Function and Importance of Glutamate for Savory Foods[1]

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ABSTRACT Flavoring systems are of vital importance in savory food manufacturing. Many industrially prepared foods are particularly attractive to potential consumers primarily because of their typical flavors. Therefore, it is no surprise that the food industry dealing with these product segments shows great interest in the use of food or food ingredients carrying the typical umami taste and flavor enhancement systems. Figures are provided showing the importance of glutamate in traditional cuisines and also in meals prepared by industrial manufacturing. It is also interesting to see how food intake patterns of glutamate differ from one cultural group to another. The ever-growing importance of balanced food formulations (carbohydrates, fats, proteins and minerals) brings special challenges to the use of different ingredients, requiring development of appropriate flavor delivery systems. Again flavor enhancement is of great importance. Questions about the addition of glutamate or the total glutamate content of foods are of little importance, from a scientific point of view. However, in a given legal framework, important business opportunities can be realized. One of the main concerns of manufacturers of savory food is how to provide the consumer with tasty foods while complying with increasingly severe local legal constraints concerning the use of many potent flavoring systems. J. Nutr. 130: 915S–920S, 2000.

KEY WORDS: • *monosodium glutamate* • *flavor enhancer* • *food* • *formulation*

A brief historical background of flavor science and the flavor industry

The first successes in flavor science were primarily in the field of "sweet" flavors. But it was not until the latter half of the 19th century that chemists began to realize the flavoring opportunities of synthetic aromatic compounds. In fact, in 1858, vanillin was first crystallized from an alcoholic extract of vanilla beans by Gobley. Two years after its empirical formula was described by Carles in 1872, Tiemann and Haarmann reported vanillin's structure. It was finally synthesized by Reimer from guaiacolin. These first attempts at the identification of a flavor active molecule were the beginning of an ever-growing effort that reached its zenith in the 1970s, when many flavor molecules in important foodstuffs (e.g., cocoa, tea and coffee) were identified by Benz and Muheim (1996).

For the food industry, monosodium glutamate (MSG)[2] is intimately linked to the world of taste and flavors (Ensor 1989). Before describing the use of MSG in food, it is interesting to look into the beginnings of industrial manufacture of the most basic of savory foods, soups. In the second part of the 19th century, Julius Maggi (Heer 1991), a pioneer in the food industry, developed rapid-cooking dehydrated soups, which then evolved into an important business segment in many countries. One of the key ingredients was hydrolyzed plant protein. These hydrolysates produced the meaty flavorings necessary for the manufacture of these rapid-cooking soups. At that time, it was not known that an important ingredient of these vegetable hydrolysates was MSG. Paralleling this development in Europe, in 1908, Japanese researchers (Ikeda 1909) isolated glutamic acid as the essence of tastiness in Japanese stock prepared from konbu seaweed; they named this distinctive taste umami. Shortly afterwards, 5′-ribonucleotides were isolated from dried skipjack and dried shiitake mushroom. Since then, this distinctive savory taste also contributes to the umami flavor note.

What is food?

Many of us have the privilege of eating three meals a day. Thus, we are naturally food specialists because we often prepare and/or select the food we favor for a specific occasion. At its most fundamental, food responds to the human body's basic needs for growth and maintenance. But its function is far beyond the ingestion of the basic nutrients carbohydrates, lipids and proteins admixed with essential nutrients such as minerals and vitamins. Food is a basic necessity for all humans.

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[2] Abbreviations used: GC, gas chromatography; IMP, inosine 5′-monophosphate; MS, mass spectrometry; MSG, monosodium glutamate.

But food can fulfil its nutritional purpose only if it is eaten and digested. The selection process for food is rather complicated. In approaching a food item, the first criterion of choice is certainly the appearance of the item. In further approaching the food, the volatile components make it attractive or repulsive. During mastication, the texture and the nonvolatile components are the prominent factors influencing the acceptance of the food. Above all, the event of eating food also involves a social expectation. Eating a meal is typically considered a pleasurable occasion to share with others.

