FOOD ADDITIVES

1. Introduction

A food additive is any substance that becomes part of a food product either directly or indirectly during some phase of processing, storage, or packaging.

Direct food additives are those that have been intentionally added to food for functional purpose, in controlled amounts, usually at low levels (from parts per million, ppm, to 1–2% by weight). Basic foodstuffs are excluded from the definition, although ingredients that are added to foods (eg, high fructose corn syrup, starches, and protein concentrates) are often included among food additives.

Included in the direct food additive category are

- Inorganic chemicals—phosphates, sulfates, nitrates, etc.
- Synthetic chemicals—dyes, silicones, benzoates, vitamin A, etc.
- Extraction products from natural sources—essential oils, gums, vitamin E, etc.
- Fermentation derived products—enzymes, lactic acid, citric acid, etc.

Indirect or *nonintentional additives* on the other hand, are those entering into food products in small quantities as a result of growing, processing, or packaging. Examples of these are lubricating oils from processing equipment or components of a package that migrate into the food before consumption.

The difference between food additives and ingredients is mainly in the quantity used in any given formulation. Food ingredients can be consumed alone as food (eg, butter, sucrose), while food additives are mainly used in small quantities relative to the total food consumption but which nonetheless play a large part in the production of desirable and safe food products (1).

The practice of adding chemicals (eg, salt, spices, herbs, vinegar, and smoke) to food dates back many centuries. In recent years, however, the ubiquitous presence of chemical additives in processed foods has attracted much attention and public concern over the long-term safety of additives to humans. Although the safety issue is far from subsiding, there is scientific consensus that food additives are indispensable in the production, processing, and marketing of many food products, and that the judicious use of chemical additives—typically in the range from a few ppm to $<1\%$ by weight of the finished food—contributes to the abundance, variety, stability, microbiological safety, flavor, and appearance of the food supply. While food additives offer a major contribution to the palatability and appeal of a wide variety of foods, their level of use is relatively insignificant in the total human diet.

2. Function of Food Additives

Direct food additives serve several major functions in foods. Many additives, in fact, are multifunctional. The basic functions are

- Extend shelf-life (eg, retard the onset of rancidity).
- Ensure microbial safety (eg, against botulism, Listeria).
- Enhance appetability and palatability (flavor, color and texture).
- Improve nutritional value (eg, vitamin and trace mineral fortification).
- Facilitate food processing (eg, emulsifiers, anticaking agents).

Substances that come under the general definition of direct food additives number in the thousands and include both inorganic and organic chemicals, natural products, and modified natural and synthetic or artificial materials. Most food additives have a long history of use; others are the result of recent research and development to fill particular requirements of modern food processing. Some are common chemicals of industry that are upgraded in terms of purity to allow their use in food.

The U.S. Code of Federal Regulations (CFR) provides classification for food additives (2). In the CFR *direct food additives* are divided into the following eight categories:

1. Food preservatives (eg, sodium nitrate, sorbates).
2. Coatings, films, and related substances (eg, polyacrylamide).
3. Special dietary and nutritional additives (eg, vitamins).
4. Anticaking agents (eg, sodium stearate, silicon dioxide).
5. Flavoring agents and related substances (eg, vanillin).
6. Gums, chewing gum bases, and related substances (eg, xanthan gum).
7. Other specific usage additives (eg, calcium lignosulfonate).
8. Multipurpose additives (eg, glycine).

Secondary direct food additives permitted in food for human consumption are divided into four different types in the CFR, as follows:

1. Polymer substances for food treatment (eg, acrylate, acrylamide resins).
2. Enzyme preparations and microorganisms (eg, rennet, amylase).

3. Solvents, lubricants, release agents, and related substances (eg, hexane).
4. Specific usage additives (eg, boiler water additives, defoaming agents).

Indirect food additives included in the CFR are divided into eight categories, as follows:

1. Components of adhesives (eg, calcium ethyl acetoacetate 1,4-butanediol modified with adipic acid).
2. Components of coatings [eg, acrylate ester copolymer coatings and poly-(vinyl fluoride) resins].
3. As components of paper and paperboard (eg, slimicides, sodium nitrate/urea complex, and alkyl ketene dimers).
4. As basic components of single- and repeated use food contact surfaces (eg, cellophane, ethylene-acrylic acid copolymers, isobutylene copolymers and nylon resins).
5. As components of articles intended for repeated use (eg, ultrafiltration membranes and textiles and textile fibers).
6. Controlling growth of microorganisms (eg, sanitizing solutions).
7. Antioxidants and stabilizers (eg, octyltin stabilizers in vinyl chloride plastics).
8. Certain adjuvants and production aids (eg, animal glue, hydrogenated castor oil, synthetic fatty alcohols, and petrolatum.

Adopted from the National Academy of Sciences national survey of food industries the FDA uses the following terms to describe the physical or technical effects for which direct human food ingredients may be added to foods:

- *Anticaking Agent or Free Flow Agent*: Substance added to finely, powdered or crystalline food product to prevent caking, lumping, or agglomeration.
- *Antimicrobial Agent*: Substance used to preserve food by preventing growth of microorganisms and subsequent spoilage, including fungistats, mold and rope inhibitors. Also includes antimicrobial agents, antimyotic agents, preservatives and mold preventing agents (indirect additives).
- *Antioxidant*: Substance used to preserve food by retarding deterioration, rancidity, or discoloration due to oxidation.
- *Boiler Water Additive*: Substance used in a steam or boiler water system as an anticorrosion agent, to prevent scale or to effect steam purity.
- *Color or Coloring Adjunct*: Substance used to impart, preserve, or enhance the color or shading of a food. Includes color fixatives, color-retention agents, etc.
- *Curing or Pickling Agent*: Substance imparting a unique flavor and/or color to food, usually producing an increase in self-life stability.
- *Dough Strengthener*: Substance used to modify starch and gluten, thereby producing more stable dough.

- *Drying Agent*: Substance with moisture-absorbing ability, used to maintain an environment of low moisture.
- *Emulsifier or Emulsifier Salt*: Substance, which modifies surface tension in the component phase of an emulsion to establish a uniform dispersion or emulsion.
- *Enzyme*: Enzyme used to improve food processing and the quality of finished food.
- *Firming Agent*: Substance added to precipitate residual pectin, thus strengthening the supporting tissue and preventing its collapse during processing.
- *Flavor Enhancer*: Substance added to supplement, enhance, or modify the original taste and/or aroma of a food, without imparting a characteristic taste or aroma of its own.
- *Flavoring Agent or Adjuvant*: Substance added to impart or help impart a taste or aroma in food.
- *Flour Treating Agent*: substances added to milled flour, at the mill to improve its color and/or baking qualities, inducing bleaching and maturing agents.
- *Formulation Aid*: Substance used to promote or promote or to produce a desired physical state or texture in food. Including carriers, binders, fillers, plasticizers, film-formers, and tableting aids, etc.
- *Freezing or Cooling Agents*: Substance that reduces the temperature of food materials through direct contact.
- *Fumigant*: Volatile substance used for controlling insects or pests.
- *Humectant*: hygroscopic substances incorporated in food to promote retention of moisture. Includes moisture retention agents and antidusting agents.
- *Leavening Agent*: Substance used to produce or stimulate production of carbon dioxide in baked goods in order to impart a light texture, including yeast, yeast foods, and calcium salts.
- *Lubricant or Release Agent*: Substance added to food contact surfaces to prevent ingredients and finished products from sticking to them (direct additives). Includes release agents, lubricants, surface lubricants, waxes and anti-blocking agents (indirect additives).
- *Malting or Fermenting Aid*: Substance used to control the rate or nature of malting or fermenting process including microbial nutrients and suppressants and excluding acids and alkalis.
- *Masticatory Substance*: Substance that is responsible for the long lasting and pliable property of chewing gum.
- *Nonnutritive Sweetener*: Substance having $<2\%$ of the caloric value of sucrose per equivalent unit of sweetener capacity.
- *Nutrient Supplement*: Substance necessary for the body's nutritional and metabolic process.
- *Nutritive Sweetener*: Substance having $>2\%$ of sucrose per equivalent unit of sweetening capacity.

- *Oxidizing or Reducing Agent*: Substance, which chemically oxidizes or reduces another food ingredient, thereby producing a more sable product.
- *pH Control Agent*: Substance added to change or to maintain active acidity or basicity. Includes buffers, acids, alkalis and neutralizing agents.
- *Processing Aid*: Substances used as a manufacturing aid to enhance the appeal or utility of a food or component. Includes clarifies, clouding agents, catalysts, flocculents, filter aids, crystallization inhibitors, etc.
- *Propellant*: Gas used to supply force to expel a product or used to reduce the amount of oxygen in contact with the food in packaging.
- *Sequesterant*: Substance, which combines with polyvalent meta1 ions to form a soluble metal complex to improve the quality and stability of products.
- *Solvent or Vehicle*: Substance used to extract or dissolve another substance.
- *Stabilizer or Thickener*: Substance used to produce viscous solutions or dispersions, to impart body, improve consistency, or stabilize emulsions. Includes suspending and bodying agents, setting agents, and bulking agents.
- *Surface-Active Agent*: Substance used to modify surface properties of liquid food components for a variety of effects, other than emulsifiers. Includes solubilizing agents, dispersants, detergents, wetting agents, rehydrating enhancers, foaming agents, defoaming agents, etc.
- *Surface Finishing Agents*: Substance used to increase palatability, preserve gloss and inhibit discoloration of foods. Includes glazes, polishes, waxes and protective coatings.
- *Synergist*: Substance used to act or react with another food ingredient to produce a total effect different from or greater than the sum of the effects produced by the individual ingredients.
- *Texturizer*: Substance, which affects the appearance or feel of the food.
- *Tracer*: Substance added as a food constituent (as required by regulation) so that levels of this constituent can be detected after subsequent processing and/or combination with other food materials.
- *Washing or Surface Removal Agent*: Substance used wash or assist in the removal of unwanted surface layers from plant or animal tissues.

3. Government Regulations

The application of food additives is highly regulated worldwide although regulatory philosophy, the approval of specific product, and the level of enforcement differ from country to country. Basic regulations in the United States, western Europe, and Japan are described below. These three major industrial regions are the largest consumers of food additives. With only 13% of the world's population these countries account over two-third of the food additive market.

In the United States, the Food and Drug Administration (FDA) of the Department of Health and Human Services has primary jurisdiction over food additives. In addition, clearance for use of additives in certain products must be obtained from other government agencies as well (3). For example, the U.S. Department of Agriculture (USDA) through the Meat Inspection Division (MID) exercises jurisdiction over additives and ingredients for meat and poultry, and the Bureau of Alcohol, Tobacco, and Firearms (BATF) of the U.S. Department of the Treasury controls the ingredients used in alcoholic beverages. Food regulations are based on the 1958 Food Additives Amendment to the Food, Drug & Cosmetic (FD&C) Act of 1938. The amendment was enacted with the threefold purpose of:

1. Protecting public health by requiring proof of safety before a substance could be added to food.
2. Advancing food technology.
3. Improving the food supply by permitting the use of substances in food that is safe at the levels of intended use.

According to the legal definition, food additives that are subject to the amendment include "any substance the intended use of which results or may reasonably be expected to result directly or indirectly in its becoming a component or otherwise affecting the characteristics of any food". This definition includes any substance used in the production, processing, treatment, packaging, transportation or storage of food. If a substance is added to a food for a specific purpose it is referred to as a *direct additive*. For example, the low calorie sweetener aspartame, which is used in beverages, puddings, yogurt, chewing gum and other foods, is considered a direct additive.

Indirect food additives are those that become part of the food in trace amounts due to its packaging, storage or other handling. For example, minute amounts of packaging substances may find their way into foods during storage. Food packaging manufacturers therefore must prove to the FDA that all materials coming in contact with food are safe, before they are permitted for use in such a manner.

For regulatory purposes, all food additives fall into one of three categories (2):

1. Generally Recognized As Safe (GRAS) substances.
2. Prior sanctioned substances.
3. Regulated—direct–indirect additives.

GRAS substances (~700) are a group of additives regarded by qualified experts as "generally recognized as safe". These substances are considered safe because their past extensive use has not shown any harmful effects.

Prior sanctioned substances (~1400) are products that already were in use in foods prior to the 1958 Food Additives Amendment to the federal Food, Drug & Cosmetic Act, and are therefore considered exempt from the approval process. Some prior sanctioned substances also appear on the GRAS list. This is the "grandfather clause" of the amendment. The FDA is involved in an ongoing review of the GRAS and prior sanctioned lists to ensure that these substances are tested by means of the latest scientific methods. Likewise, the FDA also reviews substances that are not currently included on the GRAS list to determine whether they should be added.

All other additives are regulated—ie, a specific food additive petition must be filed with the FDA, requesting approval for use of the additive in any application not previously approved. A food or color additive petition must provide convincing evidence that the proposed additives perform as it is intended. Moreover, animal studies using large doses of the additive for long periods are often necessary to show that the substance would not cause harmful effects at expected levels of human consumption.

In deciding whether an additive should be approved, the agency considers the composition and properties of the substance, the amount likely to be consumed, its probable long-term effects, and various other safety factors. Absolute safety of any substance can never be proven. Therefore, FDA must determine if the additive is safe under the proposed conditions of use, based on the best scientific knowledge available. In addition, FDA operates an Adverse Reaction Monitoring System (ARMS) to help serve as an ongoing safety check of all additives. The system monitors and investigates all complains by individuals or their physicians that are believed to be related to specific foods, food additives or nutrient supplements.

All *color additives* are subject to the Color Additive Amendment of 1960 (2,4). Colors permitted for use in foods are classified either as certified or exempt from certification. Certified colors are manmade, with each batch being tested by the manufacturer and the FDA (certified) to ensure that they meet strict specifications for purity. Color additives that are exempt from certification include pigments derived from natural sources. However, color exempt from certification also must meet certain legal criteria for specifications and purity.

Flavor substances are regulated somewhat differently, and the rules are less restrictive (5). However, the use of aroma chemicals as flavor ingredients is regulated also under laws that may differ from country to country. Following the lead of the United States, inclusion in a positive list that spells out which chemicals are permitted for food use has become the prevalent legislation for regulating flavor chemicals worldwide. The United States has a list of flavor substances that are deemed Generally Recognized as Safe (GRAS) based on history of use, review of available toxicology, and the opinion of experts. These GRAS lists through GRAS 21 (6), have been compiled since 1977 by the expert panel of FEMA (Flavor Extracts Manufacturers Association of the United States). Over the years, >1800 materials appeared on FEMA lists. Formed in 1909 FEMA is an industry association that originally started pursuing voluntary self-regulation and later was granted quasiofficial status on regulatory matters regarding flavor chemicals by the FDA. The FEMA Expert panel was formed in 1960. This independent panel, composed of eminently qualified experts recruited from outside the flavor industry, has expertise in human nutrition, physiology, metabolism, and toxicology and chemical structure–activity relationships. Most industrial countries more or less follow the U.S. system.

