Chapter 9
Practicalities from Culinology®: How Umami Can Contribute to Culinary Arts and Sciences

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9.1 What Is Culinology®? What Is Umami?

This chapter differs from the preceding ones by focusing on umami from a practical gustatory and culinary standpoint, rather than a scientific one. It focuses on the umami experience and the traditional role that umami plays in foods loved around the globe. Umami had its place in the culinary world millennia before cooks and chefs knew what it was scientifically. The day-to-day use of umami in the kitchen predated and engendered the discoveries of umami as we currently understand it. Chefs today have the possibility of gaining a sophisticated understanding of umami, allowing a deeper understanding of the chemical properties of food, from harvest through eating, and providing tools to make food even more delicious.

This chapter, while not focused on chemistry, includes brief discussions of the scientific discoveries around umami and the synergistic interaction with nucleotides (these topics are treated in more detail in Chaps. 2 and 3 of this book). This knowledge reinforces and improves daily sound cooking practices. The intersection of culinary arts and food science is the locus that gives rise to Culinology®, or culinary science. The two disciplines inform and rely on each other. This chapter is about the intentional incorporation of umami to create balanced dishes, whether this comes from foods intrinsically rich in umami, foods manipulated by further processing to further develop umami (e.g., fermentation), or the addition of MSG (monosodium glutamate), the purest form of umami available to everyday cooks. The objective of this chapter is to apply the science of umami to daily culinary preparation.

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9.2 Umami History Through the Culinary Lens

Jean Anthelme Brillat-Savarin, author of *La Physiologie du Goût* (Brillat-Savarin, 1826, 1848), written in the early nineteenth century, is most famous for his aphorism, "Tell me what you eat, and I shall tell you what you are," often shortened to "You are what you eat." Brillat-Savarin was among the first in Western literature to document the taste we now call umami, dubbing it *osmazome*, which Brillat-Savarin defined as a water-soluble substance in meat containing all its flavors. The term was used to describe the savory taste indicative of umami. At the time *osmazome* was coined, there was no word in the French language to adequately describe the taste that Brillat-Savarin was experiencing. Not until more than a century later, as the result of scientific inquiry, did Brillat-Savarin's taste impressions become understood as umami.

In 1908 Kikunae Ikeda, a professor at the School of Science's Department of Chemistry at the Japan's Imperial University (now called the University of Tokyo), discovered that MSG was the umami in a broth of kelp seaweed (Lindemann et al., 2002). Ikeda was the first to identify glutamic acid or glutamate as the source of the savory taste Brillat-Savarin identified. He named this taste *umami* and assigned it the fifth of the five basic tastes. His discovery began in the culinary realm as he sought to better understand the characteristic tastes in his wife's dashi, a stock made from *kombu* (kelp) and *katsuobushi* (cooked, smoked, dried, mold-cured, and shaved bonito) that is foundational to many Japanese dishes. Ikeda used laboratory facilities at the university to conduct experiments aimed at the extraction of the umami factor from kelp. Ikeda found that glutamic acid was a central element in the taste of dashi. Ikeda further recognized that umami was central to many of the foods he had eaten during a stay in Europe, including tomatoes, asparagus, meat, and cheese (Yamaguchi & Ninomiya, 2009).

Based on scientific studies on the umami taste receptor on the tongue, published after 2000, proof of the existence of glutamate receptors has made it widely accepted that umami is a basic taste (Chaudhari et al., 2000), along with sweet, sour, salty, and bitter. It is important to note that taste here is limited to the receptor reaction and different from flavor, which is a broader construct that includes the perception not only of taste but mainly aroma and also feelings such as heat or cooling. For chefs, this understanding of glutamate receptors crystalized scientific conclusion underscored what they already knew but couldn't precisely explain. Chefs and cooks around the world have always cooked using umami-rich sources because they were simply delicious. Now the science caught up to explain the pleasurable umami taste from a chemosensory perspective.

One prominent example of umami in ancient cooking is that of the cuisine of the Roman Empire. Key to much of the culinary fare of ancient Rome was the fermented fish sauces used as essential seasonings throughout the culinary spectrum. The Romans had four fish sauces: *garum*, *liqumen*, *allec*, and *muria*. *Garum* was the principal sauce produced by the hydrolysis of small fish or fish innards and salt fermented for several months. *Allec* was the undissolved fish material remaining from *garum* production. *Liquamen* was very similar to *garum* in production process and taste. *Muria* was the solution from osmosis during the salting of whole, gutted fish or slices of fish meat. At the time, these umami-rich products were just as ubiquitous and popular as wine and olive oil are today (Curtis, 2009).

