Vegetable Seed Production

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Abstract

Unlike field crops where the cultural practices of raising seed crops are mostly similar to the commercial crops, in case of the vegetables, not only the seed crops are grown for a much longer duration than the crops raised for the vegetable purpose, they often also have critical requirements of photoperiods, temperatures, humidity and precipitation. Moreover, compared to field crops, most of vegetable seeds are considered high value and low volume, and hence these require specific care in pre-harvest stages, i.e. isolation and roguing, during harvesting and extraction, and post-harvest operations such as drying, processing, packaging and storage. Due to their vast diversity in growth pattern, induction of flowering and pollination behaviour, seed production procedures need to be followed for each group, e.g. cole crops, cucurbits, leafy vegetables, root crops, solanaceous, malvaceous crops, etc. General principles and standard practices in vegetable seed production are provided in this chapter.

Keywords

Vegetable seed · Roguing · Pollination · Maturity indices · Vernalisation · Wet extraction

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1 Introduction

Vegetables are important source of nutrients in human diets, especially for vitamins, minerals, antioxidants, etc.; hence are essential for nutritional security of a nation, and health and well-being of its people. With the advancement of breeding technologies, mechanisation and the practice of precision agriculture in open as well as controlled growing conditions have revolutionised vegetable farming industry with ~3% annual growth rate. This has been possible due to the growth of a vibrant vegetable seed industry making available sufficient quantity of vegetable seed of varieties suitable for different production systems. The public research institutions together with the private seed industry have contributed in this. Vegetable seeds are high value and low volume in nature hence, possess a much larger share in the global seed market in economic terms. Among vegetable seed, the biggest share is of solanaceous crops.

Once a new strain or variety of a vegetable crop is developed, only a small quantity of seed, known as the nucleus seed, is available with the breeder for multiplication. To meet the demands of the vegetable growers, this small quantity is to be multiplied rapidly in a manner that not only maintains the genetic purity of the variety, but also produces seed of good planting value. Seed is the initiating point of the majority of the vegetable crops including the root and bulb crops viz., carrot, radish and onion, except those which can be propagated vegetatively or from tissue-cultured plants. Based on the duration of growing season(s) for seed production, vegetables are classified as:

- Annuals: Seed-to-seed cycle is completed in one crop season, viz. solanaceous crops, e.g., tomato, chilli, brinjal, peas and beans, okra, and majority of the cucurbits.
- Biennials: In these crops vegetative growth is completed in the first season, and the seed is produced in the next season fulfilling a low-temperature requirement (vernalization) for inducing flowering. Cole crops (e.g. cauliflower, cabbage, broccoli, knol khol and others), carrot and radish are some examples of this group.
- Perennials: Vegetables which survive for more than two years but complete their reproductive cycle annually, viz. asparagus, artichoke and pointed gourd (*Trichosanthes dioica*).

Seed production of vegetables is different from raising a commercial crop in many ways (Table 1). It is a specialized activity, and somewhat different from the seed production of the grain crops, not only because the seed crop of vegetables is harvested much after the main crop, but also because it often requires supplementary pollination by keeping the beehives, and specialized treatments to induce flowering and seed set. Therefore, a thorough knowledge of crop biology, pollination techniques and climatic requirements are the prerequisite for undertaking seed production of vegetable crops.

Table 1 Differences between seed production and crop production

Seed production	Crop production
Seed production should be taken up as per edaphic and environmental requirements, in its area of adaptation	Can be grown in any area of general adaptation
Needs isolation from other varieties	Isolation is not required
Requires technical skill for maintenance of purity and quality	Needs skill for raising the crop
Roguing is compulsory	General weeding is performed
Harvesting should be done at physiological/harvestable maturity	Harvested at commercial maturity
Special treatment may be required to induce flowering and to supplement pollination	Not required
Maturity indices need to be considered for good seed quality at harvest	Marketable quality is considered for harvesting

2 Seed Quality Parameters

The essential quality parameters are genetic purity, physical purity, germination, vigour and seed health. A systematic seed production approach has to be followed for production of quality vegetable seed. Before the seed reaches the farmer, it is multiplied through several stages. The actual nomenclature of the seed lot at each stage depends on the system of multiplication adopted, and the legislation of each country.

The testing procedure for these quality parameters is well defined in ISTA Rules (ISTA 2015), whereas the minimum requirements with respect to germination, genetic purity, physical purity and maximum permissible limit for diseased seed, other crop seed, weed seed and moisture content are maintained as per the applicable legislation viz., IMSCS and/or OECD, etc.

