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Uses, effects and properties of monosodium glutamate (MSG) on food & nutrition

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Abstract

This review article reviews the uses and effects of Monosodium Glutamate (MSG) on Food & Nutrition. Various research articles, journals, conference papers were reviewed in recognizing the uses and effects of Monosodium Glutamate from 1908. Glutamate performs numberless essential roles in intermediary metabolism and is present in large quantities in the organs and tissues of the body. Even though much published studies are not being published on glutamate intake in relation to obesity or overweight in human, a study done in China provided anthropological data that glutamate intake may be related with increased risk of overweight irrespective of physical activity and total energy intake. Thus several studies again had proven using animals and humans, that glutamate did not increase food intake or induce obesity. MSG has also been described as a trigger for migraine headache exacerbations.

Keywords: monosodium glutamate, metabolism, risk

Introduction

Flavors & Flavor enhancers

There are two main definitions of flavor which depend upon the viewpoint of the definer. Flavor can refer to a biological perception, such that it is the sensation produced by a material taken in the mouth, or flavor can refer to an attribute of the material being perceived. The attribute is the aggregate of the characteristics of the material that produces the sensation of flavor. Flavor is perceived principally by the aroma receptors in the nose and taste receptors in the mouth. Flavor is considered as one of the three key sensory properties that decides their selection, acceptance and ingestion of a certain food. Flavor enhancer is a substance that enhances the flavors of other substances without itself imparting any characteristic flavor of its own, which is the definition according to Food & Nutrition dictionary by Oxford University, 2005.

Types of flavor enhancers

Types of flavor enhancers Flavor enhancers or modulators may affect the taste, odor and or trigeminal impressions of foods. Usually only taste and/or odor are affected, although maltol and ethylmaltol have been reported to be effective in improving the mouthfeel in low fat food system [1]. Because of the lack of a firm definition of flavor enhancer or modulator, the term flavor modifier will be used for substances that enhance, suppress or otherwise modify the flavor of foods. Flavor modifiers have been classified into the five categories shown in below table. Based on this classification, monosodium glutamate and purine 5'-riboneucliotides, for example, are flavor enhancers and flavor suppressors at the same time, because they exhibit taste enhancing and odor and taste suppressing effects.

Table 1: Categories of flavor enhancers

Category	Examples	Remarks
Flavor enhancers exhibiting little or no flavor at typical usage level	Monosodium glutamate Purine 5'ribonucleotides	Enhance sweet and salty taste impressions and beef stock odor impression
Flavor enhancers exhibiting flavor at typical usage	Vanillin Ethyl vanillin Maltol Ethyl maltol	Enhance odor impressions (eg: fruity, chocolate) Improve the mouthfeel of low fat foods
Flavor suppressors exhibiting little or no flavor at typical usage level	Monosodium glutamate Purine 5'ribonucleotides	Mask or suppress odor impression
Flavor suppressors exhibiting flavor at typical usage level	Sucrose	Suppresses unpleasant odor impressions in fruit juices
Other flavor modifiers	Miraculin	Sour tasting substances are perceived as sweet tasting for approx. two hours

Umami taste

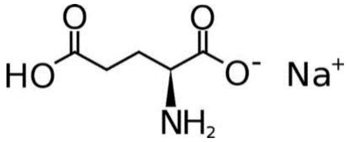
Umami is one of the five basic tastes (together with sweetness, sourness, bitterness, and saltiness). A loanword from the Japanese, umami can be translated as "pleasant savory taste" [2]. Umami has a slight nevertheless lasting aftertaste which is quite difficult to explain. It induces salivation and a sensation of furriness on the tongue, stimulating the throat, the roof and the back of the mouth [3]. Most taste buds on the tongue and other regions of the mouth can detect umami taste, irrespective of their location. The tongue map in which different tastes are distributed in different regions of the tongue is a common misconception.

Regardless of the location, most of the taste buds of the tongue are able to detect umami taste. Moreover, certain literature states that it is a misconception to identify that the tongue has different taste regions distributed in different regions. In addition, researchers have found that receptors that are responsible to identify the umami taste as modified forms of mGluR4,mGluR1 and taste receptor type 1 (T1R1 + T1R3) can be found in almost every region of the tongue [4, 5, 6].

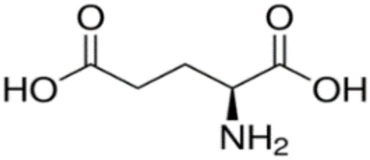
Glutamate and Monosodium Glutamate

Monosodium Glutamate and Glutamate are the monosodium salt of the glutamic acid. However, the totally dissociated form of L-(+)-glutamic acid merely exhibits the umami effect. The percentage of dissociation at various pH values are shown in the Table 02 and the pH dependent ionic forms of the glutamic acid. It is apparent from the data in table that only at pH 6 to 8 does glutamic acid show its optimal umami effect.

Chemical structures of glutamic acid and MSG.



L-glutamic acid Monosodium



Glutamate

Fig 1: Ionic forms of glutamic acid

Table 2: Percentages of Dissociation of Glutamic acid at various pH

pH	% of dissociation
3.0	5.3
3.5	15.1
4.0	36.0
4.5	64.0
5.0	84.9
5.5	94.7
6.0	98.2
7.0	99.8
8.0	96.9

***Source*:** Umami Flavor of Meat and Meat products [117]

Natural occurrence of Glutamate

Natural occurrence of Glutamate is one of the most common amino acids found in nature which is present in many proteins and peptides and most tissues. In 1994, Filer & Stegink stated that Glutamate is naturally synthesized in the body and binds with other amino acids to produce structural proteins [7]. When bound to protein molecules, glutamate is tasteless and it would not provide umami taste to food. Nevertheless, free glutamate is liberated in protein hydrolysis throughout fermentation, aging, ripening and heat cooking process [8].

