity. Often used with carbon dioxide (can be in form of dry ice) to lower fire and explosion hazards. Because of high phytoxicity, the compound is not for use on living plants and exposure of seeds to compounds may damage their ability to germinate. Widely used in low-temperature fumigation applications, particularly for the sterilization of packaged foods (candy, dried fruit, nuts). For maximum penetration, fumigation is carried out in a chamber under partial vacuum. Ethylene oxide is available in steel cylinders.

Hydrogen Cyanide. Liquid, b.p. 78.8°F (26°C), extremely toxic, burns in air, explosive in air mixtures at concentrations above 5.6%. Lighter than air, diffuses rapidly. Frequently applied in enclosures under partial vacuum to increase penetration. Corrosive to metals. One of the oldest and most widely used fumigants. First used against cottony-cushion scale insects in citrus orchards of California in 1886, and widely used for greenhouse fumigations since 1890. Hydrogen cyanide is used for practically all of the applications outlined earlier in this entry. The oldest, but no longer the most popular method of application involves adding sodium cyanide to a pot containing warm sulfuric acid and water. For large enclosures, several pots may be required and, since gas is lighter than air, the fumigator must commence with the uppermost area of a structure. Attempting to start a number of pots within an enclosure and speedily exiting the area entails risks. In the machine method, solutions of sodium cyanide and sulfuric acid are mixed by machine and the resulting gas is piped to whatever number of points of application may be required. This enables the fumigator to operate outside the enclosed target area. Hydrogen cyanide also is available in sealed containers. These can be emptied mechanically and the poisonous material piped to wherever needed. The method usually is used where very large volumes of gas are required and finds application for warehouse fumigation and tent applications over citrus trees. In the so-called dry method of application, earthen or paper-absorbent discs, previously soaked in hydrogen cyanide liquid and then sealed in canisters may be used. In application this somewhat parallels the earlier pot method, but volatilization of the poisonous gas occurs at a slower rate. The air in the treated area must contain sufficient moisture to permit a reaction of the treated discs with water in the air.

Isopropyl Formate. Liquid, b.p. about 158°F (70°C) is used for fumigating packaged dried fruits. The compound also may be used along with *ethyl formate.*

Methallyl Chloride. Liquid, b.p. 161.6°F (72°C) is frequently mixed with 1,1-dichloro-1-nitroethane and carbon disulfide as a fumigant for stored-grain and grain products.

Methyl Bromide. Gas, b.p. 24°F (-4.5°C) is stored and shipped in sealed cans. The compound mixes readily with organic solvents and is an effective fumigant for low-temperature applications. Compared with hydrogen cyanide, methyl bromide acts against pests much more slowly. It is commonly used in storage areas involving grain, seed, dried fruit, and other packaged food products. It is also used in transportation equipment and is an effective tool in connection with quarantine operations. The penetrating abilities of methyl bromide are outstanding. The germination abilities of seed are not injured and the compound is not phytotoxic, thus finding wide use in greenhouses and for fumigating fruits, vegetables, flowers, and nursery stock. The compound is also an effective soil fumigant against fungi and nematodes. In the field, the material is applied under a plastic tent. Because methyl bromide is an accumulative poison, extra precautions must be taken, including wearing a gas mask.

Naphthalene. Solid, melting point 176°F (80°C), the compound sublimes. At one time, this was the principal moth-proofing agent in the form of moth balls. Current applications are limited to use as a soil fumigant against the carrot rust fly and wireworms and in greenhouses against spider mites.

Nicotine. One of the older and safer fumigants for greenhouse operations, as well as in orchards, gardens, and poultry houses. Frequently, nicotine-soaked materials will be burned, the smoke serving to volatilize and carry the active material to points of application. Or the liquid material may be volatilized by dripping onto a hot surface. Field applications include aphid control on bean, cabbage, and pea. The compound, in the form of paint, also is commonly used in poultry houses.

Phosphine. Gas, b.p. about -130°F (-90°C), very toxic and hazardous. Used for fumigating grain-holding facilities, including sacked grain. Gas is made available by dissolving tablets which contain aluminum phosphide and ammonium carbamate. These materials in the presence of water emit phosphine gas. The tablet procedure appears to be the safest method of application because phosphine gas in heavy concentration tends to ignite spontaneously.

Sulfur Dioxide. Gas, b.p. 14°F (-10°C). Available as a liquid contained in pressurized steel cylinders. The gas also can be created by burning sulfur in air. For fumigating applications, where additional oxygen is required to produce desired quantity of gas, nitrates are admixed with the sulfur. The gas has several disadvantages, including its injurious effect on the germination power of seeds, on the baking quality of flour so treated, and because it is highly phytotoxic. Where used in an enclosure that is located near valuable live plants, the gas must be vented slowly once the fumigation process is complete.

Other Fumigants. Several other fumigants are available for use against termites and other pests that render damage to structures, but are not described here because their relation to food production is minor.

For additional information on fumigants, see entries on **Dried-Fruit Insects**; **Grain-Storage Insects**; and **Pesticide.** It must be emphasized that fumigation requires professional skills and equipment, that the operation does involve serious hazards, and that all necessary precautions must be taken, including use of gas masks where indicated and the presence of at least two skilled persons.

FUMIGATION. Date; Dried-Fruit Insects; Grain-Storage Insects; Mite; Peach; Raisin.

FUNGAL DISEASES. Foodborne Diseases; Poultry.

FUNGICIDE. A substance used to kill fungus organisms. Because of the great variety of fungi, as described in entry on **Fungus**, and because of the scores of different kinds of plant diseases resulting from fungal attacks, as described in entry on **Fungus and Related Diseases (Crop)**, there really is no universal fungicide. Each fungicide substance operates over a certain spectrum of target fungus organisms as well as host plants. There are over 70 specific fungicides described in some detail in this volume.

A correlation between the principal fungal diseases and the most effective fungicides for their control is given in accompanying Table 1. Each major crop described in this volume also features a "Chemical Control Summary," which lists fungicides, insecticides, herbicides, etc. most effective for use in conjunction with the crop.

As discussed in the entry on **Insecticide**, the commercial names of fungicides, like insecticides, is rather confusing because there is no pattern or formula followed in coining the commercial names. Also, as with the insecticides, the fungicides generally have long, complex organic names, making it most impractical to describe them by their organic chemical names. However, these formula names are included in the descriptions. In accompanying Table 2, commercial names for fungicides are listed alphabetically with notation of title of entry where that compound will be found described in this volume.

TABLE 1. TARGET DISEASES OF BACTERICIDES AND FUNGICIDES

Name or Class of Disease	Titles of Separate Alphabetical Entries in this Volume
Alternaria spp. diseases	**Antibiotic Bactericide and Fungicide (Piomy; Polyoxin), Copper Fungicide (Inorganic) (Copper ammonium carbonate), Dichlofluanid, Maneb, Propineb**
Anthracnose	**Anilazine, Benomyl, Bordeaux Mixture, Captafol, Captan, Carbendazim, Chlorothalonil, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper hydroxide; Copper oxychloride sulfate; Cupric zinc sulfate), Copper Fungicide (Organic) (Copper quinolate), Dichlone, Dithianon, Ferbam, Folpet, Mancozeb, Sulfur-Based Pesticide (Calcium polysulfide), Thiophanate Methyl, Zineb, Ziram**
Aphanomyces spp. diseases	**Fenaminosulf**
Aspergillus spp. diseases	**Botec**
Basicomycetes spp. diseases	**Antibiotic Bactericide and Fungicide (Piomy)**
Black leg	**Antibiotic Bactericide and Fungicide (Streptomycin)**
Black spot	**Antibiotic Bactericide and Fungicide (Piomy), Benomyl, Carbendazim, Metiram, Thiophanate Methyl**
Blast (leaf)	**Antibiotic Bactericide and Fungicide (Kasumin)**
Blast (node)	**Antibiotic Bactericide and Fungicide (Kasumin)**
Blast (rice)	**Antibiotic Bactericide and Fungicide (Kasumin), Benomyl, Carbendazim, Drazoxolon, Edifenphos, Guazatine, Kitazin, Rabcide, Thiophanate Methyl, Tin-Based Fungicide (Triphenyltin hydroxide), Tricyclazole**
Blight (almond leaf)	**Captan**
Blight (bacterial)	**Antibiotic Bactericide and Fungicide (Kasumin; Streptomycin), Copper Fungicide (Inorganic) (Copper ammonium carbonate; Cupric sulfate monohydrate; Cuprous oxide), Copper Fungicide (Organic) (Copper linoleate), Fentiazon**
Blight (blossom)	**Dichlone, Dicloran, Pentaphenate**
Blight (celery)	**Bordeaux Mixture, Copper Fungicide (Inorganic) (Copper oxychloride sulfate), Ferbam, Maneb, Thiram, Ziram**
Blight (*Coryneum*)	**Dichlone**
Blight (ear)	**Edifenphos**
Blight (early)	**Anilazine, Captafol, Chlorothalonil, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper ammonium carbonate; Copper hydroxide; Copper oxychloride; Cupric sulfate monohydrate), Dithianon, Folpet, Hexachlorophene, Mancozeb, Metiram, Propineb, Thiram, Tin-Based Fungicide, Zineb, Ziram**
Blight (fire)	**Antibiotic Bactericide and Fungicide (Streptomycin), Bordeaux Mixture, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper oxychloride sulfate; Cupric sulfate monohydrate; Cuprous oxide), Zineb**
Blight (*Fusarium*)	**Thiophanate Methyl**
Blight (halo)	**Antibiotic Bactericide and Fungicide (Kasumin; Streptomycin), Copper Fungicide (Inorganic) (Cuprous oxide)**
Blight (late)	**Anilazine, Captafol, Carbendazim, Chlorothalonil, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper ammonium carbonate; Copper hydroxide; Copper oxychloride; Cupric sulfate monohydrate), Copper Fungicide (Organic) (Copper quinolate), Diathianon, Dichlone, Folpet, Hexachlorophene, Mancozeb, Metiram, Propineb, Thiram, Tin-Based Fungicide (Triphenyltin hydroxide; Triphenyltin acetate), Zineb**
Blight (leaf)	**Antibiotic Bactericide and Fungicide (Kasumin; Polyoxin), Mancozeb, Pentaphenate**

TABLE 1. TARGET DISEASES OF BACTERICIDES AND FUNGICIDES (cont.)

Name or Class of Disease	Titles of Separate Alphabetical Entries in this Volume
Blight (peach)	**Copper Fungicide (Inorganic) (Copper oxychloride sulfate)**
Blight (petal)	**Antibiotic Bactericide and Fungicide (Cycloheximide)**
Blight (potato)	**Anilazine, Bordeaux Mixture, Captan, Maneb, Ziram**
Blight (rice leaf)	**Phenazin**
Blight (seed)	**Chloroneb, Ferbam, Hexachlorobenzene, Thiram**
Blight (sheath)	**Antibiotic Bactericide and Fungicide (Polyoxin; Valdamycin), Arsenic-Base Fungicide (Methylarsenic sulfide), Carbendazim, Edifenphos, Kitazin**
Blight (Southern)	**Antibiotic Bactericide and Fungicide (Validamycin), Copper Fungicide (Organic) (Copper linoleate), Methylmetiram, Metiram, PCNB**
Blight (tea blister)	**Pyracarbolid**
Blight (tomato)	**Bordeaux Mixture, Captan, Maneb, Thiram, Ziram**
Blight (twig)	**Pentaphenate**
Blight (walnut)	**Copper Fungicide (Inorganic) (Copper hydroxide; Copper oxychloride sulfate)**
Blotch (leaf)	**Tin-Based Fungicide (Triphenyltin hydroxide)**
Blotch (onion purple)	**Anilazine, Maneb**
Blotch (sooty)	**Captan, Chlorothalonil, Copper Fungicide (Organic) (Copper quinolate), Dithianon, Ferbam, Mancozeb, Thiram**
Blotch (various)	**Bordeaux Mixture, Copper Fungicide (Inorganic) (Basic copper sulfate; Cuprous oxide)**
Botrytis spp. diseases	**Anilazine, Antibiotic Bactericide and Fungicide (Polyoxin), Benomyl, Captan, Carbendazim, Chlorothalonil, Dichlofluanid, Dicloran, Ferbam, Mancozeb, PCNB (for lettuce), Propineb, Thiophanate Methyl**
Brown patch	**Benomyl, Chlorothalonil, Mancozeb, PCNB, Thiophanate Methyl**
Brown Spot	**Antibiotic Bactericide and Fungicide (Piomy), Carbendazim**
Bunt	**Carboxin, Copper Fungicide (Inorganic) (Copper carbonate [for wheat]), PCNB (for wheat)**
Cercospora spp. diseases	**Benomyl, Carbendazim, Copper Fungicide (Inorganic) (Copper ammonium carbonate; Copper hydroxide; Copper oxychloride; Cupric sulfate monohydrate), Propineb, Thiabendazole, Thiophanate Methyl, Tin-Based**
Cercospora spp. diseases (cont.)	**Fungicide (Triphenyltin acetate [for sugar beet])**
Clasterosporium spp. diseases	**Dichlofluanid**
Coffee berry disease	**Diathianon**
Curvularia spp. diseases	**Chlorothalonil**
Damping off	**Antibiotic Bactericide and Fungicide (Validamycin), Captafol, Carboxin, Copper Fungicide (Inorganic) (Copper oxychloride; Cuprous oxide), Dicloran, Ethazol, Ferbam, Fruit Packaging Fungicide (Dowcide A fruit dip), Hexachlorophene, Metiram, PCNB, Pyracarbolid (for *Rhizoctonia* spp.), Thiram, Zineb**
Downy spot	**Tin-Based Fungicide (Triphenyltin hydroxide)**
Fly speck	**Benomyl, Captan, Chlorothalonil, Copper Fungicide (Organic) (Copper quinolate), Mancozeb**
Fusarium spp. diseases	**Arsenic-Base Fungicide (Methylarsenic sulfide), Benomyl, Ethazol, Mancozeb, Thiabendazole**
Grape dead arm	**Folpet, Mancozeb**
Greasy spot	**Benomyl**
Helminthosporium spp. diseases	**Anilazine, Chlorothalonil, Copper Fungicide (Inorganic) (Cuprous oxide)**
Leaf diseases (coffee plant)	**Dithianon**
(peach leaf curl)	**Bordeaux Mixture, Copper Fungicide (Inorganic) (Copper oxychloride sulfate), Dichlone, Ferbam, Maneb, Sulfur-Based Pesticide (Calcium polysulfide), Zineb**
(tea leaf blister)	**Drazoxolon**
(tomato)	**Anilazine**
(various)	**Dithianon, Mancozeb, Pentaphenate**
Leaf spot	**Antibiotic Bactericide and Fungicide (Cycloheximide (for cherry); Piomy; Polyoxin), Bordeaux Mixture, Captafol, Captan (for cherry *Septoria*), Carbendazim, Chlorothalonil (regular and gray), Copper Fungicide (Inorganic) (Basic copper sulfate, Copper ammonium carbonate; Copper carbonate; Copper oxychloride; Copper oxychloride sulfate; Cupric sulfate monohydrate; Cupric zinc sulfate; Cuprous oxide), Copper Fungicide (Organic) (Copper linoleate [angular]), Dichlone (for cherry), Dithianon, Dodine (for cherry), Ferban (for cherry and tomato),**

TABLE 1. TARGET DISEASES OF BACTERICIDES AND FUNGICIDES (cont.)

Name or Class of Disease	Titles of Separate Alphabetical Entries in this Volume
Leaf spot (cont.)	Folpet, Hexachlorophene (bacterial and angular), Mancozeb (for *Alternaria, Cercospora,* and gray), Maneb, Nirit, Thiabendazole (for *Cercospora*), Thiophanate Methyl (for *Cercospora*), Tin-Based Fungicide (Triphenyltin hydroxide (for *Cercospora*)), Triforine, Zineb (for *Alternaria*), Ziram (for *Septoria*)
Melanose	Benomyl, Carbendazim, Copper Fungicide (Inorganic) (Copper ammonium carbonate; Copper hydroxide; Copper oxychloride sulfate), Copper Fungicide (Organic) (Copper quinolate; Copper linoleate)
Melting out	Antibiotic Bactericide and Fungicide (Cycloheximide)
Mildew (downy)	Anilazine, Arsenic-Base Fungicide (Methylarsenic sulfide), Bordeaux Mixture, Captafol, Captan, Chlorothalonil, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper ammonium carbonate; Copper hydroxide; Copper oxychloride; Copper oxychloride sulfate; Cupric zinc sulfate), Copper Fungicide (Organic) (Copper quinolate), Dichlofluanid, Dithianon, Drazoxolon, Ferbam, Folpet, Hexachlorophene, Mancozeb, Maneb, Methylmetiram, Metiram, Propineb, Sulfur-Based Pesticide (Sulfur), Pyridinitril, Thiophanate Methyl, Zineb, Ziram
Mildew (powdery)	Antibiotic Bactericide and Fungicide (Cycloheximide; Polyoxin; Piomy), Arsenic-Base Fungicide (Methylarsenic sulfide), Benomyl, Carbendazim, Chloraniformethan, Chlorothalonil, Chlorquinox, Copper Fungicide (Inorganic) (Copper oxychloride sulfate), Copper Fungicide (Organic) (Copper linoleate), Dinocap, Ditalimfos, Dodine, Drazoxolon, Ethirimol, Folpet, Fruit Packaging Fungicide (Dowcide A fruit dip), Hexachlorophene, Propineb, Pyrazophos, Pyridinitril, Sulfur-Based Pesticide (Calcium polysulfide; Sulfur), Thiophanate Methyl, Tin-Based Fungicide (Triphenyltin hydroxide), Tolylfluanid, Tridemorph, Triforine, Udonkor
Mold (blue and green)	Fruit Packaging Fungicide (Biphenyl; Dowcide A fruit dip; Frucote dip), Thiabendazole
Mold (gray)	Antibiotic Bactericide and Fungicide (Polyoxin), Benomyl, Captafol, Carbendazim, Chlorothalonil, Dichlofluanid, Dichlone, Dicloran, Folpet, Methylmetiram, Thiophanate Methyl, Thiram (for strawberry), Ziram
Mold (leaf)	Antibiotic Bactericide and Fungicide (Piomy), Dichlofluanid, Dicloran
Mold (snow and white)	Chloroneb, Dicloran, PCNB
Mold (spinach blue)	Maneb
Monilinia spp. diseases	Dicloran
Penicillium diseases	Benomyl, Carbendazim, Fruit Packaging Fungicide (Frucote dip), Thiophanate Methyl
Phomopsi spp. diseases	Carbendazim
Phytophthora diseases	Dichlofluanid, Ethazol, Fenaminosulf, Propineb, Tin-Based Fungicide (Triphenyltin acetate [for potato])
Pineapple disease	Guazatine (for sugarcane)
Pythium spp. diseases	Benomyl, Chloroneb, Drazoxolon, Fenaminosulf, Thiophanate Methyl
Red fire	Methylmetiram
Rhizoctonia spp. diseases	Anilazine (for celery), Benomyl, Carbendazim, Chloroneb, Ethazol, Hexachlorophene, Mancozeb, Methylmetiram, PCNB, Pyracarbolid
Rhizopus spp. diseases	Botec, Dicloran, Thiram
Rot (*Alternia*)	Copper Fungicide (Organic) (Copper quinolate)
Rot (apple black)	Bordeaux Mixture
Rot (basal)	Thiabendazole
Rot (bitter)	Captan, Copper Fungicide (Inorganic) (Basic copper sulfate), Mancozeb
Rot (black)	Benomyl, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper carbonate; Cuprous oxide), Dithianon, Mancozeb, Metiram
Rot (blossom)	Pentaphenate
Rot (boll)	Hexachlorophene
Rot (bottom)	PCNB
Rot (brown)	Bordeaux Mixture, Captafol, Captan, Chlorothalonil, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper ammonium carbonate; Copper oxychloride sulfate; Cupric zinc sulfate; Cuprous oxide), Dichlone, , Ferbam, Mancozeb, Maneb, Sulfur-Based Pesticide (Calcium polysulfide; Sulfur), Tin-Based

TABLE 1. TARGET DISEASES OF BACTERICIDES AND FUNGICIDES (cont.)

