
Chemical Properties and Applications of Food Additives: Flavor, Sweeteners, Food Colors, and Texturizers

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Contents

Introduction: Foods and Their Taste Attributes	102
Flavors	103
Natural Flavors	103
Synthetic Flavors	105
Flavor Enhancers	106
Meaty Flavors	106
Acidulants	107
Citric Acid	108
Malic Acid	108
Lactic Acid	108
Tartaric Acid	109
Phosphoric Acid	109
Other Acids	109
Sweeteners	109
Polyols	110
Artificial Intense Sweeteners	111
The Natural Sweeteners	111
Food Colors	112
Texturizers: Starches and Their Modified Forms	113
Cross-Linking	115
Substitution	115
Acid Hydrolysis and Dextrinization	116
Oxidation	116
Pregelatinization	116
Emulsifiers	117
Fatty Acid Esters	117
Lecithin	119
Hydrocolloids	119

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Protein Concentrates	119
Hydrocolloids: The Dominant Texturizers	120
Gum Acacia	120
Seed Gums	121
Marine Gums	121
Pectins	122
Tuber Gum	123
Biogums	123
Cellulose Derivatives	124
Conclusion and Future Directions	125
Cross-References	126
References	127

Abstract

Foods are nutrients. Besides nutrition, there are other major parameters that affect a person's like of or preference for various foods, such as appearance, odor, and taste. The environment, including noise made when biting food and background sound such as music, also has an effect. The addition of flavorings, sweeteners, and acids, either natural or synthetic, to processed foods is meant to make up the loss of odor and taste that occurs during processing, or to enhance the quality of the food. Similarly, natural or synthetic colorants are used to improve the appearance of food. Starches, emulsifiers, and hydrocolloids are food texturizers with different chemical properties that affect taste via their respective characteristics. Recently, there have been many studies on the production of foodstuffs with specific and unique characteristics in which additives were used.

Introduction: Foods and Their Taste Attributes

Foods are nutrients for people. Before being eaten, foods are first seen and smelled, so they must be attractive to people in appearance and odor. It is essential that foods have good coloring and a pleasant smell to attract potential customers. Zellner et al. (2014) studied how food presentation affected whether a person liked the taste of the food. Subjects liked a food more when it was presented in a more attractive manner. Color and taste, natural characteristics of foodstuffs, reflect the quality of the food. The sensation of the taste of food in the mouth is a complex composite of odor, taste, and texture that is affected by the appearance of the food and the sound made when biting the food and by the movement of muscles in the mouth, especially the tongue. A preference for certain flavors is a complicated combination of genetics and eating behavior traits. Adventurous people are less afraid of new foods, a trait linked to the *TAS1R1* and *PKDK3* genes (Törnwall et al. 2014). The taste buds are minute depressions located mostly on the tongue. They comprise many very small sensory receptors that detect the five basic electrical messages and send them to the brain: sweet, sour, salty, bitter, and umami. In addition, there are many volatile molecules in the flavoring materials that stimulate the nose's sensory cells. Environmental factors also affect the reception and sensation of food. A study

of the type of background music played while dining showed that food is accepted differently depending on not only the type of food served but also the kind of music played and the performer (Fiegel et al. 2014). However, this topic is beyond the scope of this chapter.

Aroma-active compounds, together with sugars, fat, and nucleotides, are the main chemical species that determine the characteristic aroma and taste of food (Lin et al. 2014). The food processing industry usually adds colors and flavors to improve the quality of the food. Adding flavors to certain types of foods is necessary to restore some of the original flavors that are partly or totally lost during the manufacturing process. Also, flavors are added to enhance the food when cooked in a microwave. Extra flavoring is necessary for many so-called health foods, along with replacing some portion of sugar or fat, so they are acceptable to consumers. Acidulants and sugar are taste integers. Currently, multiple sweeteners are used extensively in foods to replace sugar for health reasons. In this chapter, flavors, acidulants, and sweeteners added for taste are discussed. In addition, since texture contributes to the feeling of food in the mouth, starches, emulsifiers, and hydrocolloids are discussed.

Flavors

Flavors, known as flavoring materials, are composed of volatile or aromatic substances of very low molecular weight, most below 300. There are about 2,500 flavoring materials used in the food industry. Because of their strength, flavors are used in extremely small quantities, mostly on a parts per million (ppm) scale or smaller. Cavemen knew that smoking meats with apple wood could impart a pleasant barbecue flavor, which was due to the presence of volatile flavoring materials in the smoke. During the Middle Ages in Europe, natural flavor spices were used to keep meats tastier while in long-term storage. Alchemists at that time started to distill spices and herbs to obtain the concentrates, the early forms of natural flavors. Flavors are classified as natural or synthetic.

Natural Flavors

Natural flavors are extracted from volatile compounds found in different parts of plants, mostly herbs. Natural flavors come in various forms: oleoresins, which are crude extractions and 5–20 times more condensed; essential oils, which are processed by distillation, cold pressing, or solvent extraction and 80–100-fold more concentrated; and fruit juice concentrates or purees, which are added to foods.

Popular oleoresins are usually from spices and herbs such as anise, basil, cardamom, cinnamon, clove, coriander, mace, cumin, nutmeg, rosemary, sage, thyme, and vanilla. Their naturally occurring wax and oils are used as essential flavoring materials in processing culinary seasonings, condiments, and sauces. Oleoresins are oil dispersible so their application is limited. An emulsifier such as

lecithin is blended with an oleoresin to convert it into a water-dispersible aquaresin, which can have many applications.

Essential oils are used across the entire food industry. In addition to the oleoresins that are processed into this form, there are also the essential oils of orange, lemon, lime, almond, garlic, ginger, onion, peppermint, spearmint, and wintergreen. Besides their use in cooking, essential oils are used in candies, chewing gums, bakery items, pickling, beverages, frozen desserts, and snacks. Essential oils are oil-soluble flavors and are easily used by adding directly to food or to the oily portion of foods at a dose of ~0.5 to 1 %. In addition to contributing flavor and taste to foods, essential oils are therapeutics because of the specific therapeutic properties of some active bioingredients in the aromatic compounds. One study showed that L-carvone from spearmint induced apoptosis of breast cancer cells (Patel and Thakkar 2014). Diallyl sulfide, a natural organosulfuric aromatic compound in garlic, inhibits tumor necrosis factor- α (TNF- α) and histamine-induced proinflammatory responses in the aortic smooth muscle cells of rats (Ho et al. 2014).

Terpenes are major constituents of almost all essential oils. Orange, lemon, and lime oils are citrus oils that have the same constituent terpenes like D-limonene. Terpenes are hydrocarbons that are not very soluble in water, easily oxidizable in air due to the presence of double bonds, and weak in flavor. Since citrus oils are important flavors that need to be stable and soluble in water, folded oils were developed by removing the unwanted L-limonene. Terpene makes up more than 98 % of orange oil. Removal of 80 % by weight of terpene results in a fivefold oil. Similarly, 10-, 25-, and 50-fold oils are formed by removing 90 %, 96 %, and 98 % of terpenes. Terpeneless oils are also available. Folded oils have stronger flavors and are more stable and water-soluble; thus, they are used in beverages where water is the solvent. All essential oils, including the folded oils, are natural flavors used in foods at the 0.1–0.5 % level, or they are used as components in synthetic flavors.

The third type of natural flavor is obtained from the concentration of the aromatic components of fruity extracts. These volatile organic and aromatic components are flavoring materials. Gas chromatography (GC) and mass spectrometry (MS) are used by flavorists to identify the aromatic components in the extracts. Their flavor and value are highly influenced by their aroma, as dictated by volatile flavoring materials. A simple and robust method of sampling these compounds on polydimethylsiloxane has been developed (Allwood et al. 2014). In addition, during the manufacture of some fruity foods, the volatile fraction is captured and added to reinforce the extracts. Some natural flavors can be blended in small percentages with extracts from other fruits to form the “natural flavor WONF,” where WONF stands for “with other natural flavors” that one sees on an ingredients label.