The dominant free amino acid in fish sauce is glutamate. While we cannot chemically analyze the fish sauces of ancient Rome, we do know that in the current fermented fish sauces of Southeast Asia, produced through similar salting and fermenting of fish that resulted in *garum*, glutamate is present at a concentration of about 1300 mg/100 mL. Fish sauce also has an inherent nutritional value, providing other amino acids and numerous micronutrients, such as vitamin B-12 (Nakayama & Kimura, 1998, Otsuka, 1998, Yoshida, 1998).

9.3 Umami in Foods

Umami, despite its Japanese name, is not a Japanese phenomenon. Rather, it is a central part of the human taste experience that transcends history or geography. Cooks and chefs around the world gravitate toward umami-rich foods as a source of deliciousness (Lioe et al., 2010; Hajeb & Jinap, 2015). Science took thousands of years to explain what exactly this sensation is that we all crave, and chefs and cooks know so well. Examples of umami-rich foods in global cuisines include lamb daube (stew) with anchovy in Mediterranean cooking; bagna cauda (warm dipping sauce of anchovies, garlic, olive oil, and butter) from the northwest of Italy; koji-fermented soy pastes from Japan, Korea, and China; soy sauces from numerous Asian cuisines; cooked tomato and parmesan in Italian cooking; dried meat (machaca) in Mexico; ketchup on a hamburger; and dried shiitake mushrooms in meat broths in Chinese cooking.

Science has explained that the umami-rich foods enjoyed around the world are so impactful because of the presence of free glutamate. This amino acid is what our body interprets as the pleasurable taste umami. When bound to other amino acids, as is the case in proteins, glutamate is tasteless. However, certain processes, including fermentation, aging, ripening, drying, and low, slow cooking, liberate amino acids from native proteins, increasing the presence of free glutamate (Wijayasekara & Wansapala, 2017). Throughout the ages, chefs and cooks have used these tools to make superlative food. Additionally, some vegetables when ripe are more flavorful partially due to the increase in glutamate during the ripening process. Tomatoes are a good example of this (Oruna-Concha et al., 2007; Tommonaro et al., 2021).

Fermentation, responsible for the complex and heady flavors in many foods, also increases umami. Examples of fermented foods that are rich sources of umami include natto, Southeast Asian fish sauces, oyster sauce, soy sauce, miso, and kimchi fermented with seafood. A number of popular fermented products are based on either 100% fermented soy or a combination of wheat and soy (Lioe et al., 2010). Glutamic acid is the predominant amino acid in soybean and wheat proteins (Wang et al., 2018; Hou et al., 2019). During the fermentation process, a large amount of glutamate is liberated from these proteins, resulting in a significant increase in umami. A unique mold koji (*Asperigillus oryzae*) is central to the production of many of the products listed above. When fermented with koji, which contains the enzyme glutaminase, glutamine is converted into glutamic acid. This is the traditional way of making soy sauce and miso, both of which contain high levels of umami (Otsuka, 1998; Yoshida, 1998; Lioe et al., 2010; Diez-Simon et al., 2020).

Aging in products such as cheeses, meats, and sausages also results in increased concentrations of glutamate, contributing to umami taste. For example, during the ripening of cheese, proteins are broken down into smaller peptides and amino acids, including not only glutamate but also leucine, valine, lysine, phenylalanine, and valine. These amino acids and peptides contribute to flavor complexity in cheese (Umami Information Center, 2016, 2021; Zhao et al., 2016). The increased level of glutamate (Fig. 9.1) corresponds to the heightened presence of umami. Similarly, large increases in free amino acids occur during the aging process in cured hams and other dry-cured meats (Córdoba et al., 1994; Zhang et al., 2019; Heres et al., 2021). Glutamate is one of the most prominent amino acids in these aged and cured meat products (Yamaguchi & Ninomiya, 2009).