Name or Class of Disease	Titles of Separate Alphabetical Entries in this Volume
Rot (brown) (cont.)	**Fungicide (Triphenyltin hydroxide), Triforine, Ziram (for peach)**
Rot (celery pink)	**Captan**
Rot (cranberry)	**Ferbam, Folpet, Maneb**
Rot (crown)	**Benomyl**
Rot (*Diplodia* stem end)	**Fruit Packaging Fungicide (Biphenyl; Frucote dip), Methylmetiram, Thiabendazole**
Rot (foot)	**Antibiotic Bactericide and Fungicide (Validamycin)**
Rot (grape black)	**Folpet, Maneb**
Rot (*Minilinia*)	**Dicloran**
Rot (neck)	**Antibiotic Bactericide and Fungicide (Kasumin)**
Rot (root)	**Ethazol, Pyracarbolid**
Rot (*Sclerotinia*)	**Antibiotic Bactericide and Fungicide (Polyoxin), Dicloran**
Rot (soft)	**Antibiotic Bactericide and Fungicide (Streptomycin)**
Rot (stem)	**Edifenphos, Ethazol, Kitazin**
Rot (storage)	**Carbendazim, Dichlone, Dodine, Folpet, Fruit Packaging Fungicide (Biphenyl; Dowcide A fruit dip; Dowcide 1, Frucote dip), Maneb, Pyridinitril, Thiabendazole**
Rust	**Anilazine, Carbendazim, Dithianon, Folpet, Mancozeb, Maneb, Methylmetiram, Metiram, Ziram**
Rust (apple)	**Metiram, Triforine**
Rust (cereal)	**Pyracarbolid**
Rust (coffee)	**Drazoxolon, Dithianon**
Rust (pear)	**Triforine**
Rust (wheat)	**Zineb**
Scab	**Captafol, Carbendazim, Copper Fungicide (Inorganic) (Basic copper sulfate; Copper hydroxide; Copper oxychloride sulfate), Dichlone, Drazoxolon, Mancozeb, Tin-Based Fungicide Triphenyltin hydroxide)**
Scab (apple)	**Antibiotic Bactericide and Fungicide (Kasumin), Benomyl, Bordeaux Mixture, Captan, Carbendazim, Chlorothalonil, Copper Fungicide (Inorganic) (Copper carbonate; Cuprous oxide), Copper Fungicide (Organic) (Copper quinolate), Dichlofluanid, Dithianon, Dodine, Ferbam, Folpet, Metiram, Nirit, Pyridinitril, Sulfur-Based Pesticide (Calcium polysulfide; Sulfur), Thiram, Triforine, Zineb, Ziram**
Scab (citrus)	**Copper Fungicide (Inorganic) (Cuprous oxide)**
Scab (peach)	**Sulfur-Based Pesticide (Sulfur)**
Scab (pear)	**Dichlofluanid, Dithianon, Nirit, Triforine**
Scab (potato)	**PCNB**
Sclerotinia spp. diseases	**Benomyl, Carbendazim, Chloroneb, Dicloran, Methylmetiram, PCNB**
Seed diseases	**Copper Fungicide (Inorganic) (Basic copper carbonate; Basic copper sulfate; Cuprous oxide), Benquinox, Captan, Carboxin, Chloroneb, Dicloran, Drazoxolon, Ethirimol, Fenaminosulf, Guazatine, Hexachlorobenzene, Mancozeb, Maneb, PCNB, Pyracarbolid, Tachigaren, Thiophanate, Thiram, Tricyclazole, Zineb**
Segatoka disease	**Propineb, Tridemorph**
Septoria spp. Diseases	**Antibiotic Bactericide and Fungicide (Kasumin), Copper Fungicide (Inorganic) (Copper hydroxide; Copper oxychloride sulfate), Propineb, Tin-Based Fungicide (Triphenyltin acetate [for celery])**
Shot-hole	**Captafol, Captan, Carbendazim, Copper Fungicide (Inorganic) (Copper oxychloride sulfate; Cupric zinc sulfate); Dithianon, Ferbam, Maneb, Pentaphenate, Zineb, Ziram**
Smut	**Benomyl, Carboxin, Copper Fungicide (Inorganic) (Copper Carbonate; Cuprous oxide), Hexachlorobenzene, Methylmetiram, Thiophanate Methyl**
Sore-shin	**Antibiotic Bactericide and Fungicide (Validamycin), Carbendazim, Carboxin, Chloroneb, Hexachlorophene**
Stromatinia spp. diseases	**Dicloran**
Tumor (bacterial galls/knots)	**Bacticin**
Witches broom	**Antibiotic Bactericide and Fungicide (Cycloheximide)**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES

Chemical or Tradename of Compound	See Entry on
Aateck	**TEC Fungicide**
Aaterra	**Ethazol Fungicide**
Acquimite	**Pesticide**
Acti-Dione	**Antibiotic Bactericide and Fungicide**
Actispray	**Antibiotic Bactericide and Fungicide**
Afugan	**Pyrazophos Fungicide**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

Chemical or Tradename of Compound	See Entry on
Agrimycin 17	**Antibiotic Bactericide and Fungicide**
Agri-Strep	**Antibiotic Bactericide and Fungicide**
Agrosol S	**Maneb Fungicide**
Agrox 2-way; Agrox 3-way	**Captan Fungicide**
Allisan	**Dicloran Fungicide**
Anilazine	**Anilazine Fungicide**
Antibiotic compounds	**Antibiotic Bactericide and Fungicide**
Anti-Carie	**Hexachlorobenzene Fungicide**
Antracol	**Propineb Fungicide**
APL-Lustr-T	**Thiabendazole Fungicide**
Aquinite	**Pesticide**
Arasan	**Thiram Fungicide**
Asozin	**Arsenic-Base Fungicide**
Avicol	**PCNB Fungicide**
Bacticin bactericide	**Bacticin Bactericide**
BAS 3460	**Carbendazim Fungicide**
Basfungin	**Methylmetiram Fungicide**
Basicop	**Copper Fungicide (Inorganic)**
Basic copper carbonate	**Copper Fungicide (Inorganic)**
Basic copper sulfate	**Copper Fungicide (Inorganic)**
Bavistan	**Carbendazim Fungicide**
Bay 47531	**Dichlofluanid Fungicide**
Bay 78418	**Edifenphos Fungicide**
Bay 79770	**Chloraniformethan Fungicide**
BCM	**Carbendazim Fungicide**
Benlate	**Benomyl Fungicide**
Benomyl	**Benomyl Fungicide**
Benquinox	**Benquinox Fungicide**
BFV	**Pesticide**
Big Dipper	**Apple**
Binapacryl	**Dinocap Acaricide-Fungicide**
Bioquin	**Copper Fungicide (Organic)**
Biphenyl	**Fruit Packaging Fungicide**
BLAS-S	**Antibiotic Bactericide and Fungicide**
Blasticidin	**Antibiotic Bactericide and Fungicide**
Blitox	**Copper Fungicide (Inorganic)**
Bordeaux mixture	**Bordeaux Mixture Fungicide**
Bordo mixture	**Bordeaux Mixture Fungicide**
Botec	**Botec Fungicide**
Bortran	**Dicloran Fungicide**
Botrilex	**PCNB Fungicide**
Brassicol	**PCNB Fungicide**
Bravo W-75	**Chlorothalonil Fungicide**
Brestan	**Tin-Based Fungicide**
Brimstone	**Sulfur-Based Pesticide**
Brown copper oxide	**Copper Fungicide (Inorganic)**
BSZ	**Copper Fungicide (Inorganic)**
Bunt-No-More	**Hexachlorobenzene Fungicide**
Butafume	**Fruit Packaging Fungicide**
Butinox	**Tin-Based Fungicide**
Calcium polysulfide	**Sulfur-Based Pesticide**
Calixin	**Tridemorph Fungicide**
Caprane	**Dinocap Acaricide-Fungicide**
Capryl	**Dinocap Acaricide-Fungicide**
Captafol	**Captafol Fungicide**
Captan	**Captan Fungicide**
Captane	**Captan Fungicide**
Capthion	**Captan Fungicide**
Carbamate	**Ferbam Insecticide**
Carbendazim	**Carbendazim Fungicide**
Carboxin	**Carboxin Fungicide**
Carpene	**Dodine Fungicide**
CECA	**Udonkor Fungicide**
CELA W 524	**Triforine Fungicide**
Celdion	**Fentiazon Fungicide**
Cellu-Quin	**Copper Fungicide (Organic)**
Cercobin	**Thiophanate Fungicide**
Cercobin Methyl	**Thiophanate Methyl Fungicide**
Ceredon	**Benquinox Fungicide**
Cereline	**Benquinox Fungicide**
Ceresan	**Mercury-Base Fungicide**
Chemform	**Antibiotic Bactericide and Fungicide**
Chico-Spot Kleen	**Thiophanate Fungicide**
Chloraniformethan	**Chloraniformethan Fungicide**
Chloranil	**Cucumber**
Chloroneb	**Chloroneb Fungicide**
Chlor-O-Pic	**Pesticide**
Chloropicrin	**Pesticide**
Chlorothalonil	**Chlorothalonil Fungicide**
Chlorquinox	**Chlorquinox Fungicide**
Ciluan	**Pyridinitril Fungicide**
CITCOP-4E	**Copper Fungicide (Organic)**
CNA	**Dicloran Fungicide**
COBH	**Benquinox Fungicide**
Cobox	**Copper Fungicide (Inorganic)**
Cobredon	**Copper Fungicide (Inorganic)**
COCS	**Copper Fungicide (Inorganic)**
Colloidox	**Copper Fungicide (Inorganic)**
Consul	**Sulfur-Based Pesticide**
Copoloid	**Copper Fungicide (Organic)**
Copox	**Copper Fungicide (Inorganic)**
Cop-O-Zinc	**Copper Fungicide (Inorganic)**
Copper ammonium carbonate	**Copper Fungicide (Inorganic)**
Copper carbonate	**Copper Fungicide (Inorganic)**
Copper-Count N	**Copper Fungicide (Inorganic)**
Copper-Cure	**Copper Fungicide (Organic)**
Copper hydroxide	**Copper Fungicide (Inorganic)**
Copper hydroxysulfate	**Copper Fungicide (Inorganic)**
Copper 5	**Copper Fungicide (Inorganic)**
Copper linoleate	**Copper Fungicide (Organic)**
Copper naphthenate	**Copper Fungicide (Organic)**
Coppernate	**Copper Fungicide (Organic)**
Copper oxychloride	**Copper Fungicide (Inorganic)**
Copper oxychloride sulfate	**Copper Fungicide (Inorganic)**
Copper quinolate	**Copper Fungicide (Organic)**
Coppersan	**Copper Fungicide (Inorganic)**
Copper-Sandez	**Copper Fungicide (Inorganic)**
Copper sulfate	**Copper Fungicide (Inorganic)**
Copper Uversol	**Copper Fungicide (Organic)**
Copper zinc sulfate	**Copper Fungicide (Inorganic)**
Coprantol	**Copper Fungicide (Inorganic)**
Cop-R-Nap	**Copper Fungicide (Organic)**
Copro 53	**Copper Fungicide (Inorganic)**
Corozate	**Ziram Fungicide**
Cosan	**Sulfur-Based Pesticide**
Cosanil	**Zineb Fungicide**
Crotothane	**Dinocap Acaricide-Fungicide**
Cuman	**Ziram Fungicide**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

Chemical or Tradename of Compound	See Entry on
Cunilate	**Copper Fungicide (Organic)**
Cupravit	**Copper Fungicide (Inorganic)**
Cupric sulfate monohydrate	**Copper Fungicide (Inorganic)**
Cuprinol	**Copper Fungicide (Organic)**
Cuprocide	**Copper Fungicide (Inorganic)**
Cuprokylt	**Copper Fungicide (Inorganic)**
Cuprol	**Copper Fungicide (Inorganic)**
Cuprosan	**Copper Fungicide (Inorganic)**
Cuprous oxide	**Copper Fungicide (Inorganic)**
Cuproxol	**Copper Fungicide (Inorganic)**
Curitan	**Dodine Fungicide**
Curamil	**Pyrazophos Fungicide**
Curling Factor	**Antibiotic Bactericide and Fungicide**
Cycloheximide	**Antibiotic Bactericide and Fungicide**
Cyprex	**Dodine Fungicide**
Daconil	**Chlorothalonil Fungicide**
DAPA	**Fenaminosulf Fungicide**
DCMO	**Carboxin Fungicide**
DCNA	**Dicloran Fungicide**
DDPP	**Pyridinitril Fungicide**
Deccotane	**Fruit Packaging Fungicide**
Delan	**Dithianon Fungicide**
Demosan	**Chloroneb Fungicide**
Derosal	**Carbendazim Fungicide**
Dexon	**Fenaminosulf Fungicide**
Dichlofluanid	**Dichlofluanid Fungicide**
Dichlone	**Dichlone Fungicide**
Dicloran	**Dicloran Fungicide**
Difolatan	**Captafol Fungicide**
Difosan	**Captafol Fungicide**
Dikar	**Mancozeb Fungicide**
Dinocap	**Dinocap Acaricide-Fungicide**
Diphenylamine	**Apple**
Ditalimfos	**Ditalimfos Fungicide**
Dithane M-22	**Maneb Fungicide**
Dithane M-45	**Mancozeb Fungicide**
Dithane S	**Maneb Fungicide**
Dithane Z-78	**Zineb Fungicide**
Dithianon	**Dithianon Fungicide**
Ditranil	**Dicloran Fungicide**
Direz	**Anilazine Fungicide**
DNOC	**Apple**
DNOCP	**Dinocap Acaricide-Fungicide**
Dodine	**Dodine Fungicide**
Dolochlor	**Pesticide**
Doquadine	**Dodine Fungicide**
Dowcide A fruit dip	**Fruit Packaging Fungicide**
Dowcide 1	**Fruit Packaging Fungicide**
Dowco 199	**Ditalimfos Fungicide**
Drazoxolon	**Drazoxolon Fungicide**
DRB	**Nirit Fungicide**
Du-ter	**Tin-Based Fungicide**
Dynacide	**Mercury-Base Fungicide**
Dyrene	**Anilazine Fungicide**
Eau-Grison	**Sulfur-Based Pesticide**
EDDP	**Edifenphos Fungicide**
Edifenphos	**Edifenphos Fungicide**
EL 291	**Tricyclazole Fungicide**
Elgetol	**Apple**
Elvaron	**Dichlofluanid Fungicide**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

Chemical or Tradename of Compound	See Entry on
Enovit	**Thiophanate Fungicide**
Enovit-Super	**Thiophanate Methyl Fungicide**
ETCMTB	**Ethazol Fungicide**
Ethazol	**Ethazol Fungicide**
Ethirimol	**Ethirimol Fungicide**
Ethoxyquin	**Apple**
Etridiazol	**Ethazol Fungicide**
Euparen	**Dichlofluanid Fungicide**
Euparen-M	**Tolyfluanid Fungicide**
Euparene	**Dichlofluanid Fungicide**
Exotherm	**Chlorothalonil Fungicide**
Fenaminosulf	**Fenaminosulf Fungicide**
Fenolovo	**Tin-Based Fungicide**
Fentiazon	**Fentiazon Fungicide**
Fentin acetate	**Tin-Based Fungicide**
Fentin hydroxide	**Tin-Based Fungicide**
Ferban	**Ferbam Insecticide**
Ferbane	**Ferbam Insecticide**
Ferbeck	**Ferbam Insecticide**
Fermate	**Ferbam Insecticide**
Fermide	**Thiram Fungicide**
Fermucide	**Ferbam Insecticide**
Fernacol	**Thiram Fungicide**
Fernasan	**Thiram Fungicide**
Ferradow	**Ferbam Insecticide**
Ferric methanearsonate	**Arsenic-Base Fungicide**
Folpan	**Folpet Fungicide**
Folpet	**Folpet Fungicide**
Folosan	**PCNB Fungicide**
Fore	**Mancozeb Fungicide**
Formaldehyde	**Pesticide**
Formalin	**Pesticide**
Frucote	**Fruit Packaging Fungicide**
Fruit waxes and wrappers	**Fruit Packaging Fungicide**
Fuklasin	**Ziram Fungicide**
Fulcin	**Antibiotic Bactericide and Fungicide**
Fulvicin	**Antibiotic Bactericide and Fungicide**
Fungiclor	**PCNB Fungicide**
Funginex	**Triforine Fungicide**
Fungo	**Thiophanate Methyl Fungicide**
Fusarex	**PCNB Fungicide**
Ganocide	**Drazoxolon Fungicide**
Gerox	**Antibiotic Bactericide and Fungicide**
Gin-S	**Arsenic-Base Fungicide**
Glyodin	**Captan Fungicide**
Granol	**Maneb Fungicide**
Granox	**Maneb Fungicide**
Gresfeed	**Antibiotic Bactericide and Fungicide**
Grex	**Benomyl Fungicide**
Griesofulvin	**Antibiotic Bactericide and Fungicide**
Grifulvin	**Antibiotic Bactericide and Fungicide**
Grisetin	**Antibiotic Bactericide and Fungicide**
Guanoctine	**Guazatine Fungicide**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

Chemical or Tradename of Compound	See Entry on
Guazatine	**Guazatine Fungicide**
HCB	**Hexachlorobenzene Fungicide**
Hexa C-B	**Hexachlorobenzene Fungicide**
Hexachlorobenzene	**Hexachlorobenzene Fungicide**
Hexachlorophene	**Hexachlorophene Bactericide and Fungicide**
Hexaferb	**Ferbam Insecticide**
Hexasul	**Sulfur-Based Pesticide**
Hexathane	**Zineb Fungicide**
Hexathir	**Thiram Fungicide**
Hexazir	**Ziram Fungicide**
Hinosan	**Edifenphos Fungicide**
Hizarocin	**Antibiotic Bactericide and Fungicide**
HOE 2875	**Pyrazophos Fungicide**
HOE 13764	**Pyracarbolid Fungicide**
Hokko-Mycin	**Antibiotic Bactericide and Fungicide**
Hokmate	**Ferbam Insecticide**
Hydroxyisoxazole	**Tachigaren Fungicide**
Hymexazol	**Tachigaren Fungicide**
IBP	**Kitazin Fungicide**
Imugan	**Chloraniformethan Fungicide**
Iscothan	**Dinocap Acaricide-Fungicide**
Isobac	**Hexachlorophene Bactericide and Fungicide**
Kaken	**Antibiotic Bactericide and Fungicide**
Karathane	**Dinocap Acaricide-Fungicide**
Karbam Black	**Ferbam Insecticide**
Karbam White	**Ziram Fungicide**
Karsan	**Pesticide**
Kasugamycin	**Antibiotic Bactericide and Fungicide**
Kasumin	**Antibiotic Bactericide and Fungicide**
Kauritil	**Copper Fungicide (Inorganic)**
Kemate	**Anilazine Fungicide**
Kitazin	**Kitazin Fungicide**
Koban	**Ethazol Fungicide**
Kobutol	**PCNB Fungicide**
Kocide	**Copper Fungicide (Inorganic)**
Kop Karb	**Copper Fungicide (Inorganic)**
KSM	**Antibiotic Bactericide and Fungicide**
Kumulus	**Sulfur-Based Pesticide**
Kypzin	**Zineb Fungicide**
Larvacide	**Pesticide**
Lemonene	**Fruit Packaging Fungicide**
Leytosan	**Mercury-Base Fungicide**
Lime-sulfur formulations	**Sulfur-Based Pesticide**
Liquiphene	**Mercury-Base Fungicide**
Lonacol	**Zineb Fungicide**
Lonacol M	**Maneb Fungicide**
Lucel	**Chlorquinox Fungicide**
Lutrol	**Edifenphos Fungicide**
Malachite	**Copper Fungicide (Inorganic)**
Mancofol	**Mancozeb Fungicide**
Mancozeb	**Mancozeb Fungicide**
Maneb	**Maneb Fungicide**
Maneba	**Maneb Fungicide**
Manebgan	**Maneb Fungicide**
Manoc	**Maneb Fungicide**
Manzate	**Maneb Fungicide**
Manzate 200	**Mancozeb Fungicide**
MAS	**Arsenic-Base Fungicide**
MC 25	**Guazatine Fungicide**
MEB	**Maneb Fungicide**
Mebenil	**Methylmetiram Fungicide**
Melprex	**Dodine Fungicide**
Merpan	**Captan Fungicide**
Mertect	**Thiabendazole Fungicide**
Methanal	**Pesticide**
Methylarsenic sulfide	**Arsenic-Base Fungicide**
Methylene chloride	**Fruit Packaging Fungicide**
Methylmetiram	**Methylmetiram Fungicide**
Metiram	**Metiram Fungicide**
Mezene	**Ziram Fungicide**
Microcop	**Copper Fungicide (Inorganic)**
Microflotox	**Sulfur-Based Pesticide**
Mildothane	**Thiophanate Methyl Fungicide**
Milgo	**Ethirimol Fungicide**
Mil-Col	**Drazoxolon Fungicide**
Mildex	**Dinocap Acaricide-Fungicide**
Milfaron	**Chloraniformethan Fungicide**
Milmer	**Copper Fungicide (Organic)**
Milstem	**Ethirimol Fungicide**
Monzet	**Urbacide Fungicide**
Morocide	**Dinocap Acaricide-Fungicide**
Murfulvin	**Antibiotic Bactericide and Fungicide**
Mycozol	**Thiabendazole Fungicide**
Nabac	**Hexachlorophene Bactericide and Fungicide**
Nabam	**Nabam Fungicide**
Naptox	**Copper Fungicide (Organic)**
Naramycin	**Antibiotic Bactericide and Fungicide**
Neo-Asozin	**Arsenic-Base Fungicide**
Neo So Sin	**Arsenic-Base Fungicide**
Neutrocop	**Copper Fungicide (Inorganic)**
Niacide	**Ferbam Insecticide**
Niklor	**Pesticide**
Nitrochloroform	**Pesticide**
Nirit	**Nirit Fungicide**
Nix-Scalde	**Apple**
No-Bunt 40	**Hexachlorobenzene Fungicide**
Nomersan	**Thiram Fungicide**
No-Scald	**Apple**
Nu-Cop	**Copper Fungicide (Inorganic)**
Oleocuivre	**Copper Fungicide (Inorganic)**
Orthocide	**Captan Fungicide**
Ortho seed protection	**Captan Fungicide**
Orthorix	**Sulfur-Based Pesticide**
Orthoxenol	**Fruit Packaging Fungicide**
Ortho Zineb 65	**Zineb Fungicide**
Oxime copper	**Copper Fungicide (Organic)**
Oxy Cop	**Copper Fungicide (Inorganic)**
Pamosol Z	**Zineb Fungicide**
Panoctine	**Guazatine Fungicide**
Parzate	**Zineb Fungicide**
PCNB	**PCNB Fungicide**
Pelt 44	**Thiophanate Methyl Fungicide**
Pelt-Sol	**Thiophanate Fungicide**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

Chemical or Tradename of Compound	See Entry on
Pentaphenate	**Pentaphenate Fungicide**
Perchlorobenzene	**Hexachlorobenzene Fungicide**
Perenox	**Copper Fungicide (Inorganic)**
PETD	**Metiram Fungicide**
Phaltan	**Folpet Fungicide**
Phenador-X	**Fruit Packaging Fungicide**
Phenazin	**Phenazin Fungicide**
Phix	**Mercury-Base Fungicide**
Phygon	**Dichlone Fungicide**
Phytomycin	**Antibiotic Bactericide and Fungicide**
Picfume	**Pesticide**
Piomy	**Antibiotic Bactericide and Fungicide**
Plondrel	**Ditalimfos Fungicide**
PMA	**Mercury-Base Fungicide**
Polyoxin	**Antibiotic Bactericide and Fungicide**
Polyram	**Metiram Fungicide**
Polyram-M	**Maneb Fungicide**
Polyram-Ultra	**Thiram Fungicide**
Polyram-Z	**Zineb Fungicide**
Pomarsol-Forte	**Thiram Fungicide**
Pomasol	**Thiram Fungicide**
Propineb	**Propineb Fungicide**
Propinebe	**Propineb Fungicide**
Puraturf	**Mercury-Base Fungicide**
Pyracarbolid	**Pyracarbolid Fungicide**
Pyrazophos	**Pyrazophos Fungicide**
Pyridinitril	**Pyridinitril Fungicide**
Quicksan 20	**Mercury-Base Fungicide**
Quinondo	**Copper Fungicide (Organic)**
Quintozene	**PCNB Fungicide**
Rabcide	**Rabcide Fungicide**
Remasan	**Maneb Fungicide**
Resisan	**Dicloran Fungicide**
Rhizoctol	**Arsenic-Base Fungicide**
Rimocidin	**Antibiotic Bactericide and Fungicide**
Rot-Not	**Copper Fungicide (Organic)**
Sanocide	**Hexachlorobenzene Fungicide**
Sanspor	**Captafol Fungicide**
Santoquin	**Apple**
Sicarol	**Pyracarbolid Fungicide**
Smut-Go	**Hexachlorobenzene Fungicide**
Sodium polysulfide	**Sulfur-Based Pesticide**
Sodium thiosulfate	**Sulfur-Based Pesticide**
Sofril	**Sulfur-Based Pesticide**
SOPP	**Fruit Packaging Fungicide**
Sopracol	**Drazoxolon Fungicide**
Sparol	**Triforine Fungicide**
Spergon	**Cucumber**
Sperlox S	**Sulfur-Based Pesticide**
Sperlox Z	**Zineb Fungicide**
Spersul	**Sulfur-Based Pesticide**
Spotrete	**Thiram Fungicide**
Spray-Cop	**Copper Fungicide (Inorganic)**
Stop-Scald	**Apple**
Streycin sulfate	**Antibiotic Bactericide and Fungicide**
Strepcen	**Antibiotic Bactericide and Fungicide**
Streptomycin	**Antibiotic Bactericide and Fungicide**
Sulfonimide	**Captafol Fungicide**
Sulfur	**Sulfur-Based Pesticide**
Sulfuron	**Sulfur-Based Pesticide**
Sulkol	**Sulfur-Based Pesticide**
Tachigaren	**Tachigaren Fungicide**
Taytox	**Copper Fungicide (Inorganic)**
TBCS 53	**Copper Fungicide (Inorganic)**
TBTO	**Tin-Based Fungicide**
TBZ	**Thiabendazole Fungicide**
Tear gas	**Pesticide**
TEC	**TEC Fungicide**
Techazene	**PCNB Fungicide**
Tecoram	**TEC Fungicide**
Tecto	**Thiabendazole Fungicide**
Telone C	**Telone C Fungicide-Nematicide**
Termil	**Chlorothalonil Fungicide**
Terraclor	**PCNB Fungicide**
Terrazole	**Ethazol Fungicide**
Tersan 75	**Thiram Fungicide**
Tersan 1991	**Benomyl Fungicide**
Tersan LSR	**Maneb Fungicide**
Tersan SP	**Chloroneb Fungicide**
Tetrachloro-*p*-benzoquinone	**Cucumber**
Thiabendazole	**Thiabendazole Fungicide**
Thibenzole	**Thiabendazole Fungicide**
Thiolux	**Sulfur-Based Pesticide**
Thiophal	**Folpet Fungicide**
Thiophanate	**Thiophanate Fungicide**
Thiophanate Methyl	**Thiophanate Methyl Fungicide**
Thiotex	**Thiram Fungicide**
Thiram	**Thiram Fungicide**
Thiramad	**Thiram Fungicide**
Thirasan	**Thiram Fungicide**
Tiezene	**Zineb Fungicide**
Tilcarex	**PCNB Fungicide**
Tillantox	**Benquinox Fungicide**
Tin-based formulations	**Tin-Based Fungicide**
Tinestan	**Tin-Based Fungicide**
Tirampa	**Thiram Fungicide**
TMTD	**Thiram Fungicide**
TMTDS	**Thiram Fungicide**
Tolylfluanid	**Tolylfluanid Fungicide**
Topane	**Fruit Packaging Fungicide**
Topsin	**Thiophanate Fungicide**
Topsin M	**Thiophanate Methyl Fungicide**
Torsite	**Fruit Packaging Fungicide**
TPTA	**Tin-Based Fungicide**
TPTH	**Tin-Based Fungicide**
TPTOH	**Tin-Based Fungicide**
Trametan	**Thiram Fungicide**
Trevin	**Thiophanate Methyl Fungicide**
Triasyn	**Anilazine Fungicide**
Tri-Basic	**Copper Fungicide (Inorganic)**
Tricarbamix	**Zineb Fungicide**
Tricarbamix Fe	**Ferbam Insecticide**
Trichloronitromethane	**Pesticide**
Tri-Clor	**Pesticide**
Tricuzin	**Zineb Fungicide**