Under FDA, USDA, and BATF regulations, the ingredients of a food or beverage must be stated on the product label in decreasing order of predominance. For many direct additive categories, chemical constituents must be identified by their common names and the purpose for which they were added.

The FDAs Food Additives Amendment also contains what is known as the *Delaney Clause*, which mandates the FDA to ban any food additive found to cause cancer in humans or animals, regardless of dose level or intended use. The clause applies not only to new food additives but also to those in use prior to 1958. The Delaney Clause is totally inflexible in that it does not recognize any threshold level below which the additive might not present a health hazard. Thus, it has caused a number of problems for the food industry and for food additives.

Approval Process. A new substance gains approval for food use through the successful submission of a Food Additive petition that must document the following (7):

1. Safety, including chronic feeding studies in two species of animals.
2. Intended use.
3. Efficiency data at specific levels in specified food systems.
4. Manufacturing details and product specifications.
5. Methods for analysis of the substance in food.
6. Environmental impact statement.

The other pathway is a somewhat simpler route. This is the *GRAS affirmation process* by which a petitioner can affirm that a substance either has a long history of use in the food supply and/or is generally recognized as safe (GRAS) by experts in the field. The boundaries of this process are being tested by substances such as dietary fibers and bulking agents, which are physically modified forms of natural materials, and also have the potential to be used in foods in very high quantities. The GRAS affirmation process has also come under scrutiny, and is likely to undergo revision in the coming years.

In *the European Union* (EU) formation of the European Economic Community has created a requirement to bring food additive approvals of the member nations into alignment, so as to eliminate differences in laws that hinder the movement of foodstuffs among these nations (8). Historically, the member countries have differed widely in approaches to food additive approval and their tendency to approve new additives. At the time of this writing, a framework directive for food additives and several specific directives for various categories of additives are nearing completion. Food additives are regulated by Directive 89/107/EEC of December 21 1988 on the approximation of the laws of Member States "concerning food additives authorized for use in foodstuffs intended for human consumption". The European Union (EU) food additives law recognizes 106 food additives. Later, several amendment and adaptations of Directive 89/107/EEC were introduced or proposed including a list of additives the use of which is authorized to the exclusion of all others. Since 1990 several Amendments were added to the Directive, most recently Amendment 32 in 2003. Updates of the EU Directives can be found in the Internet: www.fst.rdg.ac.uk/foodlaw/additive.htm.

Efforts have been toward a uniform registration process so that a registration obtained in one country would be valid in all EU member countries. The new EU food additive law, however, will not prevent individual countries to ask for additional or country-specific requirements for new product registrations. At the EU level, several institutions and groups are involved in the development of food additives law including the Scientific Committee for Food (SCF), one of the institutions of the European Commission that deals with safety issues; representatives from different national professional organizations, representatives from the food industry, retailers, etc. The Standing Committee on Foodstuffs ensures close cooperation between the Commission and the member states.

The EU rules for the evaluation, marketing, and labeling of novel food such as genetically modified foods are also being developed. The new marketing rules would also oblige manufacturers to obtain permission before placing new foods or ingredients on the market, with the exceptions for products that are substantially equivalent to existing foods. The new rules have still to be cleared by the European Parliament, which has the power to veto under the new codecision procedure introduced in 1995.

In most countries, additives must be declared in the labeling. Within the European Community, some additive groups have been uniformly codified with "E" numbers for the orientation of consumers. A list of E numbers either by alphabetic or numerical order is shown at the website of the Federation of European Food Additives and Food Enzyme Industries (ELC), http://www.elc-eu.org. Some countries, such as Germany, have gone further, adopting regulations on an acceptable daily intake (ADI) basis that build on the newest toxicological knowledge. A further labeling change that came into force in 2000 is the quantitative declaration of ingredients (QUID). This applies to foods and beverages with more than one ingredient. The quantity of ingredients, expressed as a percentage of the food or drink, must appear in or immediately next to the name of the food or in the list of ingredients next to the ingredient concerned.

In Japan, the Food Chemistry Division of the Ministry of Health and Welfare (MHW) has jurisdiction over food additives through the Food Sanitation Law (www.mhlw.go.jp/english/index.htm), which was enacted in January 1948 with several amendments adopted since then (9). Amendments to the regulations as well as additions or deletions to *Kohetisho* (the Japanese Codex of Food Additives) were mostly influenced by two major objectives:

1. Protection of food sanitation and customer safety.
2. Harmonization with international regulatory requirements.

Most discussions on regulating food additives in Japan have been related to defining what food additives should be under legal restriction and on labeling requirements. Very often in these discussions, differentiating "synthetic" and "natural" food additives had been at issue. In Japan, those two generally used terms have often misled customers into a blind belief in natural food additives. However, regulatory bodies as well as the food additive industry no longer distinguish additives with these terms.

Under the amended Japanese Food Sanitation Law (1995), substances that are permitted for food use as food additives fall into four categories:

- Substances that are generally recognized as safe (~70 substances).
- Natural-based flavors (~580 substances).
- Natural-based substances that are recognized as safe to human health on the basis of actual results for use as food additives (~490 substances).

- Synthetic substances that are recognized as safe to human health on the basis of the results of safety evaluations (~350 substances).

The amended law requires that any new substances, regardless of whether they are natural-based or synthetic, be verified to be safe to human health through safety evaluation and then approved by MHW before being used as food additives. Also, it is required that the type of substance and the intended purpose of addition be labeled on the surface of food containers or packaging.

4. Sweeteners Polyols and Bulking Agents

4.1. Classification of Sweeteners. Sweeteners are used in formulated foods for many functional reasons as well as to impart sweetness. They render certain foods palatable and mask bitterness; add flavor, body, bulk, and texture; change the freezing point and control crystallization; control viscosity, which contributes to body and texture; and prevent spoilage. Certain sweeteners bind the moisture in food that is required by detrimental microorganisms. Alternatively, some sweeteners can serve as food for fermenting organisms that produce acids that preserve the food, thus extending shelf life by retaining moisture. These auxiliary functions must be kept in mind when considering applications for artificial sweeteners. Sweeteners may be classified in a variety of ways (10):

- Nutritive or Nonnutritive. Materials either are metabolized and provide calories or are not metabolized and thus are noncaloric.
- Natural or Synthetic. Commercial products that are modifications of a natural product (eg, honey or crystalline fructose, is considered natural; saccharin is a synthetic compound).
- Regular or Low Calorie/Dietetic/High Intensity. Although two sweeteners may have the same number of calories per gram, one may be considered low calorie or high intensity if less material is used for equivalent sweetness.
- As Foods. For example, fruit juice concentrates can impart substantial sweetness.

4.2. Sucrose. Sucrose [57-50-1] $C_{12}H_{22}O_{11}$, commonly known as table sugar (or refined sugar), is the standard against which all sweeteners are measured in terms of quality of taste and taste profile. It is consumed in the greatest volume of all sweeteners. However, sucrose, high fructose corn syrup, and other natural sweeteners, such as molasses, honey, maple syrup, and lactose sweeteners, are food ingredients rather than additives and are not covered in this section (11).

4.3. Polyols. Polyols or sugar alcohols are not sugars and they are not alcohols. They are a group of low digestible carbohydrates derived from the hydrogenation of their sugar or syrup source (eg, lactitol from lactose) (11,12). These unique sweeteners taste like sugar but have special advantages. They are a group of sweeteners that provide the bulk of sugars, without as many calories

Table 1. **Polyols: Calorie Value and Relative Sweetness to Sugar**

Polyol sweetener	Relative sweetness, sucrose = 100	Calorie value[a], Kcal/g
erythritol	60–70	0.2
isomalt	45–65	2.0
lactitol	40	2.0
maltitol	90	3.0
mannitol	70	1.6
sorbitol	50–70	2.6
xylitol	100	2.4

[a]US FDA allowances.

as sugar (Table 1). Polyols are important sugar substitutes and are utilized where their different sensory, special dietary, and functional properties make them feasible. Polyols are obtained from their parent sugars by catalytic hydrogenation. In most European countries and in the United States, polyols are utilized in low calorie food formulations. Polyols are absorbed more slowly in the digestive tract than sucrose; therefore they are useful in certain special diets. However, when consumed in large quantities (25–50 g/day) some of them have a laxative effect, apparently because of the comparatively slow intestinal absorption. Polyols offer the same preservative benefit and a similar bodying effect to food than sucrose. Polyols are more resistant to either thermal breakdown or hydrolysis than sugar. Moreover most polyols are resistant to fermentation by oral bacteria, and therefore prime ingredients for tooth-friendly confectioneries (eg, sugarless chewing gums). Food products sweetened with polyols and containing no sucrose can be labeled as "sugarless", "sugar free", or "no sugar".

Erythritol. Erythritol [149-32-6], $C_4H_{10}C4$, is ~70% as sweet as sucrose. Like other polyols, it does not promote tooth decay and is safe for diabetics. However, it is distinctive for its caloric content (the lowest of the polyols—0.2 cal/g) and its high digestive tolerance. Studies have shown that, due to its small molecular size and structure, >90% of ingested erythritol is absorbed and excreted unchanged through the kidneys within 24 h, so that the laxative side effects sometimes associated with polyol consumption are unlikely. As a result, foods containing substantial amounts of erythritol are very unlikely to cause gaseous and laxation side effects. A recent clinical study showed that daily consumption of 1 g/kg of body weight is well tolerated by adults and compared to sucrose-containing foods (11,12).

Hydrogenated Starch Hydrolysates (HSH). Hydrogenated starch hydrolysates also known as hydrogenated glucose syrup, or hydrogenated starch hydrolysates are a mixture of sorbitol, maltitol, and hydrogenated oligosaccharides. Depending on the sorbitol and maltitol content, the sweetness of HSH can vary from 0.25 to 0.5 times that of sucrose. HSH serve a number of functional roles, including use as bulk sweeteners, viscosity or bodying agents, humectants, crystallization modifiers, cryoprotectants, and rehydration aids. They also can serve as sugar-free carriers for flavors, colors, and enzymes and have been used by the food industry for many years, especially in confectionery products (12).

Isomalt. Isomalt [13718-94-0], ~0.45–0.65 times as sweet as sugar, can be used in candies, gums, ice creams, jams and jellies, fillings and frostings, beverages, and baked products, As a sweetener/bulking agent, it has no off-flavors and works well in combination with other sweeteners. Isomalt is made from sucrose and looks much like table sugar. It lacks the "cooling" effect characteristic of some other polyols. It is white, crystalline and odorless, and is more stable chemically and enzymatically than sucrose (11,12).

Maltitol. Maltitol [585-88-6], $C_{12}H_{24}O_{11}$, ~0.9 times as sweet as sucrose with similar sweetness and body, has application in products such as chewing gum, dry bakery mixes, and chocolate. It is said to behave similarly to sucrose in chocolate making. Some believe that maltitol has the best flavor of the polyol family and it has been particularly successful as an alternative to mannitol in the manufacture of sugar-free chocolates. Also, because of its heat stability and good handling properties, it is suitable for use in sugar-free baked goods. Maltitol is also increasingly being used in dairy products (11,12).

Mannitol. Mannitol [69-65-8], $C_6H_{14}O_6$ is only ~70% as sweet as sucrose and is also noncariogenic (eg. does not promote tooth decay). Because of its non-hygroscopic nature, mannitol is used as a dusting powder and an anticaking agent, besides its special dietary food application. The highest demand for mannitol is in sugarless chewing gum. Seaweeds have been used as raw material for the production of mannitol. The upper part of the seaweed *Laminaria digitara* contains up to 10% mannitol (12).

Lactitol. Lactitol $C_{12}H_{24}O_{11}$, a sugar alcohol, has physicochemical properties different from those of sugars. It is derived from milk sugar. Lactitol has a sweetness value approximately one-third that of sucrose and is therefore suitable where bulking with low sweetness is required. To increase the sweetness it can be blended with high intensity sweeteners (11,12).

Sorbitol. Sorbitol [50-70-4], $C_6H_{14}O_6$, occurs naturally in many edible fruits and berries including pears, apples, cherries, prunes, and peaches. Its nontoxic nature has long been recognized, and in 1974 the FDA named sorbitol as one of the first four chemicals on its revised list of substances of which use in foods is "generally recognized as safe" (GRAS). Sorbitol is only 70% as sweet as sucrose. However, it has many functional properties desirable in a sweetener: bulking agent ability, high viscosity, prevention of crystallization, and hygroscopicity, which results in its humectant as well as its softening nature. In general, sorbitol is used in foods to aid retention of product quality during aging, or to provide texture or other product characteristics to the formulation. In its traditional major food applications (toothpaste is not considered a food)—chewing gum and mints—sorbitol is used primarily as a bulking agent and not for its sweetness (11,12).

The two applications for crystalline sorbitol are sugarless gums and sugarless mints. Liquid sorbitol is used in hard candies, chewing gum, and soft candies. Sorbitol's noncariogenic nature may account for its wide use in these applications. Other food applications include use as a humectant and/or bodying agent in shredded coconut, cookies, glazed and dried fruits, gelatin products, and cakes. One of the most recent applications for sorbitol is its use as a lower sweetener and cryogenic stabilizer/structural preservative in *surimi* frozen seafood products. The lowered sweetness is more palatable to Americans, and the bulking/bodying properties are beneficial. In addition to food and pharmaceutical applications, sorbitol is widely used in cosmetics, adhesives, and by the textile, chemical, leather, and paper industries. It is also an important intermediate in the production of fatty acid esters and vitamin C.

Xylitol. Xylitol [87-99-0], $C_5H_{12}O_5$, is a five-carbon polyol with a sweetness similar to sucrose. It is found in small amounts in a variety of fruits and vegetables, and is formed as a normal intermediate in the human body during glucose metabolism. Xylitol has good solubility, blends well with foods, and has a lower melting point than sucrose, an advantage in the manufacture of confectionery products. There is also evidence that xylitol is not only noncariogenic but reduces dental cavities when used as a replacement for sucrose. It is mainly used in compressed candies, chewing gum, and over-the-counter products. Xylitol is expensive; therefore it is usually used in small amount in combination with other sweeteners. In a blend with aspartame, the two compounds have an excellent synergistic effect. Also, xylitol is blended with other polyols to minimize undesirable properties, such as hygroscopicity or the laxative effect of sorbitol, or to improve the solubility of mannitol, or reduce the costs contribution of sweetener (11,12).

4.4. High Intensity Sweeteners. High intensity sweeteners once used mainly for dietetic purposes, are now used as food additives in a wide variety of products (11,12). Termed "*high intensity*" because they are many-folds sweeter than sucrose and closely mimic its sweetness profile. Because of the very low use levels, however, high intensity sweeteners cannot perform other key auxiliary functions in food and often must be used in conjunction with other additives such as low-calorie bulking agents. Relative sweetness of high intensity sweeteners to sucrose sugar and their regulatory status is summarized in Table 2.