Most foods are subjected to a heat treatment—in the household kitchen or during industrial premanufacturing. This treatment has at least two functions. First, it makes nutrients more accessible for digestion; however, this aspect is not a subject of this review. Second, it aids in the preservation of foods, which must be stored for prolonged periods after harvest or slaughtering. The thermal treatment reduces the bacterial load and diminishes enzymatic activity, which otherwise can lead to rapid spoilage of raw food materials or the foods prepared from them. This aspect of preservation is growing ever more important as the trend of population movement to large urban centers increases the distance between the producer and the consumer, and the time between harvest and consumption. However, heat preservation, dehydration and other techniques that make foods more shelf-stable tend to reduce the concentration of flavor-active molecules, thus reducing the appeal of such food products. To offset such flavor loss, natural flavoring formation can be encouraged during food preparation; flavorings can also be added after the main processing steps to increase the attractiveness of semimanufactured and manufactured foods.

Foods have two main functions, i.e., they provide nutrition and an occasion for a pleasurable social event. Both functions are fulfilled only if a food is actually consumed. A food composed of the nutritional elements required for an optimal diet that is unattractive and thus not consumed provides no nutrition. Thus, flavorings can play an important nutritional role, particularly in foods that are not very flavorful, by providing the needed appeal. Long before modern science helped us to understand the function of MSG and other flavor enhancers, Eastern cultures developed food ingredients rich in these compounds that enhanced the tastiness (acceptability) of many of their dishes (Nagodawithana 1995a). The much more recent history of Julius Maggi and the industrial development of liquid seasoning (Heer 1991) is another example of the development, in the absence of scientific knowledge, of flavoring systems to make food more attractive. These developments opened up a vast range of possibilities for the economic manufacture of nutritious and flavorful foods. It is only through the use of vegetable raw materials, which are much less costly than animal proteins, that flavorful processed foods could become available to provide nutritious, tasty foods to large portions of the human population. Vegetable-based seasonings are in very widespread use in many Asian countries (soy sauce, **Fig. 1**), and hydrolyzed plant proteins are widely used in Europe, Africa and the Americas.

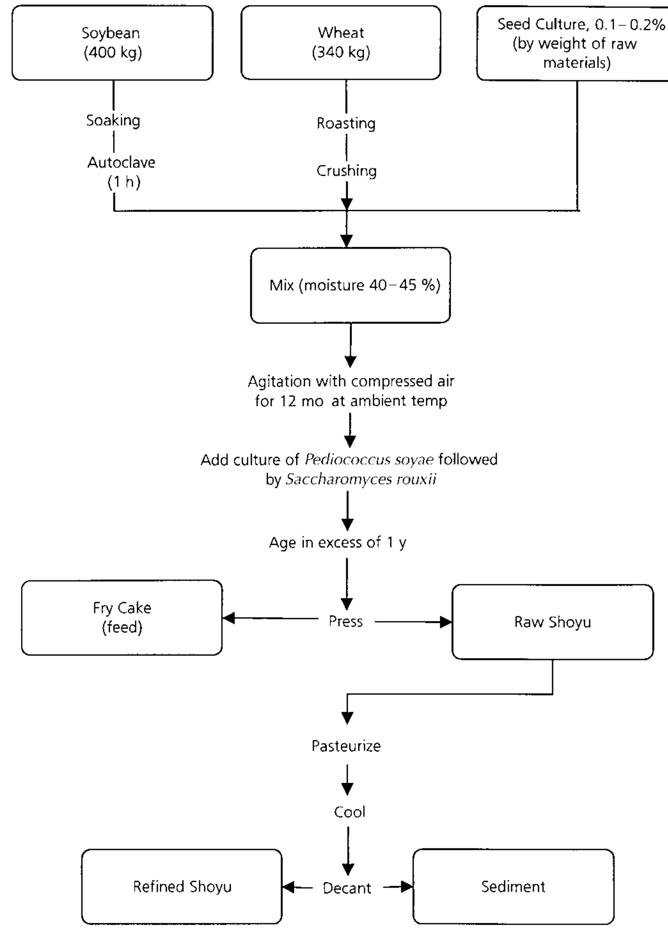

FIGURE 1 Flow sheet for traditional soy sauce manufacturing.