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

Chemical or Tradename of Compound	See Entry on
Tricyclazole	**Tricyclazole Fungicide**
Tridemorph	**Tridemorph Fungicide**
Triforine	**Triforine Fungicide**
Trifungol	**Ferban Fungicide**
Trimangol	**Maneb Fungicide**
Trimanoc	**Maneb Fungicide**
Trimastan	**Maneb Fungicide**
Trimazone	**Maneb Fungicide**
Tri-PCNB	**PCNB Fungicide**
Tropomol	**Thiram Fungicide**
Triphenyltin acetate	**Tin-Based Fungicide**
Triphenyltin hydroxide	**Tin-Based Fungicide**
Trinquintam	**Thiram Fungicide**
Tri-Rodazene	**Nirit Fungicide**
Triscabol	**Ziram Fungicide**
Tritisan	**PCNB Fungicide**
Tritofterol	**Zineb Fungicide**
Tserenox	**Benquinox Fungicide**
Tsitrex	**Dodine Fungicide**
Tuads	**Thiram Fungicide**
Tubothane	**Maneb Fungicide**
Tubotin	**Tin-Based Fungicide**
Tuscopper	**Copper Fungicide (Organic)**
Tutane	**Fruit Packaging Fungicide**
Tuzet	**Urbacide Fungicide**
Udonkor	**Udonkor Fungicide**
Ultra-Sofril	**Benomyl Fungicide**
Universal	**Mercury-Base Fungicide**
Urbacide	**Urbacide Fungicide**
Urbasulf	**Arsenic-Base Fungicide**
Validamycin	**Antibiotic Bactericide and Fungicide**
Vancide FE95	**Ferbam Insecticide**
Vancide MZ96	**Ziram Fungicide**
Vancide TM95	**Thiram Fungicide**
Vancide-Zineb 85	**Zineb Fungicide**
Viricuivre	**Copper Fungicide (Inorganic)**
Vitavax	**Carboxin Fungicide**
Vitigan Blue	**Copper Fungicide (Inorganic)**
Vomiting gas	**Pesticide**
Vondcaptan	**Captan Fungicide**
Vonodine	**Dodine Fungicide**
Wittox-C	**Copper Fungicide (Organic)**
WP Methyl	**Thiophanate Methyl Fungicide**
Z-C	**Ziram Fungicide**
Zebtox	**Zineb Fungicide**
Zerlate	**Ziram Fungicide**
Zidan	**Zineb Fungicide**
Zimate	**Zineb Fungicide**
Zinc Coposil	**Copper Fungicide (Inorganic)**
Zinc petroleum sulfonate	**Fruit Packaging Fungicide**
Zinc Copro	**Copper Fungicide (Inorganic)**
Zinc Metiram	**Metiram Fungicide**
Zineb	**Zineb Fungicide**
Zinkcarbamate	**Ziram Fungicide**
Zinosan	**Zineb Fungicide**
Ziram	**Ziram Fungicide**
Zirberk	**Ziram Fungicide**
Ziride	**Ziram Fungicide**

Some compounds which predominantly perform as bactericides and fungicides and thus listed here also serve as acaricides, insecticides, herbicides, and general pesticides. Other compounds which may be primarily identified as acaricides, insecticides, *et al.* also may serve as bactericides and fungicides. Thus, for the compound being sought, it is suggested that reference also be made to similar listings in the entries on **Herbicide**; and **Insecticide.**

Although over 500 names of bactericides and fungicides are listed here, the compilation is not complete. An attempt has been made to provide a representative cross-section of the principal chemical types of compounds used and the most commonly used products of manufacturers in Canada, France, Germany, Japan, the Netherlands, Switzerland, the United Kingdom, and the United States. As pointed out in the descriptions of many of these compounds, not all are available or registered for use in all countries.

TABLE 2. ALPHABETICAL CROSS REFERENCE INDEX OF BACTERICIDES AND FUNGICIDES (cont.)

FUNGUS. Any of a group of thallophytic plants mainly characterized by an absence of chlorophyll. As a point of reference, algae and lichens are of the same phylum (*Thallophyta*). Examples of fungus include the familiar mushrooms, toadstools, smuts, rusts, molds, and mildews. There are well over 70,000 species of fungus, with widely diverse habits and characteristics. Many species cause serious diseases of crop plants. Generalizations are difficult. Among the fungi are numerous microscopic unicellular forms, as well as plants of elaborate structure and considerable size. Fungi grow in almost every habitat where organic substances exist and external conditions are suitable. Numerous species are found in water, either fresh or saline. Others are adapted to life on land, or in the ground. During the short summers of the Arctic regions, certain species appear. Fungi are particularly abundant in the tropics because warm, humid climates tend to favor the existence of many species.

Over 40 species of fungi produce diseases in humans and other mammals. There are those fungi which attack only the hair, skin, and nails; and there are those species that invade deeper tissues of major internal organs to produce serious systemic diseases. Many more species produce a variety of diseases among plants, the various species tending to specialize in attacking certain kinds of plants and certain parts of plants. Crop damage from fungus infections runs into the many millions of dollars annually, which damage, of course, would be many times greater if effective controls were not applied.

Nature of Fungi. Except for the absence of chlorophyll, the structure of fungi resembles that of the algae, the other main division of the thallophytes. The vegetative body of a fungus, except for the unicellular forms, is always composed of slender branching threads, or hyphae, making up what is known as the *mycelium.* Mycelia in many cases are colorless, but may contain pigments of every color. Each hypha is ordinarily composed of a row of cells, each containing one (or more) minute nuclei. In many species, cross-walls are rarely formed, the hypha being coenocytic. Even the largest, most complex fungi are composed entirely of tangled masses of hyphae, which may be loosely aggregated or so densely packed as to form a hard body suggestive of woody structure, as for example, in the bracket fungi.

In their reproductive processes, fungi are quite similar to algae. Both are asexual and sexual reproduction occur in the life histories of these plants, which also often show very distinctly an alternation of vegetative growth and reproductive activity. As may be expected in so diversified a group of plants, a considerable variety of reproductive processes occurs.

Among the lower forms, many of which occur in water, asexual reproduction is accomplished by means of zoöspores. The zoöspores are formed in sporangia from which they escape at maturity. After a period of motility, each zoöspore settles down, loses its cilia and at once gives rise to a new plant. In the nonaquatic fungi, asexual reproduction ordinarily occurs by means of nonmotile spores, called conidia, which have a rigid cell wall. These conidia, often produced in immense numbers, are carried about by air currents, sometimes to great distances, and upon reaching a favorable habitat, germinate to form a new plant. The methods of sexual reproduction found in fungi can best be considered under the different groups. Sexual reproduction usually occurs in a distinct body, the sporophore, which forms in many fungi a very conspicuous part of the life cycle of a fungus. This is frequently the only part recognized by the ordinary observer. In each kind of fungus, the sporophore assumes a very definite and distinct form. In the cup fungi, the sporophore is frequently a saucer- or cup-shaped structure. Other types are found in the familiar mushroom; in the puff-balls; and in the bird's nest fungus, the sporophore here having many small, somewhat spherical objects contained in an open cuplike body. In all of these, spores are formed, often in unbelievable numbers; a common puffball contains millions of them. The spores are borne about in the air currants, and germinate when brought to a favorable environment. It is obvious that many spores must fail to reach such a favorable spot, otherwise the world would be overrun with fungi.

Classes of Fungi. The true fungi are separated into three classes: (1) The *Phycomycetes,* in which the mycelium is on-septate and coenocytic; (2) the *Ascomycetes,* characterized by having spores borne in special sacs or asci; and (3) the *Basidiomycetes,* distinguished by the basidium, a spore-bearing cell which bears externally four spores, in some cases more or less. In addition to these three classes, there is another group known as the Imperfects, or *Fungi Imperfecti,* which contains those forms of plants in which the sexual or perfect stage is not known, and which, therefore, cannot be assigned to one of the three aforementioned classes.

Phycomycetes. This group of fungi is so diverse in habit as to suggest polyphyletic origin, quite probably from several different groups of green algae, to which many of them show remarkable similarity. Simpler members of the Phycomycetes consist of but a single cell, while other species have a well-developed branching mycelium, always composed of hyphae possessing no crosswalls. Many species grow in water and are known as water-molds. Others grow out of water and among them are some of the common destructive parasites.

Also known as the lower true fungi, there are some 1500 species of the Phycomycetes. Those species which are parasitic on crop plants are of interest here. See entry on **Fungus and Related Diseases (Crop).**

Ascomycetes. The majority of the some 40,000 species making up this group of fungi are small, often minute, while a relatively few species attain heights of 3 to 4 inches (7.5 to 10 centimeters), with a diameter of 1 to 2 inches (2.5 to 5 centimeters). Occasional individuals are even larger. All are characterized by the ascus, or spore-sac, commonly an elongate cylindrical body containing eight spores. In some species, the ascus is spherical, or short cylindrical, while the number of spores may vary from two to many. Usually the asci are grouped together in a dense layer, called the hymenium. This may be composed entirely of asci, or may contain in addition numerous slender sterile filaments, called paraphyses. In some cases at least it seems the function of the paraphyses to protect the asci, since the outer tip of each paraphysis is a flattened cap which partially covers the ascus. Ascomycetes are found wherever suitable food-yielding materials exist. Many species are parasites, living on living plants; among these are species of great economic importance. Other species are saprophytes, wood-destroying species being particularly numerous.

The life-history of an Ascomycete comprises the mycelium composed of slender branching septate hyphae which penetrate throughout the substratum, and the fruiting stage in which the asci are formed. Two types of reproduction occur. One of these is the asexual type, in which asexual cells called conidia are cut off in various ways from the tips of hyphae, known as conidiophores. These conidia are single-celled spores which are disseminated by air currents. The other method of reproduction is sexual, and leads to the formation of asci. In *Pyronema confluens* this process has been carefully studied, and may be considered as typical in the main details for the process as it occurs in all the fungi of this class. The first step in this process is the formation of a multinucleate much-branched structure, which presently becomes septate. Some of the tips of this structure enlarge and become oögonia, called in this case ascogonia, while other tips become antheridia. From the oögonium a slender curved body called the trichogyne grows out. This is separated from the oögonium by a cross-wall. Since the oögonia and antheridia develop close together, the trichogyne comes in contact with the antheridium. All three bodies oögonium, antheridium and trichogyne, are multinucleate. When the trichogyne comes in contact with the antheridium the walls between them at once break down, as does the wall between the trichogyne and the oögonium. The nuclei of the antheridium pass into the trichogyne, through it and into the oögonium. After this a new wall forms separating the trichogyne from the oögonium. In the oögonium the nuclei from the antheridium pair up with the nuclei of the oögonium, the nuclei of the trichogyne disintegrating early in the period of nuclear migration. Following the pairing of the nuclei in the ascogoium, coarse hyphae grow out from the latter. Into these the paired nuclei migrate. These coarse hyphae are the ascogenous hyphae, from which the asci eventually develop. In many Ascomycetes this process is considerably shortened, the ascogenous hyphae arising directly from the mycelium, no sex cells being formed; while other species have sex cells but no fusion, the oögonium alone developing.

The life cycles of the various ascomycetes are remarkably uniform, suggesting that they are all derived from a common ancestor. Two different views are held by botanists as to what the ancestral form may have been. According to one group, they are derived from red algae; favoring this view is the very great similarity in the development of the ascogonium and that of the carpospore formation in the algae; another favorable point is the presence of the trichogyne and the behavior of the antheridial nuclei. On the other hand, the other group holds that the ancestors of the Ascomycetes are to be found in the Phycomycetes, basing this contention on the similarity of the Phycomycete sporangium and the ascus, the latter being merely a sporangium in which the number of spores has been greatly reduced, becoming stable at eight in most species.

Many members of the Ascomycetes are of major economic importance because of their destructive parasitic habits and damage to food crops. A few species are of value as food, or in the production of foodstuffs and other products. Among the largest of the Ascomycetes are species of truffles and morels, which are considered by mushroom fanciers to be particularly well flavored. Truffles are fruitbodies of the order Tuberales, and grow entirely underground. This makes it a matter of some difficulty to find them. Since they do not lend themselves to artificial cultivation, truffles are sought in their wild habitat. To aid in locating them, trained dogs or pigs are used to locate them because of the superior sense of smell of these animals.

Very important to food production are the yeasts, which are in the group of Ascomycetes.

Injurious Species of Ascomycetes include the Chestnut Blight fungus, *Endothia parasitica,* a disease probably introduced from China at the beginning of the twentieth century. In China the native chestnut trees had developed immunity; this the American trees did not have, so the fungus, which attacks the cambial tissue, was particularly destructive, nearly wiping out the native chestnut trees in a few years. Another disease caused by an Ascomycete is the Brown Rot of stone fruits, caused by *Sclerotinia cinerea.* This fungus is particularly destructive in wet seasons. Often infected fruits become shriveled up and dry, in which condition they are known as "mummies." A large group of Ascomycetes are known as Powdery Mildews, because of the abundant conidiophores which are formed by the mycelium on the surface of the leaves of infected plants. Often these are so abundant as seriously to impair the functional efficiency of the leaf.

Another group of Ascomycetes contains species which are destructive and also those which are commercially of great value; these are the ubiquitous blue and green molds, species of *Aspergillus* and *Penicillium*. The destructive species attack foodstuffs everywhere, causing rotting and spoilage. Citrus fruits become covered with the bluish-green conidial masses; as does moist bread, pie crusts and many other foodstuffs. Species of the genus *Penicillium* give to Camembert and Roquefort cheese their characteristic properties. Other species of this group are the casual organisms for skin diseases of animals, including man. Another species of this genus, *Penicillium notatum,* is the source of the important drug, penicillin.

Another important Ascomycete is the genus *Claviceps,* which is parasitic on many grasses, including several cereal grains. This fungus forms a hard black sclerotium which is known as ergot, and which completely replaces the grain in the infected flower. The sclerotia are poisonous to livestock, causing the animals which have eaten them to become emaciated and covered with sores; another result is abortion in females.

Crop plant diseases for which Ascomycetes species are the causal organisms are summarized in entry on **Fungus and Related Diseases (Crop).**

Basidiomycetes. Most of the fungi commonly observed are members of this group of fungi, which includes toadstools, mushrooms, puff-balls and many other forms. The characteristic feature which distinguishes them from other fungi is the basidium, typically a club-shaped structure bearing four spores at its apex. Members of this group are found almost everywhere plant life can exist. The majority of them are saprophytes, which live on dead wood and in soil rich in humus. A few are parasites and these can be very damaging to food crops. The life history of the common mushroom is fairly typical of this group. See Fig. 1.

There are several theories as to the origin of the basidiomycetes. Some maintain that they have evolved directly from certain primitive flagellates. Others derive them from the red algae. Many consider them to have descended from the ascomycetes. Adherents to this theory observe the dikaryon phase of the ascogenous hypha of the ascomycetes and note that if this phase were prolonged for some time it would be very similar to the secondary mycelium of the basidiomycete. They also note that the asexual reproduction by conidia occurs in the basidiomycetes very much as it does in the ascomycetes.

The vegetative phase consists of a mycelium. This is a mass of slender much-branched threads, called hyphae, which grow throughout the substratum. The mycelium is perennial. Each hypha is a long filament composed of many segments, each containing two nuclei. The hyphae absorb from the substrate the organic materials which the fungus needs in order to live, and convert it into other forms. Much of this food substance accumulates within the mycelium.

When sufficient material has been stored and conditions are suitable, the fungus fruits. The fruit body first appears as a small round object rising from the substratum. This elongates into a stalk bearing at its tip an umbrella-shaped cap or pileus.

On the lower surface of the pileus there are numerous

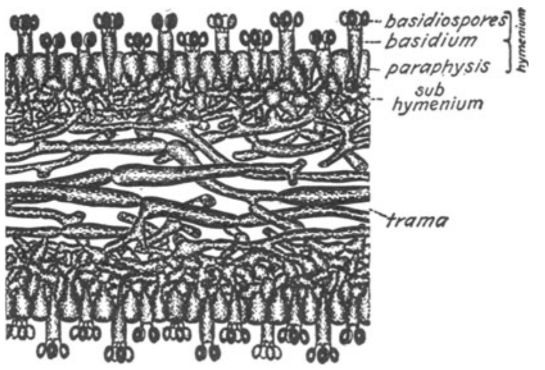


Fig. 1. A section through the fill of a mushroom, *Coprinus comatus.* The section is cut perpendicularly to the surface of the gill. (Buller's *Researches on Fungi*)

Fig. 2. Development of basidium and formation of spores in mushroom: (1) Separate mycelius with binucleate cells; (2) young basidum containing two unrelated nuclei; (3,4) fusion of nuclei in basidum; (5 6, 7) development of four-nucleate condition in basidium; (8) formation of basidiospores that receive the four nuclei. (*Redrawn from Harper*)

thin radiating plates called gills. The lateral surfaces of the gills are formed by hyphal tips which grow perpendicular to the surface and form a compact layer called the hymenium. The hyphal tips composing the hymemium are the basidia, the reproductive structures which distinguish this group of fungi from all others. See Fig. 2. Each basidium is a cylindrical, binucleate body cut off from the tip of a hypha. The two nuclei fuse and immediately divide, usually twice, so that the basidium contains four haploid nuclei. From the outer end of the basidium four slender pegs called sterigmata develop. A small spore forms at the tip of each sterigma. Into each spore one of the nuclei of the basidium migrates. The spore is discharged from the sterigma and falls down between the gills and into the air. It is carried about by air currents and eventually falls to the ground. There the spore germinates, giving rise to a slender branching mycelium composed of uninucleate segments. This is the primary mycelium. Branches of two primary mycelia unite to form a secondary mycelium. The two nuclei present in each segment of a secondary mycelium have come from different spores. The manner in which they continue their identity during division is interesting. The two nuclei divide simultaneously. When division is about to occur a small bulge forms on the side of the hypha. See Fig. 3. One of the two nuclei enters this bulge, the other remains in the hypha. After division a cross wall forms, separating the two nuclei in the hypha. The protuberance containing the other nucleus continues to grow and forms an elbow-shaped structure, which joins the two cells of the hypha. It is called a clamp connection. One of the nuclei formed in this clamp returns to the original cell, the other passes through the clamp and into the other cell. By this means the two cells each receive a nucleus derived from one of the original nuclei. Nuclear fusion occurs only in the basidium. So there is in the mushroom an alternation of generations differing from that in most plants. The haploid or gametophyte phase consists of the primary mycelia. Following this a prolonged binucleate or dikaryon phase exists. Only in the basidium does nuclear fusion occur and reduction immediately follows. So the diploid phase or sporophyte is represented only by the basidium. There are no sex organs in this group of plants. The differences between the edible mushroom and other basidiomycetes is mainly in the structure of the fruit body, the location of the hymenium and the nature of the basidia.

The nature of the hymenium is the basis for classifying basidiomycetes. The Hymenomycetes are those in which the hymenium is exposed; in the Gasteromycetes it is formed within the fruit body. The principal order of Hymenomycetes is the *Agaricales* or agarics, or the gill fungi. See Fig. 4. The agarics are described in more detail in entry on **Mushroom**.

Another well-known order of basidiomycetes is the *Polyporales;* of these the polypores or Polyporaceae are best known. The distinguishing feature of these are the pits or tubes on the lower surface of the fruit body. The hymenium lines these pits. The fruit bodies of the polypores usually do not have a stalk and pileus, but form a layer spreading over the surface of rotting wood or grow out from the wood like a shelf. This shelf-like habit has given to these plants the name bracket-fungi. The fruit bodies of bracket-fungi live for many years and often show distinct growth layers. In some species these are a foot or more across and several inches thick.