2.1 Genetic Purity

In order to maintain the genetic potential of a genotype, be it a pure line variety or the parental lines in case of a hybrid, genetic purity of seed needs to be maintained at the highest possible level, or not below the prescribed standards during the course of seed multiplication. In India, as well as in other countries, a four-generation seed multiplication system is followed for maintaining maximum genetic purity with good seed yield. The stages in the seed multiplication chain in India are described below.

2.1.1 Breeder Seed

The breeder seed [equivalent to the pre-basic seed under OECD seed scheme] is produced from the nucleus seed (including the vegetatively propagating material, such as tubers), directly under the supervision and control of the originating or sponsoring plant breeder/breeding institution and maintaining safe isolation distance to avoid any out-crossing. There are no prescribed quality standards for the breeder seed; however, care is taken so that the genetic purity of the breeder seed shall be maintained to guarantee that the subsequent progeny of the seed, that is the Foundation seed (basic seed in OECD) meets the prescribed standards of genetic purity. The germination and purity standards shall be indicated on the label on actual basis and shall not be below that of the foundation seed.

2.1.2 Foundation Seed

Foundation seed is produced from the breeder seed, the production of which is undertaken following the specific requirements of season, previous crop history of the plot and maintaining prescribed isolation from all possible contaminants. The seed crop is grown following the best agronomic practices and is inspected by the personnel of the certification agency at critical growth stages for checking the presence of off-types, obnoxious weeds and occurrence of seed-borne diseases. The seed crop is accepted and harvested only if it meets the prescribed norms of variety and genetic purity and so handled to maintain specific standards during the stages of harvest and post-harvest handling. This class of seed is equivalent to the basic seed of the OECD schemes, and is used to produce the commercial seed of certified grade (C1 andC2). In case of the hybrids, parental line seeds are advanced through the breeder seed and foundation seed stages, while the hybrid seed is produced as certified seed only. In order to meet large seed demands, two generations of foundation seed (F1 and F2) may be produced with the permission of the competent authority, and restricting to only one generation of certified seed (C1).

2.1.3 Certified Seed

The certified seed is produced from the foundation seed, which is used for commercial crop production. Its production is also undertaken following the prescribed norms of field selection, isolation, field inspections and removal of the off-types, weeds and diseased plants and harvested only if it fulfils the standards of genetic purity and is free from diseases and pests. It shall be so handled as to maintain specific genetic identity and purity according to the standards prescribed for the crop being certified. This is equivalent to C1 (also C2) of the OECD schemes. Certified seed of hybrids is produced using foundation seed of the parental lines. Post-control plots are grown to confirm the genetic purity of variety/hybrid seed in a grow-out test.

2.1.4 Labelled Seed

In India, the USA, the UK, the EU and many other countries, non-certified but labelled seed of vegetables is permitted for commercial sale and cultivation. A large proportion of vegetable seeds in commerce falls under this category, the quality assurance of this class of seed is solely the responsibility of the seed-producing agency. Seed is produced following the norms of field inspections, harvesting and processing as prescribed for the certified class of seed. Similarly, the quality parameters, following the recommended procedures of testing, must meet the standards prescribed for CS.

3 Seed Certification

Seed certification schemes have been devised to produce high-quality seed, in which the varietal purity and quality standards of the seed/propagating material of registered/notified varieties or kinds are maintained following the recommended practices and meeting the quality standards prescribed for the given species. Certification by a designated agency ensures that the genetic purity and testing in a notified/designated Seed Testing Laboratory (STL) confirms to the acceptable levels of physical purity and germination potential. The detailed procedure of seed certification is discussed under Chap. 12. Notwithstanding some variations in the operational system, the following norms are followed in most of the countries):

- Seed certification in India is conducted by the designated authority (certification agency) notified under the Seeds Act, 1966.
- Seeds of those varieties which are notified/registered shall be eligible for certification.
- Certification agency verifies the seed source, class and other requirements of the seed for producing the seed crop.
- Seed plots are inspected by the designated/certification personnel, to verify those factors which might irreversibly affect the genetic purity or health of the seed.
- Seed crop meeting field standards for certification are harvested, threshed, and transported under the guidance of certification agency to the seed processing plant.
- After processing, samples are taken by the designated personnel of the certification agency and sent for analysis to the designated/notified seed testing laboratory.
- Once the seed lot is tested and found to meet the prescribed standards of purity, germination and moisture, the certification agency ensures packaging, tagging, sealing and issuance of the certificate.
- The germination (%), purity (%), moisture content (%) and date of seed testing are declared on the tag along with the name of the crop (kind) and variety.