Flavorists must understand the type and nature of flavoring materials in natural flavors before creating synthetic flavors. Both aliphatic and aromatic flavoring materials are esters, aldehydes, alcohols, ketones, and hydrocarbons. The characteristics of the dominant flavoring materials of some individual flavors are listed in Table 1.

Because of the complicated interaction of flavoring materials with some natural foods, the analysis of their flavor spectrum is very challenging for flavorists.

Table 1 Flavors and their characteristic aromatic chemicals

Flavor	Characteristic aromatic chemical	Flavor	Characteristic aromatic chemical
Almond	Benzaldehyde	Anise	Anethole
Apple butter	Benzyl isovalerate diacetyl	Banana	Isoamyl acetate
Coconut	γ -Nonalactone	Cherry	Benzyl acetoacetate
Garlic	Allicin	Coffee	Methyl furoate
Grape	Phenylethyl anthranilate	Ginger	Zingiberone
Lemon	Citral	Honey	Benzyl cinnamate
Onion	Diallyl disulfide	Melon	Octyl butyrate
Plum	Citronellyl butyrate	Peach	γ -Undecalactone
Strawberry	3-Methyl-3-phenylglycidic acid ester	Raspberry	Geranyl formate
		Vanilla	Vanillin

For example, the analyses of the extremely delicate flavors of mango, grape, and many tropical fruits are tedious. Recently, there has been some success with the analysis of mango where its characteristic aromatic component has been identified as 4-hydroxy-2,5-dimethyl-3(2H)-furanone; 54 flavoring materials were revealed of which 16 were reported for the first time (Munafa et al. 2014). Alkyl-methoxypyrazines were shown to be important flavoring materials in the cultivars of grapes and their wines, in which a new flavoring material, 2,5-dimethyl-3-methoxypyrazine, was identified as possibly an important and common odorant in red wines (Botzatu et al. 2014).

Synthetic Flavors

In the food industry, the use of natural flavors has several disadvantages. First, their flavor profile is not consistent. It is difficult for all aromatic ingredients from raw materials to be consistent in content because of variation of the batches in harvesting and processing. Second, the strength of the flavor is usually not great enough because of the presence of many other natural components. Third, natural flavors cost more to use because of their limited quantity in nature. Synthetic flavors are an alternative to natural flavors. They are composed of volatile flavoring materials that are mixed together using the same formula as that for natural flavors. All ingredients are dissolved in a liquid carrier to form a synthetic flavor. The solvents selected for use as carriers depend on the application, i.e., ethyl alcohol is used for beverages, vegetable oil is used for any food with a lipid phase, and propylene glycol or Triacetin is used for confectioneries and baked goods. Water is used on rare occasions. Several flavoring materials may react with each other in the flavor solution to yield a stronger flavor; this is known as synergism. Flavorists create synthetic flavors that reference their natural counterparts. A good flavorist knows how to utilize synergism to obtain strong flavors with a minimal amount of

materials to keep the cost down. The dosage in foods is generally 0.1–0.2 % in baked goods or hard-boiled candies when high-temperature heating is required for processing and 0.05–0.1 % in other food products.

All flavoring materials must be generally recognized as safe (GRAS). In addition to those found in nature, there are plenty of flavoring materials that have been synthesized and have high flavoring strength. To be accepted for use as food flavoring, adequate toxicity tests must be performed on flavoring materials to verify their safety and their GRAS status must be determined. For example, vanillin is a dominant ingredient in the vanilla flavor; ethyl vanillin, a modified form of vanillin not found in nature, is more heat stable, about three times stronger, and is an important component in many flavors used by bakers.

For some convenience foods like powdered or instant formulas, synthetic flavors are preferred in powdered form. Instead of substrating the array of flavoring materials in liquid form, they are spray-dried in the presence of a solid-phase carrier such as gum acacia or glucose to form powdered flavors. One study showed that rosemary essential oil was encapsulated by spray-drying the oil with whey protein and insulin blends as the carrier (Fernandes et al. 2014). However, due to the heat involved in the spray-drying process, it is more difficult to maintain the genuine original flavor profile and the strength of the original flavor.

Flavor Enhancers

Flavor enhancers do not have their own specific flavor but enhance the effect of other flavors, producing a taste sensation known as umami. Umami can be measured by electronic tongue and near-infrared spectroscopy (Bagnasco et al. 2014). A typical flavor enhancer is monosodium glutamate (MSG). It was discovered in Japan in 1908 as an extract from seaweed that enhanced the taste of food when added during cooking. It was produced commercially the following year, and today it is made by fermentation. Other flavor enhancers are nucleotides originally extracted from bonito tuna – disodium 5'-inosinic monophosphate (IMP) and disodium 5'-guanylic monophosphate (GMP) – which have a much stronger enhancing effect than MSG. The naturally occurring mixture of 5'-IMP and 5'-GMP, known as “I + G,” has an excellent enhancing effect. Any one of these materials can be used with MSG to optimize flavor enhancement. Other popular flavor enhancers are maltol and the synthetic ethyl maltol, used in foods at 250 and 150 ppm, respectively. They are common flavoring materials used in many confectionery flavors.

Meaty Flavors

While meats are cooking, natural characteristic flavors and attractive odors are generated. In principle, meaty flavors come from two sources: the small amino acids and peptides from protein hydrolysis and the volatile molecules resulting

from the Maillard reaction. The Maillard reaction is the chemical reaction between amino acids and reducing sugars that produces sulfur- or nitrogen-containing molecules from the fragmentation of amino acids and peptides. The characteristic flavor of a particular meat is due to the type of meat and the cooking or hydrolysis process used. For example, the main active compounds that were found to contribute to the aroma of beef extract are 2,3,5-trimethylpyrazine, 1-octen-3-ol, 3-methylbutanoic acid, and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (Takakura et al. 2014). The strong smell of cooked ham is the result of 2-methyl-3-furanthiol, 2-methyl-3(methyledithio) furan, and bis(2-methyl-3-furyl) disulfide (Thomas et al. 2014). Enzymatic hydrolysis has replaced chemical reaction so that less unwanted salt and impure by-products are produced. A study found that the enzyme bromelain hydrolyzes a seaweed protein and the end-product hydrolysate was characterized as the precursor of a thermally processed seafood flavor (Laohakunjit et al. 2014). The final flavor profile is purer and much more refined. Natural meaty flavors can be produced by hydrolysis of plant proteins chemically or enzymatically. Plant or vegetable protein is broken down into tasty peptides and amino acids commonly known as hydrolyzed vegetable protein (HVP). Soy protein is usually the raw material from which HVP is made. The protein slurry is hydrolyzed at high temperature by the addition of hydrochloric acid or sodium alkaline; it is then neutralized accordingly. To obtain yeast extract, yeast undergoes autolysis, i.e., the protein inside the rigid cell wall compartment is digested or hydrolyzed by its own enzyme, to yield the much smaller volatile molecules that give yeast extract that characteristic meaty taste. Important aromatic compounds are furan derivatives, pyrazines, and sulfur-containing aldehydes, acids, and ketones, similar to typical natural meat flavors but with different component ratios. HVP and yeast extract are synergistic and used in typical meaty flavorings.

A specific flavor profile is determined by the content of the Maillard reaction materials, many constituents of which are available by chemical synthesis. To produce synthetic flavors, the product of the protein hydrolysis part of the Maillard reaction can be replaced by HVP or yeast extract. The Maillard reaction product is obtained by the finely controlled reaction between selected amino acids and reducing sugars at high temperature in a reactor. The addition of glycerol to the reacting vessel as a flavor precursor when processing a roasted meat flavor was shown to contribute to the formation of specific proline materials such as 2-propionyl-1(3),4,5,6-tetrahydropuridines, which are known for their roasted aroma (Smarrito-Menozi et al. 2013). Meaty flavorings are added at 0.5–2.0 % concentration to any type of food that needs a characteristic meaty taste, such as soups, sauces, processed meats and seafoods, imitation meat analogs, snacks, and packaged meals.