Acesulfame K. Acesulfame K [55589-62-3], $C_4H_5NO_4S \cdot K$, is an oxathiazine derivative that has a rapidly perceptible sweet taste 200 times as potent as

Table 2. **High Intensity Sweeteners: Regulatory Status and Sweetness Relative to Sucrose**[a]

Sweetener	Sweetness of sucrose = 1	United States	Canada	Europe	Japan
Cyclamate, Na Salt	30	P	A	A	N
Aspartame	200	A	A	A	A
Acesulfame K	200	A	A	A	N
Saccharin	300	A	N[b]	A	A
Sucralose[c]	600	A	A	P	N
Thaumatin (Talin)	3,000	N	N	N	A
Alitame[d]	2,000	P	P	P	P
Neotame	7–13,000	A	P	P	P
Neohesperidin DC	2,000	N	N	A	N
Stevioside	300	N	N	N	A
Glycirrhizin	50	N[e]	N	N	A

[a]A = approved; P = petition filed; N = not approved, as of 2004.
[b]Saccharin in Canada is limited for use in personal care products and pharmaceutical, but it is banned in foods and beverages.
[c]Sucralose is approved in Australia, Russia, Brazil, New Zealand, Quasar, Romania, and Mexico.
[d]Alitame is approved in Australia, New Zealand, People Rep. of China, Indonesia, Colombia, and Mexico.
[e]Glycirrhizin is approved as a flavoring, but not as a sweetener in the United States.

sucrose. One major advantage of this sweetener is its synergy with other sweeteners, including nutritive and non-nutritive types (11,12).

Alitame. Alitame, a dipeptide made of two amino acids, L-aspartic [56-84-8], C_4H_7 NO_4, and D-alanine [56-41-7] $C_3H_7NO_2$. The sweetener is 2000 times as sweet and with the same taste as sugar. Its potential market applications include bakery products, snack foods, candies and confectionery, ice cream, and frozen dairy products (11,12).

Aspartame. Aspartame, [53906-69-7], $C_{14}H_{18}N_2O_5$, is $\sim$200 times as sweet as sucrose. Unlike most low calorie sweeteners, aspartame is digested by the body to amino acids, which are metabolized normally. However, because of its intense sweetness, the amounts ingested are small enough that aspartame is generally considered noncaloric (11,12).

Cyclamate. Cyclamate, $C_6H_{13}NO_3S$, is 30 times sweeter than sugar. It has a sugar-like taste, a good shelf life, and a synergistic effect when combined with other high intensity sweeteners. Usually, either the sodium ($C_6H_{13}NO_3S.Na$) or calcium salts ($C_6H_{13}NO_3S.Ca$) of cyclamic acid [100-88-9], $C_6H_{13}NSO_3$, is used in a form of white crystalline powder. Presently it is approved in Canada and Europe, but since 1970 it is banned in the United States (10).

Neohesperidin Dihydrochalcones. Neohesperidin dihydrochalcones (DHC) are derived from bioflavonoids of citrus fruits. It is 1500–2000 times sweeter than sucrose, leave a licorice aftertaste and give a delayed perception of sweetness. Produced from bitter Seville oranges by hydrogenation of natural neohesperidin, the main flavonoid constituent of some oranges. DHC is approved in the EU countries (10).

Neotame. Neotame, formed through a modification of aspartame's dipeptide base, is $\sim$7000–13000 times sweeter than sugar (13). Following reviews of safety data from >113 animal and human studies in 2003, the FDA approved neotime for food use. It is a free-flowing, water soluble, white crystalline powder that is heat stable and can be used as a tabletop sweetener as well as in cooking applications. Examples of uses for which neotame has been approved include baked goods, nonalcoholic beverages (including soft drinks), chewing gum, confections and frostings, frozen desserts, gelatins and puddings, jams and jellies, processed fruits and fruit juices, toppings, and syrups.

Saccharin. Saccharin, [81-07-2], $C_7H_5NO_3S$, used primarily as its sodium salt [128-44-9], $C_7H_4NO_3SNa.2H_2O$, or calcium salt [6485-34-3], $(C_7H_4NO_3S)_2$.Ca.$2H_2O$, it is $\sim$300 times as sweet as sucrose. Saccharin is the most widely used nonnutritive sweetener worldwide and the least expensive on a sweetness basis. It combines well with other sweeteners and has excellent shelf life. However, it has several disadvantages: it is bitter, has a metallic aftertaste, and there is concern over its safety. Saccharin has been used primarily in soft drinks, but also as a tabletop sweetener and in a wide range of other beverages and foods (11,12).

Sucralose. Sucralose, 1,6-dichloro-1,6-dideoxy-β-D-fructofuranosyl-4-chloro-4-deoxy-a-D-galactopyranoside is a selectively chlorinated derivative of sucrose, the only high intensity sweetener based on sucrose. It is $\sim$600 times sweeter than sucrose. Sucralose is approved for food use in the United States, Canada, and several other countries (12).

Stevia (Stevia rebaudiana). Stevia, a plant native to South America, is the source of the *stevia* extract, which is the natural sweetener. It can be used in food products that require baking or cooking because of its stability in high temperatures. Approved for use as a sweetener in Japan (11).

Thaumatin. Thaumatin, a mixture of sweet-tasting proteins from the seeds of *Thaumato coccusceus daniellii*, a West African fruit, is ~2000–2500 times sweeter than sucrose. Its taste develops slowly and leaves a licorice aftertaste. Thaumatin acts synergistically with saccharin, acesulfame-K, and stevioside and potential applications include beverages and desserts. It is permitted in Japan as a natural food additive since 1979.

Tagatose. Tagatose, is a naturally occurring reduced-calorie sweetener that can be found in some dairy products. Tagatose has a physical bulk similar to sucrose or table sugar and is almost as sweet. Tagatose provides 1.5 cal/g, therefore, provides the bulk of sugar with significantly fewer calories. It is suitable for people with diabetes and does not cause cavities. Tagatose also improves the flavor profile and mouth feel of products when combined with low calorie sweeteners, such as aspartame and acesulfame potassium. Extensive human testing has been conducted on tagatose to ensure its safety and human tolerance. Mild gastrointestinal discomfort (eg, flatulence and laxation) may occur as with other incompletely absorbed ingredients. Tagatose may now be used in the U.S. food supply, FDA granted GRAS status in 2003 (12).

Trehalose. Trehalose is a multifunctional sweetener found naturally in honey, mushrooms, lobster, shrimp, and foods produced using baker's and brewer's yeast. The commercial product is made from starch by an enzymatic process. Trehalose is almost half as sweet as sucrose. It has been shown to elicit a very low insulin response and provide sustained energy. In addition, trehalose protects and preserves cell structure in foods and may aid in the freezing and thawing process of many food products by assisting in the maintenance of the desired texture of the food. It is also heat stable. However, trehalose is only half as sweet as sucrose and it is more likely to be used for cell preservation than for sweetness. Trehalose may be used in beverages, including fruit juices, purees and fillings, nutrition bars, surimi, dehydrated fruits and vegetables, and white chocolate for cookies, or chips. This sweetener has a long history of human use and has GRAS in the United States, also approved in Japan, Taiwan, and Korea. It may be used in the preservation of freeze-dried products in the United Kingdom.

4.5. Bulking Agents. Bulking agents are substances that add bulk to food products while contributing fewer calories than the ingredients they replace. In applications where sugar is replaced by a high intensity sweetener, bulking agents make up for the lost volume, and ideally provide some or all of the functional properties of the sugar. The most important properties of a bulking agent are reduced calorie content through limited digestibility, solubility, and minimal side effects (14).

Polydextrose. Polydextrose [6824-04-4], a polymer of glucose that contains traces of sorbitol and citric acid, is the most widely used soluble bulking agent in the United States (15). It is approved for use in many applications, including bakery products, frozen desserts, candy and confectionery products, jams, chewing gums, salad dressings, gelatins, and puddings. The solubility of polydextrose makes it susceptible to action by micro flora in the lower intestine, leading to flatulence and diarrhea. Accordingly, if a single serving of a food contains >15 g of polydextrose, the label of the food must include a warning statement about this side effect.

Specialty Sweeteners. These sweeteners provide a bulking effect, along with some of the sweetness and functional properties of sugar. They may be used alone to replace sugar in applications that can tolerate some reduction in sweetness. Products that fall into this category include mannitol [69-65-8], $C_6H_{14}O_6$, a sugar alcohol having 0.6 times the sweetness of sugar and one-half of the calories; isomaltitol, which is up to 0.9 times as sweet as sugar and has about one-half of the calories; some L-sugars; and fructo-oligosaccharides. Palatinit, a hydrogenated iso-maltulose that is ~0.5 times as sweet as sugar, is marketed throughout Europe, mainly for use in confectionery products (16) (see SUGAR ALCOHOLS).

5. Flavor, Taste, Appearance, and Texture Enhancers

5.1. Acidulants.

Acidulants complement fruit and other flavors in carbonated beverages (qv), preserves, fruit drinks, and desserts (see FRUIT JUICES) (17–19). Their ability to lower pH makes them useful as preservatives because an acid environment retards the growth of microorganisms responsible for spoilage and prevents enzymatic browning in fruit. They are also used to modify the acidity of wine (qv). In addition, acids are used in chemical leavening agents, as gelling agents, defoaming agents, emulsifiers, and in the production of cultured dairy products. In the choice of an appropriate acid, the effect of the acid on the overall flavor system, the rate and degree of solubility of the acid, its hygroscopicity, and its strength must all be considered.

Acetic Acid. Acetic acid [64-19-7], $C_2H_4O_2$, is the principal component of vinegar, one of the first food acidulant in use. It is found in unprocessed figs, has a pungent odor, and is utilized in pickled fruits. Pure acetic acid is produced synthetically by the oxidation of acetaldehyde and butane and as the reaction product of methanol and carbon monoxide. Smaller quantities are obtained from the pyroligneous acid liquors acquired in the destructive distillation of hard wood.

Adipic acid. Adipic acid (qv) [124-04-9], $C_6H_{10}O_4$, produced from cyclohexane, delivers a long-lasting flavor note, and is used in products that need lingering tartness. It is effective as a buffering agent and in preventing enzymatic browning in fruits. This acid improves the whipping properties of egg whites, enhances the melting characteristics of processed cheese and cheese spreads, and helps form gels in imitation jams and jellies. It can be used as a general purpose acidulant in flavor emulsions, fruit-flavored hard candies, and for hot-filled canned foods.

Citric Acid. Citric acid (qv) [77-92-9], $C_6H_8O_7$ is the most extensively used food acidulant (19). This acid is favored because of its solubility, fresh flavor character, low cost, and low toxicity. It is commercially synthesized by fermentation (qv) of molasses by *Aspergillus niger* (17). Citric acid is used in carbonated beverages to provide tartness, modify and enhance flavors, and chelate trace metals. It is often added to jams and jellies to control pH and provide tartness as well as in cured and freeze-dried meat products to protect the amino acids (qv) and improve water retention. Bakers use it to improve the flavor of fruit fillings in baked goods. Because citric acid is a good chelating agent for trace metals, it is used as an antioxidant synergist in fats and oils, and as a preservative in frozen fish and shellfish (see ANTIOXIDANTS).

Fumaric Acid. Fumaric acid [110-17-8], $C_4H_4O_4$, is unique in its low solubility in cold water and slow rate of solution, making it ideal for use in chilled biscuit leavening systems, and for dry pudding mixes and beverage powders. It is also used for gelatin desserts, pie filling, fruit juices, and wine. Fumaric acid is produced by the acid-catalyzed isomerization of maleic acid (see MALEIC ANHYDRIDE, MALEIC ACID, AND FUMARIC ACID).

Glucono-delta-lactone. Glucono-delta-lactone [90-80-2] (GDL), $C_6H_{10}O_6$, is an inner ester of gluconic acid. In conjunction with reducing compounds, GDL accelerates the rate of development of cure color in smoked meats, which reduces the smoking time considerably. It may also be employed as a chemical leavening agent, and has been used for instant bread, which needs no proofing (19).

Lactic Acid. Lactic acid [598-82-3], $C_3H_6O_3$, one of the most widely distributed acids in Nature, is used primarily in fermented foods and brine-packed products where it inhibits the growth of microorganisms. This acid has the most powerful preservative effect of all commonly used acidulants (20). There is a large market for lactic acid in cheese, where it is used as a pH adjusting agent (see MILK AND MILK PRODUCTS). It is also used to adjust the pH of other dairy products, beer, and wine. Its salt, calcium lactate [814-80-2], $CaC_6H_{10}O_6$, is used as a firming agent for processed food and as a gelling salt for low methoxy pectin. Commercial lactic acid is produced by the esterification and hydrolysis of lactonitrile, or by fermentation of carbohydrates.

Malic Acid. Malic acid [6915-15-7], $C_4H_6O_5$, similar to citric acid in acidifying character and flavor, does not exhibit the initial burst of tartness that citric acid does (18). Malic acid is mostly used in fruit-flavored carbonated beverages, but its high solubility and low melting point make it ideal for hard candy applications. Malic acid is synthesized by hydrating maleic acid and fumaric acid in the presence of a catalyst, then separating malic from the mixture by equilibrium techniques.

Phosphoric Acid. Phosphoric acid [7664-38-2], H_3PO_4, has a characteristic flavor and tartness and is used almost entirely in cola-flavored carbonated beverages (17). A small quantity is also used in some root beer brands. It is the only inorganic acid extensively employed as a food acidulant. Occasionally, phosphoric acid is utilized as a buffering agent in jams and jellies to adjust acidity for maximum gel formation. It is the least costly of all the food-grade acidulants; it is also the strongest, giving the lowest attainable pH. Phosphoric acid is produced primarily by the furnace process, wherein elemental phosphorus (P_4) is burned at $\sim$1650–2750°C, yielding phosphorus pentoxide (P_2O_5), which reacts with water to produce phosphoric acid (H_3PO_4). Although the product is relatively pure, food-grade material requires additional purification to meet standards. The alternative wet-acid process is currently not cost-effective because of high purification costs, but it is believed that it will eventually be the method of choice for food-grade phosphoric acid. Food-grade phosphoric acid is supplied mostly as 75% aqueous solutions, but 80 and 85% solutions are also available.

Tartaric Acid. Tartaric acid [87-69-4], $C_4H_6O_6$, has a strong, tart taste and augments natural and synthetic fruit flavors, especially grape and cranberry (21). Tartaric acid is a natural component of numerous fruits, including the currant, raspberry, cranberry, and grape. Tartaric acid for food acidulant applications is not manufactured in the United States. It is obtained from waste products of the wine industry such as press cakes, unfermented grape juice, or argols. In the manufacture of the acid, the by-products are first extracted with hot water and treated with hydrochloric acid and then lime. The calcium tartarate is then crystallized and decomposed with sulfuric acid to obtain the acid. As a food acidulant, tartaric acid is widely used in cranberry and grape-flavored foods and beverages and in candies to produce the sour apple, wild cherry, and other especially tart flavors. For similar reasons, it is selected as the acidulant for grape-flavored and for tart-tasting jams and jellies. Both tartaric acid and its mono-potassium salt (cream of tartar) are used in baking powders and leavening systems. Specialized uses, high prices, and limited availability inhibit tartaric acid from widespread use as a food acidulant.