Food flavor

Flavor chemistry. Flavors that are of interest in relation to MSG, i.e., savory, meaty flavors, have been studied by many scientists throughout the world. Many excellent reviews are available on the chemistry of flavors (Nagodawithana 1995b) and the physiology of flavor perception (Burdach 1988).

The role of the flavor chemist is first to analyze and study flavor and aroma-active molecules. The differentiation between volatile molecules, which can be found in the headspace over food, and those volatile and nonvolatile compounds that develop during mastication and contribute to the overall flavor perception is very important. For example, many hundreds of substances were identified in the volatile fractions of brewed coffee, but only a few of them are actually of any significance in the formation and perception of the typical coffee flavor. Second, depending on the problem to be solved, the flavor chemist will be asked to reconstitute the flavor profile of a new product. Such a profile is composed of previously identified substances that are normally found in the parent product. The task of the flavor chemist is much more complicated with respect to the taste (nonvolatile) composition of a food. By their nature, volatile compounds can be analyzed relatively easily by today's instrumental methods [gas chromatography (GC), GC-mass spectrometry (MS) and GC-MS-MS]. These techniques are not applicable to nonvolatile compounds, and the required liquid chromatographic approaches are much more tedious. In addition, a method analogous to GC-sniffing technology for nonvolatile compounds does not exist. Thus, only lengthy procedures of classical sensorial analyses can be used to identify fractions of foods that contain taste-active constituents, and only then can more laborious analytical techniques be applied to identify them.

The final task of the flavor chemist is to combine the aroma and the taste-effect compounds to reconstitute the flavor profile for a given food or for a given food application. Many aroma-active compounds can be found either as extracts from plant materials or can be synthesized. Nonvolatile taste-active

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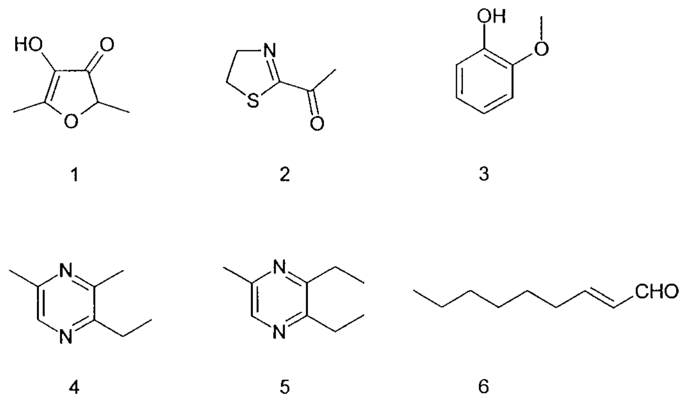

FIGURE 2 Potent odor compounds of roast beef (adapted from Grosch 1993 with permission of the editor).

compounds, however, are rather difficult to find in commercially useful amounts.