4 Seed Production Technology

The following points are to be kept in mind for obtaining economic yields of quality seed of vegetable crops during the seed multiplication process:

4.1 Environmental Requirements

Vegetable seed production should be undertaken in the best agronomic conditions preferably in the area of adaptation, recommended during the multi-location trials (or VCU trials). Best seed yield and quality is obtained when the crop is grown in the right season and in the area for which the crop is adapted. The regions with abundant sunshine, dry and moderate temperature during maturity and harvest should be preferred for seed production. In many crops flowering is controlled by the photoperiod, e.g. lettuce and spinach require long-day conditions for flowering and seed setting (Waycott 1995; Kim et al. 2000; Pennisi et al. 2020), whereas majority of temperate vegetables like cabbage, cauliflower, beetroot, European type radish and carrot require a low-temperature stimulus to initiate flowering (vernalization). High rainfall areas are not considered suitable for seed production, as it may reduce seed yield, germination and storability and increase the risk of pests and pathogens and hence the need for artificial drying. Excessive wind on the other hand increases rapid water loss, adversely affects the activity of pollinators, carries pollen through wind over long distances, and increases seed shattering. Coyne (1969) reported distinct off-types in *Phaseolus vulgaris* L. under particular environment and recommended that maintenance should be carried out in relatively cool climates. Barker et al. (1984) recommended that maintenance should be carried out preferably at the location of variety development.

4.2 Land Requirements and Planting

The field for raising a vegetable seed crop should be free from 'volunteer' plants and soil-borne disease inoculum. Volunteer plants are the plants originating from the seed/plant material of the previous crop of the same species but different variety or of the same variety of a different seed class, which might remain dormant and germinate with the seed crop. In vegetables volunteer plants are common in spinach, tomato, etc. Besides, the field should be properly levelled with appropriate drainage and should contain sufficient organic matter and nutrients. Row spacings and planting populations within the rows of the seed crops may vary from those for commercial production (Singh et al. 2010). Adequate spacing is maintained not only for flower development, pollinator activity and ease of mechanical operations, but also for undertaking field inspections of the seed crop at different growth stages. In some cases, e.g. eggplant, pepper, tomato, melons, etc., the spacings used for seed production may be the same as those for commercial production (McDonald and Copeland 1997). Most of the cultural practices of annual vegetables for seed production are similar to those for the commercial crop with proper isolation and roguing to maintain varietal purity, and adequate measures for the control of diseases, pests and weeds to be continued over an extended period.

4.3 Pollination Requirements

Vegetable crops like garden pea, cowpea, French bean, tomato, etc. are self-pollinated, and the contamination rate due to unwanted natural crossing is very low. In vegetatively propagated vegetable crops like potato, the maintenance of identity and uniformity is usually easy (Mastenbroek 1982). The majority of other vegetable crops are cross-pollinated like okra, chilli, cucurbits and brassicas, and

Table 2 Extent of natural cross-pollination and pollinating insect in vegetable crops[a]

Vegetable name	Occurrence of natural cross-pollination (%)	Pollinating insect
Brinjal	0.70–15.00	Insects
Cabbage	73.0	Honey bees/bumble bees
Capsicum	7.00–37.00	Honey bees/insects
Carrot	97.6–98.90	Insects/bees
Cauliflower	40.0–50.0	Honey bees/bumble bees
Cucumber	65.0–70.0	Honey bees/solitary bees
Muskmelon	85.0–95.0	Honey bees
Onion	95.0–100.0	Insects
Potato	0.00–20.00	Bumble bees
Radish	Highly CP	Bumble bees/honey bees
Tomato	0.00–5.00	Honey bees/solitary bees

[a](Mastenbroek 1982)

hence require longer isolation for maintenance of genetic purity. The extent of natural cross-pollination, as shown for some vegetable crops in Table 2, determines the degree of isolation required. However, environment also has a major effect on pollination behaviour and subsequent consequences in variety maintenance (Rick 1950).

Normally, the natural insect population under open conditions is sufficient to take care of satisfactory pollination, but in case of excessive application of insecticides and high plant populations grown for seed crop, the natural insect population may sometimes be insufficient to ensure proper pollination and seed set. Insufficient pollination in cucumber and other cucurbits leads to higher number of underdeveloped seeds (Gupta et al. 2021). Therefore, introduction of the supplementary bee hives and application of pollinator attractants improve pollination and seed set. However, care must be taken during application of plant protection chemicals, as indiscriminate use may affect the pollinators' population and activity. Therefore, application of chemicals should be avoided at peak flowering stage and if required, should be undertaken in the evening or late afternoon.