Vinegar. Vinegar is produced from apple cider, grapes, or wine, sucrose, glucose, or malt by successive alcoholic and acetous fermentation (22). The resulting vinegar is then pasteurized and filtered and often concentrated for convenience of handling and storage. In the United States, the use of the term *vinegar* without qualifying adjectives implies only cider vinegar. There are several popular types of vinegar produced commercially for the use as an additive in food products. Although a 4–8% solution of pure acetic acid would have the same taste characteristics as cider vinegar, it could not qualify as vinegar. In the United Kingdom, malt vinegar is supplied by trade agreement. In Europe, wine vinegar is the most common variety.

5.2. Flavors and Flavor Enhancers. The word "flavor" describes a complex sensation provided by compositions of many defined aromatic ingredients (see FLAVORS). Flavorings are concentrated preparations used to impart a specific aroma to food or beverage. Flavoring ingredients are the most numerous single group of intentional additives utilized by the food industries (23). Flavors should not be viewed as a single homogeneous class of food additives, but as a composite of closely interrelated and somewhat overlapping sectors with differentiated characteristics, in the following sections (24):

Essential Oils and Natural Extracts. These substance usually are defined as the volatile material obtained from a particular plant species by the process of distillation, expression (cold pressing), and maceration. Essential oils represent complex aroma mixtures containing as many as hundreds of chemical constituents. Included are vanilla [8024-06-4], cocoa [84649-99-0], cola, spice oleoresins, etc. Essential oils may be used as such for imparting scent or aroma to consumer products; they may be used as raw materials for compounding flavor compositions; or they may be the source of isolated aroma chemicals, also used in compounding.

Aroma Chemicals. These chemicals comprise organic compounds with a defined chemical structure that are isolated from microbial fermentation, plants, or animal sources or are produced by organic synthesis. Included are anethole [4180-23-8], $C_{10}H_{12}O$, vanillin [121-33-5], $C_8H_8O_3$, citronellol [106-22-9], $C_{10}H_{20}O$, geraniol [106-24-1], $C_{10}H_{18}O$, diacetyl [431-03-8], $C_4H_6O_2$, benzaldehyde [100-52-7], C_7H_6O, etc. Aroma chemicals may be added directly to foods and beverages or used as raw materials in flavor compositions.

Table 3. **Commercial Flavor Compositions**

Type of flavor	Classification	Manufacturing process	Raw materials	Product form
compounded flavors	natural or synthetic	blending, mixing	essential oils, natural extracts, fruit juice concentrates, aroma chemicals	liquid, spray-dried, encapsulated
natural extracts	natural	extraction, enzymatic	food substrates (eg, plants, fish, meat, etc)	liquid, paste
reaction flavors (thermally processed)	natural	heating/pressure cooking	amino acids and sugars, hydrolyzed proteins	paste, powder
enzymatically modified flavors	natural	enzymatic/ microbial reaction	food substrates (eg, cheese)	paste, powder

Flavor Compositions. Flavor compositions consist of complex mixtures of various aromatic materials from a few to 100 or more constituents. Compounded flavors (Table 3) may contain aroma chemicals, natural extracts, essential oils, solvents, and in some cases other functional additives (eg, antioxidants, acidulants, emulsifiers). A flow sheet depicting the preparation of flavors from starting materials to the end product is presented in Figure 1.

Flavor compositions are added to foods and beverages in the following reasons (25):

- Create a totally new taste.
- Enhance, extend, round out, or increase the potency of flavors already present.
- Supplement or replace flavors to compensate for losses during processing.
- Simulate other more expensive flavors or replace unavailable flavors.
- Mask less desirable flavors—to cover harsh or undesirable tastes naturally present in some food, other than hide spoilage.

Flavoring substances may be classified as (25):

- *Natural Flavoring Substance*: Obtained by physical separation, enzymatic process, or microbial process from vegetable or animal sources, either in the raw state or after processing (including drying, torrefaction, and fermentation).
- *Nature-Identical Flavoring Substance*: Obtained by synthesis or isolated by chemical processes, chemically identical to substances naturally present in vegetable or animal sources (this classification is used in Europe, but not allowed in the United States).

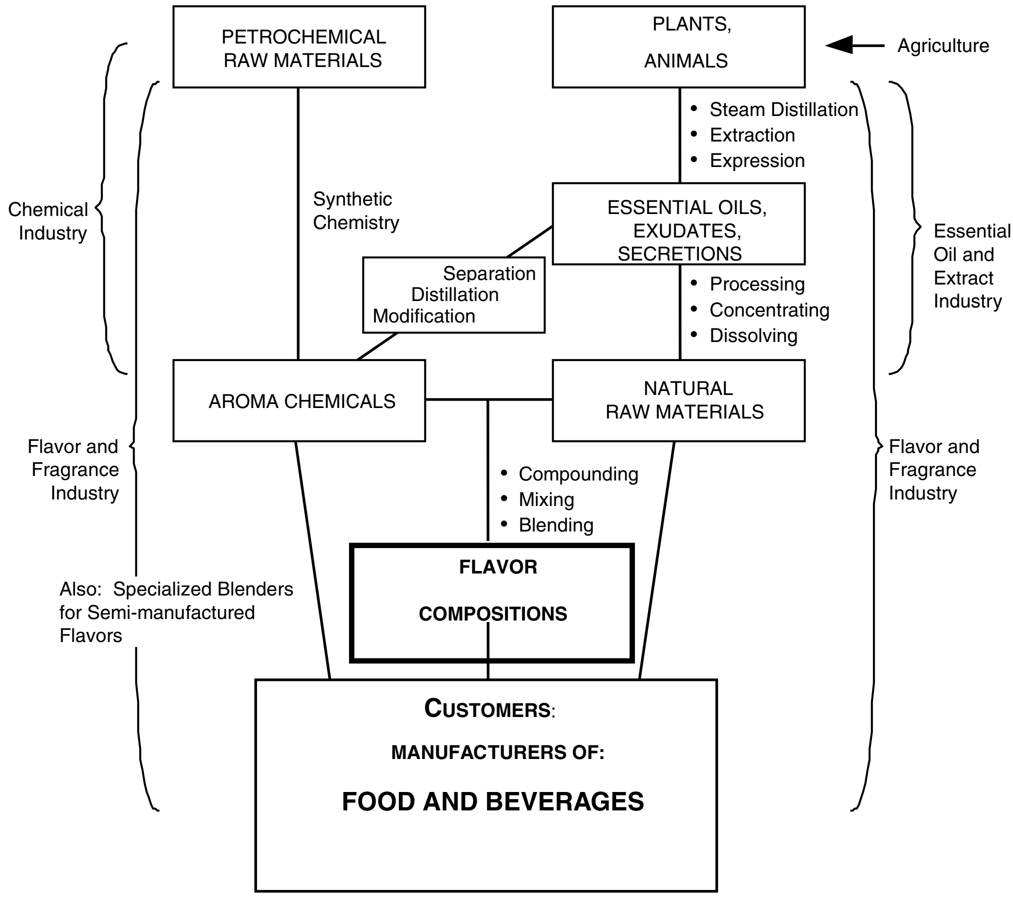

Fig. 1. The Flavor Industry: Flow of manufacturing processes for flavors.

- *Artificial Flavoring Substance*: Obtained by chemical synthesis and not found to occur in Nature.
- *Flavoring Preparation*: Products other than natural substances, whether concentrated or not, with flavoring properties, obtained by physical separation, or enzymatic or microbial processes, from material of vegetable or animal origin, either in the raw state or after processing (including drying, torrefaction, and fermentation).
- *Process Flavorings*: Products obtained by heating to a temperature not exceeding 180°C for a period not exceeding 15 min using a mixture of ingredients, not necessarily themselves having flavoring properties, of which at least one contains nitrogen (amino) and another is a reducing sugar.

  Smoke Flavoring: Smoke extracts used in traditional foodstuff smoking processes.

  Flavor Enhancers: They have the ability to enhance flavors at a level below which they contribute any flavor of their own.

Worldwide, the most popular flavor enhancers are monosodium L-glutamate [142-47-2] (MSG), $NaC_5H_8NO_4$, and the 5′-ribonucleotides: disodium 5′-inosinate [131-99-7] (IMP), $C_{10}H_{11}N_4O_8P{\cdot}2Na$, and disodium 5′-guanylate [85-75-5] (GMP), $C_{10}H_{12}N_5O_8P{\cdot}2Na$. Monosodium L-glutamate in combination with IMP and GMP are often used together in foods such as dried soups and broths, canned and frozen foods, nuts, sauces, spice blends, and other processed foods. IMP and GMP are obtained either by degradation of RNA using 5′-phospho-diesterase to form 5′-nucleotides, or by fermentation that results in the production of nucleosides that are phosphorylated into 5′-nucleotides (26). MSG is the sodium salt of the amino acid, L-glutamic acid, which occurs naturally in plants and animals (see AMINO ACIDS). It is produced by alkaline hydrolysis of the waste liquor from beet sugar refining or hydrolysis of wheat or corn gluten. Ammonium glycyrrhizinate [53956-04-0] (AG), $C_{42}H_{65}NO_{16}$, is a flavor enhancer derived from licorice root. It is ~50 times sweeter than sucrose and is often used to enhance sweetness in a wide variety of food products. Maltol [118-71-8], $C_6H_6O_3$, and ethyl maltol [4940-11-8], $C_7H_8O_3$, are used as flavor enhancers in products such as cake mixes, confections, cookies, ice cream, fruit juices, puddings, and beverages.

5.3. Colors. Colors are used in foods to improve appearance and thereby influence the perception of texture and taste (see COLORANTS FOR FOODS, DRUGS, COSMETICS, AND MEDICAL DEVICES). For centuries, natural color materials have been mixed with foods in an attempt to improve appearance. When synthetic colors were introduced in the late nineteenth century, they were immediately adopted by the food industry. These were certified FD&C color additives that were allowed for use in foods according to the Federal Food, Drug and Cosmetic Act of 1938 and its amendments, and food color additives (mostly natural materials) that were exempt from FD&C certification. In order to market their products, U.S. producers of certified colors must submit product samples from each batch of material to the FDA. The materials are analyzed by the US FDA to see that they meet specific purity classifications. In other parts of the world, only self-certification exists (4).

Food colors may be added to food to (27):

- Give attractive appearance to foods that would otherwise look unattractive or unappetizing (eg, colorless gelatin-based jelly) and thus enhance enjoyment.
- Restore the original appearance of the food where the natural colors have been destroyed by heat processing and with subsequent storage.
- Intensify colors naturally occurring in foods where the color is weaker than that which the consumer associates with a food of that type of flavor (eg, fruit yogurts, sauces, soft drinks).
- Ensure uniformity of color due to natural variations in color intensity, eg, fruits obtained at different times during the season, thereby assuring uniformity in appearance and acceptability.
- Help protect flavor and light-sensitive vitamins during shelf storage by a sunscreen effect.
- Help preserve the identity or character by which foods are recognized, ie, product identification.

- Serve as visual indication of quality—thus, in addition to enhancing the acceptability of foods, colors aid in food manufacture, storage, and quality control

Certified food colors can be divided into dyes and lakes. Color regulators specify a minimum of 85% pure dye for primary colors, but most dye lots contain from 90 to 93% pure dye. FD&C dyes are also used in the production of lakes, which are pigments prepared by combining a certified dye with an insoluble alumina hydrate substratum. Lakes are both water- and oil-insoluble and impart color through dispersion in food. Thus, they are suitable for coloring foods that cannot tolerate water and products in which the presence of water is undesirable, such as dry beverage bases and dessert powders. The FD&C lakes do not have a legal specified minimum dye content; manufacturers use formulations of from 11% (standard) to 42% pure dye (concentrated). Certified food colors are used in most products in the 50–300 ppm range.

Of the eight colors certified for use in food in the United States, eight can be used as dyes (one, Citrus Red No. 2 [6358-53-8] $C_{18}H_{16}N_2O_3$, is limited to use in coloring orange skins) and five as lakes (Table 4). Dyes are water-soluble compounds that impart color to a substance through dissolution. They are produced in a variety of forms, including powder, liquid, granules, paste, and dispersion. Certified dyes fall into several chemical classes:

- *Azodyes*: Yellow No. 5, or Tartazine [1934-21-0], $C_{16}H_{12}N_4O_9S_2.3Na$; Yellow No. 6, or Sunset yellow [2783-94-0], $C_{16}H_{12}N_2O_7S_2.2Na$; Red No. 40, or Allura red [25956-17-6], $C_{18}H_{16}N_2O_8S_2{\cdot}2Na$, and Citrus No. 2 [6358-53-8] $C_{18}H_{16}N_2O_3$.
- *Triphenylmethane dyes*: Blue No. 1, or Brilliant blue [2650-18-2], $C_{37}H_{36}N_2O_9S_3.2NH_3$; Blue No. 2, or Indigotine, [860-22-0], $C_{16}H_{10}N_2O_8S_2.2Na$; Green No. 3, or Fast green, [12777-77-4], $C_{34}H_{30}N_2O_{10}S_3.2Na$; and Red No. 3, or Erythrosine, [16423-68-0], $C_{20}H_8I_4O_5.2Na$.

Table 4. **Certified Colors Permitted in the United States**[a]

FDA name	Common name	CAS Registry number	Molecular formula
FD&C Blue No. 1	Brilliant Blue	[2650-18-2]	$C_{37}H_{36}N_2O_9S_3 \cdot 2NH_3$
FD&C Blue No. 2	Indigotine	[860-22-0]	$C_{16}H_{10}N_2O_8S_2 \cdot 2Na$
FD&C Green No. 3	Fast Green	[12777-77-4]	$C_{34}H_{30}N_2O_{10}S_3 \cdot 2Na$
FD&C Yellow No. 5	Tartrazine	[1934-21-0]	$C_{16}H_{12}N_4O_9S_2 \cdot 3Na$
FD&C Yellow No. 6	Sunset Yellow	[2783-94-0]	$C_{16}H_{12}N_2O_7S_2 \cdot 2Na$
FD&C Red No. 3	Erythrosine	[16423-68-0]	$C_{20}H_8I_4O_5 \cdot 2Na$
FD&C Red No. 40	Allura Red	[25956-17-6]	$C_{18}H_{16}N_2O_8S_2 \cdot 2Na$
Orange B[b]		[15139-76-1]	$C_{22}H_{18}N_4O_9S_2 \cdot 2Na$
Citrus Red No. 2[c]		[6358-53-8]	$C_{18}H_{16}N_2O_3$

[a]Ref. 28.
[b]Allowed only on the surfaces of sausages and frankfurters at concentrations up to 150 ppm by weight.
[c]Allowed only on the skins of oranges, not intended for processing, at concentrations up to 2 ppm by weight.