Acidulants

Acids are naturally present in almost every kind of fruit, contributing to their acidity and tartness. Acids stimulate the appetite because they affect the olfactory nerve, creating a desire for more food. Therefore, selecting the proper acid and the right

amount when formulating a food product to obtain the desired physiological and psychological reactions is a subtle skill. Citric, malic, lactic, tartaric, and phosphoric acids are those most commonly used in the food industry. Citric acid is compatible with all citrus fruit items; malic acid is usually used as a flavor enhancer; tartaric acid is added for a grape taste; and phosphoric acid is used for colas. Addition of acids to a wide variety of foods, including beverages, jams, jellies, preserves, bakery items, confectioneries, chewing gums, and dairy products, is necessary to strengthen the function of the natural acid components or to adjust the pH for taste optimization. The acidic pH can be buffered by adding a corresponding salt, usually sodium.

Citric Acid

Citric acid is present in the human body, plants, and animals and functions as an intermediary in respiration and energy metabolism. It has been used in food processing for over 100 years. It is present in about 60 % of the world market. Citric acid is tribasic and it is used mainly in citrus-type beverages, especially carbonated orange, lemon, and lime drinks, as well as in fruit juices, concentrates, syrups, and cordials. For confectioneries, chewing gums, desserts, ice creams, jams, and jellies, citric acid is an absolute must. It is also valuable in meat curing, mayonnaise, cheese, and cottage cheese. In many cases, sodium citrate is used with citric acid to buffer the pH. Citric acid is produced mainly from the fermentation of corn sugars or molasses. It is also obtained from raw glycerol by fermentation of the yeast *Yarrowia lipolytica* (Morgunov et al. 2013).

Malic Acid

Malic acid is found in many vegetables and fruits, especially apple. Its acidulating properties resemble those of citric acid, but the characteristic tartness occurs over time. Malic acid is usually paired with citric acid to reduce the sharp note of food so that the taste is more smooth and natural.

Lactic Acid

Lactic acid is widely found in nature, especially in milk and fermentation products, and has been used since the early days of human history. Since it is a viscous liquid, the acid is present in both D- and L-stereoisomers, but in general the food industry uses the DL racemic mixture. Lactic acid is mildly tart and is used in dairy products, wine, frozen desserts, and especially added to packing of Spanish olives.

Tartaric Acid

Tartaric acid occurs naturally in grapes, limes, currants, gooseberries, raspberries, and many other fruits, and contributes to the superior flavor profile of fruit drinks, jellies, preserves, sherbet, and cakes, especially when combined with citric acid. Its potassium salt, monopotassium bitartrate, commercially known as cream of tartar, is a common leavening agent in the bakery industry. Most tartaric acid is produced from the pressed cake of unfermented grape juice produced during wine manufacturing.

Phosphoric Acid

Phosphoric acid is the only inorganic acid used in the food industry, and perhaps the least costly acidulant that can achieve the required acidity in foods. Its principal use is in carbonated beverages, particularly colas, root beer, and sarsaparilla, at a usage level of a few hundred parts per million. It is also used in some dairy products such as cheese. The acid is produced by treating phosphorus-containing rock with sulfuric acid, reducing the product to elemental phosphorus, burning it to form phosphorus pentoxide which is then hydrated to yield 75–85 % phosphoric acid, and finally purifying the acid to a commercial grade of 75 %, 80 %, or 85 %.

Other Acids

Other acids include acetic acid, adipic acid, fumaric acid, tannic acid, and glucono delta-lactone (GDL). Acetic acid is not directly used in foods, but vinegar, the major ingredient of which is acetic acid, is a common additive. Adipic acid is not common but sometimes is used in bakeries instead of tartaric acid to sustain the flavor notes longer. Fumaric acid is a structural isomer of maleic acid, is more “tart” than citric acid, and can be a substitute for tartaric acid. GDL, produced from the oxidation of glucose, is the inner ester of gluconic acid and is used in the preparation of some cheeses and bean curd (tofu).

Sweeteners

People of all ages, cultures, and races desire sweet-tasting foods. Throughout evolution, sweetness played a role in human nutrition by orienting humans to ingest food for energy and essential nutrients (Drewnowski et al. 2012). Sugar or sucrose is a universal sweetener present in almost every type of food. After absorption in the gut, sucrose is hydrolyzed to glucose, which is the energy source for life. Unfortunately, overconsumption of sugar or glucose can cause serious

chronic diseases such as diabetes mellitus and obesity. *Streptococcus mutans* is considered the primary etiologic agent of dental caries and contributes significantly to the virulence of dental plaque, especially in the presence of sucrose. Sugar substitutes interfere with the formation of *Streptococcus mutans* biofilms (Durso et al. 2014). Thus, replacing sugar with alternative sweeteners in foods is an important issue in food production. In food formulation, sugar is important not only for sweetening, but also for bulking. Other parameters in food preparation, such as viscosity and humidity control, are also significant. As replacements for sugar, both the polyols and artificial or natural intense sweeteners have their specific roles. First, a suitable bulking material to replace the volume of sugar should be selected; polyols are good choice. Then, since polyols are not as sweet as sugar, an artificial or natural intense sweetener is chosen to provide the required sweetness. In addition, a small amount of hydrocolloids is recommended to adjust moisture and viscosity.

Polyols

Polyols are sugar alcohols, a group of low-calorie digestible carbohydrates similar to sugar. Polyols contain hydroxyl groups that are substitutes for aldehydes. They occur naturally in fruits and vegetables and are produced by certain bacteria, fungi, yeasts, and algae (Ortiz et al. 2013). They are produced in the food industry from catalytic hydrogenation of natural sugars, but biotechnological production by lactic acid bacteria (LAB) has been investigated as an alternative (Ortiz et al. 2013).

The first generation of polyols is derived from hydrogenation of monosaccharides: sorbitol from glucose, xylitol from xylose, and mannitol from mannose, and their sweetness is reminiscent of that of glucose. Many polyols can be produced by various microorganisms. Xylitol can be produced from xylose and corn cob hydrolysate by assimilation of the tropical mangrove yeast *Cyberlindnera saturnus* (Kamat et al. 2013). Microalga *Chlamydomonas reinhardtii* can be genetically engineered to produce xylitol at low cost (Pourmir et al. 2013). Mannitol, the first crystalline polyol discovered, is present in many plant exudates, seaweeds, and grasses. By promoting the effective use of raw glycerol, mannitol is produced by the activity of the yeast *Candida azyma* (Yoshikawa et al. 2014).

The second generation of polyols is from disaccharides: isomalt from isomaltulose, lactitol from lactose, and maltitol from maltose. Isomaltulose is a derivative of sucrose and is a mixture of two disaccharide alcohols: gluco-mannitol and gluco-sorbitol.

Erythritol is a sugar alcohol that is present in a wide variety of fruits and fermentation products. It is about 85 % as sweet as and with a profile similar to that of sucrose. It used to be produced only by fermentation on glucose media. An alternative method is production of erythritol by the yeast *Yarrowia lipolytica* on pure and crude glycerol (Mironczuk et al. 2014). A study by Heikel et al. (2012)

established the optimal synergism of erythritol with either rebaudioside A or sucralose. It was concluded that the binary sweeteners achieved sucrose-like flavor and texture profiles at an adjusted sweetness of 1.0 for both combinations (Heikel et al. 2012).