The other large group of basidiomycetes is the Gasteromycetes, distinguished by having the hymenium lining irregular cavities in the fruit body. Until these are fully mature, the spore-bearing parts are completely enclosed by sterile tissue. There are many different kinds of Gasteromycetes. One of the best known is the puff-balls or Lycoperdiales. The outer wall or peridium of the puffball surrounds the gleba or spore-bearing tissues. When the

Fig. 3. A mushroom. (*A. M. Winchester*)

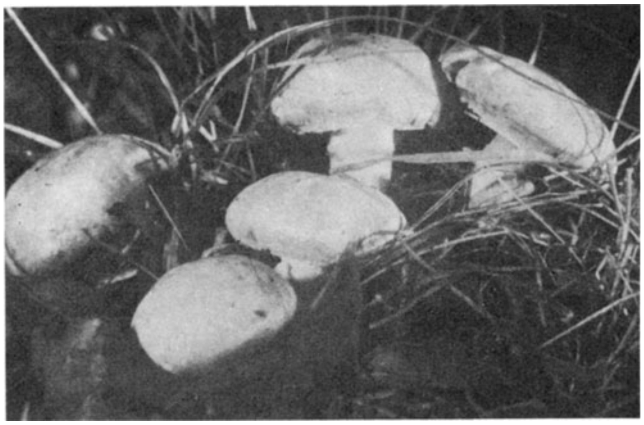


Fig. 4. *Agaricus*–field mushroom. (*Photographed by Brian J. Ford*)

spores are mature the peridium breaks. In some genera the wall breaks up into irregular fragments and leaves the spore-mass exposed; in others a pore is formed at the apex of the fruit body. The slightest pressure against the peridium will cause clouds of spores to puff from the pore. The number of spores formed in a single puff-ball is tremendous; 7,000,000 has been given as the number from a good-sized sporophore. Some of the puff-balls are the largest fungi known, reaching a diameter of a foot or more. If gathered before the spores are formed, most of the puff-balls are edible. None are poisonous.

Geasters or earth-stars develop very much as puff-balls do. But when they are mature the outer peridium splits into sectors which bend outward, revealing the spore-bearing part within. These fungi are frequently found growing on dry sandy soil.

Another group of Gasteromycetes includes the Bird's-nest fungi. The spore-bearing structures here are the "eggs," small oval bodies resting in the bottom of an open cup of sterile tissue. A last and curious group of Gasteromycetes is the stinkhorns, vile-smelling fungi whose spores are included in a mass of sticky stinking tissue, formed by the disintegrated glebal substance. This attracts carrion flies and other insects, which carry the spores about.

Other important families of basidiomycetes are the rusts and the smuts.

Rust Fungi. Uredinales. The rust fungi are parasitic basidiomycetes which owe their popular name to the reddish color of the spore masses in some of the commonest species. Because many of the thousand species found in North America attack important cultivated and wild plants, they are of great economic importance. The group possesses a remarkable variety of spore types. Many species have five kinds of spores. It is notable that any given species has a very limited range of host plants.

One of the best-known species of Rusts is the common Wheat Rust, *Puccinia graminis,* which has long been known. Five spore forms are included in its complex life-history.

On wheat plants, and on various grasses, there appear during the summer on the stem and leaves reddish spots which on examination are found to contain large numbers of one-celled spores which are called urediniospores. See Fig. 5. These are scattered by the wind and reinfect wheat plants continuously during the growing season. Near the end of the growing season, when the host plant is maturing, a new form of spore appears either with the urediniospores or in separate pustules. These spores are two-celled, of dark color, and have a very thick wall. They are called teliospores, or winter spores, and are able to survive the winter season independent of any host plant, for they can neither attack one nor parasitize it.

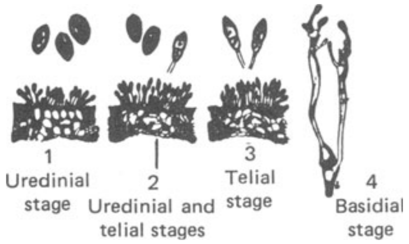


Fig. 5. *Puccinia graminis* in wheat leaves: (1) Uredinial stage; (2) uredinial stage changing to telial stage; (3) telial stage; (4) basidiospore germinating and forming basisia and basidospores. (*Tulasne*)

In the spring each cell of the teliospore puts out a short tube which becomes four-celled. From each of the four cells a small spore is formed: this is the basidiospore and the four-celled tube is therefore a basidium. The one-celled basidiospores are carried by air-currents to suitable host plants, which in this case are not wheat plants, but barberry plants. In contact with the young leaves of the latter plant the basidiospore develops a short tube which penetrates the leaf epidermis and forms a mycelium within the leaf. After a time this mycelium gives rise to a new type of spore which appears on the upper surface of the barberry leaf in small pustules called pycnia or spermagonia. See Fig. 6. These contain masses of small hyphae, from the tips of which are cut off minute one-celled bodies called pycniospores or spermatia, which seem incapable of reinfecting the host plant.

Soon after the formation of the pycnia there appear on the under side of the leaf clusters of orange-colored cups. These are the aecia or cluster cups, in which are formed chains of tightly packed aeciospores. These spores, when released, cannot reinfect barberry plants but must be carried to wheat plants before they can grow. On the wheat plant each aeciospore puts out a short germ tube which penetrates the tissue of the leaf or stem within which it forms an extensive mycelium, from which the urediniospores and later teliospores are formed.

So it is apparent that for the completion of its life-history *Puccinia graminis* must have two very different host plants. Many rusts show this character of requiring alternate hosts, and are called heteroecious. Other rusts complete their life cycle on a single host: they are said to be autoecious.

Another rust of great economic importance, especially in the northern United States and Canada, is the white pine blister rust, *Cronartium ribicola,* which, like wheat rust, has two alternate hosts, white pine having the pycnia and aecia, and currants and gooseberries the uredinia and telia stages.

In many rusts one or more of the spore forms may be entirely lacking. For example, in *Gymnosporangium juniperi-virginianae* there is no uredinial stage, while in the common hollyhock rust, *Puccinia malvacearum,* pycnia, aecia, and uredinia are all lacking, only the teliospores and basidiospores being formed.

Smuts Fungi. Ustilaginales. Parasitic Basidomycetes, so named because of the conspicuous masses of sooty black spores which they form externally on the host plant. Infection by smuts is seldom fatal to the host plant but does seriously reduce its size and may even prevent seed formation completely. The fungus grows as a septate mycelium which penetrates between the cells of the host plant; into

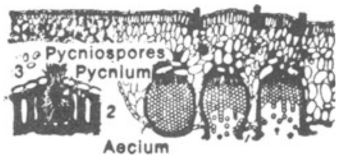


Fig. 6. (1) Section of barberry leaf infected with *Puccinia graminis* and producing pyenia and aecia; (2) section through pyenium; (3) three pycniospores.

these cells it sends haustoria, which obtain nourishment therefrom. Presently this septate mycelium gives rise to immense numbers of spores. Often the presence of the mycelium causes the host tissue to enlarge tremendously, producing irregular tumor-like growths. These are particularly conspicuous in Corn Smut. The spores are thick-walled unicellular objects capable of surviving for some time under unfavorable conditions. On germinating, each spore develops a short germ tube, or promycelium, which becomes from 1–4 cells long. Each of these cells produces a spore. The promycelium becomes a basidium; and the spores, basidio-spores. These spores are capable of infecting new host plants, producing therein a mycelium. Conjugation between cells of the mycelium occurs so that each cell comes to have two nuclei. As growth continues, the two nuclei of any cell divide simultaneously so that every cell continues to have two nuclei. When spore formation occurs, the two nuclei fuse, dividing again when the spore germinates. Many variations of this process are found; in many smuts the promycelium buds off from its apex many cells. Often fusion between two of these cells occurs immediately, even before they are separated from the promycelium.

Because of the rapidity with which smuts may spread and the great reduction of seed production which their presence may cause, smuts are of great economic importance. One species, Corn Smut, *Ustilago zeae,* causes the loss of millions of bushels of corn yearly. Oat smut, *Ustilago avenae,* may cause a 30% reduction in yield, while other smuts are equally important. Control of the parasites may be obtained by rotating crops; but due to the resistant nature of the spores, at least three years should elapse before replanting an infected field to the same crop. Other methods of control consist of soaking seeds in various solutions, such as formaldehyde solution in water, or dusting infected seeds with copper compounds.

See also specific crops known to be susceptible to fungus diseases as well as entries on **Fungus and Related Diseases (Crop)**; **Fungicide**; and **Mushroom**.

References

Walker, J. C.: "Plant Pathology," 3rd edition, McGraw-Hill, New York, 1969.

FUNGUS AND RELATED DISEASES (Crop). In addition to presentation of the principal fungal diseases affecting crop plants, the diseases produced by related organisms, the Plasmodiophorales and the Phycomycetes (lower true fungi) and the Deuteromycetes (Fungi Imperfecti) are also described. The diseases are described crop by crop in alphabetical order.

Important related information is contained in additional editorial entries of this volume. The basic nature of fungi are described in the entry on **Fungus**. Chemicals used to control fungal diseases are described in the entry on **Fungicide**. Also, many of the fungal diseases are described in more detail in some of the specific crop entries, such as Alfalfa; Potato; Wheat; etc. In each of these latter entries, a "Chemical Control Summary" is included, listing fungicides suitable for given crops, along with bactericides, insecticides, etc. for other pests and injurious organisms.

For maximum convenience of the reader, an alphabetical list of all fungal diseases and a list of the Latin or specific names of the species of fungi described in this entry are included prior to the disease descriptions.

FUNGUS AND RELATED DISEASES DESCRIBED IN THIS ENTRY

Name of Disease	Name of Crop for which Disease is Described
Aflatoxin	Maize (Corn)
Anthracnose	Bean; Blackberry and Dewberry; Cucurbit; Grape; Pea; Pepper; Raspberry
Aphanoyces root rot	Pea
Apple rust	Apple
Apple scab	Apple
Armillaria root rot	Citrus
Ascochyta disease	Pea
Banana wilt	Banana
Bitter rot	Apple; Grape
Blackleg	Crucifer
Black loose smut	Oats
Black rot	Grape; Pineapple; Sweet Potato
Black stem rot	Cereals
Black wart	Potato
Blight (Chestnut)	Chestnut
Blight (Early)	Celery; Potato; Tomato
Blight (Late)	Celery; Potato; Tomato
Blight (Leaf)	Beet; Carrot
Blight (*Mycosphaerella*)	Pea
Botrytis spp. diseases	Onion
Brown spot	Maize (Corn)
Browning root rot	Cereals
Brown rot	Diseases of Deciduous Fruit Trees
Bud rot	Coconut
Bunt	Wheat
Cabbage yellows	Crucifer
Cercospora leaf spot	Pepper
Chestnut blight	Chestnut
Clubroot	Crucifer
Coconut bud rot	Coconut
Corn smut	Maize (Corn)
Covered smut	Oats
Crown rot	Rhubarb
Crown wart	Alfalfa
Cucumber scab	Cucurbit
Damping-off (*Pythium* diseases)	Celery; Cucurbit; Eggplant; Pepper; Tomato
Diplodia disease	Maize (Corn)
Double blossom disease	Blackberry and Dewberry
Downy mildew	Cucurbit; Garlic; Grape; Lettuce; Onion
Early blight	Celery; Potato; Tomato
Ear rot	Cereals; Maize (Corn)
Endothia canker	Chestnut
Ergot	Cereals
Foot rot	Cereals; Pea; Rhubarb
Fusarium wilt	Cucurbit; Pea; Tomato
Gibberella diseases	Cereals; Maize (Corn); Oats; Rye; Sorghum
Gray-mold neck rot	Onion
Head blight (Scab)	Cereals

FUNGUS AND RELATED DISEASES DESCRIBED IN THIS ENTRY (cont.)

Name of Disease	Name of Crop for which Disease is Described
Late blight	Celery; Potato; Tomato
Leaf blight	Beet; Carrot
Leaf curl	Peach
Leaf spot	Beet; Pea; Raspberry, Tomato
Loose smut	Barley; Oats
Macrophoma rot	Grape
Mildew (Downy)	Crucifer; Cucurbit; Garlic; Grape; Lettuce; Onion
Mildew (Powdery)	Cereals; Grape
Mycelial neck rot	Onion
Mycosphaerella blight	Pea
Neck rot	Onion
Onion smudge	Onion
Onion smut	Onion
Orange rust	Raspberry
Peach leaf curl	Peach
Phytophthora root rot	Crucifer
Pod spot	Pea
Powdery mildew	Cereals; Grape
Powdery scab	Potato
Pythium (Damping-off) diseases	Celery; Cucurbit; Eggplant; Pepper; Tomato
Pythium root rot	Crucifer
Red stele root disease	Strawberry
Rhizoctonia disease	Potato
Ripe rot	Grape
Root rot	Cereals; Citrus; Crucifer; Maize (Corn); Pea; Potato; Strawberry
Rust	Apple; Bean; Cereals; Crucifer; Strawberry
Scab	Apple; Cucurbit; Potato
Sclerotinia spp. diseases	Diseases of Deciduous Fruit Trees
Seedling blight	Cereals
Small-sclerotial neck rot	Onion
Smudge	Onion
Smut	Barley; Maize (Corn); Oats; Onion; Wheat
Stalk rot	Cereals; Maize (Corn)
Stem rot	Pea; Sweet Potato
Stem rust	Cereals
Stinking smut	Wheat
Tip rot	Beet
Verticillium wilt	Tomato
Violet root rot	Potato
Wart (Black)	Potato
Wart (Crown)	Alfalfa
White heart rot	Diseases of Deciduous Fruit Trees
White rot	Onion
White rust	Crucifer
Wilt fungus	Crucifer; Sweet Potato; Tomato
Yellows disease	Carrot; Crucifer

Important Diseases Caused by Fungi

As is true of insects, nematodes, bacteria, viruses, and other injurious pests of crop plants, some of the fungi function on a rather broad spectrum, attacking several plants, whereas other species of fungi specialize and confine their attacks to one or just a few plants. This also applies to method of attack, some species of fungi injuring numerous portions of a plant, while others confine their injury to stems, leaves, roots, *et al.* With severe infections, of course, regardless of the point of attack, the end result, namely that of the plant withering and dying, is the same.

In this particular section, the principal food crops attacked seriously by fungi are reviewed briefly in alphabetical order. Essentially crop-specific fungal diseases are described under a given crop. Reference is also made to the more general fungal diseases, which are described in more detail later in this entry.

Alfalfa. Crown wart of alfalfa disease was first noted in Ecuador in 1895 and later confirmed in Europe and the United States in the early 1900s, first being reported in California in 1909. The disease, found on common alfalfa (*Medicago sativa* L.) and (*M. falcata* L.), occurs mostly in the western states and Pacific coast regions from California north and east into Montana and Utah. The disease is caused by the organism *Physoderma alfalfae* Karling, 1950. The disease produces warts or galls which occur on buds emerging from the crown of the plant. The infected buds ultimately take on a brilliant white color and grow thick and rotund. Irregularly formed galls are found below the ground level about 2 inches (5 centimeters) deep. The galls are full of spores which appear as brown masses. Plant cells and tissues are killed or severely deformed and the disease spreads rapidly, once commenced under favorable conditions.

Aphanomyces, root rot of pea, sometimes attacks alfalfa, but serious crop losses usually do not occur. See "Pea" later in this description.

Violet root rot was first reported in the United States (Nebraska) in 1890 on alfalfa. The disease attacks a number of plants and is described later.

Apple. Bitter rot of apple has been known since the early 1800s, when it was recognized in Europe. The disease is caused by the organism *Glomerella cingulata* Spauld. & Schrenk, 1903, and is generally found in the United States east of the Rocky Mountains and south of latitude 40°N. An early symptom of the disease is a light-brown discoloration noted just beneath the skin; it is essentially circular in shape. As the lesion grows to some 3 millimeters in diameter, the center becomes depressed, followed by the appearance of tiny black specks. In wettish weather, these specks rupture and ooze viscous masses of pink-colored spores. The lesions increase in size, ultimately causing a rotting of the entire fruit, a process that is accelerated by the frequent entrance of secondary infections, such as soft-rot organisms. Although many of the rotted fruits fall to the ground, unless picked off, some cling throughout the winter and are commonly referred to as "mummies." The disease also causes cankers on the tree limbs. Spread of the disease on limbs is less likely on young trees than on those that are 2 years old or older. Essential to control is prompt removal of all infected wood and fruits ("mummies"). Protective sprays, particularly the copper fungicides, are effective.

Brown rot affects apple and all stone fruits and is described later.

FUNGUS SPECIES DESCRIBED IN THIS ENTRY

Name of Species	Name of Crop for which Species is Described
Albugo candida Kunze, 1891	Crucifer
Alternaria solani L. R. Jones & Grout, 1896	Potato
Aphanomyces cochliodes	Beet
Aphanomyces euteiches Drechs, 1925	Pea
Armillaria mellea Quel	Citrus
Ascochyta pinodella L. K. Jones, 1927	Pea
Ascochyta pisi Lib., 1830	Pea
Aspergillus flavus	Maize (Corn)
Botryosphaeria ribis	Grape
Botrytis allii Munn, 1917	Onion
Botrytis byssoidea J. C. Walker	Onion
Botrytis squamosa J. C. Walker	Onion
Bremia lactucae Regel, 1843	Lettuce
Ceratocystis fimbriata Ell. & Halst	Sweet Potato
Cladosporium cucumerinum Ell & Arth	Cucurbit
Claviceps purpurea Tul., 1853	Cereals
Colletotrichum circinans Vogl, 1907	Onion
Colletotrichum lindemuthianum Scribner, 1888	Bean
Colletotrichum obiculare Arx	Cucurbit
Colletotrichum pisi Pat	Pea
Diplodia maydis Sacc., 1884	Maize (Corn)
Endothia parasitica P. J. Anerson & H. W. Anderson, 1912	Chestnut
Erysiphe graminis DC	Cereals
Formes igniarius Gill, 1878	Diseases of Deciduous Fruit Trees
Fusarium oxysporum f. *apii* Snyder & Hansen	Celery
Fusarium oxysporum f. *conglutinans,* Snyder & Hansen, 1940	Crucifer
Fusarium oxysporum f. *cubense* Snyder & Hansen	Banana
Fusarium oxysporum f. *lycoperisci* Snyder & Hansen, 1940	Tomato
Fusarium oxysporum f. *melonis* Snyder & Hansen	Cucurbit
Fusarium oxysporum f. *niveum* Snyder & Hansen	Cucurbit
Fusarium oxysporum f. *pisi,* Snyder & Hansen	Pea
Gibberella moniliforme Snyder & Hansen, 1945	Cereals
Gibberella roseum Snyder & Hansen, 1945	Cereals
Glomerella cingulata Spauld & Schrenk, 1903	Apple; Grape
Guignardia biwellii Viala & Ravaz	Grape
Gymnosporangium juniperi-virginianae Schw., 1822	Apple
Helicobasidium purpureum Pat., 1885	Potato
Melanconium fuligineum	Grape
Monilinia fructicola Honey, 1928	Diseases of Deciduous Fruit Trees
Monilinia fructigena Honey, 1936	Diseases of Deciduous Fruit Trees
Monilinia laxa Honey, 1936	Diseases of Deciduous Fruit Trees
Mycosphaerella pinodes Berkeley & Bloxam, 1841	Pea
Peronospora destructor Casp, 1860	Garlic; Onion
Peronospora parasitica Tul	Crucifer
Phoma lingam Desm., 1849	Crucifer
Physoderma alfalfae Karling, 1950	Alfalfa
Physoderma zeae-maydis Shaw, 1910	Maize (Corn)
Phytophthora infestans DBy., 1876	Tomato
Phytophthora megasperma Drechs	Crucifer
Phytophthora palmivora Butl	Coconut
Phytophthora phaseoli Thaxter	Strawberry
Plasmodiophora brassicae Wor., 1877	Crucifer
Plasmopara viticola Berl. & DeT., 1898	Grape
Pseudoperonospora cubensis Rostow, 1903	Cucurbit
Puccinia graminis Pers., 1794	Cereals
Pythium aphanidermatum Fitz.	Maize (Corn)
Rhizoctonia solani Kühn, 1858	Potato
Sclerotinia americana Norton * Ezekiel, 1924	Diseases of Deciduous Fruit Trees
Sclerotinia cinerea Schroet, 1893	Diseases of Deciduous Fruit Trees
Sclerotinia fructigena Schroet, 1893	Diseases of Deciduous Fruit Trees
Sclerotinia sclerotiorum DBy., 1884	Bean
Sclerotium cepivorum Berk, 1841	Onion
Spongospora subterranea Lagerheim, 1892	Potato

FUNGUS SPECIES DESCRIBED IN THIS ENTRY (cont.)

Name of Species	Name of Crop for which Species is Described
Synchytrium endobioticum Perc., 1910	Potato
Stemphylium botryosum Wallr.	Onion
Taphrina deformans Tul. 1866	Peach
Thielaviopsis paradoxa Hoehn.	Pineapple
Tilletia carries Tul., 1847	Wheat
Uncinula necator Burr.	Grape
Urocystis cepulae Frost, 1877	Onion
Ustilago avenae Rostr., 1890	Oats
Ustilago hordei Lagerh.	Barley
Ustilago kolleri Wille, 1893	Oats
Ustilago maydis Cda., 1842	Maize (Corn)
Ustilago nigra Tapke.	Barley
Ustilago nuda Rostr.	Barley
Venturia inaequalis Wint., 1875.	Apple
Verticillium alboatrum Reinke & Berth	Tomato

Phytophthora rot, although usually associated with late blight of potato and tomato, also affects deciduous fruits and is described later.

Apple rust occurs widely in Europe and in the United States east of the Rocky Mountains, notably in Virginia, West Virginia, New York, Iowa, and Wisconsin. The disease is caused by the organism *Gymonsporangium juniperi-virginianae* Schw., 1822. Early evidence of the disease is appearance of small greenish-yellow spots on leaves. Gradually, these spots get larger and take on an orange-yellow color, surrounded by concentric red bands at the borders. Spore cases appear on the upper side of the leaf lesions. At this time, a yellow-colored exudate will be noticed. The lower sides of lesions will take on a fuzzy appearance. The lesions usually occur on immature fruits and cause malformation and dwarfing. If infected in early spring, twigs frequently expire by the end of the season. This same organism also seriously affects red cedar trees. Some states require the removal of red cedar within a certain distance of commercial apple orchards. Ferbam is an effective control. The best control is prevention by planting only resistant varieties of apples in regions where the disease is known to prevail.

Apple scab was first noted in Sweden in 1819 and in Germany in 1833. In the following year, it was first noted in the United States, but not reported in the British Isles until 1845. It was first noted in Australia in 1862. The disease, caused by the organism *Venturia inaequalis* Wint., 1875, is confined to two economic crops, apple and crab-apple. The disease is evidenced by appearance of lesions on both sides of leaves, often first developing on the underside. They commence as olivaceous spots, but shortly convert to a dark-brown to black velvety lesion. The lesions on the upper side of leaves tend to have definable margins and are quite conspicuous; the lesions on the underside tend to blend in with healthy tissue, with extension occurring along the midrib and veins. Small, black spots appear on fruit. These develop more slowly than the leaf lesions. The velvety lesion later becomes brown and corklike in appearance. When infection occurs on immature fruit, distortion of growth is inevitable. Twig infections are infrequent. Captan, glyodin, and dodine are effective controls. At one time, Bordeaux mixture and lime-sulfur were popular, but they have a tendency to cause phytotoxic injury of the fruit. Elgetol (sodium dinitrocresylate) or Elgetol 318 (dinitro-secondary-butyl phenol triethanolamine) also are effective as ground sprays to reduce overwintering of the infection in the leaves. When dodine is used, it is usually applied once per week from the delayed dormant-bud stage through the blooming stage.