Drying has the potential to concentrate levels of glutamate, thus making dried foods more impactful from a gustatory standpoint. An example is dry-cured ham, which combines increased glutamate from the aging process with further concentration from the drying process (Zhang et al., 2019). Drying mushrooms results in the

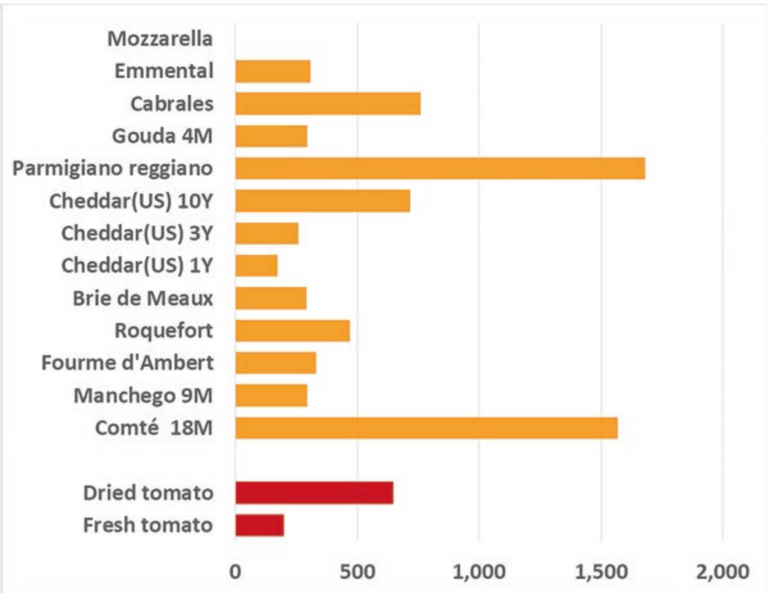

Fig. 9.1 Concentration (mg/100 g) of free glutamate in various cheeses with curation times from 4 months (M) up to 10 years (Y) and in fresh and dried tomato (Fuke & Konosu, 1991). Data were analyzed at the Japan Food Research Laboratories by the Umami Information Center

5′-nucleotide GMP (guanosine 5′-monophosphate), which has a synergistic effect on umami perception (Kuninaka, 1960; Yamaguchi et al., 1971). 5′-Nucleotides are present to varying degrees in different mushrooms. When mushrooms are dried or frozen, the cell walls are damaged, which converts nucleotides into 5′-nucleotides. The resulting GMP, combined with the mushroom's inherent glutamate, with glutamate in other foods, and/or with other free amino acids, gives a pleasurable spike in umami perception (Wijayasekara & Wansapala, 2017). A good example of this is dried shiitake mushrooms (Umami Information Center, 2016).

9.4 Concentrated Umami Sources and Products

The previous section explored the history and use of foods inherently rich in glutamate that deliver a strong umami taste. Each of those food ingredients also contributes other basic tastes, aromas, and textures—flavors that can be advantageous in various recipes. In contrast, this section looks at highly concentrated forms of umami that, aside from their strong umami character, contribute little or no additional flavors and are used in low amounts.

9.4.1 Glutamate

The ionic form of L-glutamic acid, glutamate, is an amino acid that is part of many proteins. In the production of MSG by fermentation, bacteria convert molasses or starch hydrolysates into L-glutamic acid, the non-neutralized version of MSG that tastes sour (because of its acid radical). After neutralization with sodium hydroxide, the compound adopts the form of sodium L-glutamate, and the umami taste becomes prevalent (Sano, 2009). This is how MSG is produced in its most inexpensive form—is readily available, dissolves quickly, and has immediate impact on food flavor (Lindemann et al., 2002). Before the fermentation method was adopted, L-glutamic acid was produced from wheat gluten, which contains about 25% L-glutamic acid by weight (Giacometti, 1979). The pH of most foods is close to neutral, so glutamate is almost fully found in foods in the form of the tasty sodium salt rather than the sour L-glutamic acid (Kurihara, 2009).

A good average amount for MSG inclusion is about 0.4% by weight—adding more does not necessarily render the food inedible, like a larger addition of salt would (Yamaguchi & Takahashi, 1984), but higher levels of MSG do not necessarily yield noticeably more umami character. On a practical level, MSG can be easily sprinkled onto a wide variety of savory dishes just as salt would customarily be used. It does not replace salt but is used in conjunction to provide two different taste sensations, both of which heighten overall flavor. Thus, MSG can provide an immediate and effortless increase in umami (Beauchamp, 2009).

Yet, in the culinary world, umami is not often considered when creating a dish or evaluating its overall flavor impact. For instance, chefs are trained to instinctively consider salt levels in savory dishes but rarely have they been taught to consider umami levels. When judging culinary competitions or scoring students' dishes in culinary schools, chefs often have a rubric for level of seasoning, which refers to just one taste: saltiness. Yet, considering not just saltiness but the umami axis as well, along with acid, sweet, and bitter, can provide a much more nuanced assessment of balance in tastes and flavors in a dish than simply "needing salt."