In terms of foods like seafoods, meat, cheese and broths Glutamate is a crucial component of the taste [9]. Ninomiya also reported measured free glutamic acid, which present naturally in different foods, such as meat, poultry, seafood and vegetables (Table 03). Konosu [10] showed that by mixing umami taste substances, amino acids and salt in appropriate ratios, the characteristic tastes of many natural foods could be reproduced.

Table 3: Free glutamic acid content in foods

Food items	Free glutamic acid (mg/100 g)
Meat and poultry	
Beef	10
Pork	9
Chicken	22
Vegetables	
Cabbage	50
Spinach	48
Tomato	246
Corn	106
Onion	51
Potato	10
Mushroom	42
Shiitake mushroom (fresh)	71
Fruits	
Avocado	18
Apple	4
Grape	5
Kiwi	5
Milk	
Cow	1
Goat	4
Human breast milk	19

***Source*:** Ninomiya [9].

The umami taste substances are contained abundantly in various foods, including vegetables (e.g., tomato, potato, Chinese cabbage, mushroom, carrot, soybean and green tea), seafood (e.g., fish, kelp, seaweed, oyster, prawn, crab, sea urchin, clam and scallop), meat (e.g., beef, pork and chicken) and cheese, and contribute greatly to the characteristic tastes of these foods [11]. As an example, Konosu [10] mentioned that the characteristic taste of the crab meat was disappeared when the umami constituents were removed once the snow crab meat was reproduced by mixing glycine, alanine, arginine, glutamate, IMP and salts in a particular. Consequently, umami taste substances are vital to produce the unique taste of many natural foods. The predominant flavor of mushrooms is the umami taste, also called the palatable taste or the perception of satisfaction, which is related to an overall flavor perception induced or enhanced by glutamate, and 50-nucleotides [10, 12].

It had been found that, increase of sugars free amino acids and organic acids such as tomato contribute to the increase in flavor during the ripening of vegetables. For example, increase in their natural contents of free amino acids is related with flavor maturation in ripening tomatoes. During the ripening of cheese, proteins are broken down progressively into smaller polypeptides and individual amino acids [13]. Moreover, Ramos [14] showed that growths in these amino acids are commonly recognized to be a reliable indicator of cheese ripening and also contribute to the taste and texture of the cheese. Large increase in free amino acid amounts also occurs during the curing of ham, and glutamate is identified as the most abundant free amino acid appeared in the final product [15].

History of Monosodium glutamate

The natural occurring glutamate is in the form of L-glutamic acid, firstly discovered in 1866 by Karl Ritthausen, a German scientist, who isolated it from the acid hydrolysate of wheat gluten [16]. Salts of glutamic acid were first revealed in 1908. Japanese scientist, Professor Kikunae Ikeda, identified the unique taste of umami attributed by glutamic acid. Furthermore he recognized that umami taste as the fifth basic taste of the tongue after sweet, sour, salty and bitter, where umami receptor taste found. Professor Ikeda, also has extracted and identified glutamic acid from soup stock prepared from konbu seaweed as the source of the umami taste, which from then, umami is described as savory, or meat or broth-like taste means delicious in Japanese [17, 18, 19]. Kodama [20] isolated 50-inosinic acid from dried skip jack as another key component of the Konbu seaweed stock.

In addition, Kinoshita [21] revealed a bacterial strain Corynebacterium glutamicus which could produce and accumulate large amounts of L-glutamic acid. Kuninaka [22] isolated 50-guanylate and recognized its role as key component of umami taste in the broth of dried shiitake mushroom. There have been numerous studies on umami taste and glutamate and their relation to food palatability and flavor acceptance, nutritional considerations, presence in foodstuffs, sensing in the oral cavity and gut, physiological role in the food digestion, safety and adverse effects.

Chemical and Physical properties of Monosodium glutamate

Monosodium Glutamate (Molecular Weight: 187.13) significantly soluble in water and commonly marketed as a white crystalline powder. It is not hygroscopic and it doesn't change in quality or appearance during lengthy storing conditions at room temperature as it is also found to be stable. Except in acidic conditions like pH 2.2-2.4 and at high temperatures, MSG does not decompose even during normal food processing or cooking. At such pH levels and temperatures, MSG is partially dehydrated and converted into 5-pyrrolidone-2-carboxylate. Furthermore, at very high temperatures and particularly under alkaline conditions, glutamate tends to racemize to D, L-glutamate. MSG, like other amino acids, also has the capability to undergo Maillard type reactions in the presence of reducing sugars. MSG is recognized to impart a unique taste due to its taste active chemical properties. The distinctive taste of MSG is a result of its stereo-chemical structure with the D-isomer having no unique taste [22].

The ideal palatability concentration for MSG lies between 0.2 – 0.8% and its use tends to be self-limiting as over-use reductions palatability. The largest palatable dose for humans is about 60mg/kg body weight [23].

Monosodium glutamate as a flavor enhancer

Food additives which provide umami taste are categorized as a flavor enhancer, which are salt of glutamate, namely monosodium glutamate, monoammonium glutamate, monopotasium glutamate, and ribonucleotides compounds, namely disodium 50-monoinosinate (IMP) and disodium 50-monoguanylate (GMP) [18]. Only the free form of glutamate, in its L-configuration presents flavor enhancing properties, and, for this reason, it is widely used as a flavor enhancer in the food processing industry according to Bellisle [18] and Populin [24]. Codex Alimentarius categorized glutamate and its salts, monosodium glutamate, monopotassium glutamate, calcium diglutamate, monoammonium glutamate and magnesium diglutamate, as flavor enhancer [25]. When glutamate is added to foods, it provides a flavoring function similar to naturally occurring free glutamate [22].