White heart rot affects apple as well as most other deciduous fruit trees and is described separately later.

Apricot. This fruit tree is affected by **crown gall** and **Sclerotinia diseases**, which are described later.

Banana. A vascular *Fusarium* disease known as **banana wilt** is caused by the organism *Fusarium oxysporum* f. *cubense* Snyder & Hansen. Symptoms include various degrees of chlorosis, accompanied by stunting and vascular discoloration, sometimes leading to wilting. There are numerous species of the *Fusarium* wilt fungi, but each species is usually specific to a given host. Elevated soil temperature favors the fungus and, unless strong measures such as soil fumigation are taken, the same soil should not be used for replanting the same host plant. The disease is closely allied to cabbage yellows and tomato wilt. See "Cabbage" and "Tomato" in this description.

Barley. **Black stem rot** is common to several small grains and grasses and is described later. This is also true of the following diseases and which are described later: Ergot, foot rot, Gibberella diseases, head blight, powdery mildew, scab, and seedling blight.

Loose smut of barley, caused by the organism *Ustilago nuda* Rostr., is one of three smuts that affect barley. There is also **black semiloose** or **nigra loose smut**, caused by *Ustilago nigra* Tapke; and **covered smut of barley**, caused by *Ustilago hordei* Lagerh. Loose smut of barley is very similar to loose smut of wheat, although caused by different organisms. Loose smut affects the floral organs of growing barley. Dormant organisms live in seed parts rather than plant parts. Humid, cool weather favors the disease. The black powdery mass of spores is easily distributed from an infected plant to others by action of the wind. Some varieties of barley show some resistance. Treatment of barley seed in the manner used for treating oats seed does not suffice for barley. Cold- and hot-water treatments are used, sometimes damaging to the seed. The timing and temperatures of the 2-stage water treatment is fairly critical. In the mid-1960s, the systemic fungicide vitavax (2,3-dihydro-5-carboxanilido-6-methyl 1,4 oxanthin) was reported as having some success in barley seed treatment.

Blackberry and Dewberry. These plants are affected by **anthracnose** fungus. Symptoms include small gray spots with dark margins on leaves; purplish spots, about 1 inch (2.5 centimeters) in diameter; with ash-gray centers and raised purplish margins on canes. Spotted canes may crack lengthwise. Fruit of many varieties of blackberries are not damaged; but those of Lawton are particularly susceptible. The disease also attacks raspberries. Fungus lives on the remains of diseased cane of the previous year. Distribution is throughout the United States. Control is by three applications of ferbam: The first when leaves are exposed 1/2 to 3/4-inch (12 to 18 millimeters); second, just before blossoms open; third, after blossoming.

Double blossom disease. Symptoms are twisted and wrinkled petals; abnormally large flower buds. Short, broomlike growths emerge from infected buds; no berries grow at these points. Chiefly in southeastern United States. Control is destruction of all debris after harvest.

Bean. A major disease of dry and snap beans (*Phaseolus vulgaris* L.), **bean anthracnose** was first described in Germany in 1875. The disease also affects the broad bean, cowpea, kudzu bean, lima bean, mung bean, scarlet runner bean, and tepary bean. The disease is found essentially worldwide wherever these crops are grown. The causal organism if *Colletotrichum lindemuthianum* Scribner, 1888. However, incidence of the disease has been markedly lowered in several regions of the world as the result of using anthracnose-free seed. Seldom seen on the roots, the characteristic dark-brown lesions of the disease may be found on the leaves, the petioles and stem. Plants growing from infected seed will produce blackened cankers on the cotyledon (early leaf). Brown sunken spots, which have pink centers, appear on the pods. See Fig. 1. There are elongated, dark-red cankers on stems and leaf veins. Rusty-brown spots will be seen on ripe seeds. The disease is most common during cool, moist summers. The fungus is carried on seeds and lives in soil and on remains of diseased plants. In the United States, planting of anthracnose-free seeds grown in the western states has proved quite successful. Crop rotation also is a good cultural practice. Since the late 1800s, resistance to the disease has been noted to vary considerably from one variety of bean to the next. Genetically developed resistance has proved interesting and complex and, to date, has been valuable in developing disease-resistant seeds. An excellent explanation of this is given by J. C. Walker in his book listed with references at the end of this entry.

Common bacterial blight of bean is shown in Fig. 2. Packed beans sometimes develop a soft, watery tissue caused by the organism *Sclerotinia sclerotiorum* DBy., 1884. The results of this disease sometimes occur in the center of packing hampers or containers, causing a condition referred to as "nesting," when a cottony mass of decayed material may be observed.

Rust fungus also occurs on beans. Red to black pustules (blisters) appear on leaves. The leaves turn yellow and rot.

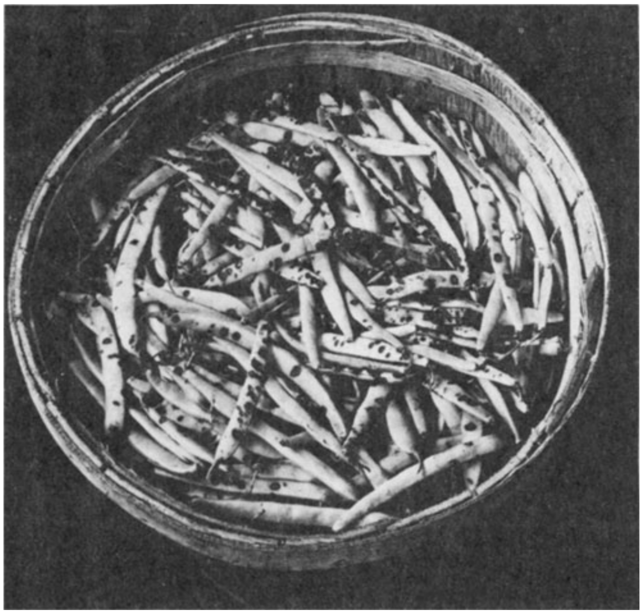


Fig. 1. Snap beans grown in the southern United States that were field-graded and shipped to northern markets without refrigeration, during which time they were destroyed by anthracnose. (*USDA photo*)

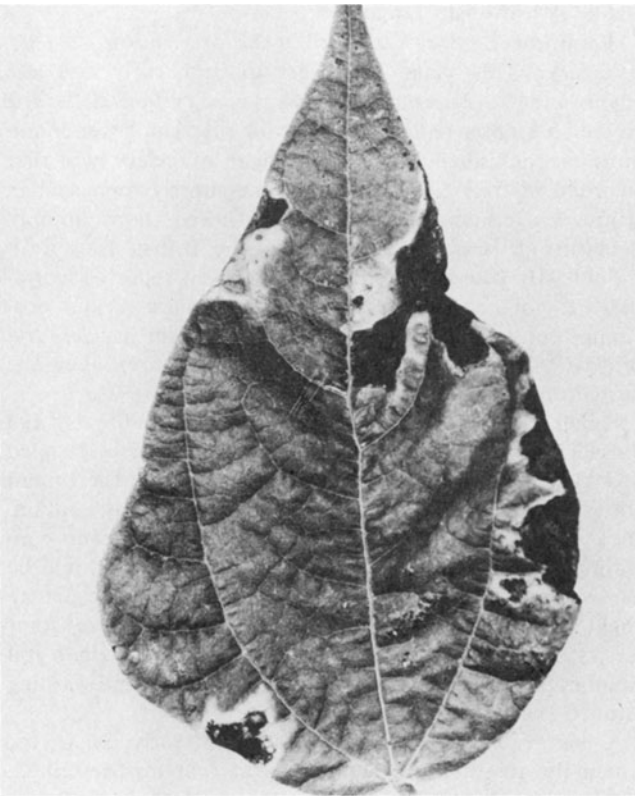


Fig. 2. Leaf showing evidence of the common bacterial blight of bean. Lesions have turned brown and have merged to form several extensive necrotic areas. As the disease progresses, more and more leaves wither and fall from the plant. (*USDA photo*)

The fungus lives through the winter on remains of diseased plants. Distribution is throughout the United States except in some semiarid regions. Sulfur spray or dust can be effective. A few bean varieties have some resistance to rust and should be considered for new plantings. These varieties include: *Cherokee Wax, Harvester, Kingham, Rust Resistant Kentucky Wonder* (pole), *Tendergreen,* and *Tenderwhite* beans.

Beet. Leaf blight or leaf spot of beet is produced by one of the *Rhizoctonia* organisms. Numerous small, round spots with light-tan centers and dark-brown borders on leaves. Fungus is carried on seed and lives in soil or remains of diseased plants. Distribution in the United States is east of the Rocky Mountains. Controls include a dust or spray containing a fixed copper fungicide or zineb. Frequently, the disease is not sufficiently severe to require regular treatments. Violet root rot, another *Rhizoctonia* disease also affects beet.

Tip rot of sugar beet occurs as the result of infection by *Aphanomyces cochlioides* Drechs. This organism is closely related to the species that causes root rot of pea and black root of radish.

Broccoli. See "Crucifer" in this description.

Brussels Sprouts. See "Crucifer" in this description.

Cabbage. See "Crucifer" in this description.

Cantaloupe. See "Cucurbit" in this description.

Carrot. This crop plant is subject to infection by **Rhizoctonia root rot, Sclerotinia rot,** and **violet root rot,** neither of which is exclusively specific to carrot. These diseases are described separately later. Carrot is also affected by **leaf blight fungus.**

Cauliflower. See "Crucifer" in this description.

Celery. This plant is subject to both early and late blight and to *Fusarium* yellows (*F. oxysporum* f. *apii* Snyder & Hansen) and to violet root rot. The latter conditions are described later. **Late blight of celery** was first recorded in Italy in about 1890, and shortly thereafter in Denmark, Germany, and the eastern United States, notably Delaware. It was not reported in the British Isles until about 1910. The seed-borne disease is now reported worldwide. If not controlled, the disease can have serious economic consequences. The causal organism is *Septoria apiicola*. In attacking seeds, the fungus causes pycnidial formation in the seed coat.

Small yellow spots appear on old leaves (Fig. 3) and stalks (Fig. 4). The spots turn dark gray and are speckled with tiny black dots. Distribution is throughout the United States. Effective control chemicals include a spray containing a fixed copper fungicide, zineb, or ziram, or a dust containing copper, zineb, or ziram. All plant debris should be removed in the autumn. Crop rotation is effective. Where blight damage is heavy, Emerson Pascal, a blight-resistant variety, may be the best solution. All residues of zineb and ziram must be removed by stripping, trimming, and washing prior to marketing.

Celery is also affected by a form of early blight, for which the treatment is identical with that just described. Along with many other plants, celery is affected by **Fusarium yellows** and **violet root rot diseases**, described later. Celery is affected by damping-off (*Pythium*) fungi.

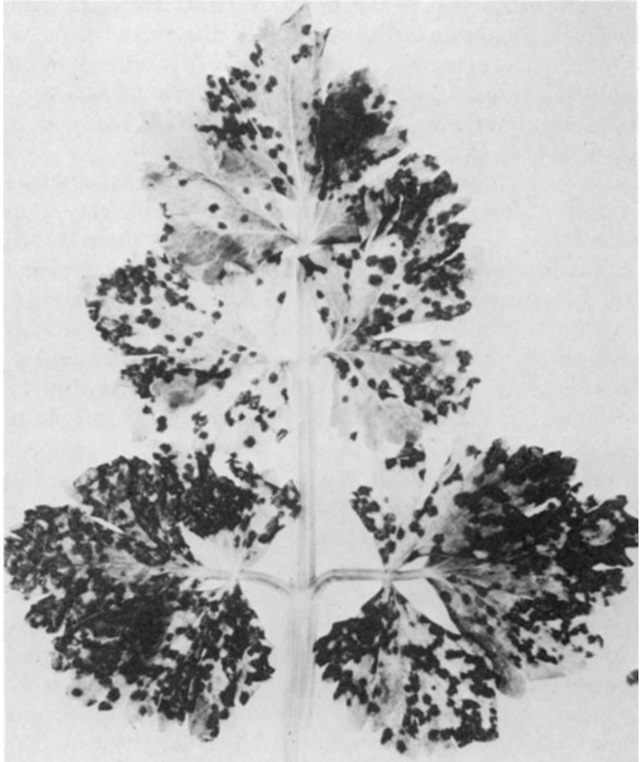


Fig. 3. Celery plant showing extensive evidence of late blight disease. (*USDA photo*)

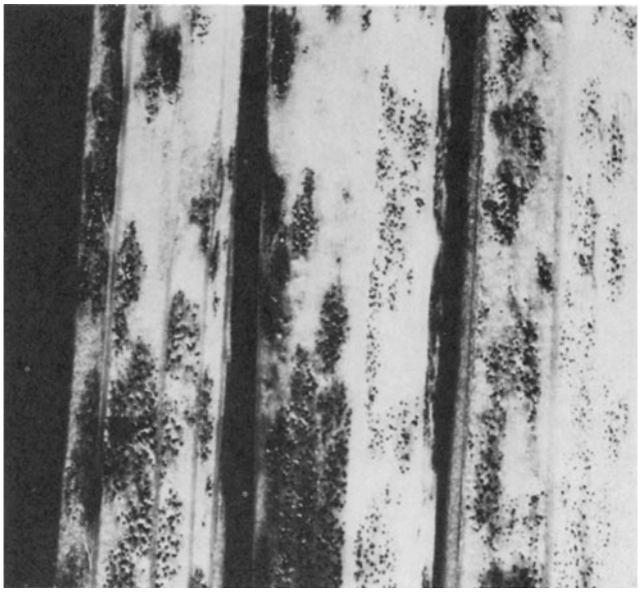


Fig. 4. Stalks of celery showing effects of late blight disease. (*USDA photo*)

Cereals. It is reported that the **browning root rot of cereals** can be a serious economic fungal disease, particularly in midwestern Canada following summer fallow. Some authorities relate the disease with a combination of low phosphorus and high nitrate nitrogen content of soil. The causal organism is *Pythium arrhenomanes*.

Ergot of grains and grasses, caused by *Claviceps purpurea* (Fr.) Tul., 1853, is a serious economic disease and occurs worldwide. The fungus affects the flowering parts of the affected plants. Rye is particularly severely affected. See Fig. 5. Infected flowers produce ergot sclerotia rather than the normal kernels, thus reducing yields. The sclerotia contains alkaloids which subsequently can be quite injurious if the affected grain is fed to livestock. Where the alkaloid substances are carried over into flour for breadmaking, humans also can be affected by the toxic content. Such materials can be removed during processing of flour, but only at a considerable additional cost. The disease and its effects were known by the early Greeks and Romans. However, a reasonably complete understanding of the causal organism and resulting disease did not occur until the mid-1850s. The drug, *ergot*, is produced from the dried and purple-colored sclerotium of the fungus. The drug has been used to stop hemorrhage and in the treatment of high blood pressure and migraine headaches. Ergot contains the amino acid thiozine found in blood. Most ergot required for pharmaceutical purposes today is synthesized from basic organic substances rather than made from the fungus directly.

The most effective control is use of ergot-free seed as well as rotation of susceptible grain crops with legumes and other resistant plants, thus reducing the population of overwintering organisms. Spraying wild host plants with maleic hydrazide has been effective because this inhibits heading, thus destroying the principal source of the organism.

Fig. 5. Ergot present in the head of rye. The purple-black fruiting bodies replace grain in the rye head, destroying the plant as a food crop. (*USDA photo*)

Gibberella diseases of small grains and maize (corn) also can be economically important. The causal organism *Gibberella roseum* affects maize and small grains and a related organism *G. moniliforme* also affects maize (corn).

The disease is sometimes called head blight (scab), seedling blight, and foot rot, depending upon the particular plant and condition of plants when affected. First described in England in 1884 and a few years later in the United States, **head blight (scab)** takes place between the flowering period and maturity of the plant. Several of the spikelets will take on a straw coloration. Particularly during warm and wet periods, a fluffy pink or red growth will occur along the spike. Floral bracts may exhibit a purplish coloration. Kernels are discolored and wrinkled when developed. Coloration is dependent on the particular plant infected—wheat kernels tend to be white, pink, or light-brown; rye kernels range from carmine red to dark-brown; barley and oat hulls are darkened.

In **seedling blight**, the seeds take on a dark brown-to-red coloration and expire prior to full rooting. In some instances, full attack may not occur until after emergence. Such plants are dwarfed and chlorotic. In the case of maize (corn), the organism *G. moniliforme* mainly attacks the tap and lateral roots. Other species of fungi cause similar conditions and it is not always easy to distinguish the exact cause unless examinations are made in the laboratory.

In the case of root rot, and foot rot, the cause may be due to *Gibberella* species or to *Diplodia* disease and again the distinction is not easy to make. *Gibberella* also causes corn ear rot, as does *Diplodia*. The distinction here is easier because *Gibberella* injury commences at the tip end rather than the butt end as is the case of *Diplodia*.

It was not until the early 1900s that an association between head blight, seedling blot, and foot rot due to *Gibberella* all arose from the same species of *Gibberella*, and that the different aspects resulted simply from different responses of particular plants and conditions prevailing at the time of infection.

The organisms winter off in seed and infected debris. Infected cornstalks are a particularly favored place for overwintering. Thus, destruction of debris and other sanitary measures in the field are effective in reducing the population of the organisms. Treatment of seed and the use of seed protectorants are also effective control measures. Seed-treatment chemicals used include captan, chloranil, dichlone, and thiram.

Powdery mildew of cereals and grasses is an important economic disease, particularly where humid summers prevail. The causal organism is *Erysiphe graminis* DC and is more damaging to barley and wheat than to other cereal and grass crops. Because of relation of the disease with humid conditions, it is logically more severe in such areas as the Pacific coast, Great Lakes, and Atlantic seaboard regions of the United States; and in British Columbia bordering the Pacific Ocean and in the eastern Atlantic provinces of Canada.

Onset of the disease is noted by appearance of white mildew places on the aerial parts of plants. The affected areas enlarge and take on a grayish or tan coloration. When serious, the entire plant will be so affected. Plants become unthrifty, kernels lose their usual plumpness, and yields and quality of grain are thus reduced. The organisms overwinter on grasses and on grains that are sown in the autumn. Much research has been conducted toward developing resistant varieties. Sulfur dust and karathane have been used as protective chemicals.

Black stem rust of grains and grasses is caused by the organism *Puccinia graminis* Pers., 1794. There are several hosts, including barley, oats, rye, timothy, and wheat. The disease is found almost everywhere that wheat is grown. The disease can be quite economically important, particularly in moist areas or during rainy spells in areas that do not receive heavy annual rainfall. The red-dust stage of the fungus may appear on leaves and culms almost anytime during the growth of grass or cereal. Spore masses noticeable are reddish-brown. In a later stage, dark brown to black smooth (not powdery) spots will appear.

An interesting interrelationship between barberry and wheat rust has been known since 1804. Experiments during the early 1800s proved that barberry hosts the organism and that it is easily transferred from barberry to cereal plants. In northern climes, the fungus carries over the winter when only barberries are present. Because of the effect of environmental conditions on the life cycle of the fungus, the effect of proximity to barberry lessens as one proceeds southward from long, severe winters to shorter, milder winters. Eradication of the barberry in northern regions served well toward controlling the disease. However, windborne spores can be carried northward from the south so that elimination of the barberry does not afford complete control. The study of these interrelationships is exceedingly interesting and quite complex and is excellently presented by J. C. Walker (see reference list). Development of resistant varieties continues to be important.

Chard. See "Beet" in this description.

Cherry. This fruit crop is affected by **brown rot of stone fruits**, described later.

Chestnut. A major fungal disease of chestnut is *Endothia* canker or **chestnut blight**. In the early 1900s, this disease destroyed most of the American chestnut trees in the Appalachian range of the eastern United States. The disease was first noted in New York City in 1904 and, within a few years, was noted several hundred miles distant in western Pennsylvania and in northern Georgia. Discovery of the disease in China in 1913 and a bit later in Japan indicates that the disease may have been brought to the United States on nursery stock from the Orient. In the early 1930s, the disease was reported in Italy and subsequently findings have been made in various parts of Europe as far east as the U.S.S.R. and also in India.

The causal organism is *Endothia parasitica* P. J. Anderson & H. W. Anderson, 1912. Early symptoms are bark lesions and the shriveling of leaves on affected twigs. Cankers then appear on many twigs and later on the main trunk. Newly formed cankers often produce a yellow exudate of spores. When the cankers become older, the bark splits and falls to the ground. On the older cankers, orange- to reddish-brown spots appear. The most effective controls found by chestnut producers is the use of resistant Asiatic varieties of the tree. A concerted research program continues toward the development of resistant species that are more suitable to American climes.

Chive. See "Onion" in this description.

Citrus. One of the fungus diseases most destructive to citrus (as well as stonefruit crops) is that caused by the organism *Armillaria mellea* Quel. This is an agaric fungus that also causes dry rot of potato tubers. The organism also is associated with the occurrence of root disease of western white pine. **Armillaria root rot** is an important economic disease of Pacific coast citrus crops in the United States. The disease, first identified in 1873, invades the root system of the citrus tree. With exception of some reduction in the healthy appearance of a tree, there is no concrete external evidence of the disease until the appearance of the fruit bodies of the fungus occur in large numbers around the base of the tree trunk. If there are stumps nearby, the fungus also may appear on them. As contrasted with many fungal invaders, the Armillaria are quite large by comparison, with the fruiting body resembling a mushroom with a tannish-colored top. Rhizomorphs of the fungus, called *shoestrings*, resemble hard black strands which branch out along the roots, trunk, and adjacent soil. Destruction of the tree occurs as the result of mechanical forces set up by the growing invader as well as by chemical juices secreted by the organism which breaks down the normal cell tissues. Bliss reports that growth of the fungus with relation to temperature varies considerably with the type of tree. Control is by soil fumigation and sterilization prior to replanting citrus or stone fruits. Prior cultivation of recently cleared areas with nonsusceptible crops is a good control practice. Crops with fleshy roots and tubers should not be planted immediately after clearing a wooded area, where the fungus may likely be found.

Penicillium species cause decay of orange when stored under improper conditions.

Clover. This plant is affected by *Sclerotinia* disease described later.

Coconut. The species *Phytophthora palmivora* Butl. causes a disease known as coconut bud rot and is similar to other *Phytophthora* diseases that affect a number of other plants, notably avocado, rhubarb, tomato, and potato.

Collard. See "Crucifer" in this description.

Corn. See "Maize" in this description.

Crucifer. Blackleg is a fungal disease that seriously affects broccoli, Brussels sprouts, cabbage, cauliflower, Chinese cabbage, kale, kohlrabi, rutabaga, and turnip. The earliest finding of the disease occurred in Germany in 1791, when the fungus was found on decayed cabbage stems. It was not reported on living plants until the mid-1800s in France. The first report of finding it on cabbage in the United States occurred in 1910. The disease was first noted on rutabaga in Denmark in 1897. In Scandinavia, the British Isles, and New Zealand, the disease is most damaging to rutabaga and turnip, althoughi it has been found on rutabaga in Minnesota. The disease is most common to cabbage in Australia and the United States.