Keeping a container of MSG alongside salt and pepper is a more complete way of balancing flavor. For both chefs and cooks, it is important to remember that MSG is not a salt replacer. Although MSG does contain sodium (as its name, monosodium glutamate, reminds us), in fact MSG contains only 12.3% sodium compared with table salt's 39.6% sodium. Using MSG as a 1:1 salt substitution would result in dishes that are undersalted and therefore out of balance. That said, MSG can be effective in reducing (but not replacing) salt, as we discuss below (Morita et al., 2021).

Monopotassium glutamate (MPG), the potassium salt of glutamic acid (just like MSG is the sodium salt of glutamic acid), is produced in a similar manner. Fermentation produces glutamic acid, which is neutralized not with sodium hydroxide like MSG but with potassium hydroxide, producing MPG. Both products are very similar in glutamic acid amount.

MPG delivers concentrated umami with an impact much like MSG's and similarly dissolves quickly and can be used topically. However, while the umami impact that MSG delivers is immediate, MPG seems to bring a slightly delayed umami impact that hits the middle of the palate, leading to a more mouth-filling sensation. It is also an important ingredient in meat analogs, contributing a "serum"-like flavor note. It is less readily available than MSG and is more expensive (Kochem & Breslin, 2017; Morita et al., 2020).

9.4.2 Yeast Extracts

Manufacturing of yeast extract starts with specifically identified yeast organisms that will produce concentrated sources of umami (Chae & In, 2001). Different yeast extracts can deliver different levels of glutamate, glutathione, or nucleotides, depending on the strain. A basic, inexpensive yeast extract has low levels of everything and is used for general background savory notes. Specialty yeast extracts are more potent and deliver specific tastes and flavors, including umami notes (Jo & Lee, 2008).

A culture medium is used to grow as much yeast as possible. The yeast is then washed and goes through a lysis process to break the cell walls, either with enzymes or through a process called autolysis (Breddam & Beenfeldt, 1991). Autolysis uses high levels of salt to break the yeast apart. Older-generation yeast extracts contained high levels of sodium, but newer yeast extracts use more modern techniques that can reduce the final levels of sodium. The cell wall material is then washed off and the remainder of the material is filtered and dried (Dimopoulosa et al., 2018). Yeast extract can also be used in a paste format—a common example of this is Vegemite spread popular in Australia. From a culinary standpoint, it is essential to know sodium levels in any yeast extract, as this will impact final taste results.

Utilization of yeast extracts in kitchen applications requires exact measurements, as they are employed in very small quantities (i.e., slightly below or above 0.15%). As a result, yeast extracts are more applicable in manufacturing settings than in daily home or foodservice environments. Using MSG is a much easier way to incorporate a concentrated umami source (Okiyama & Beauchamp, 1998). Yeast extracts are hygroscopic: when exposed to air, they will absorb moisture and clump. Yeast extracts in combination with nucleotides can have extreme impacts on flavor due to synergies between glutamates and nucleotides, as we describe below. Yeast extracts also deliver a consistent umami impact across the palate, but its overuse contributes an objectionable yeast note (Alim et al., 2019). Overall, yeast extract is less of a pure form of umami compared to MSG and MPG (J. Formanek, personal communication, September 9, 2021).

9.5 What Is Not Umami

There is a lot of confusion around what umami is, among home cooks and even among culinary professionals at high levels, who sometimes confuse the specific taste of umami with complex flavors like the unctuous sweetness of caramelized onions, the rich fatness of crispy pork belly, or the deep smokiness of Maillard-browned barbecued burnt brisket ends (Hofmann, 2005; Finot, 2006). While those foods may have many wonderful characteristics, including fattiness, unctuousness, smokiness, brown/roasted flavors, crispness, and so on, unless it was specifically prepared with umami-rich ingredients, like those described above, it probably had very low levels of umami taste, as determined both by chemical and by sensory analyses. Delicious flavor, certainly; umami taste, likely not.

There are a few reasons for the confusion around umami. It is a relative newcomer to the five basic tastes (Lindemann et al., 2002), and many people were not trained to recognize it when they were young like they did for the other basic tastes. Even at the professional level, educators have bemoaned the lack of palate training in formal culinary education (Deutsch, 2018). Without a firm understanding of umami, professional chefs do not know how to analyze their foods for optimal umami. To be umami, there must be a significant amount of glutamate that is not bound to other amino acids as a taste identified by specific umami receptors on the tongue (and elsewhere) as indicated in the previous section of *Umami History Through the Culinary Lens*. The higher the glutamate concentration in a food, the more umami will be sensed. In most cases, this sensation cannot be produced from compounds other than proteins that have glutamate—if no protein is available from which to extract the glutamate, then there can be no umami sensation on the taste receptors. If umami receptors are not activated, food may present a delicious flavor without umami (understanding flavor as the combination of taste with all the other sensations that influence food perception, such as aroma, texture, juiciness, mouthfeel, or color) (Grabenhorst et al., 2008). So, there is additional confusion around ferments that are not protein rich. For example, cabbage is a vegetable low in protein. Kimchi recipes often add anchovies to cabbage in the fermentation, yielding an umami-rich product. Without the anchovy, or the production of glutamate by lactic acid bacteria (Yoon et al., 2021), Kimchi may be salty, sour, and delicious, but it will not be as rich in umami (Lee et al., 2021).