For each food, there is an optimum glutamate concentration. Some foods, however, are not enhanced by the addition of glutamate, i.e., sweet foods in specific and some particularly bitter food [26]. Among individuals, the ideal concentration of umami taste varies widely as far as sweetness and saltiness is considered. Some like it, again at varying concentrations, whereas some seem in different to it, and some even dislike it. However, as per the findings of many studies, it is evident that most people are sensitive to its flavor-enhancing properties [27]. Studies carried out in European region suggest that the optimal concentrations (0.6–1.2%) are likely to be higher than those reported by Asian consumers [28] ; this may be due to the relative deficit in awareness of the characteristic umami taste in Europian consumers, or else due to the fact that oral sensation differs with genetics and gene-environment interactions.

Commercial production of monosodium glutamate

Presently, the vast majority of MSG is produced through fermentation processes. Among the microorganisms used, bacteria of the genera Corynebacterium and Brevibacterium are widely employed. For industrial production of MSG, molasses and starch hydrolysate are generally used as raw materials (Carbon source). Ammonium salts and urea are used as nitrogen sources for both microbial growth and product formation. The culture medium becomes acidic because of assimilation of ammonium ions and formation of l-glutamic acid. Gaseous ammonia is used advantageously to maintain the pH at 7.0 to 8.0, the optimum pH for glutamic acid production. Progress in fermentation technology has made it possible to raise the accumulation and the yield of l-glutamic acid above 100 g/L and 60%, respectively. The pH of the fermentation broth is adjusted to 3.2 to recover l-glutamic acid crystals, which are then converted to MSG of more than 99% purity by neutralization and purification [29].

Monosodium glutamate in food products

Since early 1900s, monosodium L-glutamate (MSG) has been commercially manufactured for use as a flavor enhancer, and there is ample evidence that adding MSG to suitable foods increases their palatability [30, 31]. Such hedonic changes are probably partly mediated by changes in the sensory properties of the foods, including increase in richness, savouriness and mouthfeel qualities [32, 33, 22].

Glutamate is commonly added to processed foods and shaken onto foods during preparation, mostly in Asian cuisine [34]. Based on psychometric studies on flavor of monosodium glutamate by Yamaguchi [35], pure glutamate added had no influence on aroma of the food. It can be added pure or as a hidden ingredient of yeast extracts or hydrolyzed proteins, both containing high percentages of glutamate [36, 37]. Studies carried out among Europeans suggest that the optimal concentrations (0.6–1.2%) tend to be somewhat higher than those reported by Asian consumers [28]; this may be due to the relative deficit in awareness of the distinctive umami taste in Western consumers, or else to the fact that oral sensation varies with genetics and gene-environment interactions.

As per the study done [38], the use of additional amount of glutamate didn't make the food taste better, but it actually worsens the taste. Usually, glutamate suits very well with sour or salty food. The optimal amount of glutamate added to enhance the taste was at 0.1–0.8% by weight. For instance, food of 500 g needs 0.5–4.0 g of glutamate to bring a good taste, which is the same as that of glutamate naturally found in general food. For example, protein from meat contains 11–22% of glutamate, whereas plant protein shows 40% [38]. The addition of glutamate at this amount can decrease the amount of sodium chloride added. It brings out the best natural flavors in food, working well in reduced-sodium and reduced-fat dishes and can reduce total sodium by 30–40% without influencing palatability [31].

Metabolism of MSG in human body

From two main sources, humans are exposed to dietary glutamate. That is either from the digestion of ingested dietary protein or from the ingestion of foods that contain substantial amounts of free glutamate (naturally present, or added in the form of MSG/hydrolysed protein). Glutamate is absorbed in the gut by active transport system precisely for amino acids. This process is saturable and can be competitively inhibited and is dependent on sodium ion concentration [39].

Glutamic acid available in dietary protein is digested to allow amino acids and small peptides, both which are absorbed into mucosal cells where peptides are hydrolysed to free amino acids and some of the glutamate is metabolised. Additional amounts of glutamate appear in the portal blood, where it is metabolised by the liver. Windmueller [40], Windmueller & Spaeth [41, 42] respectively confirmed that a majority of dietary glutamate is metabolised by the gastrointestinal tract.

However, minute amount of dietary glutamate enters either the systemic or the portal blood supply [43], demonstrating it is almost exclusively utilised by the intestinal tissues. Furthermore, studies carried out by Stoll [44] have revelaed that 95% of dietary glutamate presented to the mucosa was metabolised in first pass and that of this, 50% appeared as portal CO_2, with lesser amounts as lactate and alanine which specifies that glutamate is the single largest contributor to intestinal energy generation. Further it was evident that about 10% of dietary glutamate is incorporated into mucosal protein synthesis, with the balance being used for the production of proline, arginine and glutathione. Indeed, all three substances are derived exclusively from dietary glutamate, rather than the vast *in vivo* pool of glutamate.

Nutritional aspects of MSG

Glutamate performs a numberless essential roles in intermediary metabolism and is present in large quantities in the organs and tissues of the body. The daily turnover of glutamate in the adult human has been estimated as 4800mg [45].