For restricting the spread of crop-specific diseases, it is advisable to space out the seed crop from the commercial crop either by space or time. Isolating the celery stalk production fields from celery seed fields may reduce the incidence of late blight caused by *Septoria* in seed fields, whereas isolation of lettuce seed fields from leaf and head production fields reduced the incidence of lettuce mosaic virus which is seed-borne (McDonald and Copeland 1997).

4.4 Isolation Requirements

Isolation distance is the minimum separation (distance) between two or more cross-compatible species/varieties to prevent the natural outcrossing. Satisfactory isolation of seed crop helps to maintain purity in the following ways:

(a) Minimize the risk of cross-pollination between cross-compatible species/crops (helps in maintaining genetic purity).
(b) Prevents mixing of different varieties of the same crop during harvesting (helps in maintaining physical purity).
(c) Reduces the risk of transmission of pests and diseases from alternative host crops.

Isolation between crossable varieties can be achieved in three different ways.

4.4.1 Temporal Isolation

Isolation by time allows seed of different varieties of the same crop to be produced at the same location by planting at an interval. In tropical and sub-tropical regions where the growing seasons are long enough to allow two production cycles of the cross-compatible crops, these can also be isolated by time. Normally, seed crop should be sown early or late by a margin of 15–20 days than the adjacent field to prevent the outcrossing. For example, seed production of the early and mid-maturity group of cauliflower varieties.

4.4.2 Spatial Isolation

The isolation distances are determined by the flowering behaviour of the species and the mode of its pollination (vector and distance travelled). The isolation distance also depends on the direction of insect flight (in the case of insect-pollinated varieties) or the direction of winds (in the case of wind-pollinated varieties). Table 3 lists the important vegetables and their recommended isolation distances, as followed in India, which are close to those followed elsewhere.

4.4.3 Isolation by Physical Barrier

The seed crop is isolated by any physical barrier (buildings, net houses, etc.) or surrounded with densely planted plants having higher height than the seed crops to prevent the introgression of foreign pollen. In vegetable seed production, moringa, maize, pearl millet, etc. are used as barrier crops.

5 Roguing

Many vegetable varieties, which are in seed chain, occasionally may tend to show genetic alterations over several generations. It is, therefore, necessary to take care to keep the natural variation within the acceptable limits. For this purpose, the crops are inspected at different growth stages and individual plants that do not confirm to the plant type defined in the official variety description, are removed. This procedure, known as roguing, is an important routine activity in organized seed production endeavours to maintain the genetic purity of a variety.

Plant breeders use positive selection to increase the proportion of desirable plants thereby enhancing the frequency of desirable alleles in a population, whereas roguing is a negative selection that removes relatively small proportions of

Table 3 Minimum isolation requirements for vegetable seed crops in India (IMSCS 2013)

	Minimum isolation distance (m)			
	Varieties or OPs		Hybrids	
Crop	Foundation	Certified	Foundation	Certified
Amaranth	400	200	–	–
Asparagus, celery, parsley	500	300	–	–
Beetroot, radish, turnip, spinach	1600	1000	–	–
Brinjal	200	100	200	200
Carrot	1000	800	1000	800
Cauliflower, cabbage, knol khol, Chinese cabbage	1600	1000	1600	–
Cowpea, beans, dolichos	50	25	–	–
Cucumber, bitter gourd, muskmelon, bottle gourd pumpkin, sponge gourd, ridge gourd, snake gourd, snap melon, winter squash, summer squash, watermelon	1000	500	1500	1000
Fenugreek, garden pea	10	5	–	–
Indian squash, long melon	1000	500	–	–
Ivy gourd, pointed gourd	20	20	–	–
Lettuce	100	50	–	–
Okra, chilli, capsicum	400	200		
Onion	1000	500	1200	600
Tomato	50	25	200	100

off-type plants (Faulkner 1984). The off-types may present in a seed crop due to any of the following reasons:

- The presence of different morphological types within a vegetable crop may vary. This tendency is greater in predominantly cross-pollinated vegetables (e.g. cauliflower, cabbage, cucurbits and onion) than self-pollinated (e.g. peas, tomato, cowpea) crops. Hence, the varieties of self-pollinated vegetables are generally more uniform and stable than varieties of cross-pollinated crops.
- Seeds that result from cross-pollination between the vegetable seed crop and other compatible varieties or wild plants. These are difficult to identify in the first generation but show up in later generations.
- Deviations from the normal type due to mutation.
- Accidental mixture of seeds of other varieties in the seed stock during its production, processing, handling or storage.
- Presence of volunteer plants which may arise from dormant seed of the previous crop grown in the same field or leftover vegetative pieces.