Artificial Intense Sweeteners

There are a limited number of intense artificial sweeteners that the US FDA has approved for industrial use as sucrose substitutes: acesulfame potassium, aspartame, neotame, saccharin, and sucralose. The isosweetness concentration of these sweeteners compared to sucrose, or relative sweetness (RS), depends on the type of food in which the sweetener is incorporated. The isosweetness of neotame and sucralose, together with natural rebaudioside (from *Stevia*), were analyzed in a chocolate formulation and found to be 8,600, 570, and 200, respectively, which is a similar profile to that of other foods (Palazzo et al. 2011). Descriptions of the artificial sweeteners and their relative sweetness values are given below:

- (i) Acesulfame potassium, also known as acesulfame-k, has an RS of 200, a slightly bitter aftertaste, and is suggested for use in beverage mixes, gelatin confectioneries, and chewing gums.
- (ii) Aspartame, a dipeptide ester with the amino acids aspartic acid and phenylalanine, has an RS of 200, a taste in the sharp direction, and is suggested for use in desserts and beverages. Its sweetness is synergistic with acesulfame-k. It may be metabolized to phenylalanine, which can cause sensitivity for individuals with phenylketonuria.
- (iii) Neotame is a derivative of the dipeptide composed of aspartic acid and phenylalanine, has an RS in the range of 7,000–13,000, and is not metabolized to phenylalanine.
- (iv) Saccharin is the oldest artificial sweetener, having been in use since before 1900, has an RS of 300, is very stable to heat and acid, and has a slightly bitter aftertaste. There was controversy about its possible carcinogenicity, but there is no strong evidence.
- (v) Sucralose, manufactured from sugar, has an RS of 600, a profile close to that of sugar, a good clean taste, and is very stable.

The Natural Sweeteners

Because they are natural products, the compounds derived from the South American plant *Stevia rebaudiana* and monk fruit are used more and more. The leaves of the stevia plant contain a range of diterpene glycoside steviolosides, with rebaudioside A the sweetener of industrial interest. The RS of rebaudioside A ranges from 30 to 45. It has a clean taste, although there is some bitter aftertaste.

The triterpene glycoside mogrosin extracted from the monk fruit *Siraitia grosvenorii* is also gaining in popularity (Pawar et al. 2013). Monk fruit is also called *luo han guo*, a common Chinese herb. It has an RS of 250.

Food Colors

Like flavor, the appearance of food is an essential sensory characteristic. A food's appearance is the first thing that a consumer uses for a rapid judgment of quality. Food manufacturers utilize brilliant colors to attract customers in their products. In ancient Greece and Rome, dyes from inorganic heavy metal salts were added to wines. However, the inorganic coloring materials have slowly been replaced by their organic counterparts. In 1886, the US began regulating dyes by allowing organic dyes to be added to butter. In 1900, USDA established guidelines for the use of colors together with preservatives. Today, the US FDA is involved in use of food colorants to help protect the safety and health of consumers.

There are two types of food colorants approved for industrial use, certified and uncertified. Certified food colorants are synthetic dyes for which testing and approval must be processed by the FDA for every manufactured lot, whereas uncertified food colorants are natural colors that do not need batch approval by the FDA. All approved synthetic colors are assigned a Food, Drug and Cosmetic (FD&C) number. Table 2 gives the major commercial synthetic dyes.

The amount of each color that needs to be added in processed food is small, with about 10–100 ppm for red and yellow and from 3 to 10–20 ppm for blue. These additives are generally stable in acidic pH. The dyes are usually dissolved in ethyl alcohol before being added to foods in the manufacturing process. In addition to their own characteristic shades, other shades can be produced by mixing two or more dyes. Because of the insolubility of food colorants in fats or oils, lakes are used instead. Lakes are derivatives of food colorants and are made by depositing individual dyes on a substrate of aluminum or calcium salts. With a dye content of 10–40 %, the lakes are dispersed in lipid medium when added to food. The usage level of food colorants is 0.1–0.3 %.

In nature, plants and animals have a wide variety of colorful appearances. The natural color dyes are extracted from a large variety of plants. These are not certified dyes; in many cases, when they are added to foods, food processors do not have to label them as colors because they have other functions. However,

Table 2 Synthetic dyes and their FD&C numbers

Synthetic dye	Color shade	FD&C No.
Erythrosine	Bluish pink	Red #3
Allura red	Yellowish red	Red #40
Tartrazine	Yellow	Yellow #5
Sunset yellow	Reddish yellow (orange)	Yellow #6
Brilliant blue	Greenish blue	Blue #1
Indigotine	Deep blue	Blue #2

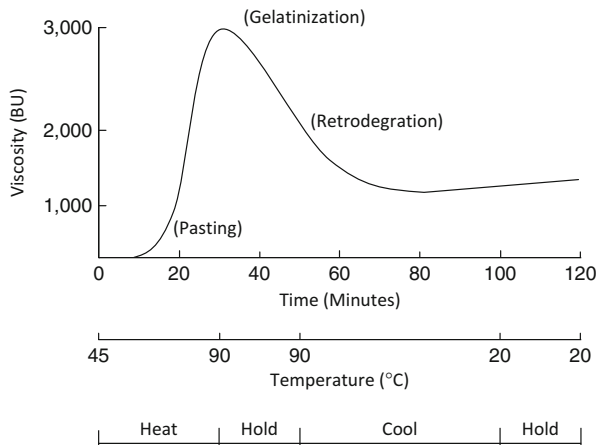
sophisticated techniques must be used and much care must be taken when using natural colors because most are soluble in oil but not in water, and they are not concentrated so that large quantities are required for use in food. In addition, they are not quite pH stable, so some natural color extracts need extra protection to safeguard them from the effects of high temperatures. One study evaluated the red cochineal extract, which showed changes in its visual color in association with high thermal stability (Fernandez-Lopez et al. 2013). Microencapsulation techniques were used to increase stability. In the extrusion of rice flour, microencapsulated lycopene yielded better color retention in the extrudates than free lycopene (Choudhari et al. 2012); the freeze-drying process was favorable for microencapsulation of curcumin by maltodextrin (Sousdaleff et al. 2013); and the encapsulation approach was a promising way to enhance the stability and dispersibility of carotenoids using sodium caseinate as the carrier (Zhang and Zhong 2013).

At present, natural dyes are increasing in popularity. The majority come from plants, e.g., Amaranthus red, annatto extract of bixin and norbixin, betanin from beets, β -carotene from carrots, curcumin from turmeric, gardenia blue, konjac rice red, lutein, paprika red, paprika orange, riboflavin yellow, spirulina blue, and tomato red. Recently, anthocyanins from blueberry and eggplant, orange color from avocado, and betanin were studied in more depth. The extraction of bixin from annatto seeds has increased because it is nontoxic (Barrozo et al. 2013). Paprika and tomato were studied for use as natural pigments in cured meat products to compensate for nitrite-reduced meat batters (Bazan-Lugo et al. 2012). In addition to extracts from plant sources, there are other natural colors: carmine cochineal comes from an insect; caramel is manufactured from the polymerization of phenolic molecules that result from high-temperature treatment of sugar; carbon black is made from minute purified charcoal particles, with one of the pure forms processed from rice husk by hydrolysis, carbonization, and pyrolysis (Wang et al. 2011); and titanium oxide is a mineral used for opaque white with a bright shiny look. A new method for extracting carminic acid from the dried bodies of cochineal insects is by pressurized liquid and supercritical fluid extraction techniques (Borges et al. 2012). Caramel-colored solution can undergo ultrafiltration to remove as much of the toxic chemical 5-hydroxymethyl-2-furaldehyde as possible to increase the intensity of browning (Guan et al. 2011).

Texturizers: Starches and Their Modified Forms

Starches are the most widely used food texturizers and are well known worldwide, especially to chefs and bakers. Since they are readily available almost everywhere, they are inexpensive. Starches are obtained from cereal grains such as wheat, corn, and rice, as well as from tubers like the potato and cassava root (tapioca). As a major constituent of the human diet, starches are a primary energy source for the human body. In addition to being a source of nutrition, starches and their modified forms can be added to many kinds of foods for needed thickening, gelling, moisture retention, and texturization. Many chefs and bakers are experts in making use of

Fig. 1 Brabender viscosity curve of a typical starch



starches in their foods and bakery items. In the food industry, the above-mentioned properties have been fully utilized in food processing to attain various texturization functionalities.