9.6 Synergies Between Ribonucleotides and Umami

Umami taste can be enhanced through synergistic interactions with the 5′-ribonucleotides GMP and IMP (Yamaguchi, 1998a, b) (see also Chaps. 2 and 3 of this book). IMP is found in large amounts in meat, poultry, seafood, and dairy, and guanylate is found most significantly in dried mushrooms. Both are also available in pure commercial/concentrate form (Wang et al., 2020). A small amount of inosinate and/or guanylate in combination with glutamate creates a strong umami taste (see Table 9.1).

Chefs have turned to these enhancement combinations (glutamate + inosinate/guanylate) intuitively throughout history to make food more delicious. Traditional preparations that employ this synergistic combination include the cheeseburger,

Table 9.1 Umami taste intensity of MSG + IMP mixtures of various percentages

% MSG	% IMP	Rated taste intensity
100	0	0
95	5	3.5
82	18	6.8
70	30	7.4[a]
50	50	7.5
30	70	7.3
10	90	5.3
5	95	3.7
2	98	1.8
0	100	0.3[b]

Data show responses (on a scale of 1 to 10) by trained panelists to the taste of various percent mixtures of MSG (monosodium glutamate) and IMP (5′-inosine monophosphate), generated by combining constant concentrations of 0.05 g/dL. Simplified from Yamaguchi (1967)

[a]As the percentage of MSG decreases from 100% to 70% and the percentage of IMP correspondingly increases from 0% to 30%, the taste intensity increases. A maximum is reached at this point. This forms an inverted U-shaped function with the optimal taste intensity mixture about 50% to 75% MSG and 25% IMP

[b]IMP has little or no umami taste intensity at 100% (no MSG in the mixture)

Table 9.2 Examples of food combinations for dishes that employ the synergistic effects between glutamate and IMP or GMP

Glutamate source	IMP or GMP source	Final synergistic combination
Glutamate + IMP foods		
Aged cheese	Tuna	Tuna melt sandwich
Kombu (kelp)	*Katsuobushi* (cured bonito)	Dashi
Onions, celery, carrots	Poultry	Chicken soup
Dashi	Pork	Ramen
Aged cheese	Beef	Cheeseburger
Glutamate + GMP foods		
Aged cheese	Dried porcini	Mushroom pasta
Scallop	Dried morels	Scallop with morel sauce
Kombu	Dried shiitake	Vegetarian dashi

Japanese curry, anchovies on pizza, mushroom gravy, and French onion soup. It also explains why dashi, the base stock in Japanese cooking, is so tasty despite being made from only two ingredients that are cooked for a short period of time (Umami Information Center, 2016): the *kombu* contributes glutamate, and either the *katsuobushi* contributes inosinate or, in vegetarian dashi, dried shiitake mushrooms contribute guanylate (see Table 9.2).

9.7 Benefits of Umami in Cooking

9.7.1 Aids in Salt Reduction

Flavor-enhancing and umami-rich ingredients such as MSG offer a possible sensory strategy to mitigate the low palatability of reduced salt. Medical evidence indicates that reduced sodium intake in diets can improve certain disease states such as hypertension and diabetes (Feldstein, 2002). Compliance with low-sodium diets is problematic due to the decrease in palatability (Roininen et al., 1996; Okiyama & Beauchamp, 1998; Yamaguchi & Ninomiya, 2000). MSG was acknowledged in 2019 by the National Academies of Sciences, Engineering, and Medicine as a viable strategy to reduce sodium in the food supply (Institute of Medicine, Food and Nutrition Board et al., 2010). The amount of sodium in MSG (12.28 g/100 g) is one-third that in salt (39.34 g/100 g), and the usage level as a food additive is quite low (0.1–0.8% by weight) (Maluly et al., 2017; Halim et al., 2020). Adding MSG in excess will create unbalanced flavors, decreasing palatability, so its use is self-limiting (Yamaguchi & Takahashi, 1984). This means that MSG has the potential to play a key role in reducing salt in food products while maintaining or increasing likability (see Chap. 4 of this book for more detail on this topic).