It is relatively easier to conduct intensive rouging in breeder seed plots than in large commercial seed production plots. The crop should be grown in such a way so that individual plants can be observed. Normally, a paired row system of planting

Fig. 1 A seed crop of onion at flowering (Courtesy: Dr. Yogeesha HS, ICAR-IIHR, Bengaluru).

may be followed so that each plant can be observed by walking between rows. Such a planting pattern also facilitates the detection of dwarf off-type plants. Field inspections are to be undertaken at right stages, by walking systematically through the crop so that each plant is observed well (Fig. 1). Plants bearing fruits showing undesirable characteristics (NOT true to type) must always be removed, rather than the plucking such fruits, as the remaining flowers of the off-type plant may continue to contribute to the production of undesirable fruits bearing off-type seeds in the next generation. In cross-pollinated crops, the undesirable (off-type) plants should be removed before flowering. Furthermore, cross-compatible weeds and their wild relatives, diseased and infected plants must be eliminated. Inspection of the crop with the sun behind is recommended as it is difficult to examine plants against the light. Proper training and supervision of the field staff involved in roguing is required. The roguing personnel should have adequate knowledge of the morphological characters of the variety. Morphological characters like leaf shape, flower colour, stem colour/pigmentation, fruit shape and colour are usually good markers for rouging the off-types, while characters which are strongly affected by environment, e.g. leaf colour, plant height and earliness of flowering, are not considered very reliable basis for roguing.

5.1 Different Stages of Rouging

(a) Pre-flowering: Plants having different morphological characteristics like plant height, foliage morphology, colour, etc. should be removed from seed production fields before flowering.
(b) Flowering: To prevent mixing of varieties of the same crop, rouging is done based on curd maturity in cauliflower, sex expression in cucurbits and flower initiation time in solanaceous crops.
(c) At fruit development: Based on true-to-type characteristics of developing fruits like fruit shape, ripening colour, size, etc., the off-types are removed.
(d) At maturity: Late maturing plants in case of early maturing varieties (specially in fruit vegetables) and vice versa are to be discarded.

6 Harvesting, Threshing and Seed Extraction

The best time of harvesting any seed crops is at a stage when the highest yield of best quality seed could be obtained. Premature or delayed harvest often adversely affects seed quality. The appropriate stages of harvest, as determined by visual maturity/ harvest indices in some vegetable crops, are presented in Table 4.

In vegetables, seeds are either extracted from dry seed heads or fruits or from mature wet fruits. Hence, vegetable crops are classified as dry-seeded, which include the brassicas, legumes (Fig. 3), chilli and onion, and wet-seeded crops such as cucurbits, brinjal and tomatoes. The right stage of harvesting the seed crop is determined by morphological or physiological indices such as the colour of the fruit, the colour of the calyx and firmness, and fruit cracking. Tomato fruits harvested from pink to red-ripe stage and seed extracted through the fermentation method showed higher seed quality in terms of germination, field emergence and vigour index (Pandita et al. 1996). The methods of harvest and extraction depend on the type of fruit, with threshing done manually or mechanically. Utmost care should be taken during the shifting of harvested produce from the field to threshing/processing floor. The trolley/vehicle, threshing floor, processing machines and jute bags should be clean/free from the seed/plant parts of other varieties of the same crop or weeds to avoid contamination at this stage. Threshing machines should be properly cleaned to avoid admixture and run at a safe speed to avoid mechanical damage to the seed.

In some fleshy fruit/vegetables like cucumber, pumpkin, melons, etc., the post-harvest ripening (PHR) of fruit is needed to maximize the seed yield and quality, as the seeds continue to develop and mature in the fruit even after harvest until the seed extraction (Gupta et al. 2021).

Fruit vegetables like tomato (Fig. 4), brinjal, cucumber, watermelon, muskmelon and ash gourd (Fig. 5) bear ripe seed in the fleshy fruits with a gelatinous layer around the fresh seed. The seed is separated from this gelatinous material by any of the following methods.