Some of the significant metabolic characteristics of glutamate include:

- A substrate for protein production –L-glutamic acid is an important substrate for protein production. Glutamic acid holds physical and chemical characteristics which makes it a key contributor to the secondary structure of proteins, namely the α-helices [43];
- A transamination partner with α-ketoglutarate – In a reaction catalysed by L-glutamate dehydrogenase, L-glutamate is synthesized from ammonia and α-ketoglutarate. This reaction is of fundamental importance in the biosynthesis of all amino acids [46].
- A precursor of glutamine – from glutamate, glutamine is formed by the action of glutamine synthetize. It is considered as an important reaction in amino acid metabolism as it is the main pathway for converting free ammonia into glutamine for transport in the blood [47].
- An important neurotransmitter – Watkins and Evans [48] expressed that glutamate is the key excitatory transmitter within the brain, mediating fast synaptic transmission and is active in perhaps one third of central nervous system synapses.
- Important energy source for certain tissues – intestinal tissues are accountable for noteworthy metabolism of dietary glutamate, where it functions as a energy yielding substrate [43].

Consumption of MSG

In Western societies, there is a general trend to an increased consumption of flavored convenience food [49]. Based on survey on measured added glutamate content in food items obtained from the grocery, the daily dose of glutamate in UK was about 12 mg/kg/ day for whole population [50].

This is comparable to U.S since NAS [51] stated that approximately 0.55 g/day of the average consumer In Asia, especially in Japan and Korea, glutamate and other glutamate salts are consumed more intensively than in Europe. It is estimated as 1.2–1.7 g/day was the intake of added glutamate the said countries. A study done in Malaysia showed lower quantities of free glutamic acid in locally processed foods and prepared dishes, 0.24–8.16 mg/g. Moreover in Taiwan, per capita consumption records are much lower, averaging 3 g/day [52]. However, these amounts are significantly high compared to those consumed in European countries.

Impact of MSG on human health

Overweight or obesity

There was a safety concern of glutamate with respect to epidemic overweight or obesity. Even though much published studies are not being published on glutamate intake in relation to obesity or overweight in human, a study done by He [34] in China provided anthropological data that glutamate intake may be related with increased risk of overweight irrespective of physical activity and total energy intake. Nevertheless, Ebert [53] raised an objection to this paper with some scientific key facts and supports from other publications. He referred to long-term animal feeding [55] and human studies [54, 44] which have shown that glutamate did not increase food intake or induce obesity.

Asthma exacerbations

Additionally, several studies have unveiled the possibility that glutamate can serve as a triggering agent for asthma exacerbations [56, 57]. Single-blind study with 32 subjects was done by Allen and Baker [58] conducted, which reported a history of asthmatic symptoms after eating Chinese food. However, findings of Allen were not replicated in a parallel study done by Moneret and Vautrin [59] in the same year. Studies by Schwartzstein [60] and Germano [61] followed similar procedures. None of the subjects in Schwartzstein [60] study had a positive response (i.e. reduction in pulmonary function test results). Although some epidemiological studies demonstrated correlations between glutamate and adverse responses in severely asthmatic patients, a single-blind, placebo-controlled challenge study did not detect symptoms of wheezing or reduction in forced expiratory volume. Long-term health effects also did not occur [62]. From these studies, it is apparent that there are no consistent evidences that glutamate can trigger an asthma exacerbation.

Asthmatic bronchospasm, urticaria, angio-oedema, and rhinitis

However, a recent review [62, 63] prevents a critical review of the available literature related to the possible role of glutamate in eliciting asthmatic bronchospasm, urticaria, angio-oedema, and rhinitis. Despite the concerns raised by previous records, researches have failed to demonstrate a perfect and reliable relationship between the consumption of glutamate and the development of these conditions.

Migraine headache

Glutamate has also been described as a trigger for migraine headache exacerbations [64, 65] suggested that glutamate causes a generalized vasomotor reaction. The claim derived not from a clinical trial but from an advice from the Diamond Headache Clinic. On the other hand, it would not be precise to conclude about glutamate as a potential trigger for migraine headaches in a situation where clinical data, is absent. Since consistent data is absent to prove that glutamate causes any type of headache, more clinical researches are required to identify the relationship between glutamate and migraine headaches.

Safety evaluation and Recommendations

In 1958, Safety evaluation and Recommendations of U.S. Food and Drug Administration (FDA) declared glutamate as a Generally Recognized as Safe (GRAS) ingredient, along with other commonly used food ingredients such as salt, vinegar and baking powder [66]. The safety evaluation of monosodium glutamate was first evaluated by JECFA at the fourteenth and seventeenth meetings [67]. At that time, an Acceptable Daily Intake (ADI) of 0–120 mg/kg body weight was allocated, encompassing the L-glutamic acid equivalents of the salts; this was considered additional to the intake from all non-additive dietary sources.

A more comprehensive safety evaluation was conducted in 1987 [67]. The JECFA and the review showed that glutamate has a very low acute toxicity under normal circumstances; the oral dose that is lethal to 50% of subjects (LD50) in rats and mice was 15,000–18,000 mg/kg body weight, respectively. The overall safety evaluation directed the JECFA to conclude that the total dietary intake of glutamates arising from their use at levels necessary to achieve the desired technological effect and from their acceptable background in food do not represent a hazard to health. Therefore, the establishment of an ADI expressed in numerical form was not considered necessary and an ‘‘ADI not specified’’ was allocated to L-glutamic acid and the monosodium, potassium, calcium and ammonium salts. The Scientific Committee for Food of the Commission of the European Communities [68] conducted a safety evaluation similar to that of the JECFA and reached the same conclusion that glutamate could be allocated an ‘‘ADI not specified,’’ and this is the current situation in the European Union.