Native starches are contained in granules extracted directly from various sources. Chemically, starches are polysaccharides, which are polymers consisting of *d*-glucopyranose or anhydroglucose units (AGU) linked together by α -1,4 and α -1,6 glycosidic bonds. The polymers that are linked together by α -1,4 bonds forming straight chains are amylose, and those molecules with a number of units linked by α -1,6 bonds are known as amylopectin. Amylose is a linear structure and is smaller than amylopectin. Amylopectin is branched and much bigger, with a molecular weight about 300 times that of amylose; therefore, it is more thermally stable and has a higher viscosity in water. The difference in the properties and functionalities of native starches from different sources is due largely to their ratio of amylose to amylopectin. Waxy corn has an exceptionally high ratio of amylopectin of almost 100 %; potato, tapioca, and rice starches also have a high amylopectin content compared to that of wheat and dent corn starches. The behavior of starch also depends on small quantities of phosphorus, protein, and lipids.

The different sizes and shapes of starch granules also contribute to the diverse properties of starches. Different starches have their own unique characteristics and behave differently, which is reflected by the change in viscosity when the starch grain is dispersed in water, heated, and then cooled. These viscosity changes are recorded by viscoamylography. The Brabender viscosity curve shows the change in viscosity in a standardized heating environment where the starch is heated from 45 to 90 °C from 0 to 30 min, held at 90 °C from 30 to 50 min, cooled to 20 °C from 50 to 100 min, and then held at 20 °C from 100 to 120 min (Fig. 1).

When a slurry of starch grains is heated, the amylose and amylopectin gradually become hydrated so that the swelling of the granules causes an increase in the viscosity of the water solvent. The pasting temperature is where the viscosity begins to increase. The granules pass into a paste form; this is known as the cooking or gelatinization

process. After the viscosity reaches its peak, the amylose chains begin to reassociate in a parallel array structure causing a drop in viscosity; this is called retrogradation. Letting the starch stand leads to dispersal by loosening the hydration and rigid gel formation. Different starches have their own specific viscosity and Brabender curve shape. Different treatments also affect the properties of starches, e.g., heating or freezing the starch suspension. According to one study, repasting the potato starch produced by preheating preparation increased the viscosity by 50 % compared to that of its native form; the strength of the produced gel was also greater from preheating (Gryszkin et al. 2014). Waxy maize starch prepared in nanocrystal form could be used as a particle emulsifier to stabilize oil in water emulsion because of its ability to absorb both phases at the oil-water interface, resulting in stabilization (Li et al. 2014). The addition of syrups, amino acids, and acidulants greatly affects certain parameters of starches such as pasting temperature swelling power, aqueous solubility, gel strength, and light transmittance. The addition of hydrocolloids has significant effects on starches, which is particularly evident when they are added to foods.

To create starches with specific properties, parameters, stability, and applications, they are modified chemically or physically. There are various modified starches on the market.

Cross-Linking

One way to increase the stability of starch is by cross-linking. It is the most common chemical modification technique and is the result of the reaction between the slurry of granular starch containing 30–45 % solid and an agent in the alkaline medium. Covalent bonds form between the agent and the hydroxy groups of two strains of starch polymers with the same or different molecules. Cross-linking affects the swelling of starch granules so that they can resist high temperature, high acid, and stress conditions. Common agents used for cross-linking are sodium trimetaphosphate (STMP) and phosphorus oxychloride. A cross-linked tapioca starch prepared with 0.25–6 % concentration of STMP and sodium tripolyphosphate (STPP) at a ratio of 99:1 w/w was tested for its physiochemical properties. The paste clarity decreased with higher STMP/STPP concentration, and variations in swelling power, solubility, pasting, gelatinization, and rheological properties were observed such that cross-linking exhibited the strongest gel characteristic and greater shear resistance at 1.0 % (Wongsagonsup et al. 2014). Another study indicated that cross-linked wheat starch was more resistant to acids than its native counterpart; the effect of lactic acid was greater than that of acetic acid on the degradation of starch properties (Majzooobi and Beparva 2014).

Substitution

Introduction of a monofunctional agent into the starch amylose molecule blocks it and delays amylose reassociation, i.e., retrogradation. Starches with this

substitution are called starch esters. Starch acetate is formed by the agent acetic anhydride, which is used in food products such as refrigerated and frozen foods to increase stability. Starch with a substitution by 1-octenyl succinic anhydride (OSA) or succinic anhydride results in starch octenyl succinate, which is an effective emulsifier for carbonated beverages and an alternative to gum acacia when there was a shortage. There is also starch ether, a hydroxypropylated starch that results when the starch slurry reacts with propylene oxide under highly alkaline conditions. Starch ether paste is more viscous but clearer, with better freeze-thaw stability and less syneresis. Thus, it is used extensively in gravies, sauces, puddings, and pie fillings.

Acid Hydrolysis and Dextrinization

Acid-converted starches are hydrolyzed products produced by acidifying starches in slurry under stringent control; they are called thin-boiling starches. The lower aqueous viscosity of an acid-converted starch makes it readily dispersible in water without excessive unrequired thickening. A specific use for these starches is in candies with soft and jellylike yet firm texture. When starches are heated dry under agitation, many glycosidic bonds are broken to form dextrans, which are used in the coating of foods. Controlled enzymatic hydrolysis with amylase results in a range of products such as maltodextrin, corn syrup, and dextrose (glucose), depending on the degree of conversion. A study on maltodextrin obtained from tapioca starch after enzymatic esterification showed that it had a higher viscosity than native maltodextrin. It could be used as an emulsifier to make *n*-hexadecane oil-in-water (o/w) emulsions that are characterized according to their oil droplet behavior (Udomrati and Gohtani 2014).

Oxidation

Oxidation is used to bleach starches to remove colored impurities like carotene, xanthophyll, and related pigments. The solution has a slightly lower viscosity but becomes very transparent, suitable for use in batters or breadings to coat many types of meats and vegetables. A study on ozonation of cassava starch found that pH 3.5 reduced the peak viscosity, breakdown, setback, and final viscosity (Klein et al. 2014).

Pregelatinization

Pregelatinization is when starches are gelatinized and then dehydrated to dry powder form. When they are placed in water, hydration occurs immediately to form gel. Commercially, pregelatinized starches are cold-water swelling (CWS) starches or pregels that are used as thickeners in foods that require a minimal amount of heating, e.g., instant soups and sauces. The concentration of pregelatinized waxy maize starch has a significant impact on the stability of the emulsion with respect to creaming and

the capacity to hold fat, a worthwhile trait to exploit for the development of low-fat health-oriented food emulsions (Bortnowska et al. 2014).

Additional information on starches is available in the chapter “Starch and Nanoparticle” in Dufresne 2015.

Emulsifiers

Water and oil cannot be mixed together; they automatically separate into two distinct phases. However, an emulsifier can cause them to mix, forming an emulsion. An emulsion is a two-phase system, where one phase presents as finite globules in the other continuous phase. In most cases, the two phases are aqueous and lipid. Emulsifiers play important roles in humans, with the bile salts, cholesterol, and saponins just a few examples. There are many emulsion systems in foods, e.g., citrus oil-containing beverages, milk, dressings, shortening, coffee creamer, meat products, margarine, and peanut butter. To function properly, an emulsifier must have hydrophilic and lipophilic groups. It must be soluble in either or both phases. The groups align themselves on the phase boundary in one direction and in one layer forming micelles to separate the phases. By reducing the surface tension at the phase boundary in this manner, the system is stabilized. There are two systems: oil-in-water (o/w) and water-in-oil (w/o). The o/w system is more stable after emulsification with an emulsifier with a stronger hydrophilic group, whereas with the w/o system, the reverse is true. The suitability of the use of a specific emulsifier is determined by its hydrophilic and lipophilic balance (HLB) value that fits the particular emulsion system. The HLB value ranges from 2 to 18 and is based on the tendency of the emulsifier to dissolve in oil or water: a low HLB (2–8) indicates that it is more oil-soluble and a high HLB (14–18) indicates that it is more water-soluble. Table 3 lists the HLB values of some of the more commonly used emulsifiers (O’Brien 1998).