Table 5. **Selected Food Color Additives Exempt from Certification**

	Color	Source
annatto extract	yellow	vegetable
beet juice	red	vegetable
beets, dehydrated (beet powder)	purple	vegetable
canthaxanthin	red	synthetic
caramel	brown	semisynthetic
apo-carotenal	orange	synthetic
beta-carotene	yellow	synthetic
carrot oil	yellow	vegetable
chlorophyll	green	vegetable
cochineal extract (carmine)	red	insect
corn endosperm oil	yellow	vegetable
dried algae meal	yellow	plant
ferrous gluconate	black	synthetic
ferrous lactate	black	synthetic
fruit juice (grape and cranberry)	red	fruit
grape skin extract (enocyanin)	red	fruit
paprika	red	vegetable
paprika oleoresin	red	vegetable
red cabbage juice	red	vegetable
riboflavin	yellow	synthetic
saffron	yellow	vegetable
titanium dioxide	white	synthetic
turmeric (curcumin)	yellow	vegetable
turmeric oleoresin	yellow	vegetable

Noncertified colors (sometimes called “natural” colors) can be from either natural origins (primary sources), such as vegetables (carrot oil, red beet juice, paprika, etc) and fruits (grape skin, cranberry juice concentrate), or produced synthetically, eg, annatto extract [8015-67-6], ferrous gluconate [299-29-6], β-apo-8′-carotenal [1107-26-2], riboflavin [83-88-5], etc). Food color additives exempt from certification, their colors, and sources are listed in Table 5. In general, the traditional markets for noncertified food colors have been the lipid-based, high fat food systems such as butter, margarine, shortening, popcorn oil, processed cheeses and spreads, salad dressing, and snack foods (28). Water-soluble forms are often also available, and other applications include baked foods, fruit juice drinks, confections, and dairy products. Certain noncertified food colors are important in the beverage industry. For example, caramel [8000-42-8] is used in beverages, primarily in cola drinks, and synthetic carotenoids are important in orange drinks. Although a great number of non-certified food colorants are used by the U.S. food processing industry, demand is concentrated in a few products, namely paprika, caramel (principal use is in cola beverages), annatto, and synthetic carotenoids (29).

5.4. Thickeners and Stabilizers. Thickeners and Stabilizers (also called hydrocolloids, gums, or water-soluble polymers) provide a number of useful functions to food products. The technical base for these effects results from the ability of these materials to modify the physical properties of water. Most food and beverage products largely consist of water. Hydrocolloids are high molecular weight polymers that are either extracted from plants, seaweed, or animal collagen, or are produced by microbial synthesis. They are widely used for their general thickening properties, as well as their ability to provide stability for emulsions, suspensions, and foams. The structure of hydrocolloids gives them a slippery, creamy mouthfeel that mimics the organoleptic properties of fats and oils, thus making them useful as fat replacers. Many of the fat replacers that are on the market are based on one or a combination of hydrocolloids. Hydrocolloids fall into two classes: polysaccharides and proteins. Most stabilizers and thickeners are polysaccharides and function in foods as:

- Rheology modifiers, affecting the flow and feel (mouth) of food and beverage products.
- Suspension agents for food products containing particulate matter.
- Stabilizers of oil–water mixtures.
- Binders in dry and semidry food products.
- Gel-forming agents in food that require this physical form.

During the 1990s, fat replacement became a major application for modified starches and gums as these additives provide unique texturing, bulking and emulsifying properties of the displaced fat. Also, natural gums being offered as good sources of dietary fiber. Thickeners and stabilizers are generally used in very small amounts in most food products, in concentrations of 0.15% in jam, 0.35% in ice cream, and 1–2% in salad dressings.

Two principal classes of these materials are utilized in food (30) (a third class known as synthetic polymers obtained from petroleum or natural gas precursors are not used in food):

- Natural materials obtained from plants or animals, including gum Arabic, locust bean gum, guar gum, alginates, carrageenan, pectin, starches, casein, gelatin, etc.
- Semisynthetic materials, which are manufactured by chemical derivatization of natural organic materials (generally based on a polysaccharide), or by microbial fermentation. This group includes carboxymethylcellulose (CMC), and other modified cellulose compounds, dextran, and gellan and xanthan gums.

Natural Hydrocolloids. Unmodified Starch. Unmodified, commonly called natural starch or pearl starches [9005-25-8], produced by the wet milling of filed corn, supply the major amount of thickening material for the American food and beverage market. Other commercial starches include wheat, potato, sago, rice, and tapioca. Owing to low cost, unmodified starches are used extensively as thickening agents in the food industry. Starch is often pregelatinized so it can be used to impart thickening properties in foods that are not normally heated, such as instant pie fillings.

Modified Starch. Starch is often modified by hydrolysis with hydrochloric or sulfuric acid (31). The resulting product is resistant to syneresis, keeps food in suspension after cooking, and exhibits much greater freeze–thaw stability than unmodified starch. Modified starch is commonly used in baby food, frozen prepared foods, pie fillings, meat products, and candy.

Agar. Agar [9002-18-0] is obtained from a variety of red marine algae of the *Rhodophycae* class found along the coast of Japan. Food applications include frozen desserts, confectionery products, and baked goods (30,31).

Alginates. Alginates are extracted from different types of seaweeds, mainly from brown seaweeds (*Macrocytis pyrifera and Laminaria sp.*) found along the rocky coasts of the north Atlantic coastline and the Pacific coast along southern California. They are unique because they are able to form irreversible gels by reaction with calcium salts without heat. They are used in ice cream, bakery products, puddings, dressing, and beer (for foam stabilization) (30,31).

Locust Bean Gum. Locust bean gum [9000-40-2], also known as carob seed gum, is a galactomannan extracted from the endosperm of the carob tree seed which is cultivated in the Mediterranean area. The primary use of locust bean gum is in dairy applications such as ice cream. It is often used in conjunction with carrageenan because the chemical structures of the two enable them to cross-link and form a gel (30,31).

Guar Gum. Guar gum [9000-30-0], also a galacotmannan is extracted from the endosperm of the guar plant seed (*Cyamoposis tetragonolobus*), which is grown primarily in India and Pakistan. Guar hydrates rapidly in cold water and is used extensively in ice cream, cheese, and baked goods. Chemically, guar is closely related to locust bean gum (30,31).

Gum Arabic. Gum Arabic [9000-01-5] is an exudate of the Acacia tree (*Acacia Senegal* and other *Acacia* genus), found in the Middle East. It dissolves readily in water to produce low viscosity solutions. It is used in confectionery products, bakery toppings, beverages, frozen dairy products, and dry drink mixes (30,31).

Carrageenan. Carrageenan [9000-07-1] is extracted from Irish moss (*Chondrus* and *Gigartina* species) found along the shores of the western United States, Nova Scotia, and the British Isles. The largest food use for carrageenan is in dairy products such as flavored milk and frozen desserts. Carrageenan is comprised of a mixture of polymers and interacts synergistically with other food gums and is often used in conjunction with locust bean gum (30,31).

Pectin. Pectin [9000-69-5] is a mucilaginous substance extracted from the cell walls of citrus peel, sugar beet pulp, and apple pomace. Two classes of pectins exist. High methoxy pectins, which have a degree of esterification higher than 50%, are used in jams, jellies, and gummy candies. These pectins require the presence of sugar and acid in order to form a gel. Low methoxy pectins, which have a lower degree of esterification, form gels in the absence of sugar, but require the presence of calcium to aid with cross-linking. Low methoxy pectins are often used in low sugar jams and jellies (30,31).

Casein. Casein [9005-46-3] is a protein occurring and obtained from milk. It is the main ingredient of cheese. Casein is marketed a sodium, calcium, potassium, or magnesium caseinate and is used in confections, puddings, bakery fillings and frostings, and whipped toppings.

Gelatin. Gelatin, a protein-based hydrocolloid, is a polymer made up of amino acids. It is obtained from beef (Type B) or pork (Type A) skin, hides, and bones by hydrolysis and extraction of collagen with hot water. The most popular usage of gelatin is in the preparation of gelatin desserts, but it is also used in marshmallows and other confectionery products, processed meats, frozen foods, and dairy products. Wine, beer, cider, and fruit juices use gelatin as a clarifying agent (30,31).

Ghatti gum [9000-28-6] supplied from India and Sri Lanka, *tragacanth gum* [9000-65-1] from the Middle East, and *karaya gum* [9000-36-6] from India is also used, but not as frequently as the others, because of their high price and erratic supply.

Semisynthetic Hydrocolloids. Cellulose Derivatives. The principal structural component of plant cell walls is cellulose (qv). The most widely used cellulose derivative is the sodium salt of *carboxymethylcellulose* (CMC). [9004-32-4]. It is made by treating cellulose with sodium hydroxide and chloroacetic acid [79-11-8], $CH_2ClCOOH$. Carboxymethylcellulose is widely used in the food industry in products such as baked goods, icings, syrups, glazes, frozen dairy products, and dry drink mixes. *Methylcellulose* "Methocel" [9004-67-5], another useful cellulose derivative, is made by the reaction of cellulose and sodium hydroxide with methyl chloride. It is used to prevent syneresis in frozen foods, and as a thickener and stabilizer in salad dressings. *Microcrystalline cellulose*, "Avicel"(MCC) is a partially depolymerized from of cellulose prepared by the hydrolysis of wood pulp with hydrochloric acid. Microcrystalline cellulose is used as a stabilizer in frozen desserts, meats, dairy products, baked goods, and aerosol toppings (30,31).

Xanthan Gum. Xanthan gum [11138-66-2] is produced by industrial fermentation of a carbohydrate under aerobic conditions by culturing the bacterium *Xanthomonas campestris*. It is unique in that it gives high viscosity solutions at low concentrations, exhibits little change in viscosity with variation in temperature, and is stable over a wide pH range. The greatest usage of xanthan gum is in salad dressing, but it is also used in baked goods, confectionery products, syrups, toppings, dry beverage mixes, frozen foods, and dairy products. Xanthan gum is synergistic with locust bean gum and guar gum, and they are often used together for enhanced gelation or viscosity (30,31).

Gellan Gum. Gellan gum, the first to receive FDA approval for food use since xanthan gum in 1968, is produced from *Pseudomonas elodea* by a pure culture fermentation process (31). Gellan gum can be used at levels substantially below those required by other hydrocolloids. It is recommended for use in icings, frostings, bakery fillings, and confections.

5.5. Emulsifiers. Emulsifiers or surfactants (qv), are additives that allow normally immiscible liquids, such as oil and water, to form a stable mixture. Emulsifiers possess both hydrophilic and lipophilic groups within the same molecule; the ratio of hydrophilic to lipophilic groups, known as the HLB value, is a characteristic indicator for emulsifiers, which allows assessment of their action and performance. Emulsifiers are widely used in foods in order to perform one or more of the following functions:

- Increase stability and prevent phase separation in food emulsions (eg, mayonnaise, salad dressings).

- Improve the shelf life of flavors and retard the onset of rancidity in fats and oils containing food emulsions.
- Improve texture, reduce crumb firmness, and complex with starches (baked goods).

Recent interest in this category of food additives has been encouraged by consumers' health consciousness. As most emulsifiers can decrease the amount of fat or oil in the product or add bulkiness or soften texture by increasing the amount of air suspended throughout the product, emulsifiers can serve to some degree as substitutes for fat and can decrease calories. In the case of lecithin, the growth of its market is supported by some functions of lecithin itself, such as improvement in and/or prevention of adult diseases such as hypertension, arteriosclerosis, and hyperlipidemia.

Emulsifiers are classified by the hydrophilic–lipophilic balance (HLB) system. This system indicates whether an emulsifier is more soluble in water or oil, and for which type of emulsion (water-in-oil or oil-in-water) it is best suited. Emulsifiers having a low HLB value are more oil soluble, and are better suited for water-in-oil applications such as margarine. Conversely, emulsifiers having a high HLB value are more water soluble, and function more effectively in oil-in-water emulsions such as ice cream (32). The use of this system is somewhat limited because the properties of emulsifiers are modified by the presence of other ingredients and different combinations of emulsifiers are needed to achieve a desired effect.

The most common and commercially important emulsifiers are monoglycerides and diglycerides of fatty acids and their esters (eg, glyceryl monostearate), lactylated esters (eg, sodium stearoyl lactylate [25383-99-7]), propylene glycol esters (eg, propylene glycol monostearate), lecithin [8002-43-5], $C_8H_{17}O_5NRR'$(R and R' are fatty acid groups), sorbitan esters (eg, sorbitan monostearate [9005-67-8], $C_{64}H_{126}O_{26}$, and polysorbates (eg, polyoxyethylene sorbitan monolaurate, also called polysorbate 20).

A great number of other emulsifiers listed in Table 6 are used by the food industry. With the possible exception of lecithin, few emulsifiers are used as a single additive. Mostly, emulsifiers are offered as blends of emulsifiers, emulsifiers and water, emulsifiers and fats, or as blends with other functional additives (colors, flavors, gums for specialized applications, ie, ice cream, baked goods). These products are formulated for specific applications or specific customers so that the combination provides both enhanced performance and ease of use.

Lecithins [8002-43-5] are by far the main products. They consist of a mixture of fat-like compounds that includes phosphatidyl choline, phosphatidyl ethanolamines, inositol phosphatides, and other compounds (33). Commercial lecithin was originally obtained from egg yolks, but is now extracted from soybean oil. Lecithin is the most widely used chocolate emulsifier. Other important applications include baked goods and dairy products. The more prominent food uses of emulsifiers include baking, shortenings, ice cream, imitation dairy products, prepared mixes, margarine, salad dressings, and miscellaneous prepared foods (eg, confectionery, pasta, potatoes, peanut butter).

Table 6. **Emulsifiers and Their Regulatory Status in the United States and Europe**

Emulsifier	United States[a]	European no.
mono- and diglycerides (GRAS)	182.4505	E 471
succinyl monoglyceride	172.830	
lactylated monoglyceride	172.852	E 472
acetylated monoglyceride	172.828	E 472
monoglyceride citrate	172.832	E 472
monoglyceride phosphate (GRAS)	182.4521	
stearyl-monoglyceride citrate	172.755	E 472
diacetyl-tartrate ester of monoglyceride (GRAS)	182.4101	E 472
polyoxyethylene monoglyceride	172.834	
polyoxyethylene (8) stearate	172.838	
propylene glycol monoester	172.854	E 477
lactylated propylene glycol monoester	172.850	
sorbitan monostearate	172.842	E 491
sorbitan tristearate	172.842	
polysorbate 60	172.836	E 435
polysorbate 65	172.836	E 436
polysorbate 80	172.840	E 433
calcium stearoyl lactylate	172.844	E 482
sodium stearoyl lactylate	172.846	E 481
stearoyl lactylic acid	172.848	
stearyl tartarate		E 483
stearyl monoglyceridyl citrate	172.755	
sodium stearyl fumarate	172.826	
sodium lauryl sulfate	172.822	
dioctyl sodium sulfosuccinate	172.810	
polyglycerol esters	172.854	E 475
sucrose esters	172.859	E 473
sucrose glycerides		E 474
lecithin (GRAS)	184.1400	E 322
hydroxylated lecithin	172.814	E 322
triethyl citrate (GRAS)	182.1911	

[a]Code of Federal Regulation (CFR) Title 21.