Federation of American Societies for Experimental Biology (FASEB), based on a review of stated adverse reactions to glutamate and described in 1995, concluded that there is no evidence to support a role for dietary glutamate or other forms of free glutamate in triggering or worsening serious, long-term medical problems resulting from degenerative nerve cell damage. In 1995, a directive of the European Commission (95/2/CE) on food additives fixed a limit of 10 g/kg for the sum of L-glutamate and salts present in food products, except for unprocessed foods, baby foods (for which Glu and salts use are not allowed) and ‘‘seasoning and spices’’ (for which no maximum level is specified).

Moreover, The FDA wanted that when glutamate is added to food, it must be mentioned in the ingredient list by its common or usual name, ‘‘monosodium glutamate’’ (IFIC, 2003). Even so, many food manufacturers have gradually adopted a strategy of placing additional prominent messages regarding glutamate on food labels. As a result, food labels promoting ‘‘No MSG,’’ ‘‘No MSG Added,’’ or ‘‘No Added MSG’’ have become regular [49].

Manufactured Vs Natural MSG

Natural free glutamic acid is glutamic acid that has been freed from ingested protein during digestion, or glutamic acid that has been transaminated (created) from other amino acids. There are some small amounts of natural free glutamic acid associated with some unadulterated, unprocessed, unfermented protein. Natural free glutamic acid is made of L-glutamic acid only which are found in higher organisms. "Natural food protein, as well as protein in the human body, contains only L-forms of amino acids" [69].

"Unlike amino acids derived from natural protein, which possess only the structure (S)-12, synthetic amino acids are composed of equal mixtures of (S)-12 and (R)-12." [70] (In here, (S)-12 refers to the L-amino acids and (R)-12 refers to the D-amino acids)."There were contrasting views expressed on the use of the various isometric forms (the natural L-form or the commercially available mixtures of DL-forms) of amino acids." [71] According to Maga [72] the L form (dextrorotary form with the L-configuration) is the predominant natural form.... “, because D-amino acids are rare in higher animals..." [72]. Manufactured free glutamic acid is made up of L-glutamic acid and D-glutamic acid, and may bring with it pyroglutamic acid, mono and dichloro propanols (which are carcinogenic), heterocyclic amines (which are carcinogenic), and other unwanted byproducts (impurities). "Foods contain a large assortment of xenobiotics (foreign, unnatural substances) that can have both positive and negative nutritional implications. One example is the occurrence of the uncommon D-stereo isomers of amino acids in some dietary proteins. These D-amino acids are produced from the common L-stereo isomers during food preparation and processing." [73]. In a research conducted by Rundlett and Armstrong [74], present a list of all of the processed foods analyzed by them for L and D-glutamate (glutamic acid) content and every one of the 38 processed foods evaluated contained D-glutamate.

Three of the analysed, found to have D-glutamate content were three brands of monosodium glutamate, containing Accent Flavor Enhancer, marketed by Pet Incorporated [74] "Hydrolysis of proteins causes racemization of amino acids, even under milder conditions of hydrolysis using lower temperatures and shorter exposure time, racemization of amino acids occurs." [72] "Savory ingredients like hydrolyzed vegetable protein have been produced by extreme conditions, promote a variety of chemical reactions, thus a range of unwanted by-products are produced as well." [75].

Natural food sources

Glutamic acid, which occurs naturally in many of the protein foods and it is one of the common amino acids found in nature, present in numerous proteins and peptides and many tissues. Not only the glutamic acid, other umami taste substances are contained abundantly in various foods, including vegetables (e.g., tomato, potato, mushroom, carrot,). And also combination of tomato, potato, mushroom and garlic can give vast flavor profile, because tomato, potato, mushroom, carrot and garlic have many volatile and nonvolatile flavor compounds.

Mushroom

Presently mushrooms are regarded as a macro-fungus with a distinctive fruiting body which can be either epigeous or hypogeous and large enough to be seen with the naked eyes and to be picked by hand [76]. Bano [77] determined the nutritive value of Pleurotus flabellatus as 0.974% ash, 1.084% crude fibre, 0.105% fat, 90.95% moisture, 0.14% non-protein nitrogen and 2.75% protein. Bano [77] proposed that food value of mushrooms lies between meat and vegetables.

Oyster mushrooms

Oyster mushrooms are a diverse group of saprotrophic fungi belonging to the genus Pleurotus [78]. According to Croan [79], these mushrooms are a good source of non‑starchy carbohydrates, with high content of dietary fiber and moderate quantity of proteins, including most amino acids, minerals, and vitamins. The protein content varies from 1.6 to 2.5%, and the niacin content is about ten times higher than that of any other vegetable. Moreover, Randive [80] reported that oyster mushrooms are rich in Vitamin C, B complex, and mineral salts required by the human body.

Table 4: Proximate composition of oyster mushrooms

Constituent	Amount
Moisture	88.60 ± 0.65
Dry matter	11.40 ± 0.65
Crude Protein	23.90 ±1.91
Crude Fat	2.16 ± 0.05
Ash	7.59 ± 0.13
Carbohydrate	61.10 ± 1.90
Crude fiber	5.33 ± 0.11

*Moisture and dry matter are based on fresh weight; others are based on dry weight. Yang [81]

Taste components in mushrooms

Taste components present in mushrooms are soluble sugars and polyols, organic acids, free amino acids, and 5′-nucleotides. Chen [82] conducted a series of sensory evaluations on synthetic mushroom extracts prepared by the omission and addition of soluble components and found that major taste-active components in common mushrooms (Agaricus bisporus) are mannitol, oxalic, malic, citric, aspartic, glutamic acids, glycine, threonine, alanine, 5'-inosine monophosphate (5′-IMP), 5′-guanosine mono phosphate (5′-GMP), and 5′-xanthosine mono phosphate (5′-XMP).