There are many emulsifiers that are used in a wide range of foods. Only the more common ones are discussed below.

Fatty Acid Esters

The most commonly used emulsifier is glycerol monostearate (GMS) of the mono- and diglyceride series. GMS was the first emulsifier to be added to a food (margarine) and has about a 70 % market share of all emulsifiers, with its major use in bakeries. GMS is produced by adding glycerol to fat or oil which results in a mixture of monoglyceride and diglyceride. One emulsifier has a minimum monoglyceride content of 40 % and another has a minimum monoglyceride content of 52 %. A GMS with a monoglyceride content of over 90 %, which resulted from distillation, is valuable in the production of w/o emulsion. GMSs have various forms: liquid, semiliquid, soft plastic, flakes, beads, and powder. The main use for GMS is to delay flour or starch retrogradation in yeast-raised baked goods.

Table 3 Emulsifiers and their HLB values

Emulsifier	HLB value
Mono- and diglycerides	
40 % mono (min)	2.8
52 % mono (min)	3.5
Distilled monoglycerides	4.3
Propylene glycol ester (PGME)	3.4
Sorbitan ester monostearate (Span 60)	4.7
Sorbitan ester tristearate (Span 65)	2.1
Polyoxyethylene sorbitan ester	
Tween 60	14.9
Tween 65	10.5
Tween 80	15.0
Lactated ester SSL	2.6

Retrogradation occurs when the baked goods are left standing for several days and the amylose of the flour retrogrades forming a parallel array of polymers and the amylopectin crystallizes slowly, resulting in a loss of crispness and flavor of the bread crumbs. The added emulsifier at a concentration of 0.25–0.5 % attaches to the amylose to form a helical complex that retards the retrogradation of the starch. In another application of GMS, the addition of 1.5 % GMS significantly influenced the rheological properties of pistachio spread, such as the consistency, thixotropy, and yield stress, because the monoglycerides as lipophilic emulsifiers prevented oil separation (Shakerardekani et al. 2013).

By reacting with acids, the chemical structure of mono- and diglycerides can be modified to that of ester derivatives that are soluble in water. Diacetyl tartaric acid ester of monoglycerides (DATEM) and lactic acid ester are used extensively in baking, e.g., the aeration of cakes, icings, and toppings. A study on frozen bread dough showed that the addition of DATEM (0.75 %) with hydrocolloids to both hard and soft wheat flours yielded the best results with respect to baking quality, including loaf volume and prevention of staling (Sungur and Ercan 2013).

Other emulsifiers include the propylene glycol monoesters (PGME); the so-called Span range, i.e., the sorbitol-derived sorbitan esters; and the Tween or polysorbate range, i.e., the polysorbate fatty acid esters produced by the reaction of sorbitan esters with ethylene oxide. Span 60 and 65 are sorbitan monostearate and tristearate, respectively; Tween 60, 65, and 80 are polyoxyethylene sorbitan monostearate, tristearate, and mono-oleate, respectively. Span 60 was added to whipping cream to study its effect on particle size distribution, microstructure, apparent viscosity, partial coalescence of fat, and overrun of this emulsion. The study showed improvement in overrun and organoleptic properties (Zhao et al. 2013). With the need for confectionery fat blends that are heat-stable, the addition of Span 60 could be the answer (Peyronel and Marangoni 2014). Tween 80, in combination with a hydrocolloid (e.g., guar, xanthan, carrageenan, or alginate), improved the stability of conventional meat sausages during cooking and storage (Ramos et al. 2004).

Another popular emulsifier range includes the lactic acid esters or lactated esters; the most common ones are sodium stearyl lactylate (SSL) and calcium stearyl lactylate (CSL). When wheat flour dough is baked, the added SSL affects the extent and rate of gluten polymerization by causing less gliadin to be incorporated into the polymer gluten network and by interacting with gluten (Steertegem et al. 2013). Many of these types of emulsifier are used in combinations of two or more, and preferably with GMS. The HLB values of the individual emulsifiers create a synergism that improves the flour grain to produce softer dough. Improvement in quality is attained with the use of emulsifiers, yielding better product structure with denser but finer air cells, larger volume, anti-staling characteristics, and longer shelf life.

In addition to baked goods, these emulsifiers are valuable additives in other foods that have both aqueous and lipid phases. They are used in ice cream, shortenings, salad dressings, and mayonnaise, as well as for defoaming in pudding production, lubrication of extruded goods, oil stabilization in peanut and sesame butters, and starch complexing for pasta.

Lecithin

Lecithin was the first emulsifier discovered, in egg yolk, in 1846. It is present naturally in almost all living cells. Today, most lecithin comes from soybean oil. Lecithin is not a single product but a group of four phosphatidyl (PP) lipids: PP-choline, PP-ethanolamide, PP-inositol, and phosphatic acids. Rich in polyunsaturated fats and with no cholesterol, most lecithin is in the form of flakes, while the de-oiled version is granular. It is an emulsifier with a wide HLB range of 3.5–6.5 and used extensively in both w/o and o/w emulsions.

Hydrocolloids

Gum acacia (or gum arabic) and propylene glycol alginate (PGA) are excellent emulsifiers. Gum acacia contains arabinogalactan protein complex (AGP), which comprises hydrophilic and lipophilic groups. It emulsifies citrus oil in sugar solution to form stable citric emulsified flavors for carbonated beverages. PGA is manufactured by the reaction of propylene oxide with alginic acid. In foods rich in oil, it improves acid stability and resists precipitation by calcium and other polyvalent metal ions. It is used in salad dressings and mayonnaise.

Protein Concentrates

Both soy protein isolate (SPI) and whey protein isolate (WPI) are more than 90 % protein and are used to emulsify fat in sausage-making; they prevent fat from leaking from the meat emulsion filling. One study used WPI hydrolysate to produce

o/w nanoemulsions with good stability and better storage properties. This demonstrated the value of tailor-made nanoemulsions for use in a wide range of food applications and they should be studied further (Adjonu et al. 2014). Sodium caseinate is another excellent emulsifier for use in high-fat-content beverages. In coconut drinks, it distributes the coconut oil evenly thus preventing an oily layer to form on top of the beverage.

Hydrocolloids: The Dominant Texturizers

Like starches, hydrocolloids are food-texturizing agents. However, they are used in much smaller quantities and their behavior and function are different. Texture is important for food palatability and safety, and hydrocolloids play an important role in controlling food texture (Funami 2011). In fact, hydrocolloids and starches are synergistic when added together, although the amylose content of the starch is a greater determinant of pasting, paste, and gel properties than the added hydrocolloid (Kim et al. 2013). Hydrocolloids are also known as gums. They are dispersible in water and have a strong water-binding characteristic. A grain of gum dropped into water will immediately modify the rheology by either increasing viscosity or gelling. In food, a high aqueous viscosity increases water or moisture retention, particle suspension, emulsion, and foam stabilization; improves volume; and prevents ice crystal formation. The formed gel controls movement of water molecules and stabilizes the freeze-thaw cycle. Hydrocolloids, like starches, are polysaccharides, but unlike starch in AGU, various gums have a different chemical composition of complex monosaccharides such as glucose, mannose, galactose, arabinose, and rhamnose. Some monosaccharides are attached with positive or negative charges. Each monosaccharide has unique properties that play a role in its application and performance in food texturization.

Hydrocolloids are extracted from various parts of plants such as tree exudates, seeds, seaweeds, fruits, tubers, and microorganisms, and some come from chemical modification of wood pulp. Hydrocolloids are used in almost all kinds of foods that contain water; they cannot be used in chocolate, chewing gum, and edible oil due to the absence of enough water to function. Because of their strong water-binding capacity, only small amounts of hydrocolloid are added to food, usually in the range of 0.05–0.2 %. Hydrocolloids are commonly used in bakery products, including dough conditioner, glazes, and pie filling; beverages such as fruit juices, concentrates, and soft and hard drinks; dairy products such as ice cream, yogurt, cheese, whipping cream, and pudding; desserts like water gel and smoothies; frozen foods; sauces and dressings; snacks; and meat products and their analogs.