Cooking foods and reaction flavors. The flavor development of meats, e.g., that during aging and processing (cooking), is linked to many different chemical and biochemical processes (Imafidon and Spanier 1994). The chemical entities responsible for development of the meaty taste are not very well understood and many attempts have been made to characterize them (Imafidon and Spanier 1994, Warendorf and Belitz 1992). A great deal of energy has been deployed to gain a better understanding of taste-active molecules. In recent publications, an important discussion has continued regarding the "Beefy Meaty Peptide" (BMP), and only very recently was it shown (Hau et al. 1997) that this peptide actually has none of the claimed organoleptic properties. Meaty aroma components are now better understood, and powerful analytical techniques have been developed, e.g., by Belitz and Grosch (1992), among others. **Figure 2** shows some of the most potent aroma-active compounds identified in roasted beef. Substances 1 and 2 smell earthy, 3 burnt, 4 caramel-like, 5 roasty and 6 of cucumber. These flavor attributes are for the pure substances only. It is their correct mix that gives the full aroma of the food product. It has been shown by Belitz and Grosch (1992) and Nagodawithana (1995b) that compounds that are often found in savory products are of a similar nature and can be derived from the interaction of hydrolyzed proteins (amino acids and peptides) with reducing sugars forming Maillard reaction products. These aroma-active compounds are of great importance in the development of the typical aroma notes of many heat-treated foods, e.g., roasted coffee, meats and bread.

The formation of the typical roasted notes (for example, of foods such as meats or breads) is linked directly to the formation and degradation of Maillard reaction products, which can also be found rather abundantly in reaction flavors (Manley and Ahmedi 1995, Schreier and Winterhalter 1993). From carbohydrates and amino acids, under the action of heat, a great variety of compounds are formed; these both contribute and constitute the typical flavor notes of many heat-cooked (heat-treated) foods (**Table 1**).

Flavor perception. Flavor perception in humans involves three distinct sensory systems (olfactory, gustatory and trigeminal) that respond to food components (Imafidon and Spanier 1994). These three sensory systems, however, are influenced greatly by many other properties of the foods in which these flavor stimuli are released. Texture (e.g., crunchiness, chewiness or creaminess), fat content and composition and many others contribute indirectly to flavor perception. The fat content is important with respect to flavor release/retention in a food. The basic tastes of sweet, salty, sour and bitter stimulate gustatory receptors within the oral cavity in response to the presence of soluble compounds. Volatile compounds (aromas) stimulate the olfactory sensory organs in the roof of the nasal cavity. On the other hand, the trigeminal sense, a system that is dependent on free nerve endings in the eyes, nose and mouth, is stimulated by the presence of coolness, heat, astringency, acridness and pungency.

From a sensory point of view, the four basic taste stimuli, bitter, sweet, salty and acid are the constituents of many foods. It is now also becoming accepted that a fifth taste dimension is needed to describe the impressions produced by the meat, fish and vegetable stocks that are far outside the common tetrahedral presentation of these four basic taste descriptors (Yamaguchi 1987) (**Fig. 3**).

This additional dimension of taste, umami (Yamaguchi 1995), is located well outside the common taste tetrahedron, and above all, increases the stimuli of all vegetable stocks (Fig. 3). This representation tries to cope with the difficulty of presenting four dimensions in a two-dimensional space. In this representation, a solution of 0.005% of inosine 5′-monophosphate (IMP) was added and produced the increased response (Fig. 3*B*). Umami describes the savoriness, deliciousness or succulence of a food and is considered by many Japanese researchers to represent a fifth taste dimension.

Flavor enhancement. The basic sensory function of MSG is clearly attributed to its ability to enhance the presence of

TABLE 1

Significant flavor components found in process flavors[1]

Component type	Specific example	Aroma character	Range of odor thresholds for component type
Aldehydes	2,4-Dodecadienal	Fruity, green	15 ppm–0.2 ppb
Furans	Hydroxymethylfuran	Sweet-burn, rum-like	5 ppm–6 ppb
Furanones	4-Hydroxy-2,5-dimethyl-(2H)-furanone	Sweet caramel	10 ppm–0.03 ppb
Pyrazines	2-Ethyl-3,5-dimethylpyrazine	Roasted, green, Nutty, popcorn	25 ppm–0.006 ppb
Thiazoles/Thiazolines	4-Methylthiazole	Roasted, cooked Onion, meaty	3 ppm–0.003 ppb
Thiophenes	2-Mercaptothiophene	Fried onion, Mustard-like	0.2 ppm–1 ppb
Polysulfides (thianes)	3-Methyl-1,2,4-trithiane	Onion, garlic	0.05 ppm–2 ppb