9.7.2 Provides a Bass Note in Cooking

The bass note that MSG provides in cooking may not be recognizable to average consumers, yet without it, some dishes taste like something is missing, an absence of full flavor potential. Like the bass part in music, it may not be overtly noticeable, but it provides the foundation that all the other parts build on—in dishes, MSG supports and enhances overall flavor. MSG has been described as "fullness of the mouth" and "richness" (Yamaguchi & Ninomiya, 2000) (see Chap. 2 of this book for more detail).

9.7.3 Increases Salivation

Umami, which has been shown to increase salivation (Schiffman, 1998), is notable by persistence in the palate and salivation at the end of the palate, signs of the presence of umami. This factor has been utilized in elderly patients to increase food intake (Sasano et al., 2015). The most important roles of saliva are during chewing food and in maintaining oral health. Saliva helps protect the teeth and mucosa from infection and maintain healthy taste receptors and speech communication (Uneyama et al., 2009) (see Chap. 7 of this book for more detail).

Taste dysfunction is shown to have a negative effect on health, correlating with poor appetite, reduced dietary intake, and weight loss (Sasano et al., 2014). This affects the elderly population most of all (Schiffman, 2000). Taste function and salivation are closely related, and the umami taste is shown to promote salivary secretion. A 2015 study found that treating decreased salivation reduced hypogeusia (Sasano et al., 2015), showing that salivation is essential to maintain normal taste function. The increased salivary flow rate, due to the gustatory-salivary reflex from umami taste stimulation, improved taste function, appetite, weight, and overall health in elderly people (Sasano et al., 2014, 2015).

9.7.4 Adds "Meatiness"

While it is hard to describe what umami tastes like, it is often referred to as meaty or savory. These flavor notes are particularly important in plant-based formulations for creating both meatiness and depth, pleasurable sensations that are absent in dishes that do not contain animal products (Yamaguchi, 1998a, b).

9.8 Conclusion

This chapter has focused on umami from a culinary point of view, as a basic, global taste that has played a traditional culinary role as a source of deliciousness for millennia before it was scientifically identified. The ancient Romans added umami with their fermented fish sauces, and the French gastronome Brillat-Savarin defined a water-soluble substance in meat flavors, but umami compounds—glutamate, IMP, and GMP—were not identified until 1908, by Professor Ikeda. Even so, it took another century for scientific evidence to reveal the existence of umami receptors on the tongue, identifying it as a bona fide taste element. These discoveries have helped chefs and cooks around the world understand why they traditionally gravitated toward umami-rich foods in their cuisines. Fundamental to what makes these foods delicious is the presence of glutamate and nucleotides that, from a chemosensory perspective, are a source of a fundamental, pleasurable taste. The analysis of umami compounds in foods and ingredients has given light to the cooking processes and food technologies that deliver a strong umami taste through such ingredients as MSG. For chefs and culinary students, learning how to recognize and distinguish the umami taste is an important part of their training in the kitchen, allowing the mindful application of umami-rich ingredients in recipes and menus. Understanding umami helps chefs and culinary students build balanced and complex flavor profiles. From a health perspective, this taste has been proven advantageous in reduced-sodium foods, mitigating the low palatability of low-salt products, and can aid digestion in the elderly by increasing saliva production. MSG and other concentrated umami ingredients can also provide the meaty and savory flavor notes that can be especially useful in plant-based formulations. Combined, these benefits of umami make it an attractive option to improve both health and flavor.

References

Alim, A., et al. (2019). The behavior of umami components in thermally treated yeast extract. *Food Research International, 120*, 534–543.

Beauchamp, G. K. (2009). Sensory and receptor responses to umami: An overview of pioneering work. *The American Journal of Clinical Nutrition, 90*(3), 723S–727S.

Breddam, K., & Beenfeldt, T. (1991). Acceleration of yeast autolysis by chemical methods for production of intracellular enzymes. *Applied Microbiology and Biotechnology, 35*(3), 323–329.

Brillat-Savarin. (1848). *Physiologie du goût*. Project Gutenberg.

Chae, H. J., & In, H. J. M. J. (2001). Utilization of brewer's yeast cells for the production of food-grade yeast extract. Part 1: Effects of different enzymatic treatments on solid and protein recovery and flavor characteristics. *Bioresour Techology, 76*(3), 253–258.