5.6. Bleaching, Maturing, and Dough-Conditioning Agents. Because some chemicals serve as both bleaching and maturing agents, and other are referred to as dough-conditioning agents or bread improvers, it is perhaps desirable to consider all of them under one heading. Bleaching agents are used in the production of certain cheeses, processed fruits, crude fats and oils and meat products to neutralize color that may be present naturally. As an example, after crude oils are refined to remove impurities, they must be further treated by bleaching to remove coloring materials that are usually present in crude fats and oils. Sulfuric acid [7664-93-0], H_2O_4S and meta-phosphoric acid [37267-86-0], $(H_3PO_3)_x$ and hydrogen peroxide [7722-84-1], H_2O_2 have been used for this purpose. Calcium hypochlorite [7778-54-3], $Ca(OCl)_2$ is used in bleaching sugar syrup prior to crystallization.

Bleaching plays special importance in the flour milling and baking industries. Freshly milled flour contains carotenoid pigments that cause the flour to have a yellow color. In addition, when the flour is made into dough the product is sticky and unmanageable. As the flour ages, a natural process will take place that turns the flour white and improves its baking qualities. Because the natural process takes quite a bit of time, additives are used to speed up the process. Benzoyl peroxide [94-36-0], $C_{14}H_{10}O_4$, is a bleaching agent that is typically added at the flourmill at a level between 0.015 and 0.075%. This additive oxidizes the carotenoid pigments, resulting in a white flour. Benzoyl peroxide does not affect baking properties, however, and a number of other additives can be used for this effect. Gases that exert an effect on the flour upon immediate contact include chlorine gas, chlorine dioxide [10049-04-4], ClO_2, nitrosyl chloride [2696-92-6], NOCl, nitrogen oxides [10024-97-2], N_2O, and nitrogen tetroxide [10544-72-6], N_2O_4. Others that exert their effect when the flour is made into dough include potassium bromate [7758-01-2], $KBrO_3$, potassium iodate [7758-05-6], KIO_3, calcium iodate [7789-80-2], $Ca(IO_3)_2$, and calcium peroxide [1305-79-9], CaO_2 (34).

5.7. Firming Agents. Fruits and vegetables contain pectin components that are relatively insoluble and form a firm gel around the fibrous tissues of the fruit and prevent its collapse. Addition of calcium salts causes the formation of calcium pectate gel, which supports the tissues and affords protection against softening during processing. The calcium salt is sometimes added to the canned vegetable in the form of a tablet containing both sodium chloride and calcium chloride (21).

Canned vegetables, canned apples, frozen apples, and tomatoes are sometimes treated during processing with calcium chloride [10043-52-4], $CaCl_2$, calcium citrate [813-94-5], $Ca_3(C_6H_5O_7)_2$, monocalcium dihydrogen phosphate [7758-23-8], $Ca(H_2PO_4)_2$, calcium lactate [814-80-2], $CaC_6H_{10}O_6$, or calcium sulfate [7778-18-9], $CaSO_4$, to prevent them from becoming soft and disintegrating (see CALCIUM COMPOUNDS). Suggested level of use of these calcium salts is 0.02%, calculated as calcium in the final food product. In canned potatoes, calcium chloride and calcium citrate at a level of 0.5% (calculated as calcium) are used.

Acidic aluminum salts, such as aluminum sulfate [10043-01-3], $Al_2(SO_4)_3$, ammonium aluminum sulfate $(NH_4)Al(SO_4)_2$, potassium aluminum sulfate [10043-01-3], $KAl(SO_4)_2$, and sodium aluminum sulfate $NaAl(SO_4)_2$ are used as firming agents in pickles and relishes. A more recently introduced firming agent is aluminum sulfate for canned crabmeat, lobster, salmon, shrimp, and tuna. Calcium chloride acts as a firming agent in cheddar and cottage cheese.

5.8. Glazing and Polishing Agents. These agents are used on coated confections to give luster to the otherwise dull coating. Chemicals that are used for this purpose include acetylated monoglycerides, beeswax [8012-89-3], carnauba wax [8015-86-9], gum Arabic [9000-01-5], magnesium silicate [1343-90-4] $Mg_2O_8Si_3$, mineral oil [8012-95-1], petrolatum, shellac, and zein [9010-66-6]. Generally these compounds are used at levels of $\sim$0.4%, with the exception of mineral oil and petrolatum, which are used at 0.15%, and zein at 1.0%.

6. Preservatives

6.1. Antimicrobials. The choice of a preservative takes into consideration the product to be preserved, the type of spoilage organism endemic to it, the pH of the product, period of shelf life, and ease of application. No one preservative can be used in every product to control all organisms, and therefore combinations are often used. In certain foods, specific preservatives have very little competition. In the concentrations used in practice, none of the preservatives discussed here is lethal to microorganisms in foods. Rather, their action is inhibitory (35).

Preservatives may be divided into two main groups: (a) antioxidants and (b) antimicrobials.

- *Antimicrobial agents* are capable of retarding or preventing growth of microorganisms such as yeast, bacteria, molds, or fungi, and subsequent spoilage of foods. The principal mechanisms are reduced water availability and increased acidity. Sometimes these additives also preserve other important food characteristics such as flavor, color, texture, and nutritional value.
- *Antioxidants* are food additives that retard atmospheric oxidation and its degrading effect, thus extending the shelf life of foods.

The primary food additives used for this function are as follows (36): *Benzoic acid* [65-85-0], $C_7H_6O_2$, and its sodium benzoate [532-32-1], $C_7H_5O_2 \cdot Na$, and potassium benzoate [582-25-2], $C_7H_5O_2$.K salts of are most effective against yeast and mold. They are used in beverages, fruit products, chemically leavened baked goods, and condiments. Owing to their inhibitory effect on yeast, they cannot be used in yeast-leavened products. Potassium benzoate was developed for use in reduced-sodium products. Benzoates are permitted for use in foods up to a level of 0.1% (37).

Sorbic acid [110-44-1], $C_6H_8O_2$, and its sodium [7757-81-5] $C_6H_7O_2$.Na, and potassium [590-00-1], $C_6H_7O_2$.K, salts are used as mold and yeast inhibitors in dairy products, chemically leavened baked goods, fresh and fermented vegetables, dried fruit, beverages, confections, and smoked meat and fish. They are widely used in Japan as preservatives in processed products made with fish paste. Sorbates have the ability to inhibit the growth of yeast at the surface of food during fermentation, but do not inhibit the organisms that are used in the fermentation process. Sorbates are typically added directly by dipping the food into a sorbate solution, or by spraying them on the surface of the food. Usage ranges from 0.025 to 0.2% (38).

Propionic acid [79-09-4], $C_3H_6O_2$, and its calcium [4075-81-4], $C_6H_{10}CaO_4$, and sodium [7757-81-5] $C_6H_7O_2$.Na, salts are effective mold inhibitors (52). They are particularly useful in yeast-leavened baked products because they do not affect the activity of yeast. In addition to being widely used in baked goods, they are used as mold inhibitors in cheese foods and spreads (39).

Parabens. The *p*-hydroxybenzoic acid methyl ester [99-76-3] $C_8H_8O_3$ and *p*-hydroxypropyl benzoate [91-13-3], $C_{10}H_{12}O_3$, are used as preservatives in the United States. Unlike other antimicrobials, the parabens are active up to a pH 8. They are used as mold and yeast inhibitors in baked goods, beverages, fruits, jams, syrups, olives, and pickles.

Organic acids. One method of controlling the growth of microorganisms in food is to increase the acidity of the product. This can be accomplished by adding an organic acid such as acetic acid [64-19-7], $C_2H_4\ O_2$, citric acid [77-92-9],

$C_6H_8O_7$, malic acid [6915-15-7], $C_4H_6O_5$, lactic acid [598-82-3], $C_3H_6O_3$, adipic acid [124-04-9], $C_6H_{10}O_4$, tartaric acid [87-69-4], C_4H_6 O_6, or caprylic acid [124-07-2], $C_8H_{16}O_2$. Because acids can affect the functionality of other ingredients in food, care must be taken in selecting the appropriate one. These acids also function as acidulants (40).

Sulfur dioxide [7446-09-5], SO_2 and sulfite salts (eg, potassium sulfite [10117-38-1], $O_3S.2K$, potassium metabisulfite [16731-55-8], O_5S_2K, sodium bisulfite [7631-90-5], $HO_3S.Na$, sodium metabisulfite [7681-57-4], $O_5S_2.2Na$, and sodium sulfite [7757-83-7], $O_3S.2Na$ are the most effective inhibitors of deterioration of dried fruits and fruit juices. Sulfur compounds also used in the fermentation industry to prevent spoilage by microorganisms and as a selective inhibitor of undesirable organisms (41).

Nitrates and nitrites are used in the meat-curing processes to prevent the growth of bacteria that cause botulism. Nitrates have been shown to form low, but possibly toxic, levels of nitrosamines in certain cured meats. For this reason, the safety of these products has been questioned, and use is limited (42).

Salt, sugar, alcohol, spices, essential oils, and herbs also inhibit growth of microorganisms, but usually their primary function is different when added to food.

Natural alternatives. Concern over the safety of synthetic preservatives has led to the research and development of natural alternatives (42). Natamycin [7681-93-8], $C_{33}H_{47}NO_{13}$, an antibiotic produced by *Streptomyces natalensis*, has gained approval in the United States for use against molds on cured cheeses. Natamycin selectively inhibits molds while allowing the growth of bacteria needed for the ripening process (43). Nisin [1414-45-5], $C_{143}H_{230}N_{42}O_{37}S_7$, a polypeptide produced by the fermentation of a modified milk medium *by Lactococcus lactis*, is particularly effective against spore-forming gram-positive bacteria. It is used worldwide as a preservative in processed cheese, dairy products, canned foods, cured meat, and beer (44).

6.2. Antioxidants. Antioxidants are food additives that retard atmospheric oxidation and its degrading effects, thus extending the shelf life of food. Examples of food oxidative degradation include products that contain fats and oils in which oxidation would produce objectionable rancid odors and flavors, some of which might even be harmful. Antioxidants are also used to scavenge oxygen and prevent the discoloration of cut or bruised fruits and vegetables. Oxidative browning, which is caused by the action of oxidase enzymes with catechol tannins, is a very important problem in handling most fruits, especially peaches, nectarines, apples, and cherries. Discoloration is encountered in all methods of processing, but mainly with methods that do not involve cooking, such as freezing, drying, and making juices. Changes in flavor accompany changes in color. Browning may take place before peeling, due to bruising, but is accelerated once the skin is broken or tissue cells are ruptured. One of the important methods of controlling browning of fruits is by using water-soluble antioxidants. They are also added to the packaging materials of some cereals (see FOOD PACKAGING). Even though cereal is low in fat, the fat it contains is highly unsaturated, and vulnerable to oxidation. Because it is difficult to get an antioxidant in contact with the fat phase of the cereal, the antioxidant is often added to the cereal box liner, where it slowly diffuses into the product (45).

Table 7. **Food Antioxidants and Their Manufacturing Processes**

Antioxidant compound	Manufactured by
Oil-soluble antioxidants	
butylated hydroxyanisole (BHA)[a]	synthesis
butylated hydroxytoluene (BHT)[a]	synthesis
tert-butyl-hydroxquinone(TBHQ)[a]	synthesis
propyl gallate (PG)[a]	synthesis
tocopherols[a]	extraction / synthesis
thiodipropionic acid	synthesis
dilauryl thiodipropionate	synthesis
ascorbyl palmitate	synthesis
ethoxyquin	synthesis
Water-soluble antioxidants	
ascorbic acid[a]	fermentation
sodium ascorbate[a]	fermenttion
erythorbic acid[a]	fermentation
sodium erythorbate[a]	ferementation
glucose oxidase/catalase enzymes	fermentation
gum guaiac	extraction
sulfites[a]	synthesis
rosemary extract	extraction

[a]Major products.

Food antioxidants are effective in very low concentrations (0.01% or less of the fat content of foods) and not only retard rancidity, but also protect the nutritional value of the food by minimizing the breakdown of vitamins and essential fatty acids. Both synthetic and natural antioxidants exist and listed in Table 7.

Synthetic antioxidants commonly used in food include butylated hydroxyanisole (BHA) [25013-16-5], $C_{11}H_{16}O_2$, butylated hydroxytoluene (BHT) [128-37-0], C_{15} $H_{24}O$, propyl gallate (PG), [121-79-9], $C_{10}H_{12}O_5$, and *tert*-butylhydroquinone] (TBHQ) [1948-33-0], $C_{14}H_{22}O_2$. In Europe, other gallate esters, such as octyl gallate [1034-01-1], $C_{15}H_{22}O_5$, and dodecyl gallate [1166-52-5], $C_{19}H_{30}O_5$, are also used. Both BHA and BHT are fat-soluble, are effective in protecting animal fat from oxidation, and are often added during the rendering process. Propyl gallate is also effective, but it has limited fat solubility, and turns bluish black in the presence of iron. It is typically used as a synergist in combination with BHA or BHT. The TBHQ is most effective against oxidation in polyunsaturated vegetable oils is (qv), and is often used in soybean oil. FDA regulations permit the use of BHA, BHT, PG, and TBHQ singly or in combinations of two or more in food products at a maximum concentration of 0.02% based on the weight of the fat or oil in the food product (46).

The most frequently used *natural antioxidants* are ascorbic acid (vitamin C) [50-81-7], $C_6H_8O_6$ its stereoisomer erythorbic acid $C_6H_8O_6$ and their sodium salts (sodium ascorbate $C_6H_7NaO_6$, sodium erythorbate [$C_6H_7NaO_6 \cdot H_2O$]), plus the mixed delta and gamma tocopherols. Tocopherols are not as effective in vegetable fats and oils as they are in animal fats. Erythorbic acid (iso-ascorbic acid) is virtually devoid of vitamin C activity (only 5% that of ascorbic acid). Citric acid [77-92-9] $C_6H_8O_7$, and tartaric acid [87-69-4], $C_4H_6O_6$, are also natural antioxidants (and antioxidant synergists) but are predominantly added to foods as acidulants.

In addition, several plant extract are recommended as natural antioxidands, including rosemary extracts (*Rosmarinus officinalis*), and gum guaiac, a resinous secretion of a tropical evergreen, *Guaiacum officinalis*. This resin contains complex phenolic compounds chemically related to guaiacol, guiaretic acid, and guaiaconic acid. Like other phenolic compounds, gum guaiac [9000-29-7] is more effective in animal fats than vegetable oils. Gum guaiac is an approved antioxidant for natural flavoring substances and other natural substances used in conjunction with fruit flavors. It is also approved for addition to food packaging materials. However, herb extracts have several drawbacks, which limit their use. They often impart undesirable colors or flavors in the products where used. In addition, natural antioxidants cost considerably more than synthetic ones. Despite this, the public's uncertainty of the safety of synthetic antioxidants continues to fuel the demand for natural ones (47,48).