Mannitol and organic acids contribute most to the sweet and sour tastes, respectively [83]. However, they are not the taste characteristic of mushroom flavor. The predominant flavor of mushrooms is the umami taste, also called the palatable taste or the perception of satisfaction, which is an overall food flavor induced or enhanced by monosodium glutamate (MSG) [35]. In addition to four basic tastes such as our, sweet, bitter, and salty tastes, as well as hot taste, the umami taste is the sixth taste in mouth perception.

Table 5: Content of free amino acids with taste characteristics in oyster mushroom

Taste characteristic	Content (mg g^{-1} dry weight)
MSG-like	0.84 ± 0.15
Sweet	2.25 ± 0.45
Bitter	0.78 ± 0.13
Tasteless	0.21 ± 0.02
Total	4.08 ± 0.48

Yang [81]

Mushrooms contain considerably high amounts of free amino acids, which impart the food taste with a smooth feeling, thereby softening a sharp taste from some substances. Consequently, the combination of free amino acids at all times gives increase to a unique natural flavor. On the basis of their flavor characteristics as described by [84], free amino acids are grouped into four classes of taste components, including MSG-like, sweet, bitter, and tasteless components. The bitter taste in bitter components might be removed or blocked by the soluble sugars and polyols and sweet components. Because they give the most typical mushroom taste, MSG-like components Asp and Glu are also called umami amino acids, and their relative umami intensities are showed in Table 06 [85].

Six 5′-nucleotides are typically detected in mushrooms, including 5′-adenosine monophosphate (5′-AMP), 5′-cytosine monophosphate (5′-CMP), 5′-GMP, 5′-IMP, 5′-uridine monophosphate (5′- UMP), and 5′-XMP. Amongst these 5′-nucleotides, four—5′-AMP, 5′-IMP, 5′-GMP and 5′-XMP—are also called umami 5′-nucleotides, and their relative umami intensities are also showed in Table 6. 5′-GMP gives a meaty flavor and is a much stronger flavor enhancer than MSG [83]. In addition, the synergistic effect of umami 5′-nucleotides and umami amino acids may greatly increase the umami taste of mushrooms [85].

Table 6: Relative Umami Concentration (RUC) for Umami Amino Acids and Umami 5- Nucleotides

Umami amino acid	RUC
Glutamic acid, MSG (Glu)	1
Aspartic acid (Asp)	0.077
Umami 5′-nucleotide	RUC
5′-Inosine monophosphate (5′-IMP)	1
5′-Guanosine monophosphate (5′-GMP)	2.3
5′-Xanthosine monophosphate (5′-XMP)	0.61
5′-Adenosine monophosphate (5′-AMP)	0.18

*The EUC value is the concentration of MSG equivalent to the umami intensity of that given by the mixture of MSG and the 5′-nucleotide.,
* Yamaguchi [85]

Tomato

The tomato is a member of the Solanaceae family. According to plant sciences, it is a berry fruit, but it is being cultivated and used as a vegetable. It is a tender, warm season perennial. There are different varieties of tomato, and the 5.0 and 7.5% is the dry matter content of ripen fruit [86]. Percent composition of dry matter is shown in Table 07.

Table 7: Composition of Dry Matter Content of Tomato

Constituent	%
Fructose	25
Glucose	22
Protein	8
Minerals	8
Lipids	2
Pigments	0.4
Other amino acids, vitamins, and polyphenols	1
Volatiles	0.1

Source: Petro- Turza [86]

The free sugars of tomatoes are predominantly reducing sugars, and the quantity of sucrose is negligible. The pectins, arabinogalactans, xylans, arabinoxylans, and cellulose are the major polysaccharides. In fresh tomato juice, Glutamic acid comprises up to 45% of the total weight of free amino acids and aspartic acid being the second highest. Moreover, citric acid is the most abundant organic acid present in tomato [87].

Tomato Flavor

The Flavor of tomato is a combination of taste and aroma sensations [88]. Due to the sugar and organic acids present,a pleasant and a sweet-sour taste can be experienced when consuming tomato. However, unique tomato flavor, is produced by the complex interaction of the volatile and non-volatile components [86]. Free amino acids, Sugars, organic acids and salts are the main components backing to tomato taste. The typical sweet-sour taste of tomato is due to a mixture of the sugars and organic acids present. Majority of the dry matter composed of sugars, mostly the reducing sugars, glucose and fructose. Also, small amounts of saccharose, raffinose, arabinose, xylose, galactose, and sugar alcohol myoinositol have been found.

According to Kader [89], organic acids comprise about 15% of the dry content of fresh tomatoes. Apart from other carboxylic acids, sugar acids, and alicyclic acids, Citric and malic acids are the major organic acids. 2-2.5% of the total dry matter of tomatoes comprised with free amino acids. Other than that, glutamic acid, g-aminobutyric acid, glutamine, and aspartic acid comprise about 80% of the total free amino acids in tomatoes. Other effects of free amino acids were ascribed to their own taste, taste-enhancing capacity, and buffering capacity on tomato taste [86].