[1] Adapted from Manley and Ahmedi (1995).

other taste-active compounds. The literature reports that MSG on its own is "sweet-saline with some tactile properties capable of providing some feeling of mouth satisfaction" (Foster 1955). Others have described it as a brothy, mouth-watering sensation with a considerable increase in salivation (Yamaguchi 1995). Because it contains 12.3% sodium (e.g., one third of table salt), it is understandable that foods containing MSG have a typical salty taste. The detection threshold for MSG is 6.25×10^{-4} mol/L which, interestingly, is higher than that for bitterness or sourness, lower than that for sweetness and about equal to that for saltiness. In general, the usage level of MSG in savory foods is approximately one tenth that of salt; thus the sodium contribution of MSG is roughly one thirtieth of the total added sodium. It has also been shown by Yamaguchi and Takashashi (1984) that for an equal sensation of saltiness, the sodium provided by sodium chloride can be reduced and compensated for by much lower amounts of MSG. By adding MSG appropriately, the sodium chloride addition could be reduced by 30–40% while maintaining the same perception of saltiness.

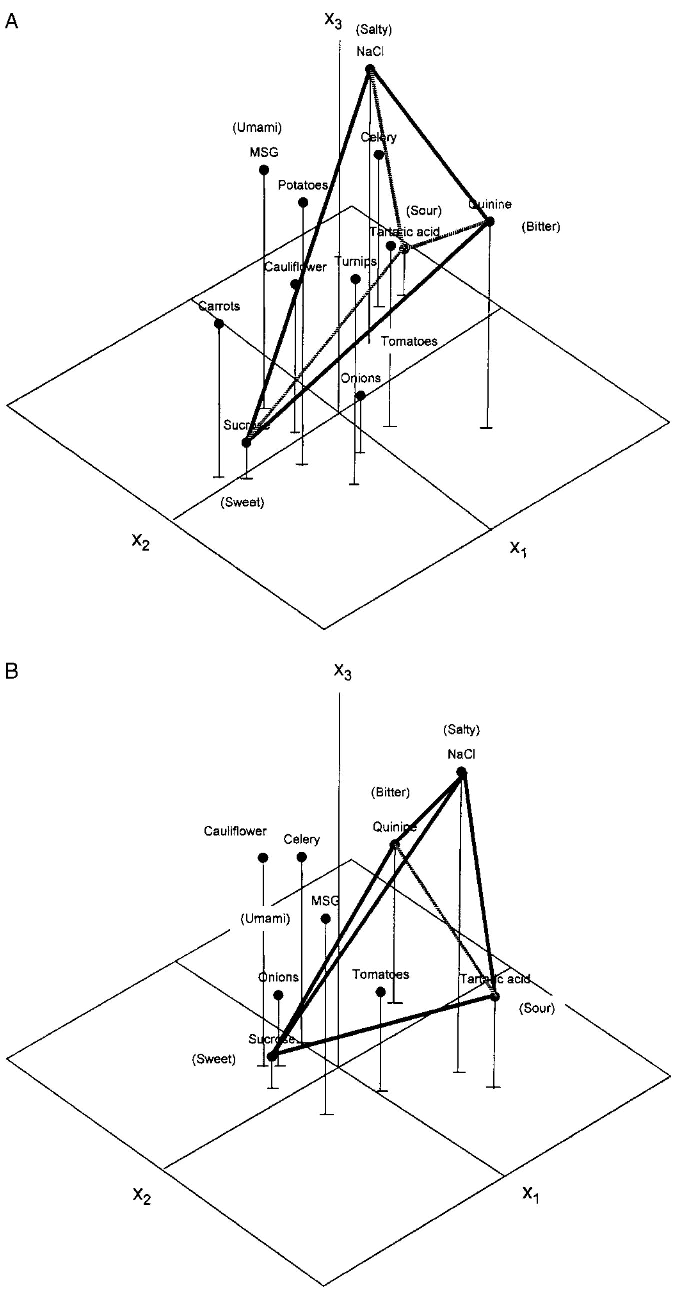

FIGURE 3 Graphical representation of the four basic tastes and the effect of the fifth taste, umami (adapted from Yamaguchi 1987). (*A*) vegetable broth; (*B*) same broth with 0.005% inosine 5′-monophosphate (IMP) added.