The disease shows up within a few weeks after transplanting. Bleached or pallid spots of a rather indefinite shape, first appear on leaves. These later turn into easily identifiable spotty areas with gray centers. Spots also are noted along the stem and any lesions near the ground level will be found to extend into the root system. Because destroyed roots may be replaced by new roots, a plant may

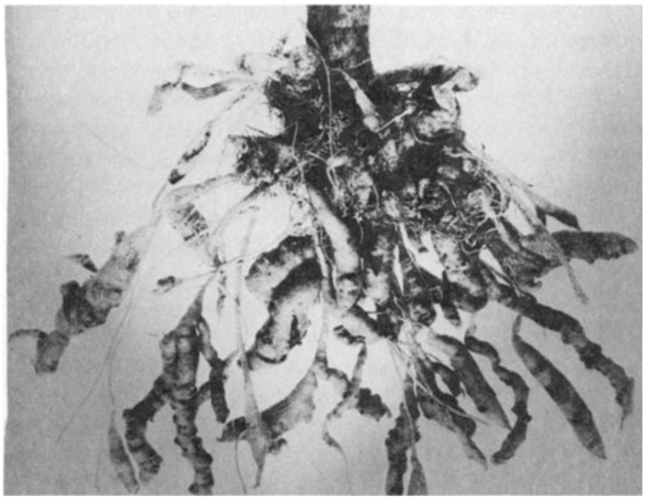


Fig. 6. Malformed, spindlelike roots of cabbage plant affected by club root disease. (*USDA photo*)

stay alive sufficiently long to produce medium-size heads. Such a plant may show a reddish tinge along the margins of the outer leaves. In addition to attacking living plants, the organism, *Phoma lingam* Desm., 1849, may also attack cabbage heads while in storage. The organism also invades seed pods of seed plants, causing the seeds to shrink. Wintering over of the organism is in the seed coat of infected seed, or in debris from diseased plants.

Weather plays an important role in determining the extent of the disease. Absence of rainfall during seedbed season in the Pacific Coast areas of the United States helps to deter blackleg. For control, crop rotation at least every 3 years is necessary. However, rotation must be accompanied by careful cultural practices, including field sanitation and removal of all debris. In the United States, seed from the Pacific coast is generally considered more likely to be free of infection than other seed. Treating all seed with hot water (122°F; 50°C) for a period of a half-hour is effective.

Clubroot disease has been known since the 1200s in western Europe. The disease was well established on rutabaga and turnip in the early 1800s and was reported on cabbage in the U.S.S.R. in the 1870s. The causal organism is *Plasmodiophora brassicae* Wor., 1877. Many species, wild and economic, of the mustard family (Cruciferae) serve as hosts for the disease. Like many other fungal infections, the disease is not immediately apparent from inspection of the emerged parts of an affected plant during the early stages. The disease is named from the fact that roots that are infected become enlarged and clubby in appearance. See Fig. 6. Some clubs are spheroidal; others in the shape of a spindle. Rapid growth of the club tissue invites secondary infection by soil-rot bacteria, hastening the process of complete deterioration. With decay of the roots, wilting of the tops occurs. See Fig. 7. A small percentage of plants may recover, but will be stunted and yields and quality will be low. Possibly the worst feature of clubroot disease is making a plant ready for a series of secondary rot infections. Infected cells throughout the plant tend to enlarge and root and stem galls may be formed.

Clubroot, also known as slime mold, is distributed throughout the United States. Control is principally by crop rotation and cultural practices and cleanliness.

Fig. 7. Wilting of half-grown cabbage plants that developed severely clubbed roots. (*USDA photo*)

Downy mildew of cabbage and other crucifers is not usually of major economic importance, usually appearing only on the older leaves of a plant. However, development of the disease in young seedlings can be disastrous to the crop. The causal organism is *Peronospora parasitica* (Fr.) and the disease is widespread throughout the United States. The organism is quite temperature-sensitive, the most severe penetration of a host plant taking place at about 60°F (15.6°C). However, after infection, spread of the disease requires higher temperatures in the range of 75°F (23.9°C). In the United States, the disease is found most frequently in seedbeds where the average winter temperature is from 50° to 59°F (10° to 15°C).

Root rot of cauliflower is caused by the organism *Phytophthora megasperma,* a disease that is related to numerous other plant diseases, such as crown rot of rhubarb and pink rot of potato.

Pythium root rot and **soft rot** affect many of the crucifers. Crucifer fruits, such as cabbage, are affected by soft rot during storage and transit and in the marketplace. Infection usually occurs when the fruit has been wounded or in touch with wet soil. Sometimes difficult to distinguish from bacterial soft rot, the *Pythium* rot progresses very rapidly once started. Care in handling the fruit during and after harvest is paramount in controlling this infection.

Rhizoctonia fungal diseases are common in the crucifers and many other plants are described later.

White rust of crucifers is found on cabbage and cauliflower in Europe, but infrequently in North America. In the United States, it is found on horseradish and radish, particularly on greenhouse crops during the winter season. White rust also attacks spinach. Although damaging, the disease is not considered of major economic importance. The causal organism is *Albugo candida* Kunze, 1891, and infection may be localized or systemic. In localized infections, shiny white areas (1 to 2 millimeters in diameter) occur on stems and leaves. Later development of a pustule with a powdery consistency occurs. The disease becomes systemic when young stems and flowering parts are infected. This results in deformation of various parts of the plant, particularly of the flowering portion. Because of the limited economic important of the disease, research has been minimal. Crop rotation is an effective control. Bohemian type horseradish exhibits a greater resistance to the disease than other varieties of the plant.

Yellows or cabbage yellows disease is caused by the organism *Fusarium oxysporum* f. *conglutinans* Snyder & Hansen, 1940. The disease was first noted on cabbage in New York state in 1899. After this discovery, the disease spread rapidly to the west, invading Ohio and parts of Illinois, Wisconsin, and Iowa. In addition to this cabbage-growing belt in the United States, the disease also has been reported in Brazil, Cuba, and Trinidad in Central and South America, and in Australia, Japan, the Philippines, and Rhodesia. It has been found that different races of the pathogen attack different crucifers, so-called Race 1 attacking Brussels sprouts, cabbage, cauliflower, broccoli, Kohlrabi, mustard, rape, rutabaga, and turnip; whereas Race 2 attacks all of the foregoing hosts with exception of cabbage, Brussels sprouts, and cauliflower. Two additional races have been designated: Race 3 which attacks stock in California; Race 4 which attacks stock in New York.

The disease attacks a plant at any time in the plant's growth process. A pallid, yellow-green color of the foliage is a first symptom. Often there is a lateral curling of the leaves. See Fig. 8. The diseased tissues shortly turn brown and expire. Later, the vascular system turns yellow and brown. The disease is frequently confused with black rot. Control measures include planting seed in clean soil. Yellows-resistant varieties, such as *Badger Market, Globe, Jersey Queen, Marion Market, Resistant Detroit, Wisconsin All-Season,* and *Wisconsin Ballhead* should be planted in areas where the disease is suspected. Chemical treatment is of little value.

Cucurbit. A rather large number of fungal diseases attack the cucurbits. **Anthracnose disease** attacks cucumber, muskmelon, and watermelon. The related bean anthracnose disease is described here under "Bean." Symptoms include reddish-brown, circular spots on leaves; elongated, tan cankers on stems; round, sunken spots with pinkish-tan centers (later turning dark) on fruits. Damage is worse during period of moist, warm weather. The fungus *Colletotrichum obiculare* is carried on seeds and lives in the soil. Distribution is throughout the central, eastern, and southern United States. Cucurbits should not be grown in the same soil more frequently than once in 3 years. Control chemicals include dusts of captan or ziram. Where mildew also is present, a spray containing a fixed copper fungicide or an organic fungicide can be used. Ferbam should not be used.

Downy mildew of cucurbits was noted first in the late 1860s from specimens found in Cuba. Some years went by before it was again noticed in a New Jersey greenhouse in the late 1880s. Shortly thereafter, it was found on cucumbers from Japan. The disease progressively spread along the Gulf and Atlantic Coast states in the United States and is distributed in several other regions of the world with similar climates. The causal organism is *Pseudoperonospora cubensis* Rostow., 1903. Host plants include cucumber, gourd, muskmelon, pumpkin, squash, and watermelon, as well as certain minor members of Cucurbitaceae.

Fig. 8. A partially grown cabbage plant showing distortion of lower leaves caused by the yellows disease. (*USDA photo*)

Symptoms include yellowish, angular spots on older leaves; fruits are not affected, but leaves dry, curl, and die. Fungus is not carried on seeds and does not overwinter in soil. Control chemicals include a dust or spray containing a fixed copper fungicide or an organic fungicide. Ferbam should not be used. Mildew-resistant varieties, such as *Ashley, Fletcher, Palmetto, Palomar, Santee, Smoothie,* and *Stono,* should be grown in suspected areas.

Fusarium wilt of cucurbits is allied with Fusarium yellows of cabbage previously described. The specific causal organism for muskmelon wilt is *Fusarium oxysporum* f. *melonis* Snyder & Hansen; and for watermelon wilt, it is *F. oxysporum* f. *niveum* Snyder & Hansen. Control is through prevention, selecting varieties that are known to possess some resistance to the disease and employment of improved cultural practices.

Powdery mildew disease affects muskmelon in some regions of the United States.

Pythium soft rot affects cucurbit fruits during storage and transit.

Cucumber scab is caused by the organism *Cladosporium cucumerinum* Ell & Arth. Symptoms include sunken, dark-brown spots on fruits. Gummy substance oozes from fruits. In moist weather, spots are covered by grayish-olive fungus growth. Some small, brown spots may appear on leaves and stems. This fungus also attacks summer squash, particularly crookneck and yellow straightneck varieties. The damage increases in cool, moist weather. This fungus lives in the soil. Distribution is throughout the north-central and northeastern United States. Cucumbers or squash should not be grown in the same soil more often than once in 3 years. Scab-resistant varieties, such as *Ashe, Fletcher,* and *Highmoor,* among the slicing varieties; and *Wisconsin SMR 12* and *Wisconsin SR 6,* among the pickling varieties, should be selected. Spraying or dusting is not very effective against scab.

Sclerotinia disease affects the cucurbits as well as many other plants and is described later. Cucurbits are affected by *Pythium* (damping-off) disease.

Eggplant. Occasionally eggplant may be attacked by late blight disease, a disease that is more frequently associated with potato. See "Potato" in this description. Eggplant also is subject to *Pythium* damping-off fungi.

Garlic. The **downy mildew of garlic,** caused by the organism *Peronospora destructor* Casp., 1860, is similar to the same condition on onion and is described under "Onion" later in this entry. This is also true of the fungal diseases, **neck rot** and **white rot.**

Grape. Downy mildew of grape is distributed throughout the United States and North America. The disease was first noted in the United States in 1837. While encountered elsewhere, it is most serious in the eastern states. The disease was not observed in Europe until 1878, when it was found near Bordeaux, France, in a nursery which had imported seedlings from the United States. The disease became extremely serious in western Europe and it was to fight this disease that Bordeaux mixture was developed in the early 1880s. The disease is considered to be under reasonably good control. Early symptoms of the disease are small greenish-yellow spots which appear on the upper side of leaves. These spots are about 1/5-inch (1/2 centimeter) in diameter and have an oily appearance. The downy mildew appears on the under side of the leaf shortly thereafter. It is most severe in moist weather. See Fig. 9.

Immature berries develop brown spots which later are covered over with downy growth. See Fig. 10. Older fruits develop larger brown patches and have a tendency to harden. Subsequently, the skin shrivels and the color changes to a gray-blue or dark brown. The causal organism is *Plasmopara viticola* Berl. & DeT., 1898. The fungus overwinters in diseased leaves. As the leaves disintegrate during the winter and spring, the fungus is released. It reproduces during rainy weather and is splashed onto new growth, causing infection. If the infection is late in the season, a brown rot develops without the usual development of downy fungus growth. Ferbam and zineb are used as control chemicals in many regions instead of the earlier Bordeaux mixture. However, because grape is affected by a number of diseases that require control, a mixture of chemicals is normally used.

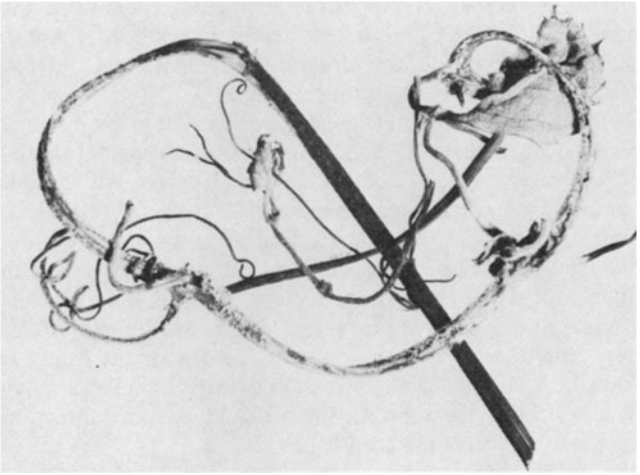


Fig. 9. Tips of grapevine killed by downy mildew. (*USDA photo*)

Fig. 10. Extensive evidence of downy mildew on young grape berries. (*Cornell University, Department of Plant Pathology*)

Powdery mildew attacks all parts of the vine and appears as a grayish, powdery mold on the upper leaf surfaces and stems. The organism *Uncinula necator* Burr causes the disease. The fungus can attack the fruit in most stages of growth, causing a russetlike surface. Infected fruit will sometimes crack open and drop from the vines. In severe cases, powdery mildew can russet all fruit on some varieties. It also reduces the size and quality of the berries harvested. The fungicide, benlate, is effective against powdery mildew as well as black rot.

Anthracnose of grape can cause extensive losses in poorly kept vineyards, but it can be controlled economically. Anthracnose overwinters on infected canes and spreads to all new growth during wet periods in early spring. The appearance of anthracnose on fruit, stems and leaves is not readily confused with black rot and other diseases. Fruit infections appear as a "bird's eye" effect, having light-gray centers and reddish-brown borders. Stem lesions are similar in color, sunken, with slightly raised borders. Severely infected leaves become distorted and curl down from the margins. Individual spots are gray with a dark border. Later, the center of the lesions drop out, giving a ragged effect. Ferbam is effective against anthracnose.

Black rot is a serious economic disease of grape in many regions. In such regions, the entire cultural program should be pointed toward its control. Other diseases will be less troublesome when recommended practices for black rot control are carried out. The causal organism is *Guignardia bidwellii* Viala & Ravaz. Black rot fungus overwinters in infected canes and on old, rotten grapes that fall to the ground during harvest. In early spring, the fungus infects new growth as soon as it appears. The disease then spreads from new shoots to the young grapes. Fruit infection can occur at any time before maturity, but most infection occurs by the time the fruit is half-grown.

The first sign of fruit infection is dry, black, scabs or pimples on the fruit. These spots can occur in all stages of maturity. Leaf infection appears as tiny, reddish-brown spots on the upper leaf surface. The lesions enlarge to about 1/4-inch (6 millimeters) or more in diameter and turn brown with black borders. A ring of black fungus bodies develops near the outer edge of the brown area. These tiny bodies produce spores which infect other leaves.

Severe annual pruning is a very important practice for controlling anthracnose and black rot. All excess growth should be pruned and burned. The only part of the vine to be kept year after year is the trunk. Only strong, healthy canes of the prior year's growth should be selected to produce the following season's crop. The selected canes should be as free of disease spots as possible. After fruiting canes have been selected, all excess growth, dried berries, and leaves should be removed. The remaining vine should contain only the permanent trunk, 1-year-old fruiting canes, and short spurs to produce new canes.

The fungus which causes black rot can also come from old berries and leaves on the ground. Cultivation of the soil just before new growth begins in the spring covers old berries and greatly reduces black rot infection. Timely cultivation or the use of herbicides throughout the spring and summer controls weeds which might prevent good air circulation and hinder spraying operations. In hot, humid areas, more spray applications are required than in cooler areas. Vineyards where excessive foliage causes shading will require more spraying than those where the fruit is exposed to sunlight and good air circulation.

Popularly used in many areas of the United States is maneb (80% wettable powder) at the rate of 2 pounds per acre (2.2 kilograms per hectare). Where powdery mildew is also a problem, wettable sulfur or karathane may be added to the mixture.

Bitter rot caused by the organism *Melanconium fuligineum* is common in most *muscadine* grape vineyards. The fungus can overwinter in stem lesions, or be blown into the vineyard by wind. The disease damages the fruit primarily, although it can cause leaf and stem infections as well. Fruit is most susceptible when it approaches maturity. The first sign of disease is a dark, watersoaked spot on the fruit which could resemble insect injury. Later, the fungus spreads over the entire berry, causing it to become wrinkled. After a few days, infected berries shrink and turn dark. Tiny, black fungus fruiting structures appear on the discolored fruit surface.

Ripe rot caused by the organism *Glomerella cingulata* Spauld. & Schrenk, 1903, is different to distinguish from bitter rot without microscopic examination. The fruit symptoms are almost identical. Ripe rot may occur a bit closer to harvest and cause the fruit to take on a somewhat darker color than bitter rot. Ripe rot is accelerated when fruit has been injured by insects or damaged during harvest. The fungus consumes most of the berry, leaving only a shriveled black shell.

Macrophoma rot caused by the organism *Botryosphaeria ribis* attacks the fruit near harvest time. The fungus is windborne. The spots caused by the fungus are more distinct than those of bitter rot or ripe rot. But, in the latter stages of infection, macrophoma is difficult to distinguish from other rots. Soon after the fungus invades the fruit surface, a light-brown spot develops which later turns dark. Several spots can run together, making the entire berry a watery mass of rotten tissue.

Horseradish. See "Crucifer" in this description.

Kale. See "Crucifer" in this description.

Kohlrabi. See "Crucifer" in this description.

Leek. See "Onion" in this description.

Lettuce. Downy mildew of lettuce, caused by the organism *Bremia lactucae* Regel, 1843, was first described in Europe by Regel. No record of the disease in the United States was made prior to 1875. Distribution of the disease is worldwide wherever lettuce is produced. The disease is damaging from several aspects. Diseased leaves must be trimmed, reducing the weight of lettuce going to market as well as increasing packing costs; the disease remains active during storage and transportation stages; the disease makes the plant susceptible to numerous secondary infections. The disease causes wilting of outer leaves; watery soft rot on stems and old leaves; wilted and decayed plants. The disease is aggravated by wet weather and humid conditions. In the United States, mainly because of climate, the disease is worst in the central, eastern, and southern states. Prevention includes avoidance of close planting and planting in poorly drained soil. The soil should be ridged slightly about the plants to prevent water from accumulating.

Lettuce is also affected by *Rhizoctonia* and *Sclerotinia* diseases, described later.

Maize (corn). Maize is affected by numerous fungal diseases. **Brown spot of maize** is a serious economic disease. The disease was first reported in India in 1910 and a year later in the United States. In the United States, the disease is most prevalent in the southeastern states. All varieties of *Zea mays* L., including field corn, popcorn, and sweet corn, are susceptible. The causal organism is *Physoderma zeaemaydis* Shaw, 1910. Rarely affecting the husks, the disease is found on culms, blades, and sheaths. The disease is usually confined to the lower portions of the plant. First symptoms are a large number of yellowish spots that appear on the blade and sheath of the plant. These spots range from 1 to 5 millimeters in diameter. Severely infected parts of the plant die prematurely. Sometimes tissue is sufficiently weakened to cause lodging. Crop rotation and cultural methods are the main preventive measures. Research continues on improving resistant varieties.

Diplodia disease of corn, caused by the organism *Diplodia maydis* Sacc., 1884, has several other names, including **ear rot, root rot, stalk rot,** and **seedling blight**. The disease is most prevalent in the southern portion of the corn-producing states—Illinois, Indiana, Iowa, and Ohio. The disease is often associated with similar conditions produced by *Gibberella* species. Losses from this disease (or combination of diseases) can total in the many millions of dollars per year. Once the roots are infected, involvement of the rest of the plant in the disease cycle may be rapid. The stalk loses its green color and the leaves appear frost-bitten. The ears are attacked from the butt end and as the ears rot, the leaves of the plant turn purple and die prematurely. Even where ears may be harvested, progress of the disease may continue during storage and transportation phases, resulting in variations of kernel infection.

Crop rotation, very sanitary cultural practices, and treatment of seed are necessary to keep the disease within control in some regions. Captan is frequently used for seed treatment. Varieties with a maximum resistance to the disease should be selected.

Gibberella diseases (ear rot, seedling blight, stalk rot) of maize are described in this entry on "Cereals."

Corn smut is a common disease and can cause heavy damage. The causal organism is *Ustilago maydis* Cda., In common corn smut, galls are produced on stems, leaves, axillary buds, ears, and parts of the male flowers. Such galls can be quite large, up to 4 inches (10 centimeters) in diameter. Initially, the galls are whitish and they remain of a light coloration until spore formation inside finally causes the outer membrane to break, thus exposing a powdery black mass of spores. Location of the galls is critical to how the plant is affected. When galls are present on young seedlings, dwarfing or expiration of the plant is inevitable. Stem galls tend to bend the stem and cut yields. When the infection is present in the silk, small galls replace the normal kernels. The principal control mechanism is the careful selection of the most resistant varieties.

Aflatoxin, a dangerous fungus or mold known as *Aspergillus flavus*, will sometimes develop on shelled corn (maize) when environmental conditions are just right. An outbreak of this problem occurred in the southeastern United States in the fall of 1977. Unless the disease is prevented or corn is processed to remove toxicity, the aflatoxin can be lethal to poultry and livestock to which poisoned grain is fed. Aflatoxin is so toxic that the maximum tolerance allowed by the United States Food and Drug Administration for consumption is 20 parts per billion. The *Aspergillus flavus* fungus develops when the corn in the field is damaged to the extent that the mold spores can get beneath the shuck. Once the mold comes in contact with moist grains of corn, it produces the toxic agent. When the toxicity exceeds 150 parts per billion, heavy mortality occurs in swine under 8 weeks of age and inhibits the growth of older swine. The tolerance level for dairy cattle is considered zero because aflatoxin is a carcinogenic agent and is secreted directly into cow's milk.

A new experimental process for reducing the toxicity of affected corn became available in the mid-1970s and is capable of reducing toxicity from 1200 parts per billion to 15 parts per billion. Grain dealers should have the necessary laboratory equipment for checking grain samples for aflatoxin. The following procedures are quite effective in reducing the incidence of aflatoxin on corn: (1) Allow corn to mature to 23 or 24% moisture on the stalk; (2) adjust the combine for minimum cracking and maximum cleaning of grain; (3) dry all shelled corn as soon as possible, preferably within 48 hours after combining; (4) cool after drying; (5) store in clean, dry locations; (6) aerate stored corn whenever possible; and (7) store corn with a lot of moisture in airtight structures. Mold growth is essentially stopped when corn is dried to 14% moisture or lower. Of course, any aflatoxin present prior to reduction of moisture level will remain.