Tomato pulp, which contains the seeds, had more umami taste. Analysis of tomatoes of the free amino acids and 5'-ribonucleotides in the various parts of 13 varieties showed that the pulp contained higher levels of glutamic acid, 5'-adenosine monophosphate (AMP), 5'-guanosine monophosphate, 5'-uridine monophosphate, and 5'-cytidine monophosphate. The mean concentration of glutamic acid in the flesh was 1.26 g/kg and that in the pulp 4.56 g/kg. The mean concentration of AMP in the flesh was 80 mg/kg and in pulp it was 295 mg/kg. Those are the contributing umami flavor compounds in tomato [90].

Potato

Potato is the world's most popular vegetable according to CI [91] and stated as a vital source of many essential nutrients and rich in vitamin C, potassium, and other vital nutrients. The popularity is further recognized as FAO in 2008 published as potato's success is its great diversity in colours, textures and tastes. In addition, the ability of the tuber to be prepared in a number of different ways, including simple boiling, baking, deep-fat frying and dehydration is one more reason for its vast popularity. In addition, Its relatively neutral and bland, yet typical, flavour is another reason for the wide recognition of the potato [92].

Table 8: Approximate Levels of Potato Tuber Components

Compound	Percent Fresh Weight
Starch	18.0
Protein	2.0
Fiber (suberin, lignin)	1.3
Sugars (glucose, fructose, and sucrose)	1.0
Minerals (K, Mg, Ca, P, Na)	1.0
Free amino acids	0.8
Lipids	0.1

Source: Shelly [93]

Flavor compounds in potato

The compounds in potatoes predominantly include aldehydes, alcohols, ketones, acids, esters, hydrocarbons, amines, furans and sulphur compounds. The pattern and the num¬ber of volatile components obtained from potatoes can be quite different, depending whether raw potatoes are used or the method used to prepare them [94]. Organic acids determine the acidity of potato tubers. They are formed by the incomplete oxidation of sugars and deamination of amino acids, ascorbic acid, and polyphenolic acids [95]. In 1979 [96], it was noted that tubers containing 120mg/100g chlorogenic acid tasted somewhat sour to some panelists. Starch is the main carbohydrate in potato tubers. Although starch is tasteless, it effects texture and can also form stable complexes with flavor compounds during cooking. Further, these tubers also contain low levels of sugars such as glucose, fructose, and sucrose, which are not typically considered to directly contribute to taste. Furthermore, umami compounds in potato.

Umami compounds in potato

Ribonucleotides act as precursors for flavor potentiates, known as umami compounds, which are associated with desirable flavor. Further, it has higher levels of 5' ribonucleotides than any other plant food. While they are present in low quantities in raw potatoes, 5' ribonucleotides are liberated by enzymatic hydrolysis of RNA as tubers are heated during cooking [97]. The most important ribonucleotides for flavor enhancement are inosine 5'- monophosphate (IMP) and GMP. Both levels and types of ribonucleotides vary among potato cultivars [98]. Moreover, Halpern [99] have stated that when 5' ribonucleotides interact with amino acids, a synergistic effect is detected, particularly glutamate. Indeed, the products of interactions between amino acids and 5' ribonucleotides are known to be mainly responsible for flavour in boiled potato.

Sugars may also contribute to umami taste characters in the form of glutamate glycoconjugates [98]. Furthermore, Ugawa and Kurihara [100] had previously noted that salts of potassium are also responsible to enhance umami taste strength. However, according to Bethke and Jansky [101], during boiling process, significant levels of potassium leach out from potatoes

Garlic

Garlic is liliaceous biennial herbaceous plants underground bulb of garlic, spicy taste, and strong garlic smell. It is well known that garlic is abundant of garlincin, alliinase, allin, and alanine. Studies have shown that the main bioactive substances of garlic are the alliin and the organic compounds containing sulfur which was generated by endogenous alliinase reaction, such as thio-dipropylene, diallyl thisulfide. Those organic compounds, such as sulfur, not only have the efficacy of sterilization and antiphlogistic, reducing serum cholesterol and triglyceride, and prevention of coronary heart disease and cerebral thrombosis but also can strengthen power for the prevention of cancers [102].

Flavor compounds in garlic

Flavor compounds in garlic Garlic contains 0.1-0.36% of a volatile oil, these volatile compounds are generally considered to be responsible for most of the flavor properties of garlic. According to an article written by Tammy D. Motteshard [103], at least 33 sulfur compounds are present in Garlic. S-allylmercaptocystein, sallylcysteine, ajoene, aliin, allicin are some examples. Moreover sulfure compounds of garlic contains seventeen amino acids and their arginine and glycosides. The sulfur compounds are responsible for garlic's pungent odor. In addition, the characteristic odor is a result of allinase enzyme on the alliin sulphur compound.

Free amino acid in garlic

The free amino acid content of garlic samples analyzed ranged from 1121.7 to 3106.1 mg/100 g of fresh weight. The major free amino acid present in all species was glutamine. The main free amino acids present in the garlic are Glutamine, Asparagine, Glutamic acid, Cystine, and Lysine (in decreasing order). Triptophan, Isoleucine, Phenylalanine, Valine, Threonine and Leucine are the important amino acids found in garlic. The three most abundant essential amino acids present overall were Lysine, Triptophan, and Valine (in decreasing order) [104].

Analytical methods available for analysis of MSG

The monosodium glutamate is present in numerous foods, for example soups and meat products, because it is an excellent enhance of the flavor.Its determination is important, because it is related with food sanitary quality. There are a lot of methods to determine this additive in foods for example; amperometric [105], enzymatic [106], spectrometric (ISO 4134, 1978) and liquid chromatographic techniques [107].