Table 4 Harvest maturity indices for different vegetable seed crops

Crop	Harvest maturity stage	Harvesting time
Solanaceous vegetables		
Brinjal	Colour of fruit turn yellow/straw (Fig. 2c)	Day time
Chilli/ capsicum	Green colour of fruits changes to red or yellow (Fig. 2d)	Day time
Tomato	Skin colour changes from green to red or pink	Day time
Peas and beans		
Beans	Basal pods become dry like parchment and turn yellow	During the day
Peas	Majority of pods become parchment like	Morning hours
Other pod vegetables		
Okra	Pods become grey or brown (Fig. 2a)	Day time
Bulb crops		
Onion	Seeds become black on ripening in silvery capsules	Morning hours
Cole crops		
Cauliflower, cabbage	Plants start drying and pods become brown in colour	Morning hours
Leafy vegetables		
Fenugreek	Plants turn brown	Morning hours
Spinach	Plants start turning yellow	Morning hours
Root crops		
Carrot	Secondary and third-order umbels turn brown	Morning hours
Radish	Pods turn brown parchment like	Day time
Turnip	Haulms turn brown parchment like from green colour	Morning hours
Cucurbits		
Cucumber	Fruit stalk shows withering. Actual seed maturity can be ascertained by cutting several fruits longitudinally while mature seeds separate easily from the flesh	Day time
Muskmelon	On seen maturity, fruits tend to separate (full slip) from the stem easily. Skin coat becomes waxy and fruit aroma increases	Day time
Squashes/ pumpkin	The rind of fruits becomes hard and its colour changes from green to orange yellow or straw (Fig. 2b)	Day time
Watermelon	At maturity the tendrils have withered on shoot bearing the fruit. Skin colour of the fruits changes from green to yellow on the underside of fruit touching the soil	Day time

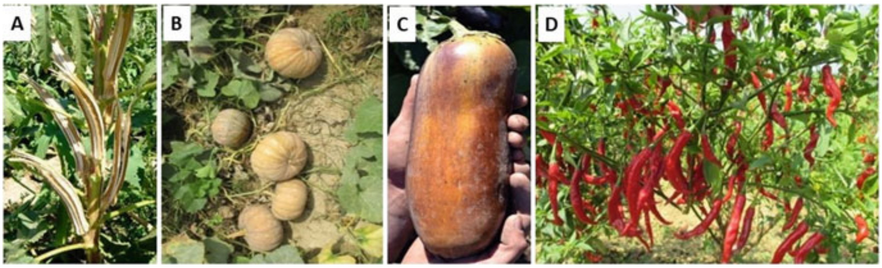

Fig. 2 Seed harvesting stages of vegetables: (**a**) Okra, (**b**) Pumpkin (**c**) Brinjal, (**d**) Chilli

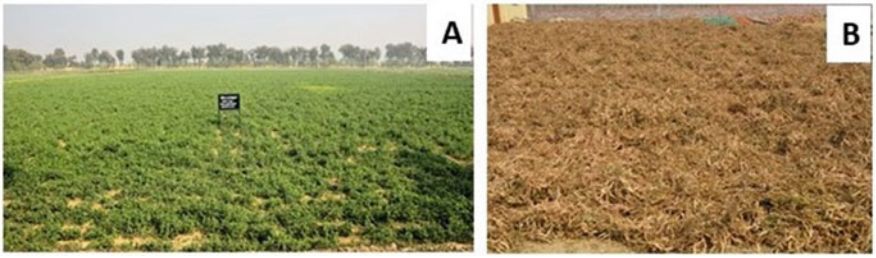

Fig. 3 (**a**) Standing vegetable pea crop for seed production. (**b**) Harvested mature pea crop for seed extraction

6.1 Fermentation

In this method, the crushed fruit pulp containing seeds are kept in a container and allowed to ferment for 1 to 5 days depending upon the vegetable, ripeness and temperature of the surrounding. The pulp mixture is stirred daily to avoid discolouration of the seed and to maintain a uniform rate of fermentation. After completion of the fermentation process, the seeds are washed thoroughly by a displacement method. The good seeds settle at the bottom layer, while the pulp and other debris which float on the surface are removed. After the separation, the clean seeds are dried in shade or using low-temperature dryers.

6.2 Acid Treatment

The seed can also be separated from the gelatinous coating by acid treatment. In this method about one litre of commercial grade HCl (hydrochloric acid) is mixed with 100 kg of tomato pulp and kept for 30 min with occasional stirring, after which the seed is washed thoroughly. It is important not to allow the seed to remain for a longer duration in the acid as this will reduce the seed germination. Containers used for fermentation should be made of a safe alloy to avoid seed discolouration.