Chaudhari, N., et al. (2000). A metabotropic glutamate receptor variant functions as a taste receptor. *Nature Neuroscience, 3*, 113–119.

Córdoba, J. J., et al. (1994). Evolution of free amino acids and amines during ripening of Iberian cured ham. *Journal of Agricultural and Food Chemistry, 42*, 2296–2301.

Curtis, R. (2009). Umami and the foods of classical antiquity. *American Journal of Clinical Nutrition, 90*(3), 712S–718S.

Deutsch, J. (2018). *We Eat What? A cultural encyclopedia of unusual foods in the United States*, Greenwood.

Diez-Simon, C., et al. (2020). Carmen Diez-Simon 1 2, Charlotte Eichelsheim 1, Roland Mumm 2 3, Robert D Hall. *Journal of Agricultural and Food Chemistry, 68*(42), 11612–11630.

Dimopoulosa, G., et al. (2018). Effect of pulsed electric fields on the production of yeast extract by autolysis. *Innovative Food Science & Emerging Technologies, 48*, 287–295.

Feldstein, C. (2002). Salt intake, hypertension and diabetes mellitus. *Journal of Human Hypertension, 16*(Suppl 1), S48–S51.

Finot, P.-A. (2006). Historical perspective of the maillard reaction in food science. *Annals of the New York Academy of Sciences, 1043*, 1–8.

Fuke, S., & Konosu, S. (1991). Taste-active components in some foods: A review of Japanese research. *Physiology & Behavior, 49*(5), 863–868.

Giacometti, T. (1979). *Free and bound glutamate in natural products*. Raven Press.

Grabenhorst, F., Rolls, E. T., Bilderbeck, A. (2008). How cognition modulates affective responses to taste and flavor: top-down influences on the orbitofrontal and pregenual cingulate cortices. *Cereb Cortex, 18*(7), 1549–1559. https://doi.org/10.1093/cercor/bhm185. Epub 2007 Dec 1. PMID: 18056086

Hajeb, P., & Jinap, S. (2015). Umami taste components and their sources in Asian foods. *Critical Reviews in Food Science and Nutrition, 55*(6), 778–791.

Halim, J., et al. (2020). The Salt Flip: Sensory mitigation of salt (and sodium) reduction with monosodium glutamate (MSG) in "Better-for-You" foods. *Journal of Food Science, 85*(9), 2902–2914.

Heres, A., et al. (2021). Characterization of umami dry-cured ham-derived dipeptide interaction with metabotropic glutamate receptor (mGluR) by molecular docking simulation. *Appli Sciences, 11*(17), 8268.

Hofmann, T. (2005). Taste-active maillard reaction products: The "tasty" world of nonvolatile maillard reaction products. *Annals of the New York Academy of Sciences, 1043*(20–29), 20.

Hou, Y., et al. (2019). Composition of polyamines and amino acids in plant-source foods for human consumption. *Amino Acids, 51*, 1153–1165.

Institute of Medicine, et al. (2010). *Strategies to Reduce Sodium Intake in the United States*.

Jo, M.-N., & Lee, Y.-M. (2008). Analyzing the sensory characteristics and taste-sensor ions of MSG substitutes. *Food Science, 73*(5), S191–S198.

Kochem, M., & Breslin, P. A. S. (2017). Clofibrate inhibits the umami-savory taste of glutamate. *PLoS One, 12*(3), e0172534.

Kuninaka, A. (1960). Studies on taste of ribonucleic acid derivatives. *Journal of Agricultural Chemical Society of Japan, 34*, 487–492.

Kurihara, K. (2009). Glutamate: From discovery as a food flavor to role as a basic taste (umami). *American Journal of Clinical Nutrition, 90*(3), 719S–722S.

Lee, H. J., et al. (2021). Free amino acid and volatile compound profiles of jeotgal alternatives and its application to Kimchi. *Food, 10*(2), 423.

Lindemann, B., et al. (2002). The discovery of umami. *Chemical Senses, 27*(9), 843–844.

Lioe, H., et al. (2010). Soy sauce and its umami taste: A link from the past to current situation. *Food Science, 75*(3), R71–R76.

Maluly, H. D. B., et al. (2017). Monosodium glutamate as a tool to reduce sodium in foodstuffs: Technological and safety aspects. *Food Science & Nutrition, 5*(6), 1039–1048.

Morita, R., et al. (2020). Quantitative verification of the effect of using an umami substance (L-glutamate) to reduce salt intake. *Hypertension Research, 43*(6), 579–581.