HPLC Method

Initially dilution series of MSG is prepared using deionozed water and pH was adjusted to 7.8 using sodium bicarbonate (5 % w/v) to make the standard curve. Then sample solution is prepared using deionized water and filteration is carried out. Then the filtrates containing isolated MSG which is collect and the pH is adjusted to 7.8. Both the standard MSG and the MSG isolated from samples needed pre-column derivatization. Among several derivatizing agents, DNFB is used for the HPLC analysis [108].

After mixing DNFB and sample, it is shaken in water bath. Thereafter, remaining aqueous solution is being acidified with HCL (6M) before extracting DNP amino acid along with diethyl ether. Then sample is injected for chromatographic analysis. Sample is run on HPLC with UV/visible detector. Reversed phase C18 analytical column is used and Samples are separated with mobile phase, consisting of methanol: water (1:1) with a flow rate of 1.2 mL / min at ambient temperature 25^{o}C and peak is detected at 254 nm.

Enzymatic method

Several types of L-glutamate biosensors have been reported, including L-glutamate oxidase (L-GLOD), L-glutamate dehydrogenase (GDH) and L-glutamte decarboxylase (GDC) [109,110,111]. However, the GDC and GDH have some drawbacks due to poor substrate specificity and the requirement for expensive coenzyme such as NAD+. L-glutamate oxidase (GLOD) is used instead because it has relatively high substrate specificity compared to GDH and GDC and does not require additional coenzyme. GLOD is an enzyme that specifically catalyzes oxidative deamination of L-glutamate in presence of water and oxygen with the formation of α-ketoglutarate, ammonia and hydrogen peroxide [112].

$$\text{L-glutamate} + O_2 \ \text{L-GOLD} \xrightarrow{\quad} \alpha\text{-ketoglutarate} + NH_3 + H_2O_2$$

L-glutamate can be quantified either by substrate disappearance (O_2), or by the product formation (NH_3 or H_2O_2). This simple and rapid chromogenic method for determining MSG in food, without complicated sample pre-treatment or using advanced equipment. The principle of the chromogenic reaction in this study was as follows (POD: peroxidase):

$$2\ H_2O_2 + \text{Phenol} + \text{4-aminiantipyrine} \ \text{POD} \xrightarrow{\text{Red quinine}} + 4\ H_2O$$

Then absorbance at 502 nm is measured by spectrophotometer method. This study based on the bioreaction for quantitation of MSG in food, established a method with several advantages. It is rapid and simple, and does not need pre-treatment of the samples.

AOAC official method

Glutamic acid is extracted from foods using water, separated from other amino acids by using an ion-exchange resin chromatography and titrated potentimetrically using 0.1N NaOH. For products in dry form reduce to powder and for undiluted concentrated soups or canned green beans, homogenize entire undiluted content of can in blender. After dilution with water activated carbon is added. For products containing starch, add acetone to precipitate starch and to aid in making a solution of the sample). Then HCl is added to prevent conversion of glutamic acid to pyrrolidone carboxylic acid. After preparing the column and adjust flow to about 0.5 ml/min. After all the solution enters the resin, wash the column with water and let the washings pass into resin. Then HCl is added which will eluate any serine, threonine and aspartic acid. Then it should titrate potentiometrically to pH 8.9 with NaOH. Then amount of monosodium glutamate is calculated via calculation.

Impact of MSG on other nutrient in natural system

Glutamate, can be used to maintain the palatability of fat-reduced foods [30, 113, 114]. The addition of participant-specific optimal glutamate amounts to the fat reduced foods reinstated some of the palatability, while maintaining the decrease in ingested fat and energy [28]. Umami taste substances when combined with salt (sodium chloride) which improve the acceptance of many foods can be an answer to the problem of less edible foods with reduced salt content. Subsequently, umami taste substances might be of value in maintaining the palatability of foods in which the salt content must be reduced [115]. As an illustration of this concept [31] reported that palatability could be maintained when reducing NaCl content by the addition of glutamate.

Other umami substances

Umami substances can synergistically act in the foods. Synergism is defined as the cooperative action of two or more components of a mixture whose total effect is greater than the sum of their individual effects. Table 09 illustrates such effects in MSG/IMP and MSG/GMP combinations. 1:1 mixture of MSG/GMP produces a thirtyfold increase in umami intensity over MSG alone. Typically a 95:5 ration of MSG/purine 5-ribonucleotides is used in the food industry, the purine 5-ribonucleotides being a 1:1 mixture of IMP/GMP. This combination yields a synergistic effect of approximately six fold over MSG [37, 72, and 92, 116].

Table 9: Umami effect intensities of MSG/IMP and MSG/GMP combinations

Ratios		**Relative umami intensity**
MSG	**IMP**	
1	0	1.0
1	1	7.0
10	1	5.0
20	1	3.5
50	1	2.5
100	1	2.0
1	0	1.0
1	1	30.0
10	1	18.8
20	1	12.5
50	1	6.4
100	1	5.4

Source: Flavourings: Production, Composition, Applications, Regulations [118].

Conclusion

Monosodium Glutamate (MSG) is one of the world’s most extensively used food additives which is ingested as part of commercially processed foods. As a flavor enhancer, MSG increases the sapidity of food. MSG enhances a flavor that cannot be provided by other foods. However at the same, time people do have a very high preference towards the taste given by MSG commonly known as Umami taste. The production of an additive/enhancer minimizing the problems in MSG while maintaining the Umami taste using natural recourses would be a great innovation in the food industry. The benefit could be enhanced by adding supplementary effect (Fiber and Micronutrient content) on the product that will eventually upgrade the product.

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