Gum Acacia

Gum acacia is also known as gum arabic. It is extracted from the true exudates of the plant *Acacia senegal*, which grows in Sudan. The gum was traded by Arabs in

Table 4 Seed gums and their galactose:mannose ratio

Seed gum	Galactose:mannose
Fenugreek gum	1:1
Guar gum	1:2
Tara gum	1:3
Locust bean gum	1:4

the Middle Ages, which is how the name gum arabic came about. Gum acacia is a mixture of glycoproteins and the polysaccharides arabinose, galactose, rhamnose, and glucuronic acid. Its exceptionally low aqueous viscosity makes it usable in high-protein drinks, and its great adhesive qualities make it useful in gum drop-type candies. As an emulsifier, gum acacia is used in citrus beverages that contain citrus oil.

Seed Gums

Seed gums are a family of galactomannans. Commercially, they include fenugreek gum, guar gum, tara gum, and locust bean gum (LBG), which are produced in Canada, South Asia (India and Pakistan), South America, and Mediterranean countries, respectively. All gums have polymannose as the backbone formed by α -1,4 bonds, with a galactopyranose side chain of α -1,6 bonding to mannose in different ratios, as shown in Table 4.

The properties of seed gums vary. Fenugreek and tara gums are cold water-soluble and LBG dissolves in hot water. Fenugreek and guar gums cannot form a gel, while tara gum and LBG react with xanthan, carrageenan, and konjac to form gels of different strengths. Guar gum is used to increase viscosity in foods like sauces and gravies. The viscosities of guar and xanthan synergize such that they are used in gluten-free flour to strengthen the air cells in the flour matrix. The antisyneresis property of LBG makes it useful in jellies either alone or in combination with xanthan. Tara gum can be used to replace both guar gum and LBG when they are in short supply. Fenugreek gum contains amino acids that increase sensitivity to insulin; thus, it is used mainly in herbal drinks.

Marine Gums

There are three marine gums: agar, alginate, and the carrageenans.

- (i) Agar is extracted mostly from the genera *Gracilaria* and *Gelidium*; its sugar units are galactose-linking sulfate acid ester groups that form agarose and agaropectin. It dissolves in near-boiling water, forms a strong, brittle, and hysteretic gel at 40–50 °C, and then melts at 80–85 °C. Agar is synergistic with LBG. Agarose is the jellifying agent in stabilizing the structure of foam and is used extensively in jelly sweets and aerated products like marshmallow.

- (ii) Algin, or alginic acid, is extracted from the brown algae *Phaeophyceae*. The backbone polysaccharide is composed of mannuronic acid and guluronic acid. Since algin is insoluble, it is chemically converted to sodium alginates of various viscosities. Sodium alginate reacts with a calcium cation to form the thermoirreversible gel calcium alginate; gel formation is usually controlled by using phosphate or polyphosphate as the sequestrant. The characteristics of algin have made it useful in many gelation products such as ice cream and imitation fruit purees. In molecular gastronomy, sodium alginate is the “magic” material used in making caviar.
- (iii) Carrageenan comes from the red seaweeds *Rhodophyceae*, *Chondrus crispus*, and *Gigartina*, with structures of mixed galactan and half ester sulfates. The sulfate is at position 1 or 3 in about every two monosaccharide units, forming κ (kappa) carrageenan and λ (lambda) carrageenan, respectively. In addition, the structure of the red seaweed *Eucheuma spinosum* has two sulfates in two monosaccharides, forming the ι (iota) carrageenan. Since sulfate groups affect the stereostructure of the backbone chain, the κ -carrageenan reacts with potassium ions to form a rigid but elastic gel and the ι -carrageenan reacts with calcium ions to form a softer gel; the λ -type carrageenan does not gel. The carrageenans react with milk protein to prevent whey-off; therefore, they are used in dairy products like ice cream, milk puddings, flan, pie fillings, and chocolate milk. κ -Carrageenan is also used in water gel, either alone with potassium salt or synergistically with konjac gum or locust bean gum. κ -Carrageenan was analyzed for any therapeutic uses upon enzymatic hydrolysis to oligosaccharides. A study of the mixture of κ -neocarrabiose-sulfate, κ -neocarrahexaose-sulfate, and κ -neocarraoctaose-sulfate showed antitumor and antiangiogenic activities in vivo and in vitro (Yao et al. 2014).

Pectins

Pectin is extracted from the peel albedo and lamella of citrus fruits, mostly lemon and lime, as well as from apple pomace. This hydrocolloid is composed of partial methyl esters of polygalacturonic acids, with side chains comprising arabinose, galactose, and xylose; its molecular weight is in the range of 20,000–40,000. Upon extraction, it is 70–75 % esterified and is regarded as high-methoxyl (HM) pectin. De-esterification occurs upon acid hydrolysis. When the percentage of esterification goes below 50 %, it becomes low-methoxyl (LM) pectin. Alkaline can be used in low-temperature hydrolysis. If ammonia is involved, some ester groups are converted to acid amide groups and the pectin is regarded as amidated (AM). HM pectins are soluble in hot water and at high temperature form smooth solid gels with sugar of 65° brix. They are used in fruity jams, jellies, and marmalades. HM pectins in foods give a sense of fullness with respect to mouthfeel; people are sensitive to a pectin concentration of just a few parts per million. It is also used in yogurt, whereas the positive charges in the pectin keep milk protein from coagulating when the acidity of the lactic acid bacterial culture decreases to its isoelectric point.

Commercial pectins are classified as rapid set (RS), medium set (MS), and slow set (SS), depending on the degree of methylation: the higher the degree, the more rapid the setting. The LM and AM types of pectin behave very differently. They are soluble in cold water and form thixotropic, brittle, and irreversible gel with calcium ions, very similar to alginate gels. The thixotropy characteristic is valuable in making center-filling gels for cakes, breads, and biscuits.

Tuber Gum

Konjac gum is extracted from the tubers of *Amorphophallus konjac*. It is composed of polyglucmannan of β -1,4 linkages and has a molecular weight of 200,000–2,000,000 Da; its nonionic structure is composed of glucose and mannose in a 1:1.6 ratio. There are acetyl groups along the backbone in every 9–19 sugar units. Because of its high molecular weight, it exhibits very high viscosity in water with a pH of 4–7. Konjac is soluble in cold water and reacts with xanthan, carrageenan, locust bean gum, and tara gum to form thermoreversible gels. However, when treated with alkaline, an irreversible gel is formed via alkaline cleavage of the acetyl groups. Konjac also amplifies the pasting and gelling effects of starches. Konjac gum is used extensively in a large variety of foods such as konjac jello, which is a gelation of konjac and carrageenan. It is also used to make “konjac noodles” by spray-extruding slurries of concentrated konjac solution into the alkaline calcium hydroxide bath. By esterification with octenyl succinic anhydride using the microwave method, a new polymeric surfactant, konjac glucomannan octenyl succinate, was created, with good hydrophilic and lipophilic characteristics (Meng et al. 2014).

Biogums

The biogums are represented by xanthan and gellan.