Chelating agents (qv), react synergistically with many antioxidants. It is believed that these compounds improve the functional abilities of antioxidants by complexing the metal ions that often initiate free-radical formation. Citric acid and ethylene diamine tetraacetic acid [60-00-4] (EDTA), $C_{10}H_{16}N_2O_8$, are the most common chelating agents used (49).

Another group of compounds called oxygen scavengers retard oxidation by reducing the available molecular oxygen. Products in this group are water-soluble and include erythorbic acid [89-65-6], C_6H_8 O_6, and its salt sodium erythorbate [6381-77-7], $C_6H_8O_6Na$, ascorbyl palmitate [137-66-6], $C_{22}H_{38}O_7$, ascorbic acid [50-81-7], $C_6H_8O_6$, glucose oxidase [9001-37-0], and sulfites.

Recently, definitive studies have shown and widely publicized in the news media that antioxidant nutrients such as ascorbic acid (vitamin C) and tocopherols (vitamin E) can protect against harmful cell damage and thus prevent certain human diseases. Foods formulated with antioxidants and other vitamins are now recommended to prevent and cure cancer, cardiovascular diseases, and cataracts. The same antioxidants that are used to prevent oxidative deterioration of food may be used in functional foods (also called *nutraceuticals*, designer foods, etc) to create products that prevent or cure certain chronic diseases.

6.3. pH Adjusting Agents. A large group of chemical additives that are widely used in foods might be considered under the broad heading of pH adjusting agents. Other terms that describe these chemicals include acids (see ACIDULANTS), alkalis, buffers, and neutralizers. These chemicals are used in most segments of the food processing industries, including (50):

- The baking industry as chemical leavening agents.
- In soft drinks to provide tartness.
- In certain dairy products to adjust the acidity.
- In cheese spreads for emulsification.
- In confectionery products as flavoring, to control the degree of inversion of sugars, and to control the texture in the processing of chocolates.
- In jams, jellies to provide proper gel formation.

Citric acid [77-92-9], $C_6H_8O_7$, is the most versatile and widely used of the food acids, and very large volumes of phosphoric acid [7664-38-2], H_3O_4P, is required for cola beverages. Other acids frequently used in processed foods include acetic, adipic [124-04-9], $C_6H_{10}O_4$, fumaric [110-17-8], $C_4H_4O_4$, hydrochloric [7647-01-0], HCl, lactic [50-21-5], $C_3H_6O_3$, malic [6915-15-7], $C_4H_6O_5$ and tartaric acids [87-69-4], $C_4H_6O_6$ and glucono-delta-lactone [90-80-2], $C_6H_{10}O_6$ (51).

Important alkalies used in the food field include: ammonium bicarbonate [1066-33-7], $HCO_3 \cdot H_4N$, ammonium hydroxide [1336-21-6], $H_4N \cdot HO$, calcium carbonate [1317-65-3], $CA_3 \cdot Ca$, calcium oxide [1305-78-8], CaO, potassium bicarbonate [298-14-6], $KHCO_3$, potassium hydroxide [1310-58-3], HKO, sodium bicarbonate [144-55-8], $NAHCO_3$, sodium carbonate [497-19-8], $CO_3 \cdot 2Na$, sodium hydroxide [1310-73-2], NaOH, and sodium sesquicarbonate [533-96-0], $Na_2CO_{3\text{-}}$ $NaHCO_3 \cdot 2H_2O$.

Quite often, the pH may be difficult to adjust or to maintain after adjustment. Stability of pH can be accomplished by the addition of buffering agents. Within limits buffers can effectively maintain the desired pH even when additional acid or alkali may be added. Examples of representative buffer solutions used in food systems are as follows:

- Phosphoric acid : dibasic potassium phosphate.
- Formic acid : sodium formate.
- Acetic acid : sodium acetate.
- Sodium bicarbonate : sodium carbonate.
- Dibasic sodium phosphate : sodium hydroxide.

6.4. Fumigants for Insect and Pest Control. These compounds are volatile substances used for controlling insects or pests. Ethylene oxide [75-21-8], C_2H_4O, is used for the control of microorganisms and insects in ground spices and other natural seasonings. Propylene oxide [75-56-9], C_3H_6O, is used as a fumigant on cocoa, gums, processed spices, starch, and processed nutmeats (except peanuts). Methyl bromide [74-83-9], CH_3Br, provides the same function in wheat and other cereal grains (qv).

6.5. Gases. Gases provide three basic functions as food ingredients: preservation, carbonation, and aeration. Nitrogen [7727-37-9], N_2, or carbon dioxide [124-38-9], CO_2 gas is frequently used to fill the headspace of packaged foods, or is used to blanket foods, to prevent oxidative deterioration. Carbon dioxide is regularly added to provide carbonation to soft drinks or to supplement existing carbonation (in beer, for example). Nitrogen oxide [10024-97-2], N_2O, nitrogen, and carbon dioxide are used to help dispense fluid food products from pressurized aerosol containers (see AEROSOLS) (52). Ozone [10028-15-6], O_3 was recently approved as GRAS as an antimicrobial agent to reduce /eliminate pathogens in fresh produce, meat, poultry and fish (53,54).

6.6. Sequestering Agents. These agents also called chelates, combine with polyvalent meta1 ions to form a soluble metal complex to improve the quality and stability of products as free metallic ions promote oxidation of food. They are used in various aspects of food production and processing chiefly to obviate undesirable properties of metal ions without the necessity of precipitating or removing these ions from solutions (55).

Ethylenediaminetetraacetic acid (EDTA) [64-02-8], $C_{10}H_{12}N_2O_8 \cdot 4Na$, is the most commonly used sequestering, or metal-complexing, agent used in the food industry. This compound, as well as the disodium salt [139-33-3], $C_{10}H_{14}$-$N_2O_8 \cdot 2NA$, or calcium disodium salt of tetraacetic acid retards discoloration of dried bananas, beans, chick peas, canned clams, pecan pie filling, frozen potatoes, and canned shrimp. Also, these compounds improve flavor retention in canned carbonated beverages, salad dressings, mayonnaise, margarine, and sauces, retard struvite formation in canned crabmeat and shrimp; and protect against rancidity in dressings, mayonnaise, sauces, and sandwich spreads. EDTA is used at concentrations of 33 to 800 ppm.

Other chemicals that may be included in this category are calcium acetate [62-54-4], $C_4H_6O_4 \cdot Ca$, calcium gluconate [299-28-5], $C_{12}H_{22}O_{14} \cdot Ca$, calcium sulfate [7778-18-9], $CaSO_4$, citric acid [77-92-9], $C_6H_8O_7$, stearyl citrate, tartaric acid, [87-69-4], $C_4H_6O_6$, sodium tartarate [868-18-8] $C_4H_4O_6 \cdot 2Na$, calcium monoisopropyl citrate, sodium hexa-meta-phosphate [10124-56-8], $O_{18}P_6 \cdot 6Na$, phosphoric acid [7664-38-2], H_3O_4P, potassium citrate [866-84-2] $C_6H_5O_7 \cdot 3K$, and various calcium, potassium, and sodium phosphates.

7. Processing Aides

7.1. Anticaking Agents. Dry food products that contain hygroscopic substances require the addition of an anticaking agent. These additives must be insoluble in water, have the capacity of absorbing excess moisture, or by coating particles making them water repellent (56). Calcium silicate [1344-95-2], $CaSiO_3$, used to prevent caking in baking powder, table salt, and other food products, absorbs oil in addition to water, and can be used in powdered mixes and spices that contain free oils. Calcium and magnesium salts of long-chain fatty acids, such as calcium stearate [1592-23-0], $C_{36}H_{70}CaO_4$, are used as anticaking agents in dehydrated fruit and vegetable products, salt, and onion and garlic powder. Other anticaking agents employed in the food industry include sodium silicoaluminate [1344-00-9], Na_2SiAlO_3, tricalcium phosphate [7758-87-4], $Ca_3(PO_4)_2$, magnesium silicate [1343-88-0], $MgSiO_3$, and magnesium carbonate [546-93-0], $MgCO_3$. Shredded or grated cheeses have a tendency to clump together, and microcrystalline cellulose is often used to prevent this. Colloidal silicon dioxide is also used at a level of 1% as an anticaking agent in salt (NaCl). The decahydrate of sodium ferrocyanide [13601-19-9] $Na_4\ Fe(CN)_6 \cdot 10H_2O$, or Yellow Prussiate of soda at the extremely low level of 5 ppm is also used in the trade in dentritic salt, that is less likely to cake.

7.2. Antifoaming (Defoaming) Agents. These agents are substances used to reduce foaming caused by proteins or gases that may be interfere with processing (57). Foaming may be largely suppressed or completely eliminated by the use of small quantities, generally $\sim$10 ppm, of dimethylpolysiloxane, [9016-00-6] [63148-62-9], mono- and diglycerides, oleic acid [112-80-1] $C_{18}H_{34}O_2$, silicon dioxide, white mineral oil [8012-95-1], and a number of other fatty acids. These compounds have been suggested for use in the preparation of certain comminuted meat products, bakery products, confections, dairy products, vegetable oils, alcoholic and nonalcoholic beverages, jams and jellies, molasses, soups, starches, syrups and pickles.

7.3. Enzymes. Enzymes are biological catalysts that make possible or greatly speed up chemical reaction by combining with the reacting chemicals and bringing them into the proper configuration for the reaction to take place. They are not affected by the reaction. All enzymes are proteins and become inactive at temperatures above $\sim$40°C or in unfavorable conditions of acidity or alkalinity. Some of the specific functions food enzymes perform are to (58):

- Speed up reactions.
- Reduce viscosity.
- Improve extractions.
- Carry out bioconversions.
- Enhance separations.
- Develop functionality.
- Create/intensify flavor.
- Synthesize chemicals.

Food enzymes usually classified into the following categories:

- Carbohydrases (amylases are commercially the most important subgroup hydrolyzing 1,4 glycosidic bonds in carbohydrates).
- Proteases, hydrolyze peptide bonds in proteins.
- Lipases, split hydrocarbons from lipid.
- Pectic enzymes and cellulases, hydrolyzing the plant cell wall material.
- Specialty enzymes

These enzyme categories can be divided further into $\sim$15–20 subgroups. Traditional roles of enzymes in the food industry have been in the processing of bakery goods, alcoholic beverages and starch conversion. But interest is now focused on newer and more varied applications such as hydrolysis of lactose, the preparation of modified fats and oils, the processing of fruit juices and other processes where newer enzymes are being identified.

Important food applications of enzymes are listed in Table 8. The commercially important food enzymes are alpha amylase [9000-85-5], glucoamylase [9032-08-0], and glucose isomerase [9055-00-9], which are especially significant in the United States because of their widespread use in the conversion of cornstarch into high fructose corn syrup (HFCS). Rennin, which is used in cheese making, is also of significant volume, followed by a host of other enzymes including: pectin methylesterase [9025-98-3], polygalacturonase [9032-75-1], invertase [9001-57-4], lactase [9031-11-2], and maltase [9001-42-7] (used for the modification of starches and sugars), catalase [9001-05-2], pepsin, glucoseoxidase [9001-37-0] (an antioxidant for canned foods), and bromelin, ficin [9001-33-6], and papain [9001-73-4] (plant proteases used for tenderizing meat and producing

Table 8. **Enzyme Applications in Food Industry**

dairy products	milk coagulation (rennet), milk protein modification, cheese flavor development, enzyme modified cheeses and removal of hydrogen peroxide
baking and cereals	antistaling, dough improvement, improved crust color and gluten hydrolysis
sugar processing	removal of starches and processing from cane sugar
starch conversion	starch modification, liquefaction, isomerization, saccharification, modification and increasing yield
oils and fats	improving yields, inter-esterification, oil extraction and lecithin production
flavors	synthesis of flavors, production of natural esters
alcohol fermentation	starch liquefaction, improving yeast growth
brewing	adjunct liquefaction, enhanced fermentability, filtration improvement, production of light beer and removal of protein haze
fruit juices, and wines	increasing press yields, juice clarification, shelf life extension
coffee processing	separation of bean, viscosity control of concentrate
chemical processes	biotransformation, synthesis (eg, emulsifiers)
analytical	tests for dietary fiber, sugars
waste treatment	breakdown of cellulose, lignin, oil residues and other solid waste material

easily digestible foods). Enzymes are extremely specific and can act only on a single class of chemicals such as proteins, carbohydrates, or fats.

Enzymes are produced from animal tissues (eg, pancreatin, tripsin [9002-07-7], lipase), plant tissues (eg, ficin, bromelin) and most frequently by microorganisms (eg, pectic, or starch enzymes). Microbial production from a variety of species of molds, yeast, and bacteria is increasingly becoming the predominant source of enzymes.

Application of genetic engineering to the development of enzymes has already made a significant impact. The first food ingredient produced by genetic engineering was chymosin "Chy-Max" (59) a microbial rennet developed by Pfizer (now marketed by Chr. Hansen), which has been approved by the regulatory agencies in the United States, Canada, the United Kingdom, Australia, Italy, and several other countries.

7.4. Humectants. In certain foods, it is necessary to control the amount of water that enters or exits the product. It is for this purpose that humectants are employed. Polyhydric alcohols (polyols), which include propylene glycol [57-55-6], $C_3H_8O_2$, glycerol [56-81-5], C_3H_8 O_3, sorbitol [50-70-4], $C_6H_{14}O_6$, and mannitol [69-65-8], $C_6H_{14}O_6$, contain numerous hydroxyl groups (see ALCOHOLS, POLYHYDRIC). Their structure makes them hydrophilic and enables them to bind water in foods. Examples of products that use humectants include shredded coconut, cookies, glazed and dried fruit, gelatin products, and cakes. High dosages of polyhydric alcohols may cause a laxative effect and usage is somewhat limited as a result (60).

7.5. Leavening Agents. Many bakery products, such as self-rising flours, prepared baking mixes, and refrigerated doughs, rely on chemical leavening agents to produce the gas that gives them volume (see BAKERY PROCESSES AND LEAVENING AGENTS). Bicarbonates produce carbon dioxide in the presence of heat and moisture. Sodium bicarbonate [144-55-8], $NaHCO_3$, is the most commonly used product, but ammonium bicarbonate [1066-33-7], NH_4HCO_3, and potassium bicarbonate [298-14-6], $KHCO_3$, are used as well (61). When used alone, sodium bicarbonate reacts to give products a bitter, soapy flavor. Thus it is always combined with a leavening acid.

Leavening acids are classified according to the rate at which they release carbon dioxide from sodium bicarbonate. Some acids begin producing carbon dioxide as soon as they come into contact with water; others do not begin to react unless heat is present as well. The type of leavening acid needed depends on the product. For example, refrigerated dough products require limited carbon dioxide release initially so that they can be packed into containers, but need significant activity upon heating. A slow-acting leavening agent would be used for this product. Doughnuts, which must be leavened prior to being exposed to heat, require fast-acting leavening acids. Most products use both slow- and fast-acting leavening acids to obtain the appropriate volume (61). The leavening acids most frequently used include potassium acid tartrate [868-14-4], $K_2C_4H_4O_6$, sodium aluminum sulfate [10102-71-3], $AlNa_9(SO_4)_2$, glucono-delta-lactone [90-80-2], $C_6H_{10}O_6$, and ortho- and pyrophosphates. The phosphates include calcium phosphate [7758-23-8], $CaHPO_4$, sodium aluminum phosphate [7785-88-8], and sodium acid pyrophosphate [7758-16-9] $Na_2H_2P_2O_7$ (62).