Fig. 4 Different stages of maturity, harvesting and seed extraction in tomatoes

Fig. 5 Ash gourd seed crop at harvest and manual cleaning

6.3 Alkali Treatment

Alkali extraction is also equally effective, where an equal volume of alkali (in a ratio of 84 g ordinary washing soda with one litre of boiling water) is added to the fruit pulp in an earthen pot. After thorough mixing, it is allowed to stand overnight for seeds to settle. After decanting the clear liquid, the seeds will be washed thoroughly.

7 Seed Drying

At the time of harvest or seed extraction, the moisture content of seed is usually higher than the optimum range for good germination and storability. The pulpy fruits like tomato, brinjal, cucumber, watermelon, muskmelon and ash gourd possess higher moisture content at harvest and absorb still more during wet extraction, whereas other vegetable seeds like peas, cowpea, French bean, onion, brassicas and fenugreek have relatively lower moisture at harvest. Sometimes the seed may also have high moisture content due to adverse climatic conditions. Hence, it is very important to bring the seed moisture to an optimum level before storage. It is reported (Harrington 1973) that most of the vegetable seeds attain equilibrium moisture content (EMC) of 9–12% at >75% relative humidity (RH) at 25 °C in storage, whereas these are around 6–8% at 45–60% RH. Thus, for storage of seed in unsealed containers at ambient conditions, seed moisture should be kept in the range of 9–12%, and for vacuum/sealed storage it should be less than 6–8%. Both natural and artificial/forced drying methods can be used (see Chap. 10) for drying vegetable seeds, but the temperature should not be more than 35 °C. However, seed drying methods are described in detail for field and vegetable crops in Chap.10.

8 Seed Processing

Raw vegetable seed that is received for processing after extraction and drying usually contains some percentage of undesirable materials. Seed processing operations remove undesirable components and plant debris such as empty pod, chaff, straw, flower heads as well as stone pieces, soil clods, coarse dust, etc., and damaged and broken seeds and seeds of other crops and weeds (Fig. 6). Thus,

Fig. 6 Machine type used for vegetable seed processing. (**a**) Air screen cleaner, (**b**) Indented cylinder, (**c**) Specific gravity separator

Table 5 Screen aperture sizes for vegetable seed processing (Trivedi and Gunasekaran 2013)

Vegetable crops	Screen aperture size (mm)	
	Top*	Bottom*
Bitter gourd, bottle gourd pumpkin	11.00r	6.50r
Cucumber	8.00r	2.00r
Muskmelon	5.00r	1.00r
Ridge gourd, sponge gourd	9.50r	6.40r
Watermelon	6.00r	1.80r
Brinjal, chilli, tomato	4.00r	0.80s/2.10r
Okra	6.00r	4.30r
Methi	3.25r	1.20r
Spinach (round seeded)	5.00r	2.75r
Spinach (sharp seeded)	8.00r	2.50r
Cauliflower	2.75r	1.10r
Cabbage	2.75r	0.90r
Onion	3.80r	2.00r
Carrot	2.30r	1.00r
Radish	4.50r	2.00r
Turnip	1.80r	1.20r

*Where *r – screen with round perforation, s – screen with slotted perforation*

cleaning improves the physical purity and appearance of the seed lot. If the seed lot contains substantial amounts of inert materials, it is first passed through a scalping machine, whereas if it possesses more of plant appendages, clumping, etc., then a debearder is used to ensure a free flow of seed (see Chap. 10 for different techniques involved in seed processing). Usually, the air and screen cleaner machine with two vibrating perforated screens is used in the processing of vegetable seed. The upper screen eliminates impurities larger than the seed whereas, the lower screen separates out any seed or other impurities smaller than the optimum seed size of the crop. Table 5 presents the screen aperture sizes for seeds of different vegetable crops as recommended in India.

9 Seed Quality Control

Quality of seed represents the overall value of the seed for its intended purpose. Poor quality seed leads to loss of money and potential crop failure. Seed quality involves genetic and physical purity, germination potential and seed health.