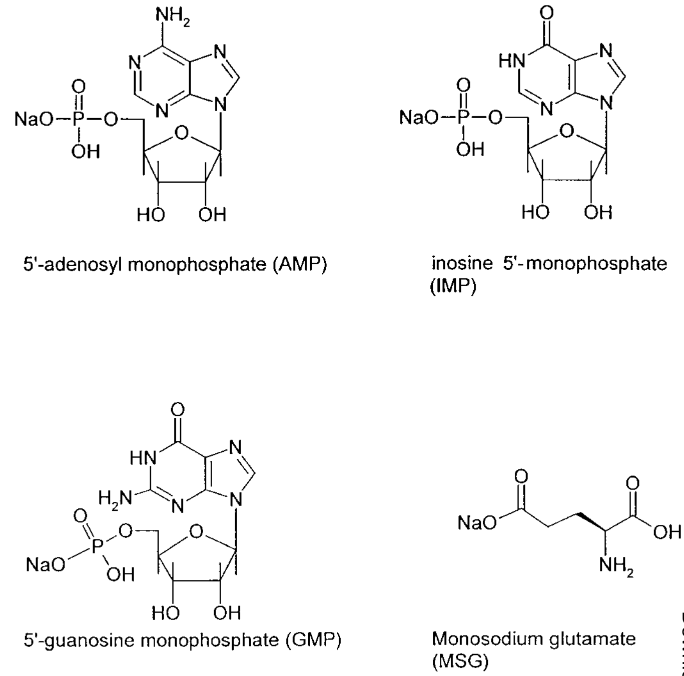

FIGURE 4 Formulas of the most common flavor enhancers: AMP precursor, [inosine 5′-monophosphate(IMP)], GMP and monosodium glutamate (MSG).

The other commonly used enhancers (**Fig. 4**) GMP, IMP and 50:50 blends thereof, have also been reported in the literature to have characteristic tastes different from the four basic sensations. IMP is often described as beefy and GMP as oak-mushroom. It also seems that mixes of IMP and GMP can suppress some bitter and sour notes, but enhance sweet and salt perceptions (Woskow 1969). MSG and IMP differ widely in the way in which they exhibit their taste intensities in relation to concentration. Results of taste panel studies on processed foods indicate that an MSG level of 0.2–0.8% of food by weight optimally enhances the natural food flavor. Similarly, the corresponding levels of 5′-ribonucleotides required to generate the equivalent flavor intensity may be in the 0.02–0.04% range. However, these levels are likely to change, depending on the type of food application and the specific flavor enhancer chosen for the purpose.

The phenomenon of synergism is of the utmost importance, because this unique property of nucleotide flavor enhancers provides an opportunity for the food processor to use less MSG in the formulation without affecting flavor quality. For example, it has been found that food processors who use 100 g of MSG can now reduce usage levels to 17 g in the presence of 0.9 g of 50:50 blends of GMP and IMP with a substantial (25–30%) cost reduction and without an adverse effect on the organoleptic properties of the processed food.