- (i) Xanthan is extracted from a culture of *Xanthomonas campestris* grown on glucose or starch. It is a polysaccharide with its main backbone chain composed of α -1,4-linked *D*-glucopyranose units, and the trisaccharide side chains of mannose and glucuronic acid are attached to every other backbone sugar. The solution is stable within a wide pH range of 2–12 and is thermally stable, and its viscosity behaves in pseudoplastic fashion. Xanthan synergizes with guar resulting in an increase in viscosity, and it forms gels of various characteristics with locust bean gum, tara, carrageenan, and konjac. It is a universal hydrocolloid with many applications. In many starchy food systems, the addition of as little as 0.05–0.5 % of xanthan reduces the amount of starch needed while improving the rheology and stability. The effect of modified tapioca starches and xanthan on the viscoelasticity and texture of dough was investigated after starch sheets for Chinese shrimp dumplings were stored at 4 °C, and hydroxypropylated starch and hydroxypropylated-cross-linked

starches were substituted for natural starch. The viscoelasticity of the dough made with the hydroxypropylated starch was much softer and the dough made with the cross-linked counterpart was stiffer and more strain-resistant. Both formulations gave the gel sheet the least change in texture, which is potentially beneficial for frozen/chilled dumpling wrappers (Seetapan et al. 2013). Xanthan was evaluated as a carrier of a preservative solution in an edible coating applied to a freshly cut apple. The solution, which contained 1 % glycerol, 0.5 % xanthan, 1 % calcium chloride, 1 % ascorbic acid, and 0.25 % citric acid, reduced mass loss and oxidative browning of the apple, increased its firmness, and decreased the growth of psychotropic microorganisms, molds, and yeasts. Total and thermotolerant coliforms *Escherichia coli* and *Salmonella* sp. were also absent with the use of the preservative solution containing xanthan (Freitas et al. 2013).

- (ii) Gellan is a relatively new gum that is extracted from the culture of *Sphingomonas elodea*. There are two types of gellan: high acyl and low acyl. Both form very transparent gels when mixed with calcium ions at very low dosage in water. The gel of high-acyl gellan is soft, elastic, and nonbrittle, while that of low-acyl gellan is harder, less elastic, and more brittle. Combining the two gels using different ratios yields gels of various structures. Some food manufacturers use gellan in the colored beads that float in fancy beverages. The addition of hydrocolloids improves the quality of drinks; for example, for reduced-calorie carrot juice, adding 0.3 % gellan gum greatly enhances the stability of the juice cloud during storage (Sinchaipanit et al. 2013). A study concluded that a mixture of 0.2 % gellan and 8 % modified starch was the best replacement for gelatin in puddings in terms of gel strength, water absorption range, and elasticity (Wu et al. 2013).

Cellulose Derivatives

Cellulose is fiber that is present in all plants. Similar to starch, it is composed of a long chain of anhydroglucose units (AGU) that are bonded with β -1,4 linkages, which cannot be hydrolyzed by digestive enzymes like amylase. In the food industry, cellulose is converted to different kinds of gums.

- (i) Microcrystalline cellulose (MCC) is conventionally used for anticaking in cheese. To produce MCC, which is also known as cellulose gel, a caustic soda is used to swell the selected soft wood pulp, which is then spray-dried to obtain fine microsized crystals. Although insoluble in water, these crystals are porous and are able to absorb and attach an ample amount of contact water after vigorous shearing. Therefore, they can be used as a carrier of oil or water to transform some foods from paste to solid form. After taking up water, the MCC crystals become gel-like and can be used in a wide variety of health or low-fat foods because they mimic fat. Commercially, MCC at 85–90 % is co-compressed with 10–15 % of other gums like guar, carboxymethyl cellulose, or maltodextrin so that it can take up water faster.

- (ii) Sodium carboxymethyl cellulose (CMC) is the sodium salt of the polycarboxymethyl ester of cellulose, the gum most widely used by food manufacturers because it is inexpensive. CMC is obtained by treating the hydroxyl groups of softwood cellulose with caustic soda, followed by reaction with sodium chloroacetate. Commercial CMC, also known as cellulose gum, has many viscosity grades. It does not form a gel, but its low cost and wide range of viscosities enable manufacturers to use it in many kinds of foods that need increased viscosity, including bakery dough, yogurt, ice cream, beverages, soups, sauces, and dressings. Unlike other hydrocolloids which are natural, CMC is considered an artificial gum.
- (iii) Methyl cellulose (MC) and hydroxypropylmethyl cellulose (HPMC) are also artificial gums. MC is produced by the reaction of methyl chloride with caustic-treated wood cellulose. To prepare HPMC, there is an additional reaction with propylene oxide and then the by-product methoxy groups are removed as impurities. Aqueous solutions of these two hydrocolloids do not form a gel at low temperature, but gelation occurs upon heating; the HPMC solution has a higher viscosity. MC and HPMC are used to stabilize foods, in particular, batter coating. Recently, studies have compared the effect of HPMC when other hydrocolloids were added to various foodstuffs. In developing an onion powder-containing pasta, the inclusion of HPMC was shown to yield better product quality and sensory characteristics by increasing the shear value of the pasta dough (Rajeswari et al. 2013). To prepare sweet potato starch noodles with a high content of broccoli powder, several hydrocolloids with distinct water-binding capacity were tested to control rheology and structure. HPMC and xanthan were the most effective because they were more efficient in controlling the degree of swelling of the vegetable particles and starch granules in the starch noodles (Silva et al. 2013). The addition of hydrocolloids is essential for gluten-free dough and bread because as polymeric substances they mimic the viscoelasticity of gluten and increase the gas-retaining ability of the dough. A study showed that adding selected hydrocolloids at 1–1.5 % to dough led to increased loaf volume, superior color, and prolonged shelf life; bread containing 1.5 % HPMC was preferred by a trained panel (Sabanis and Tzia 2011). Hydrocolloids are effective in reducing oil uptake in fried goods. Among the hydrocolloids tested, HPMC demonstrated the best moisture retention and oil uptake in French fries, which were prepared from potatoes after pretreatment with water, calcium chloride, and citric acid, and then coated with different hydrocolloids (Pahade and Sakhale 2012).

Conclusion and Future Directions

Foods are meant to be eaten. They come into contact with a large number of sensory cells in the mouth before being swallowed into the body via the digestive tract. Foods are for living, and quality foods are for quality living. Quality foods must be

nutritious and palatable so that people can enjoy them, especially at that initial contact in the month.

Foods provide energy for the activities and metabolism of the body. The source of all kinds of energy on earth is the sun, and all kinds of foods, whether produced from plants, animals, microorganisms, or minerals, originate from the surface of the earth. The earth transforms the energy of the sun into food form for people to enjoy. All native crops and livestock can be considered a primary form that resulted from the intimate interaction between the sun and earth. They are later transformed into many varieties of food for human beings to enjoy. The colorful, nutritious, and tasty foods are works of art created by nature, our father sun and mother earth. All creatures, including human beings, depend on food to survive. Today, food processors transform native foods into other foods for modern man's enjoyment. Unlike our ancestors who lived in the wilderness, we dwell in communities where the area where primary foods are produced is far away. Processed foods are necessary.

Processors break down primary foods into different portions of their components and then recombine the selected components to structure them into secondary foods, which go to the markets and eventually consumers' plates and palates. People want to live quality life. In addition to the necessities to sustain life, people need enjoyment, and that includes eating. Eating has now become an art; therefore, food processing is also an art, and food processors are actually artists. These artists use various parts of primary foods as building blocks and combine them with colorants, acidulants, sweeteners, flavoring materials, emulsifiers, starches, and hydrocolloids, which are for combining with nutrients, preservatives and processing aids, to satisfy palatal desires and nutritional needs.

Quality foods are created by combining the best available components. Today, people are enjoying delicious foods at home and in restaurants. They should appreciate the artists who create the wonderful secondary foods. In addition, these artists are expected to create much more, so we can continue to lead quality lives.

From all perspectives, nature's art is the most beautiful and perfect. What will our secondary artists do then? Learn and discover more from nature. Reflect nature's beauty in developing our food. Yes, there have been many wonders in natural foodstuffs, particularly the ingredients that have been discovered by scientists. However, there is much more to be discovered and used, like natural colors, natural stabilizers, and natural flavoring substances. It is the mission of all food scientists to create the most wonderful foods, in harmony with nature.

Cross-References

- ▶ [Chemical Composition of Bakery Products](#)
- ▶ [Chemical Composition of Beverages and Drinks](#)
- ▶ [Chemical Composition of Sugar and Confectionery Products](#)

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