The *Pythium* organisms cause **root rot** and **stalk rot of maize (corn).** These fungi also attack numerous other plants, including oats, sugar cane, sorghum, and wheat. The fungi attack in different ways. When the fibrous root system is first attacked, rootlets are softened and killed, resulting in stunting, wilting, and expiration of the plant. Where infection occurs above groundlevel, lesions develop and may or may not become a serious threat to the plant. The organism causing stalk rot of corn is *Pythium aphanidermatum.*

Head smut is caused by the organism *Spacelotheca reiliana* Clint and, in the United States, occurs mainly in the western states. However, in India, South Africa, the U.S.S.R. and other maize-producing regions, it is the principal smut disease. Sorghum is also affected by this disease.

Maple. Along with many other trees, maples are affected by **white heart** rot, described later.

Muskmelon. See "Cucurbit" in this description.

Mustard. See "Crucifer" in this description.

Oats. The **black loose smut disease** and the **covered smut disease** of oats have many parallels and commonly occur in the same crops at the same time. In black loose smut, black powdery masses of spores are found in the panicle among individual flowers, where the spores replace the mature kernels. The covered smut is similar with exception that the smut is covered over by a semipermanent membrane of host tissue. Causal organisms are *Ustilago avenae* Rostr., 1890 for black loose smut; and *Ustilago kolleri* Wille, 1893 for covered smut. Several races of each of these organisms have been identified and considerable research has gone forward in improving disease-resistant varieties of the host plants. The principal control method is seed treatment, which should be practiced even with resistant varieties. Because the fungicide used must be volatile in order to reach spores lodged beneath the hull, formaldehyde has been popular for a number of years.

Ergot, which affects oats, is described in this entry under "Cereals."

Gibberella diseases (foot rot, head blight, seedling blight) of oats are described in this entry under "Cereals."

Onion. Downy mildew of onion, caused by the organism *Peronospora destructor* Casp., 1860, was first reported in the British Isles in 1841, but not found in North America (Wisconsin) until 1884. The disease is widespread throughout the world and is notably damaging in cool, moist climates. In Europe, it is common in those regions which border the North Sea and, in the United States, it is most prevalent along the northwest coasts (California, Oregon, and Washington) and the northeast coasts (New York to New England), but also has been found in Louisiana. The organism also affects chive, garlic, leek, shallot, and Welsh onion. The disease may be present as a localized infection or as a systemic infection. In the latter situation, the plants remain dwarfed and leaves are pale and distorted. See Fig. 11. When the weather is sufficiently humid, the fungus fruits on the surface of leaves and seed stems. The mildew has a characteristic purple or violet color. Progress of the disease is hastened by humid conditions. Local lesions cause paling and yellowing of leaves and stems. Complete expiration of plants seldom occurs, but quality is severely affected. Bulb tissue tends to be spongy and storage capability of the commodity is greatly reduced. Sometimes, a secondary organism *Stemphylium botryosum* Wallr accompanies onion mildew lesions. This disease produces prominent black mold.

Fig. 11. Evidence of presence of downy mildew on seedstems of onion grown in Imperial Valley, California. (*USDA photo*)

Gray-mold neck rot of onion, caused by the organism *Botrytis allii* Munn, 1917, has been known since 1876 when it was discovered in Germany. First reports in the United States were in 1890, followed in the British Isles in 1894. The disease is now quite widespread throughout onion-growing regions of the world. Related species of this organism produce specific variations of the disease, namely, *Botrytis byssoidea* J. C. Walker causes **mycelial neck rot;** and *B. squamosa* J. C. Walker causes **small-sclerotial neck rot**. These organisms overwinter as sclerotia in the soil and in bulbs. The disease is easily spread by decayed bulbs during storage and transportation phases of the commodity. It has been established that the *Botrytis* fungi may also trigger blast or leaf spotting of the plant during the growing season.

Experience has shown that white varieties of onion are more susceptible to the disease than the yellow and colored varieties. However, the colored varieties are not immune and can be severely affected. Crop rotation is usually not practical as a control mechanism.

Often, the disease is not noticed until time of harvest. Early infection may appear on the neck tissue as a slightly sunken and scalded or cooked area. Later, this tissue turns gray with a definite demarcation between diseased and healthy tissue. Dense, gray mold develops and spreads down the entire bulb and, if allowed to proceed without destruction of the bulb, the bulb takes on the appearance of a "mummy."

Practical controls include careful handling during harvesting and optimal storage conditions. Forcing warm, dry air through bulbs in bins helps to keep the scales dry and thus reduces susceptibility not only to neck rot, but to smudge and bacterial soft rot as well. In the growing phase, carbamate sprays sometimes are used.

Onion smudge, caused by the organism *Colletotrichum circinans* Vogl, 1907, was first found in the British Isles in the mid-1800s and it is common today in Europe and North America, particularly in the northeastern and midwestern United States. The disease is most prevalent among white varieties of onion. Its economic importance relates to the fact that the disease causes blemishes on the outer scales of the commodity and thus reduces market value. See Fig. 12. Damage is essentially limited to the scales and unthickened leaves. The fungus is capable of living in the soil for many years without a host to attack. Development of the fungus requires moist weather. Dissemination is often accomplished by spattering rain. Controls are essentially the same as those described for neck rot.

Onion smut, caused by the organism *Urocystis cepulae* Frost, 1877, was first noted in the United States (Connecticut) in 1869 and the disease spread rapidly throughout all onion-producing regions, ultimately reaching Canada and westward to Oregon. Evidence indicates that the pathogen originated in Europe. The disease occurs in many European countries, as well as India, Egypt, and New Zealand. Generally, the fungus thrives best in northern climes and, in the United States, for example, is seldom noted south of Kentucky. The disease is essentially absent from southern

Fig. 12. Appearance of onion smudge on onions otherwise ready for market. (*USDA photo*)

France, Italy, and Spain. In addition to onion, the disease affects leek and Welsh onion.

The disease is often lethal. A high percentage of infected plants expire within 3 to 4 weeks after emergence. If infection is late and the commodity reaches storage, this particular fungus does not cause a storage rot, but does weaken the bulbs to invasion by other fungal and bacterial pathogens.

Control measures include avoidance of soil where disease has occurred. A formaldehyde solution (1 teaspoon in 1 quart of water; about 5 grams to 1 liter of water) sprinkled over seeds before covering row with soil can be effective.

White rot of onion, caused by the organism *Sclerotium cepivorum* Berk, 1841, was first noted in the British Isles in 1841, but was not regarded seriously until the early 1900s, when it damaged garlic crops in Italy. The disease also affects leek and shallot. White rot is known in most of western Europe, on the island of Cyprus, in countries of South America, in Egypt, India, and South Africa. Appearance of the disease in North America was first noted in 1923 (Virginia), later spreading west to California, south to Louisiana, and north to Canada. There is no particularly vulnerable period for the plant, invasion by the fungus being more dependent upon environmental conditions than by age of plant. When young plants are attacked, the disease usually progresses rapidly, with the plants expiring within a few weeks. First external signs of the disease are a yellowing and dying back of the leaf tips and gradually working back to the major area of the leaf. At this time, damage to the root structure underground is also occurring. Fluffy and white branched mycelium may be noticed on the host tissue. The fungus lives for many years in the soil in the absence of host plants. Cool, moist areas are most favorable to the disease, but it should be noted that the warm regions of Spain where lots of onions are produced are relatively free of the disease. Various control chemicals have been used over the years, including mercuric chloride drench around the plants, liming of the soil to return the soil pH to normal, and, in more recent years, soil treatment with botran (2,6-dichloro-4-nitroaniline).

Pea. This plant is affected by **anthracnose,** caused by the organism *Colletotrichum pisi* Pat. This is a condition similar to that of anthracnose of bean. See "Bean" in this entry.

Aphanomyces root rot of pea is caused by the organism *Aphanomyces euteiches* Drechs., 1925. The disease was not described until 1925, a few years after it was first noted in Wisconsin. The disease is found today in many other states and in Australia and Europe. In the early 1940s, scientists concluded that many thousands of acres of garden peas for canning had been list to this disease in Wisconsin over a number of years. The fungus also affects alfalfa, cowpea, hairy vetch, sweet clover, sweet pea, and tomato, but the disease is not considered a serious economic threat to these crops. Closely related *Aphanomyces* species are causal organisms of black root of radish and damping-off and tip rot of sugar beet.

Early symptoms are appearance of soft, water-soaked tissue about the lower portion of the stem and root. The infection kills off the fine roots as well as damaging the upper portion of the taproot. Decay may be noted to only a few inches above groundlevel, adding to the difficulty of early diagnosis. A plant that has been infected for some time may be pulled up easily because of the diseased taproot. Exact diagnosis may require a microscopic examination of affected roots. External signs of disease progress are very general—a dwarfed structure, shriveling and dying leaves. A well-planned crop rotation schedule, along with exacting cultural practices, are essential to control. Soils high in clay should be avoided. Beds should be well-drained and fertility maintained at a high level.

Mycosphaerella and Ascochyta diseases of pea. These are closely related diseases and affect garden pea. Actually, there are three species of fungi which are functional in this family of diseases: **Mycosphaerella blight** caused by the genus *Mycosphaerella;* **Ascochyta leaf and pod spot** is caused by *Ascochyta pisi;* and **Ascochyta foot rot** is caused by *A. pinodella* L. K. Jones. Worldwide in occurrence, these diseases have been known for a few hundred years in Europe, but the first description did not appear in Europe until 1830. *A. pinodella* was not completely identified until 1927. Blight is found mainly east of the Rocky Mountains and on the Pacific coast. Foot rot occurs in the same regions, but is aggravated by irrigation. Wet weather favors these diseases.

Best control is effected through careful planning and cultural practices. Seed crops should be produced in regions of low rainfall during the growing season. Since the fungi do not inhabit the soil permanently, they overwinter above soil in various plant debris. Such debris can be thoroughly destroyed, or allowed to completely deteriorate over a period of a few years, using the plots for other crops meanwhile. Because the ascospores are blown by the wind, any new plantings should be made at a minimum of 1/4-mile (0.4 kilometer) from known infected areas. Treatment of pea seed with protectorants is excellent practice for the control of other pathogens, but has little or no effectiveness on the causal organisms of these diseases. Some authorities, however, have indicated that soaking seeds for a full day in captan or thiram suspensions (0.2%) can be effective.

Fusarium wilt of pea may result from one of two organisms: *Fusarium oxysporum* f. *pisi* race 1 Snyder & Hansen; and *F. oxysporum* f. *pisi,* race 2 Snyder & Hansen, the latter causing a condition known as **pea near-wilt**. Symptoms of *Fusarium* wilt are yellowed leaves; wilted plants. Interior of stems are lemon yellow. Disease sometimes kills plants. The fungus lives in soil and enters through the roots. Distribution is throughout the United States and many other pea-producing areas of the world. The most effective control is selection of disease-resistant varieties, such as *Alaska, Alderman, Grant Stride, Progress No. 9,* and *World Record.*

Pythium species of fungi cause root rot and stem rot and a foliage blight of some varieties of pea. The pre-emergence rotting of pea has been found to be more pronounced in the wrinkle-seeded varieties than in the smooth-seeded varieties. It also has been found that varieties of pea that have colored flowers (with colored seed coats) have a greater resistance to *Pythium* than those with colorless flowers and seed coats. This increased resistance is considered by Ewing[1] to arise from the presence of phenolic compounds in the colored seed coats.

Rhizoctonia solani, while primarily associated with potato, also attacks pea. See "Potato" in this description.

Peach. Brown rot of peach is described later in this entry—as the disease relates to all stone fruits.

Peach leaf curl, caused by the organism *Taphrina deformans* Tul., 1866, has been known in Europe and North America since the early 1800s. The disease is distributed worldwide wherever peaches are produced. The disease is of particular economic importance in the United States in the Great Lakes region, in the coastal valleys of Oregon and Washington, and in central and northern California. The early symptoms are curling and puckering of the leaves in early spring. This is caused by an abnormal thickening of the blade. As the disease develops, the leaves turn yellow-to-red, ultimately assuming a silvery appearance. Thickening of the leaves causes them to become brittle. Twigs also can be infected. Any affected fruits drop to the ground promptly. Fortunately, the disease is relatively easy to control by applying a dormant spray of 5-50 lime-sulfur, or a 1-20 lime-sulfur, 3-4-50 Bordeaux mixture. The organic fungicide omadine is also effective. Usually one application, made in the fall or early spring, suffices to bring about good control.

Pear. The pear is susceptible to **brown rot**, described later, and to **Phytophthora diseases**, described in this entry under "Potato." Pear is also susceptible to **white heart rot**, described later.

Pepper. Anthracnose of pepper causes large, dark-brown or black spots (whose centers have black specks) on fruits. Sunscalded fruits often attacked by another fungus that causes spotting similar to anthracnose. The fungus is carried on seed and lives in the soil. Distribution is in the central, southern, and Atlantic Coast states of the United States. Control is by planting clean seed and treating seeds with a dust or spray containing zineb.

Cercospora leaf spot disease is most common in the southeastern and Gulf states of the United States. Symptoms include circular, water-soaked spots on leaves and stems. Spots enlarge to 1/4- to 1/2-inch (6 to 13 millimeters) in diameter, turn white in centers, and have dark margins. Infected leaves often drop. Occasionally does serious damage. Fungus is carried on seed. Control is by planting in new seedbed soil. If plants show damage, application of a dust or spray containing a fixed copper fungicide is effective.

The pepper is also subject to **damping-off** (*Pythium*) fungi. The seeds decay in the soil and young plants collapse. Seeds should be treated with a fungicide prior to planting.

Pineapple. This plant is attacked by the organism *Thielaviopsis paradoxa* Hoehn, producing a condition known as pineapple black rot. The condition is controlled after harvesting and prior to packing by applying benzoic acid to the cut stalk. This procedure was developed in Australia.[2]

Plum. The plum is susceptible to **brown rot**, described later.

Potato. This plant is affected by a number of fungal diseases. **Black wart of potato**, caused by the organism *Synchytrium endobioticum* Perc., 1910, was first discovered in Hungary in 1895, but is found in nearly all countries of Europe, in Central and South America, and India. It was not reported in Canada until 1909 (Newfoundland) and 1918 (Halifax). It was also noted in the United States (Pennyslvania) in 1918. The disease is rare in the United States because of effective quarantine measures. The fungus is also parasitic to tomato and a number of nonfood plants. The disease when present can be extremely damaging. Infected potatoes become horribly disfigured. The warts range considerably in size and growth usually starts on buds on stems, stolons, and tubers. Embargo on importation of potatoes from countries where wart is known, quarantines, and requirements to plant only disease-resistant potatoes in known susceptible areas—all have been effective measures in controlling the disease in the United States.

Early blight of potato, caused by the organism *Alternaria solani* L. R. Jones & Grout, 1896, has been known in the United States since 1882. Tomato is also a host of this pathogen. The disease is of economic importance on both plants. Prior to effective insecticide controls for leaf hopper, it was difficult to sort out the damage caused by the insect and by early blight disease because the two sources of injury were usually coexistent. Leaves show small, irregular, dark-brown spots, which often enlarge and have targetlike markings. The disease injures foliage and reduces yields. The fungus is carried in the soil and may be present in tubers. Distribution in the United States is mainly in the central, southern, and eastern states, although regions of the west and northwest which have overhead irrigation also are affected.

Control is by planting clean tubers and the application of a dust or spray containing a fixed copper or organic fungicide. Applications may be required every 7 to 10 days. Ferbam or ziram should not be used. One of the most effective controls is that of planting only blight-resistant varieties, such as *Cherokee, Kennebec, Plymouth, Pungo, Saco,* and *Sebago*. Tubers of diseased plants should not be dug until the tops are dead and dry.

---

[1] Ewing, E. E.: "Factors for Resistance to Pre-Emergence Damping-Off in Pea," *Dissertation Abstr.* **20**, 1518 (1959).

[2] Dickson, B. T., *et al.*: "The Control of Soft Rot (Water Blister) of Pineapples caused by *Thielaviopsis paradoxa*," *J. Australian Council of Science and Industrial* Research, **4**, 152-161 (1931).

Late blight of potato, caused by the organism *Phytophthora infestans* DBy., 1876, has been known in Europe since the 1500s, having been introduced there from South America. The disease was first reported in the United States about 1830. There was a severe epidemic of the disease in Europe in 1845, when the disease was a major cause of the *Irish potato famine.* The disease continues to be serious in cool and wet regions of the temperate zones. The disease also affects tomato. See "Tomato" in this description. In Europe, the regions around the North Sea are favorable to development of the disease. The eastern Atlantic coast states of the United States also provide a favorable environment. The disease is observed in the more arid areas, such as California, on occasion.

Symptoms include dark, irregular dead areas on leaves and stems. Infected tubers may rot in storage. See Fig. 13. Disease may kill plants early in the season. The fungus is carried in the tubers. Control is by planting clean tubers. A spray of a fixed copper or organic fungicide, applied about every 7 to 10 days, can be effective. Ferbam or ziram should not be used. Best prevention is growing blight-resistant varieties, such as *Cherokee, Kennebec, Plymouth, Pungo, Saco,* and *Sebago.* Diseased tubers should not be dug from diseased plants until tops are dead and dry.

Powdery scab of potato, caused by the organism *Spongospora subterranea* Lagerheim, 1892, was first noted in Germany in 1841. In 1885, it had spread throughout most of Europe. Reports of discovery in South America were noted in the early 1890s. It is believed that the disease may be native to South America, from which it had been transported to Europe. By 1913, the disease was found in nearly all potato-producing regions of the world, including Canada and the United States. Symptoms of the disease are rough, scabby, raised or pitted spots on tubers. The fungus is carried on tubers and lives in soil. Today, distribution is throughout the United States. Control is mainly by prevention and cultural practices. Only clean tubers should be planted. Plantings should not be made in any areas where the disease has been known previously. Lime, wood ashes, or fresh stable manure should not be used on infested soil. Scab-resistant varieties, such as *Cayuga, Cherokee, Early Gem, Menominee, Ontario,* and *Seneca,* should be planted.

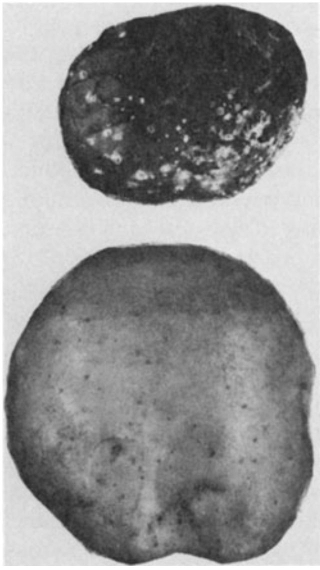


Fig. 13. Effects of late blight shown on potato tuber at top of view. Lower tuber shows no effect of late blight. Both potato plants were artificially inoculated with spores to demonstrate effects on non-resistant and resistant varieties. (*USDA photo*)

Rhizoctonia disease of potato is caused by the organism *Rhizoctonia solani* Kühn. Rhizoctonia fungi were first noted on crocus (saffron) in Europe in the very early 1800s. Investigations later showed that the species found on saffron were responsible for what is known today as **violet root rot.** This is differentiated by most authorities from what is known as *Rhizoctonia* disease. This disease takes on different forms, depending upon the host plant. For example, there is the **Rhizoctonia head rot of cabbage, black root rot of beet, black scurf of potato, stem canker of potato, aerial tuber** and **top rosette of potato,** and others. Variations also arise from the fact that manifestations of the disease depend upon the stage or phase of the disease, of which there are several, including: (1) Damping-off, a disease of young seedlings; (2) stem canker and root rot, which particularly affects potato; and (3) storage-organ decay; and (4) foliage blight or spot.

Seed tubers are notably susceptible to *R. solani* when they sprout and, in some cases, the tubers may be killed prior to emergence. Environmental conditions greatly affect development of the disease. A growing plant usually develops more resistance with time and the stem cankers found on older stems of potato may be quite shallow. The production of stem cankers on potato tends to inhibit the normal downward flow of carbohydrates from plant to tubers. After harvesting and during storage, potato tubers may develop brown or black sclerotia coincident with the skins. In this stage, the pathogen usually does not invade the tuber and hence damage is cosmetic and superficial.

Violet root rot is difficult to distinguish from the above groundlevel symptoms of the several stages of common *Rhizoctonia* disease. Violet root rot is caused by the organism *Helicobasidium purpureum* Pat., 1885. Examination of affected roots that are in advanced stage of the disease will show that they are of a red-violet or violet-brown coloration.

Fungus diseases of potato are also described in separate alphabetical entry in this volume on **Potato.**

Pumpkin. See "Cucurbit" in this description.

Radish. See "Crucifer" in this description.

Raspberry. Anthracnose of raspberry occurs throughout the United States. Symptoms are small gray spots that have dark margins on leaves; purplish spots, about 1 inch (2.5 centimeters) in diameter that have ash-gray centers and raised purplish margins on canes. Badly infected canes are girdled; canes crack lengthwise. Fruits often fail to ripen normally, or wither on canes. Black raspberry canes are more susceptible than those of red varieties. The fungus lives on diseased canes. Control is by planting clean nursery stock. Also three applications of ferbam are effective: First, when leaves are exposed to 1/2 to 3/4-inch (12 to 18 millimeters); second, just before blossoms open; third, after blossoming. Fruiting canes should be burned after harvest. Any new canes that appear to be infected should be destroyed.

Leaf spot of raspberry occurs mainly in the eastern United States, particularly in the south. Symptoms are circular or irregular gray spots, about 1/8-inch (3 millimeters) in diameter, on leaves; stunted canes; reduced yields. Severely spotted leaves drop; canes may be nearly bare in fall. Disease worsens in hot weather. The fungus lives on diseased leaves on the ground. Control is by application of ferbam three times at intervals of 3 to 4 weeks. First application should be made after harvest, when old canes have been removed.

Orange rust is a fungal disease of raspberry that occurs throughout the United States. Symptoms are spindly shoots; small, pale-green leaves; blisterlike pustules on the underside of leaves. The pustules burst, releasing reddish-orange fungus spores. When disease occurs in old hills, only a few canes rust the next spring; in new plantings, infected canes do not blossom, and plants are rusted as long as they survive. The fungus attacks black raspberries, rarely affecting red varieties. The fungus lives in diseased canes. Control is by planting only rust-free stock. If young plants show rust, they should be dug and burned. In the case of old hills, parts of crowns that have been injured should be cut and burned; the remainder of plant may be saved.

Rhubarb. Foot rot or crown rot, caused by the organism *Phytophthora parasitica* Dast, is found in the central and eastern United States. Symptoms include brown sunken spots at base of leaf stalks; decayed stalks; wilted leaves. The disease spreads rapidly in the row. The fungus is carried on roots and lives in the soil. Control is by removing and destroying all diseased plants. Roots from beds where disease has occurred must not be used. Application of a fixed copper spray deep into the crowns of plants is also effective.

Rutabaga. See "Crucifer" in this description.

Rye. Black stem rust, **ergot disease**, and **Gibberella diseases** of rye are described under "Cereals" in this entry.