Physical purity represents the pure seed fraction of seed lot on percentage by weight basis. Whereas, germination is one of the most important and widely accepted indices of seed quality (Chap. 13 describes the concept of seed quality in detail). Germination testing is carried out in accordance with the specifications for material, testing conditions and procedures specified in ISTA Rules, with some minor modifications, if needed. Normally, a minimum sample of 400 seeds, using

Table 6 Standard laboratory germination testing protocols for some vegetable seeds (ISTA 2019)

Crop	Prescription for				Remarks (additional treatments)
	Substrate	Temperature (°C)	First count (days)	Final counts (days)	
Cauliflower, cabbage	TP; BP	20 ↔ 30; 20	5	10	Prechill/KNO_3
Okra	TP; BP; S	20 ↔ 30	4	21	–
Onion	TP; BP; S	20;15	6	12	Prechill
Chilli/ capsicum	TP; BP; S	20 ↔ 30	7	14	KNO_3
Muskmelon	BP; S	20 ↔ 30; 25	4	8	–
Cucumber	TP; BP; S	20 ↔ 30; 25	4	8	–
Pumpkin	BP; S	20 ↔ 30; 25	4	8	–
Tomato	TP; BP; S	20 ↔ 30	5	14	KNO_3
Pea	BP; TPS; S	20	5	8	–
Brinjal	TP; BP; S	20 ↔ 30	7	14	–
Broad bean	BP; S	20	4	14	–
Cowpea	BP; S	20 ↔ 30; 25	5	8	–

TP – top of paper, BP –between paper, S – sand

four replicates of 100 seeds each, is recommended for a statistically dependable germination test. The time required for germination testing depends on the respective crop species. The conditions (media and temperature) and duration for germination tests of some vegetables are given in Table 6, while the minimum germination and purity limits as per the Indian system of seed certification are presented in Table 7.

10 Genetic Purity

Maintenance of the genetic constitution of an improved vegetable variety is achieved through the selection of true-to-type plants and seed collection at the nucleus seed stage and careful multiplication of seed in subsequent generations. Trueness to type can be assessed by post-control plot test or grow-out tests. Post-control plot test is recommended for hybrid seeds, as well as breeder seeds of open-pollinated varieties, specially of cross-pollinated species. Moreover, biochemical, molecular and cytological methods can also be used to access the variety/hybrid purity, if needed (see Chap. 15 for more details pertaining to assessment of variety/hybrid purity). Seed certification schemes, including the post-control grow-out plots, can effectively

Table 7 Minimum seed germination and purity standards of vegetable crops as per OECD seed scheme and IMSCS, 2013

S. No.	Crop	IMSCS Minimum (%)		OECD Minimum (%)	
		Germination	Purity	Germination	Purity
1.	**Cucurbits** Ridge gourd, bitter gourd, bottle gourd, sponge gourd, pumpkin Muskmelon, watermelon Cucumber, squash	60 60 60	98 98 98	80 75 80	98 98 98
2.	**Solanaceous** Brinjal, tomato Chillies, capsicum	70 60	98 98	75	97
3.	**Peas and beans** Dolichos Frenchbean Peas	75 75 75	98 98 98	75 80	98 98
4.	**Sundry vegetables** Bhindi	65	99		
5.	**Bulb crops** Onion	70	98	70	97
6.	**Cole crops** Cauliflower Cabbage, khol khol	65 70	98 98	70 75	97 97
7.	**Leafy vegetables** Amaranthus Asparagus Methi Lettuce Spinach beet (palak)	70 70 70 70 60	95 96 98 98 96	70 75 70	97 95 97
8.	**Root crops** Carrot Beetroot Radish Turnip	60 60 70 70	96 96 98 98	65 70 70 80	95 97 97 97

control the genetic purity of the seed crop (see Chap. 8 for standard procedure for conduct of grow out test in seed crops).

11 Opportunities in Vegetable Seed Production

With increasing living status and consciousness of the masses towards health and nutritional food habits, the consumption of vegetables has increased over the years, increasing the demand for quality vegetable seeds. Major issues of concern in vegetable seed sector are high seed price and quality. Farmers face the problem of spurious seed, low germination percentage and timely availability of quality vegetable seeds (Roy et al. 2020).

Seed germination standards in India are rather low in most of the vegetables such as cucurbits, carrot, radish, tomato, etc. In crops like carrot where seed matures at different times on different order umbels, germination of seed lots remains low, whereas in case of cucurbits such as cucumber, higher number of unfilled seeds is the cause of low germination. In lesser known vegetables including chenopodium, basella and moringa, seed production, processing and testing protocols, and seed standards need to be developed, as these vegetables are nutritionally rich and the demand for the seed of such crops is in the rise.

Seed production under protected conditions of cultivation needs to be promoted in view of better quality, higher yield and low chances of pest attack. This offers a better scope for organic seed production and of seed export.

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