Morita, R., et al. (2021). Effect of monosodium glutamate on saltiness and palatability ratings of low-salt solutions in Japanese adults according to their early salt exposure or salty taste preference. *Nutrients, 13*(2), 577.

Nakayama, T., & Kimura, H. (1998). Umami (xian-wei) in Chinese food. *Food Reviews International, 14*(2–3), 257–267.

Okiyama, A., & Beauchamp, G. K. (1998). Taste dimensions of monosodium glutamate (MSG) in a food system: Role of glutamate in young American subjects. *Physiology & Behavior, 65*(1), 177–181.

Oruna-Concha, M.-J., et al. (2007). Differences in glutamic acid and 5′-ribonucleotide contents between flesh and pulp of tomatoes and the relationship with umami taste. *Journal of Agricultural and Food Chemistry, 55*(14), 5776–5780.

Otsuka, S. (1998). Umami in Japan, Korea, and southeast asia. *Food Reviews International, 14*(2–3), 247–256.

Roininen, K., et al. (1996). Effect of umami taste on pleasantness of low-salt soups during repeated testing. *Physiology & Behavior, 60*(3), 953–958.

Sano, C. (2009). History of glutamate production. *American Journal of Clinical Nutrition, 90*(3), 728S–732S.

Sasano, T., et al. (2014). Important role of umami taste sensitivity in oral and overall health. *Current Pharmaceutical Design, 20*(16), 2750–2754.

Sasano, T., et al. (2015). The important role of umami taste in oral and overall health. *Flavour, 4*(10).

Schiffman, S. S. (1998). Sensory enhancement of foods for the elderly with monosodium glutamate and flavors. *Food Reviews International, 14*(2–3), 321.

Schiffman, S. S. (2000). Intensification of sensory properties of foods for the elderly. *Journal of Nutrition, 130*(130), 4.

Tommonaro, G., et al. (2021). Determination of flavor-potentiating compounds in different Italian tomato varieties. *Journal of Food Biochemistry, 45*(5), e13736.

Umami Information Center. (2016). UMAMI.

Umami Information Center. (2021). *Cheese and Umami*. https://www.umamiinfo.com/richfood/foodstuff/cheese.html.

Uneyama, H., et al. (2009). Contribution of umami taste substances in human salivation during meal. *The Journal of Medical Investigation, 56*, 197–204.

Wang, X., et al. (2018). Textural and rheological properties of soy protein isolate tofu-type emulsion gels: Influence of soybean variety and coagulant type. *Food Biophysics, 13*, 324–332.

Wang, W., et al. (2020). Characterization and evaluation of umami taste: A review. *TrAC Trends in Analytical Chemistry, 127*, 115876.

Wijayasekara, K., & Wansapala, J. (2017). Uses, effects and properties of monosodium glutamate (MSG) on food & nutrition. *International Journal of Food Science and Nutrition, 2*(3), 132–143.

Yamaguchi, S. (1967). The synergistic effect of monosodium glutamate and disodium 5′-inosinate. *Journal of Food Science, 32*, 474–478.

Yamaguchi, S. (1998a). Basic properties of umami and its effects on food flavor. *Food Reviews International, 14*(2&3), 139–176.

Yamaguchi, S. (1998b). Basic properties of umami and its effects on food flavor. *Food Review International, 14*(2&3), 139–176.

Yamaguchi, S., & Ninomiya, K. (2000). Umami and food palatability. *The Journal of Nutrition, 130*(4), 921S–926S.

Yamaguchi, S., & Ninomiya, K. (2009). What is umami? *Food Reviews International, 14*(2–3), 123.

Yamaguchi, S., & Takahashi, C. (1984). Hedonic functions of monosodium glutamate and four basic taste substances used at various concentration levels in single and complex systems. *Agriculture and Food Chemistry, 48*(4), 1077–1081.

Yamaguchi, S., et al. (1971). Measurement of the relative taste intensity of some L-amino acids and 5′-nucleotides. *Journal of Food Science, 36*, 846–849.

Yoon, S.-R., Dang, Y.-M., et al. (2021). Correlating capsaicinoid levels and physicochemical properties of kimchi and its percived spiciness. *Food, 10*, 86.

Yoshida, Y. (1998). Umami taste and traditional seasonings. *Food Reviews International, 14*(2–3), 213–246.

Zhang, J., et al. (2019). 1H NMR-based metabolomics profiling and taste of boneless dry-cured hams during processing. *Food Research International, 122*, 114–122.

Zhao, C. J., et al. (2016). Formation of taste-active amino acids, amino acid derivatives and peptides in food fermentations – A review. *Food Research International, 89*(pt1), 39–47.

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