Salsify. This plant is affected by **white rust of crucifers** disease, described under "Crucifer" in this entry.

Sorghum. This crop plant is affected by **corn smut**, described in this entry under "Maize (Corn);" and by **Gibberella diseases**, described in this entry under "Cereals."

Spinach. This plant is affected by **white rust of crucifers** disease, described under "Crucifer" in this entry.

Squash. See "Cucurbit" in this description.

Strawberry. The *Phytophthora phaseoli* Thaxter fungus is known to incite **red stele root disease** of strawberry.

Sugar Beet. See "Beet" in this description.

Sugarcane. Fungal diseases of this crop include *Gibberella* diseases, described in this entry under "Cereals." Sugar cane is occasionally infected by common *Rhizoctonia* disease; and *Pythium* root rot.

Sweet Potato. Black rot of sweet potato is caused by the organism *Ceratocystis fimbriata* Ell. & Halst. A black spot develops on the base of young potato stems before the plants are removed from the bed. The foliage of affected transplants becomes yellow and appears stunted. A dark to nearly black spot shows up on the potato in the field or in storage. These spots begin as small, round areas, but enlarge until the whole potato is covered. The surface of diseased spots has a somewhat metallic sheen. The tissue just beneath the spot is greenish and has a bitter taste. Dipping of seed pieces in Mertect 340-F may be an effective control.

Sweet potato is also affected by **white rust disease**, described under "Crucifer" in this entry.

Stem rot or wilt fungus of sweet potato causes infected vines to take on a slight off-color or yellowish tinge. Puckering of the foliage and wilting of the plant follows. The older leaves drop off first, leaving yellow leaves near the vine tip. When young vines are affected, many short stems grow at the center of the hill, giving a rosette appearance. If the skin is peeled from the stem, the exposed tissue will show a dark discoloration. This extends long distances up and down the stem and into the roots. Wilt does not cause the stem to rot unless other soil organisms get into the diseased vines. The disease occurs nationwide in the United States. Treatment is the same as for black rot of sweet potato, previously described.

Timothy. This plant is affected by **black stem rust**, described in this entry under "Cereals."

Tomato. Late blight of tomato is caused by the organism *Phytophthora infestans* DBy., 1876. This disease, which is also very serious on potato, was not noted on tomato until about 1854 (France). It will be recalled that tomato was not a popular food substance until the early 1800s in Europe and somewhat later in North America. There was an epidemic of the disease on tomato in the eastern United States in 1946, with crop losses running into many millions of dollars.

Symptoms include dark, water-soaked spots on leaves; large water-soaked spots on fruits; white fungus growths on underside of leaves and occasionally on fruits during moist weather. Spots on leaves enlarge and turn brown; leaves wither. See Fig. 14. Spots on fruits turn brown and remain firm. See Fig. 15. The disease is worse in cool, moist weather. Main distribution in the United States is in humid areas, notably east of the Mississippi River. Control is by application of a dust or spray containing a fixed copper or organic fungicide. Ferbam or ziram must not be applied. Treatments may be required every 7 to 10 days.

Fusarium wilt of tomato is caused by the organism *Fusarium oxysporum* f. *lycoperisci* Snyder & Hansen. Symptoms include a gradual yellowing and wilting of foliage (beginning with lower leaves); browning of woody tissue under the outer green portion of the stem. See Fig. 16. Plants are often killed by the disease. The fungus lives in soil and enters through roots. The disease is found throughout the United States, notably in the southeastern states. The best control is planting of wilt-resistant varieties, such as *Campbell's 17, Enterpriser, Floradel, H 1350, Homestead, KC 146, Kokomo, Manalucie, Manapal, Marion, Pinkshipper* (pink), *Porte*, and *Sunray* (yellow)

Leaf spot is a fungus disease of tomato. Symptoms include small spots that have light centers and dark margins on leaves; dark specks in centers of spots. Many leaves may be killed, and crop reduced. Disease is worse in warm, moist weather. The fungus lives in the soil and on perennial weeds. Distribution is the north central, northeastern, and southeastern United States. Control measures include removal or turning under of vines in the fall, as well as destruction of perennial weeds. Crop rotation can be effective. Chemical controls are a dust or spraying containing a fixed copper or organic fungicide.

Verticillium wilt of tomato is caused by the organism

Fig. 14. Leaves of tomato plant showing dark blotches which are characteristic of late blight disease. (*USDA photo*)

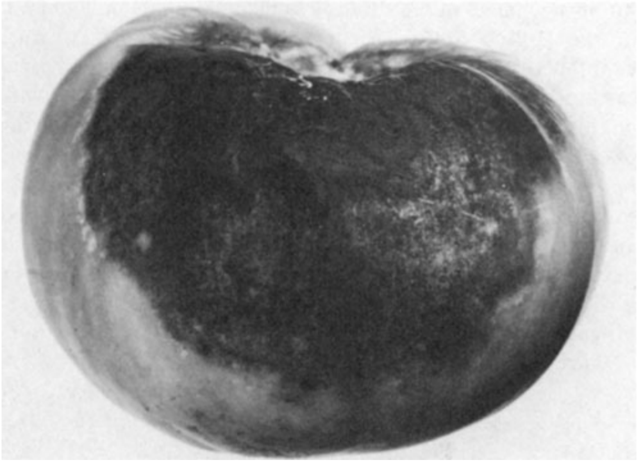


Fig. 15. Effects of late blight disease on tomato. Fruit has a firm, wrinkled surface. (*USDA photo*)

Verticillium alboatrum Reinke & Berth. Symptoms of *Verticillium* wilt are easily mistaken for those of *Fusarium* wilt; both diseases cause the branches to wilt and die. However, the symptoms of *Verticillium* wilt usually appear at the same time on all branches, whereas those of *Fusarium* wilt may appear on a single shoot that will wilt and die before the rest of the plant is affected. *Verticillium* fungus lives in the soil. Fruit of plants attacked by the disease may

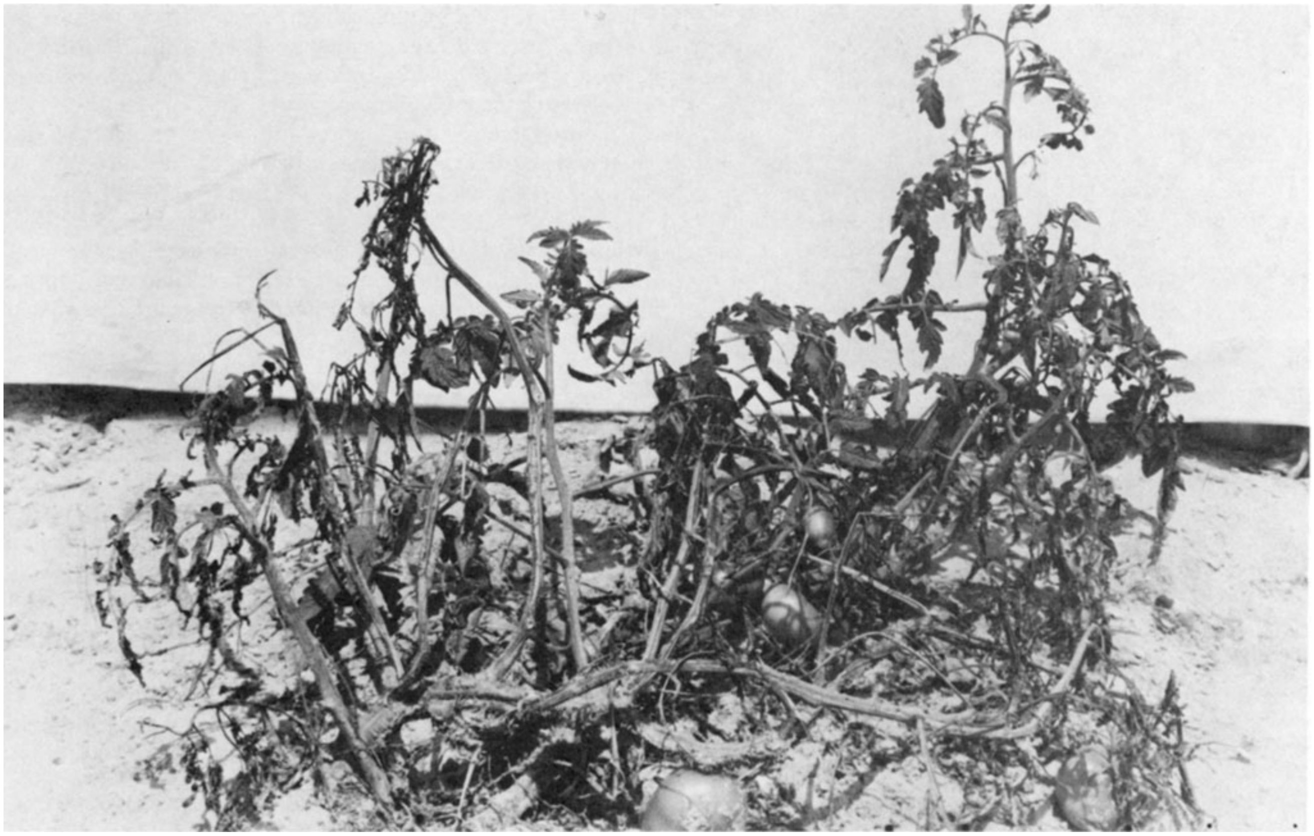


Fig. 16. Evidence of *Fusarium* wilt on tomato plant. Some shoots are dead; others have drooping leaves. (*USDA photo*)

sunburn when exposed directly and some plants may expire. In the United States, the disease is found in California, Utah, Washington, Colorado, the north central and northeastern states, and southern Florida. Sprays and dusts are not effective against this disease. Best control is planting of resistant varieties, such as *Campbell's 17, Enterpriser, H 1350, Pearson types VF6 and VF 36,* and *Porte.* These varieties are also resistant to *Fusarium* wilt. *Loran Blood* and *VR Moscow* varieties are resistant to *Verticillium* wilt only.

Tomato is also susceptible to **damping-off** (*Pythium*) fungus; and to early blight. See Figures 17 and 18.

Turnip. See "Crucifer" in this description.

Fig. 17. Leaves of tomato plant showing symptoms of early blight disease. Targetlike markings are characteristic of disease. (*USDA photo*)

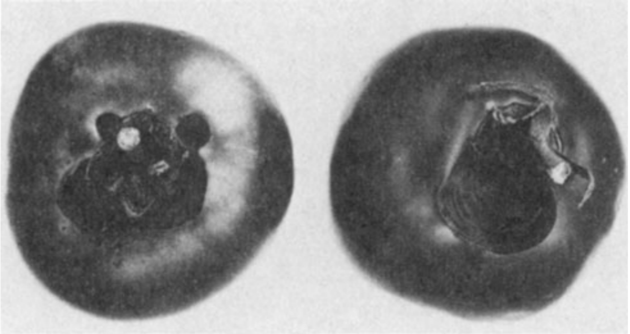


Fig. 18. Effects of early blight disease on tomato. Infection usually occurs near stem scar and spots show characteristic concentric markings. (*USDA photo*)

Watermelon. See "Cucurbit" in this description.

Wheat. Several fungal diseases of wheat also affect other grains and grasses. **Black stem rust, ergot disease, Gibberella diseases,** and **powdery mildew** are described in this entry under "Cereals." **Pythium diseases** are described under "Maize (Corn)."

Bunt or stinking smut of wheat is caused by two organisms: *Tilletia caries* Tul., 1847; and *Tilletia foetida* Liro, 1920. This is a classical fungus disease, in that it dates back to the Middle Ages, at which time it was a serious economic disease. One of the first thorough descriptions was published by Prévost in 1807. The term *stinking smut* derives from the fact that the spores of bunt fungi smell like decaying fish. Consequences of the disease include reduced yields and quality. Spore dust from smutted grain also produces allergic responses among some people and thus it is a hazard for some handlers.

The disease is first noted in the heading stage. Stunting of growth may be noted, depending upon progress of the disease. The affected plants also are considerably more susceptible to infections of other injurious organisms. Early diagnosis in the field may be difficult. Later, it will be observed that diseased kernels are not of the right color, but tend to be gray-brown instead of golden-yellow or red. There also appears a black powdery mass of fungus spores occupying the kernel within the pericarp.

Over the years, three practices have brought the disease within control: (1) Rotation of crops, timing of planting, and other desirable cultural practices; (2) planting of resistant varieties; and (3) treatment of seed. Seed-treating chemicals include hexachlorobenzene dust, ceresan MDB dust, and the liquid fungicides, such as Ortho seed protectorant. Dusts are usually preferred where the quantity of seed to be treated is relatively small. It is now common practice for the grower to procure pretreated seed.

Loose smuts, often more intimately associated with barley, also affects wheat. See "Barley" in this entry.

Diseases of Deciduous Fruit Trees

White heart rot, caused by *Formes igniarius* Gill, 1878, is of worldwide distribution and affects apple and pear, among others. Although the disease is most frequently associated with decay of dead logs in forests, notably of beech, birch, maple, and poplar, fruit producers must always be on the lookout for it. The fruiting bodies of the fungus are called "conks" and produce what resembles a small, rounded shelf protruding from the trunk bark. Although usually smaller, such shelves can reach a foot (0.3 meter) in width. The perennial conks may live for many years. At one time, use was made of the conks, giving rise to the name "tinder fungus." The disease is damaging to trees to be cut for lumber because the fungus invades into the heartwood. In fruit trees, the parasite generally lowers the health and productivity of the trees. The fungus normally invades a host through old branch stubs. Thus, after trimming, wounds should be treated with fungicide or covered over with a creosote-tar paint.

Brown rot of stone fruits was first recognized in the late 1790s. For many years, it was believed that different fruit trees were affected by different injurious organisms. Part of the confusion arose from the fact that the organism was noted in various stages. Most authorities now designate three species: *Monilinia fructigena* Honey, 1936, (or *Sclerotinia fructigena* Schroet, 1893); *Monilinia laxa* Honey, 1936 (or *Sclerotinia cinerea* Schroet, 1893); and *Monilinia fructicola* Honey, 1928 (or *Sclerotinia americana* Norton & Ezekiel, 1924).

Brown rot affects peach most seriously, but is also very damaging to cherry and plum. Although green fruits may be infected, fruit close to maturing may be infected, exhibited by tiny brown specks that enlarge rapidly, to the extent that nearly all fruit on a given tree may be destroyed within a relatively few days. A gray mold develops on the fruit. Fruit that doesn't drop or that is not otherwise removed will ultimately dry out to form a "mummy." These may cling to the tree all winter.

In Europe, the species *Monilinia laxa* and *M. fructigena* are most prevalent and affect apple as well as other stone fruits. The disease on apple and pear is less serious in the United States. The disease organisms overwinters in twig cankers, in fruit mummies, and in the soil or at groundlevel. Control includes removing all debris and cultivating in orchards in the interest of maintaining sanitary conditions. Any wild *Prunus* also should be eradicated from the area. For treating soil, calcium cyanamide has been effective for some growers. Dormant sprays are used on the Pacific Coast and midwestern states to lessen the formation of sporodochia. Calcium arsenite and sodium pentachlorphenate have been used, as well as Bordeaux misture and other sprays. There is no agreement on a universal fungicide for all species of the organism and varieties of hosts which are attacked.

References

Armstrong, G. M., and J. K. Armstrong: "Races of *Fusarium* f. *conglutinans*," *Phytopathology*, **56**, 525–530 (1966).

Beckman, C. H.: "Cell Irritability and Localization of Vascular Infections in Plants," *Phytopathology*, **56**, 821–824 (1966).

Bourke, P. M. A.: "Emergence of Potato Blight - 1843–1846," *Nature*, **203**, 805–808 (1964).

Channon, A. G., *et al.*: "Studies on Two Races of *Bremia lactucae* Regel," *Ann. Appl. Biol.*, **56**, 389–397 (1965).

Cherewick, W. J.: "Inheritance of Pathogenicity in Oat and Barley Smuts," *Phytopathology*, **54**, 890 (1964).

Corden, M. E.: "Influence of Calcium Nutrition of *Fusarium* Wilt of Tomato and Polygalacturonase Activity," *Phytopathology*, **55**, 222–224 (1965).

Flentje, N. T., and D. J. Hagedorn: "*Rhizoctonia* Tip Blight and Stem Rot of Pea," *Phytopathology*, **54**, 788–791 (1964).

Gabrielson, R. L. and R. G. Grogan: "The Celery Late Blight Organism *Septoria apiicola*," *Phytopathology*, **54**, 1251–1257 (1964).

Halisky, P. M.: "Physiologic Specialization and Genetics of the Smut Fungi," *Bot. Rev.*, **31**, 114–150 (1965).

Hancock, J. G., and J. W. Lorbeer: "Pectolygic and Cellulytic Enzymes Produced by *Botrytis alli*, *B. cinerea*, and *B. squamosa* in Vitro and in Vivo. Role of Pectolytic and Cellulytic Enzymes in *Botrytis* Leaf Blight of Onions," *Phytopathology*, **54**, 928–935 (1964).

Hoppe, P. E.: "*Pythium* Species Still Viable after Twelve Years in Air-dried Muck Soil," *Phytopathology*, **56**, 1411 (1966).

Main, C. E., and M. E. Gallegly: "The Disease Cycle in Relation to Multigenic Resistance of Potato to Late Blight," *Amer. Potato J.*, **41**, 387–400 (1964).

Manners, J. G. and S. M. M. Hossain: "Effects of Temperature and Humidity on Conidial Germination of *Erysiphe graminis*," *Trans. Brit. Mycol. Soc.*, **46**, 225–234 (1963).

Manzer, F. E., *et al.*: "Resistance to Powdery Scab in *Solanum tuberosum* L.," *Amer. Potato J.*, **41**, 374–376 (1964).

Masri, S. S., and A. H. Ellingboe: "Germination of Conidia and Formation of Appressoria and Secondary Hyphae in *Erysiphe graminis* f. sp. *tritici*. Primary Infection of Wheat and Barley by *Erysiphe graminis*," *Phytopathology*, **56**, 304–308; 389–395 (1966).

Matta, A., and A. E. Dimond: "Symptoms of *Fusarium* Wilt in Relation to Quantity of Fungus and Enzyme Activity in Tomato Stems," *Phytopathology*, **53**, 574–578 (1963).

Maude, R. B.: "Pea Seed Infection by *Mycosphaerella pinodes* and *Ascochyta pisi* and Its Control By Seed Soaks in Thiram and Captan Suspensions," *Ann. Appl. Biol.*, **57**, 193–200 (1966).

Menke, G. E., *et al.*: "Physiology of *Rhizopus stolonifer* Infection on Carrot," *Z. f. Pflanzenkrh.*, **71**, 128–140 (1964).

Metcalfe, D. R., and W. H. Johnson: "Inheritance of Loose Smut Resistance," *Can. J. Plant Sci.*, **43**, 390–396 (1963).

Mitchell, J. E., and C. Y. Yang: "Factors Affecting Growth and Development of *Aphanomyces euteiches*," *Phytopathology*, **56**, 917–922 (1966).

Moll, R. H., *et al.*: "A Quantitative Genetic Study of the Inheritance of Resistance to Brown Spot (*Physoderma maydis*) of Corn," *Crop Sci.*, **3**, 389–391 (1963).

Mortimer, C. G., and R. E. Wall: "Stalk Rot of Corn in Relation to Plant Population and Grain Yield," *Can. J. Plant Sci.*, **45**, 487–492 (1965).

Moseman, J. G.: "Genetics of Powdery Mildews," *Ann. Rev. Phytopathology*, **4**, 269–290 (1966).

Pappelis, A. J., and F. G. Smith: "Relationship of Water Content and Living Cells to Spread of *Diplodia zeae* in Corn Stalks," *Phytopathology*, **53**, 1100–1105 (1963).

Saaltink, G. J.: "Nature of Plugging Material in Xylem and Its Relation to Water Flow in *Fusarium*-Infected Tomato Plants," *Phytopathology*, **54**, 1137–1140 (1964).

Schroeder, H. W., and J. J. Christensen: "Factors Affecting Resistance of Wheat to Scab Caused by *Gibberella zeae*," *Phytopathology*, **53**, 831–838 (1963).

Shands, R. G.: "Inheritance and Linkage of Stem Rust and Loose Smut Resistance and Starch Type in Barley," *Phytopathology*, **54**, 308–316 (1964).

Shaw, M: "The Physiology and Host-Parasite Relations of the Rusts," *Ann. Rev. Phytopathology*, **1**, 259–294 (1963).

Sherwood, R. T.: "Pectin Lyase and Polygalacturonase Production by *Rhizoctonia solani* and Other Fungi," *Phytopathology*, **56**, 279–286 (1966).

Swinburne, T. R.: "Infection of Wheat by *Tilletia caries* (DC.) Tul., the Causal Organism of Bunt," *Trans. Brit. Mycol. Soc.*, **46**, 145–156 (1963).

Thompson, D. L., *et al.*: "Inheritance and Breeding Information Pertaining to Brown Spot Resistance in Corn," *Crop Sci.*, **3**, 511–514 (1963).

Walker, J. C.: "Disease Resistance in the Vegetable Crops," *Bot. Rev.*, **31**, 331–380 (1965).

Walker, J. C.: "Plant Pathology," 3rd edition, McGraw-Hill, New York (1969).

Wall, R. E., and C. G. Mortimer: "The Growth Pattern of Corn in Relation to Resistance to Root and Stalk Rot," *Can. J. Bot.*, **43**, 1277–1283 (1965).

Williams, P. H.: "Starch Synthesis in Clubroot Galls," *Phytopathology*, **55**, 1084 (1965).

Williams, P. H.: "A System for the Determination of Races of *Plasmodiophora brassicae* that Infect Cabbage and Rutabaga," *Phytopathology*, **56**, 624–626 (1966).

Williams, P. H., and Y. Yukawa: "Ultrastructural Studies on the

Host-Parasite Relations of *Plasmodiophora brassicae,*" *Phytopathology,* 57, 682–687 (1967).

Wilson, M., and D. M. Henderson: "British Rust Fungi," Cambridge University Press, England (1966).

Wysong, D. S., and A. L. Hooker: "Relation of Soluble Solids Content and Pith Condition to *Diplodia* Stalk Rot in Corn Hybrids," *Phytopathology,* 56, 26–35 (1966).

FUNGUS GNAT (*Insecta, Diptera*). Of the family *Mycetophilidae,* fungus gnats are of several species and of only minor imporance as economic pests on food crops. The eggs of this insect are usually laid in fungi, decaying organic matter, and in damp and dark locations. They cause injury to mushroom beds and to the roots and seeds of some vegetable crops. Potato scab is caused by one species of fungus gnat. The gnat serves to transmit the disease (*Oöspora scabies*), which produces a scab and roughness of the tubers. See **Potato.**

FURADAN INSECTICIDE. Beet; Insecticide; Tomato.

FURROW IRRIGATION. Irrigation.

FUSARIUM. Yeasts and Molds.

FUSARIUM WILT DISEASE. Cucumber; Fungus and Related Diseases; Pea; Tomato.

FUSEL OIL. Whiskey; Yeasts and Molds.