Presence of glutamate in foods

It is important to note that the concentration of both glutamates and the flavor-enhancing nucleotides or their pre-

TABLE 2

Natural glutamate content of foods[1]

	Bound glutamate	Free glutamate
	mg/100g	
Milk/dairy products		
Cow's milk	819	2
Human milk	229	22
Parmesan cheese	9847	1200
Poultry products		
Eggs	1583	23
Chicken	3309	44
Duck	3636	69
Meat		
Beef	2846	33
Pork	2325	23
Fish		
Cod	2101	9
Mackerel	2382	36
Salmon	2216	20
Vegetables		
Peas	5583	200
Corn	1765	130
Beets	256	30
Carrots	218	33
Onions	208	18
Spinach	289	39
Tomatoes	238	140
Green peppers	120	32

[1] By permission of Anonymous (1987).

cursors is relatively high in biological systems. These flavor enhancers are present as the building blocks of proteins and nucleic acids. Hence, it is not surprising to find these components in natural form in virtually all foods, including meat, fish, poultry, milk and vegetables. Flavor enhancers generally exist in bound form; in most instances, however, they become partially free during processing, thereby accentuating their characteristic flavor properties. Meat, fish and poultry are specially rich in IMP; crustaceans, mollusks and some vegetables, on the other hand, are rich in AMP, which eventually serves as the precursor for the formation of IMP (for formulas see Fig. 4).

Mushrooms, especially the Shiitake varieties, are particularly high in GMP. In traditional Chinese cooking, Shiitake mushrooms and sea tangle serve as ingredients to accentuate the flavor of foods containing weak savory properties. The active components of these natural products, namely, MSG, GMP and IMP, are now used extensively in pure form as seasonings or condiments to supplement, enhance or round-off the flavors of many savory-based processed foods.

TABLE 3

Daily intake of monosodium glutamate[1]

Country	Intake of MSG *g/d*
USA	0.55
Netherlands	0.66
Thailand	1.5
Japan	1.42
Indonesia	0.6
Korea	1.57
Malaysia	0.37

[1] Adapted from Anonymous (1991) with permission.

TABLE 4

Glutamate content of selected plant proteins[1]

Protein	Glu g/100 g
Gliadin (wheat)	45.7
Zein (maize)	26.9
Edestin (flax)	20.7
Hordenin (barley)	38.4
Globulin (coconut)	21.8
Arachin (peanut)	20.8
Globulin (cottonseed)	23.6
Glycinin (soybean)	20.5
Glutenin (wheat)	24.7
Lupin (lupin bean)	27.2

[1] Giacometti (1979).

The ever-growing importance of the industrial preparation of foods is a consequence of the pressure generated by demographic movements toward urban agglomerations, but also a request from consumers to have foods that require less preparation time and have built-in convenience. The industrial manufacture of foods cannot be regarded simply as a scaled-up version of household preparation. Flavors, which develop during long cooking periods when vegetables and meat are gently heated together, can be replaced acceptably by flavorings that contain the same types of substances for flavor formation.

In considering the amino acid composition of many different foods, it can be shown that the glutamate content is extremely variable, ranging from 2 mg/100 g in cow's milk (free glutamate) to 9.8 g/100 g in parmesan cheese (bound glutamate). Glutamic acid is a major component of the proteins of most of our foods (**Table 2**).

The average consumption (see **Table 3**) of MSG in the diet in Korea is the highest of all reported countries at 1.6 g/d. In the U.S., however, only about one third of this amount appears in the average diet. Table 2 reports some of the foods in our diet and their contents of both free and protein-bound glutamic acid. **Table 4** lists several food proteins and their glutamate content; in these proteins, glutamic acid contributes substantially to the total amino acid content (e.g., ~45% for wheat gliadin) (Giacometti 1979) .

Knowing the beneficial contribution of glutamate to many savory flavors, it is not at all surprising that industrial processes take advantage of the rather high natural glutamate concentrations of some vegetables in the production of vegetable protein hydrolysates. These hydrolysates contain considerable amounts of free glutamic acid (sodium glutamate), e.g., traditional soy sauce (Yokotsuka 1986). Today's soy sauce is the product of thousands of years of development. This age-old discovery is understood today and it is used to enhance the pleasure of eating industrially processed food.

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