7.6. Lubricants and Release Agents. These agents are substances added to food processing equipment to prevent food ingredients and finished products from sticking to them. These compounds are used to prevent confectionery and to a lesser extent baked goods from sticking to equipment or to the container in which they are heated. They are also used to prevent pieces or confection from adhering to each other. Ingredients that fall into this category include calcium stearate [1592-23-0], magnesium carbonate [546-93-0] $MgCO_3$, magnesium silicate [1343-88-0], $MgSiO_3$, magnesium stearate [557-04-0], $Mg(C_{18}H_{35}O_2)_2$, mannitol [69-65-8], $C_6H_{14}O_6$, mineral oil [8012-95-1], mono- and diglycerides, sorbitol [50-70-4], $C_6H_{14}O_6$, stearic acid [57-11-4] $C_{18}H_{36}O_2$, lecithin [8002-43-5], $C_8H_{17}O_5NRR'$and starch.

7.7. Manufacturing Aids. These aids including catalysts, filter aids, clarifying and clouding agents are used to improve the appearance or performance of food products. Functions of these additives include (63):

- *Catalysts*, facilitate a chemical reaction, are used for the hydrogenation of oil, transesterification of fats, modification of starches, and many enzyme reactions. Raney nickel [7440-02-0], Ni, sodium methoxide [124-41-4], CH_3ONa, and a variety of acids are typical catalysts.
- *Filter aids* break down or entrap undesired substances in fruit juices, wines, milk, oils, beer, and vinegar, thus making it easier to remove these substances by filtration.
- *Clarifying agents* (flocculants) eliminate turbidity and particle suspension in products such as beer, wine, fruit juices, oils, and vinegar. Gelatin and lime are frequently used for this purpose.

- *Clouding agents* add a turbid appearance to products such as syrups, soft drinks, and powdered beverage mixes. Brominated vegetable oils [8016-94-2], gums, and citrus pulp are commonly used clouding agents.

7.8. Solvents. Solvents are generally used to either extract particular compounds, such as an essential oil from a plant, or to carry additives into a food system, such as a flavor into a powdered mix. Common solvents include ethanol [64-17-5], C_2H_6O, glycerin [56-81-5], $C_3H_8O_3$, propylene glycol [57-55-6], $C_3H_8O_2$, triethyl citrate [77-93-0], $C_{12}H_{20}O_7$, polyhydric alcohols, carbon dioxide [124-38-9], acetylated monoglycerides, hexane [110-54-3], C_6H_{14}, methylene chloride [75-09-2], CH_2Cl_2, acetone [67-64-1], C_3H_6 O, and trichloroethylene [79-01-6], C_2HCl_3.

7.9. Water-Correcting Agents. Water used in the beverage industries is often corrected to a uniform mineral salt content that corresponds to water known to give the most satisfactory final product. Some of the chemicals in addition to standardizing the salt contents also control the acidity, thus providing uniform conditions for yeast fermentation in the breweries. A wide variety of salts are used for this purpose, including:

- Monoammonium phosphate [7772-76-1], $NH_4H_2PO_4$, diammonium phosphate [7783-28-0], $H_6N_2 \cdot H_3O_4P$, calcium dihydrogen phosphate [7758-23-8], $Ca(H_2PO_4)_2$, monosodium phosphate [7558-80-7], NaH_2PO_4, disodium phosphate [7558-79-4], Na_2HPO_4, and trisodium phosphate [7601-54-9], $Na_3PO_4 \cdot 12HOH$.
- Calcium chloride [10043-52-4], $CaCl_2$, calcium hydroxide [1305-62-0], CaH_2O_2, and calcium oxide [1305-78-8], CaO.
- Calcium sulfate [7778-18-9] $CaSO_4$, magnesium sulfate [7487-88-9], $MgSO_4$, potassium sulfate [7778-80-5], K_2SO_4, potassium aluminum sulfate [7784-24-9] $AlK(SO_4)_2 \cdot 12H_2O$, and sodium bisulfate [7681-38-1], $NaHSO_4 \cdot HOH$.
- Potassium chloride [7447-40-7], ClK.

8. Nutrients

8.1. Dietary Fibers. Dietary fibers (qv) is a broad term that encompasses the indigestible carbohydrate and carbohydrate-like components of foods that are found predominantly in plant cell walls (see CARBOHYDRATES) (64). It includes cellulose [9004-34-6] (qv), lignin [9005-53-2] (qv), hemicelluloses [9034-32-6] (qv), pentosans, gums (qv), and pectins [9000-69-5]. Those fibers that have colligative properties, such as gums, are referred to as soluble fibers. They are often used to provide viscosity and texture in processed foods, and have been linked to lowered serum cholesterol [57-88-5] levels. Insoluble fibers, such as cereal brans and specialty flour ingredients, tend to cause a laxative effect when consumed in large quantities. Dietary fiber has become an important food additive owing to the link between high fiber intake and the lowering of serum cholesterol, the prevention of cancer, and the avoidance of digestive tract disease.

Dietary fibers are used in several food categories, including breakfast cereals, pasta, snack foods, and baked goods, as well as some pharmaceutical categories such as enteral nutritionals, bulk laxatives, and diet beverage mixes (65).

8.2. Vitamins. Vitamins are nutritive substances required for normal growth and maintenance of life. They play an essential role in regulating metabolism, converting fat and carbohydrates into energy, and forming tissues and bones. Vitamins are typically divided into two groups: fat soluble and water-soluble vitamins (Table 9). The fat-soluble group usually measured in International Units (IU). The water-soluble group usually measured in units of weight.

Thirteen vitamins are recognized as essential for human health, and deficiency diseases occur if any one is lacking (66). Because the human body cannot synthesize most vitamins, they must be added to the diet. Most vitamins are currently consumed as pharmaceutical preparations, or over-the-counter vitamin supplements. Some, like vitamins B, C, D, and E, however, are added directly to food products (Table 10). Ready-to-eat breakfast cereals are a successful example of fortification. Because the primary use of these cereals is as a complete breakfast entree, they are commonly formulated to provide 25–100% of the daily value (% DV) per serving of 10–12 important vitamins and minerals common to cereals.

Table 9. **Vitamins Consumed as Food Additives and Recommended Daily Intake Values**

Vitamin	Principal synonym	Market form	Daily value
Vitamin A			5000 IU
A_1	retinol	vitamin A acetate	
A_2	dehydroretinol	vitamin A palmitate	
Vitamin B			
niacin	vitamin B_3	nicotinic acid	20 mg
thiamin	vitamin B_1	thiamin hydrochloride	1.5 mg
riboflavin	vitamin B_2	riboflavin	1.7 mg
pantothenic acid	vitamin B_5	calcium pantothenate	10 mg
pyridoxine	vitamin B_6	pyridoxine hydrochloride	2 mg
cyanocobalamin	vitamin B_{12}		6 mcg
folic acid,	vitamin B_c	folate	400 mcg
biotin	vitamin$_H$		300 mcg
Vitamin C	ascorbic acid	ascorbic acid sodium ascorbate	60 mg
Vitamin D		calcium ascorbate	400 IU
D_2	ergocalciferol		
D_3	cholecalciferol		
Vitamin E	tocopherols	DL-alpha tocopherol acetate D-alpha tocopherol D-alpha tocopheryl acid succinate	30 IU
Vitamin K			
K_1	phytonadione	phylloquinone	80 mcg
K_3	menadione		

Table 10. **Fortified Food Groups**

Food	Vitamin	Use Level	Remarks
milk	vitamin D	420 IU/L	optional but generally added
beverages (noncarbonated)	vitamin C	15–100% of US RDI per serving	optional; also added as an antioxidant
cereals	most essential vitamins	25–100% of US RDI per serving	optional; added to 90% of cold cereals
flour	thiamin, riboflavin, niacin	8–15% of US RDI per 2 oz. serving	mandatory
margarine	vitamin A	33,100 IU/kg	optional, but generally added
miscellaneous foods (eg, instant breakfast, energy bars)	most essential vitamins		added to position food as complete meal replacement

Vitamins are added to processed foods for several related reasons:

- To restore vital nutrients lost during processing—this is important with dried milk, dehydrated vegetables, canned foods, and refined and processed foods.
- To standardize nutrient levels in foods when they fluctuate because of seasonal variations, soil differences, and methods of preparation.
- To fortify fabricated foods that are low in nutrients and promoted as substitutes for traditional products. This includes complete breakfasts, breakfast drinks, meat extenders, and imitation products such as eggs, milk, cheese, and ice cream.
- To fortify a major staple, such as bread, with a nutrient known to be in short supply.
- For the preparation of designer food (*nutraceuticals*) containing vitamins that are shown to be useful in preventing chronic diseases.

In addition, vitamins may be used as functional ingredients in foods. Vitamin E (tocopherol) and vitamin C (ascorbic acid) protect foods by serving as antioxidants to inhibit the destructive effects of oxygen. This helps protect the nutritive value, flavor, and color of food products. In addition, ascorbic acid enhances the baking quality of breads, increases the clarity of wine and beer, and aids color development and inhibition of nitrosamine formation in cured meat products. Beta-carotene and beta-apo-8′-carotenal are vitamin A precursors, which are brightly pigmented and may be added to foods such as margarine and cheese as coloring to enhance their appearance. The roles of these substances outside their nutritional functions are discussed elsewhere (see ANTIOXIDANTS, PRESERVATIVES, AND COLOR).

In the United States, foods are restored, enriched, or fortified with nutrients. Restoration refers to addition of nutrients to foods to replace those nutrients that are lost in processing. Enrichment is similar to restoration, but federal guidelines specify the exact amount and kinds of nutrients added to specific products. Fortification refers to the addition of nutrients that do not naturally occur in the food. This last is typically done to prevent diseases of nutritional deficiency. The enrichment program followed in the United States is

1. Enrichment of flour, bread, and degerminated and white rice using thiamin [59-43-8], $C_{12}H_{17}N_5O_4S$, riboflavin [83-88-5], $C_{17}H_{20}N_4NaO_9P$, niacin [59-67-6], $C_6H_5\ NO_2$, and iron [7439-89-6].
2. Retention or restoration of thiamin, riboflavin, niacin, and iron in processed food cereals.
3. Addition of vitamin D [67-97-0] to milk, fluid skimmed milk, and nonfat dry milk.
4. Addition of vitamin A [68-26-8], $C_{20}H_{30}O$, to margarine, fluid skimmed milk, and nonfat dry milk.
5. Addition of iodine [7553-56-2], I, to table salt; and the addition of fluoride [7782-41-4], F, to areas in which the water supply has a low fluoride content (66).

9. Market Overview

Food additive suppliers are an important part of the food manufacturing system, supplying products to both commodity processors and food processors. Practically every food manufacturing operation depends to some degree on the use of food additives. Overall, the food additive industry is highly fragmented, consisting of >600 companies. Suppliers tend to be either highly specialized participants in the major product categories (eg, Novozimes with enzymes, Sensient Colors, Inc. with food colors), or large chemical companies that offer food grade versions of a few industrial products (eg, Eastman Chemicals Inc. emulsifiers, FMC Corp. cellulose derivatives).

Manufacturers are typically involved in supplying additives in limited number of food categories (eg, colors, vitamins, enzymes) or serving selected food industry sectors (eg, processed meats, dairy based products, bakery products). While a company or group of companies may tend to dominate sales in each of the specific categories (eg, Rhodia with vanillin, Novozimes with enzymes) no single company dominates the entire food additive industry. The large majority of participants have <\$100 million annual sales; only a handful has >\$500 million. This relatively small size contrasts sharply with the multibillion dollar food companies that represent the customer base for food additives. There are signs, however, that this might be changing. Recent merger of Danisco AS and Cultor Corporation marked the creation of what some see as functional food additive giant. The combined companies are major players in acidulants, enzymes, emulsifiers, and flavors, have a significant presence in antioxidants,

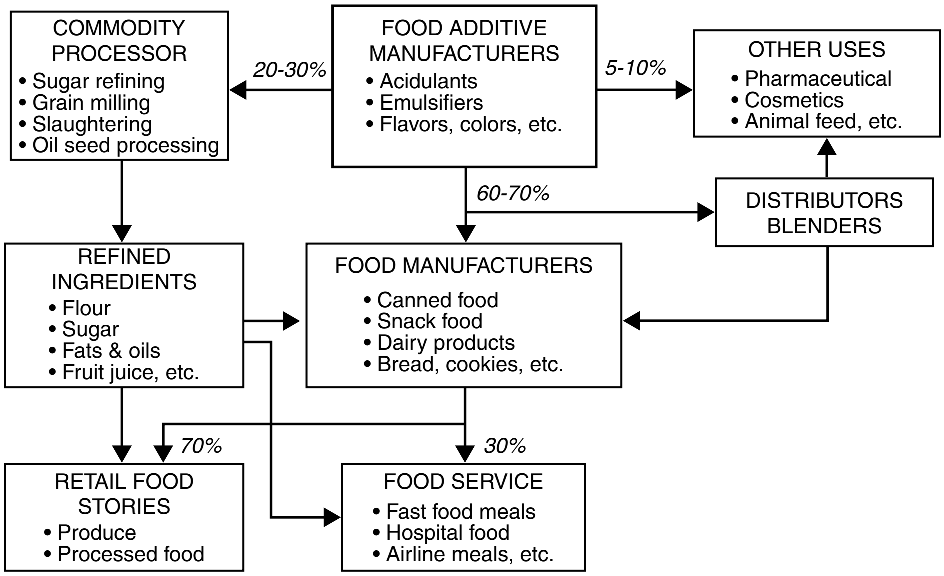

Fig. 2. Food Additives: Pattern of Use in Food and Other Applications.

alternative sweeteners and bulking agents, texturizers and fat substitutes with a wordwide sales of >$1.2 billion.

Figure 2 depicts the food industry structure and flow of products. Some 60–70% (by volume) of food additives is used in manufacturing of food, while 20–30% is used in commodity processing operations such as fruit juice processing, vegetable packing, oils seed crushing, flour milling, meat packing, and the remaining 5–10% in other uses such as pharmaceutical and personal care products.

Compounding companies and distributors also play an important role in the food additive market. Additive manufacturers typically use distributors to service their smaller accounts. Compounders specialize to formulate and produce mixed products such as dairy blends, baker's mixes, etc that are ready to use in the manufacturing plant. For an up to date list of food additive suppliers consult the *Chemical Buyers Directory*: http://www.chemexpo.com.

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LASZLO P. SOMOGYI
Food Industry Consultant