16 Food Additives

1 Introduction

1.1 History of Chemical Additives

Substances added to foods in the United States (US) number about 10,787. About one-half of the compounds (5292 substances) are designated as food additives (Table 16.1). Another 4646 of the substances added to foods have Generally Recognized As Safe (GRAS) status; the significance of this is explained later in the chapter. Another 849 of the substances added legally to foods are classed as "other" referring to colors and compounds in common use prior to 1958 (Nicole 2013). About 3000 designated food ingredients are listed in a document titled "Everything added to food in the United States (EAFUS)" (U.S. Food and Drug Administration 2014a).

There was little control over chemical additives used as preservatives or colorings up until about 1906. In 1903, Dr. Harvey Washington Wiley, then the Chief of Bureau of Chemistry of the U.S. Department of Agriculture, established a "poison squad" that consisted of young men who consumed foods treated with known amounts of chemicals commonly used in foods. The goal of the project was to determine whether these compounds were deleterious to health. The result of the efforts of Dr. Wiley and the "squad" was the passage of the Food and Drug Act of 1906, which is also referred to as "The Pure Food Act." In September of 1958, the FD&C Act was amended to prohibit the use of food additives that had not been adequately tested to establish their safety (Lewis 2002).

1.2 Significance of Food Additives

The intentional use of food additives is unavoidable in the modern food industry though often attached with controversy (Fennema 1987). One reason for considering food additives as indispensable is that, they are used in order to achieve a variety of pre-defined technological goals; additives are intended to improve sensory, nutritional, safety and shelf life of products. Additives are also employed as processing aides, in order to assist with the manufacturing process. Frequently also, the distinction between food additive and ingredient is not so clear-cut. However, exposure to food additives is regulated in the same way as exposure to other environmental agents.

Each additive is approved for use only after prolonged evaluation for their safety and upper limits of intake by the FDA (Neltner et al. 2011). The scientific discipline concerned most with the evaluation of food additives, is toxicology. Some basic concepts must be remembered when dealing with food additives:

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Table 16.1 Food additives and other substances added to foods

1.	Food additives Direct food additives Indirect food additives (few additions after 1997) Substances covered by FCS notifications (began in 1997) FCS below threshold of regulation (began in 1995) Radiation sources
2.	GRAS substances Common food ingredients in use before 1958 Manufacturer self-determined Association expert panel-determined FDA-listed (ended in 1973) FDA-affirmed (began in 1973 and effectively replaced after 1997) Substances covered by FDA-reviewed GRAS notification (began in 1997)
3.	Prior-sanctioned substances (federally sanctioned before 1958)
4.	Color additives (began in 1960)
5.	Pesticide chemicals or residues (modified in 1996)
6.	Drugs in animal feed (modified in 1968)
7.	Dietary supplements (began in 1994)

Adapted from Neltner et al. (2011), FCS = Food contact substance

- All foods are composed of chemical compounds. Any food component can be extracted and added to other foods in which case the extracted substance is classed as an additive.

- Any additive can be injurious to health but only at sufficiently high levels.
- Any additive can be safe to use at low levels
- Each additive must be assessed for toxicity using scientific procedures, regardless of how safe its proponents say it is and how toxic its opponents say it is.
- The use of radiation for preserving foods is declared an additive.

In general, additives cannot be added to foods, unless the FDA has approved their use. Moreover, additives are tested for toxicity in concentrations much greater than those allowed in foods. Most food additives are components obtained from natural foods and without such additives, the quality of many foods would be inferior to that to which we have become accustomed. The shelf life or availability of many foods would also be greatly limited. Food additives are classified by their function (see below) because they overlap each other in terms chemical structure.

Table 16.2 Some food additives and packaging terms[a]

Food Additive. A food additive is defined in Section 201(s) of the FD&C Act as "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 characteristic of any food (including any substance intended for use in producing, manufacturing, packing, processing, preparing, treating, packaging, transporting, or holding food; and including any source of radiation intended for any such use); *if such substance is not GRAS or sanctioned prior to 1958 or otherwise excluded from the definition of food additives".* Food Contact Substance (FCS) – Section 409 of the FD&C Act defines an FCS as "any substance that is intended for use as a component of materials used in manufacturing, packing, packaging, transporting, or holding food if such use of the substance is not intended to have any technical effect in such food". Colorant – "A colorant is a dye, pigment, or other substance that is used to impart color to or to alter the color of a food-contact material", but that does not migrate to food in amounts that will contribute to that food any color apparent to the naked eye. The term 'colorant' includes substances such as optical brighteners and fluorescent whiteners, which may not themselves be colored, but whose use is intended to affect the color of a food-contact material" (21 CFR 178.3297(a)).

From Food and Drug Administration (USDA) (2015).
[a]Closely follows the regulatory text

1.3 Definitions of Food Additives

A food additive is defined in Section 201(s) of the United States FD&C Act (Table 16.2). Many nutrients, extracted food components as well as gasses are used as additives. However, many compounds added to foods, are excluded from regulatory oversight as food additives (David 1988).

Similarly, a food additive is defined by the WHO/ FAO as "*any substance not normally con-*

sumed as a food by itself and not normally used as a typical ingredient of the food, whether or not it has nutritive value, the intentional addition of which to food for a technological (including organoleptic) purpose in the manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food results, or may be reasonably expected to result (directly or indirectly), in it or its by-products becoming a component of or otherwise affecting the characteristics of such foods" (Codex Alimentarius Commission 1995). The codex definition implies that contaminants or and substances that improve nutritive characteristics should be considered additives – but this latter requirement is not always adopted by nation states – as shown by discussions of amino acids and other nutrients, below.

Food additives are defined in EU legislation in manner similar to the statements offered by codex. e.g. "*any substance not normally consumed as a food in itself and not normally used as a characteristic ingredient of food whether or not it has nutritive value, the intentional addition of which to food for a technological purpose … results … in it or its by-products becoming directly or indirectly a component of such foods*" (Europa 2014).

1.3.1 Categories of Food Additives

Several subcategories of food additives have been defined (Neltner et al. 2011). (a) direct food additive (from 21 CFR 173) refers to materials used as processing aides for their technical effect in the food but which are largely absent in the finished products. (b) Indirect food additive – a substances or substances that come into contact with foods as a result of packaging, or processing equipment, (c) Food Contact Substance (FCS) – materials that come into contact with foods, by virtue of their use for manufacturing packaging and not directly added to foods for some technical function. Some FCS occur in very low concentrations below that deemed to require regulation. (d) Radiation sources (Table 16.1).

1.3.2 Distinguishing Additives and Food Ingredients

The distinction between food additives and food ingredients is important. A food ingredient refers to "*substance, excluding a food additive, used in the manufacture or preparation of a food and present in the final product*" (Codex Alimentarius Commission 1981).

1.3.3 Other Exclusion from Additives

Some materials added to foods are not considered either food additives or ingredients (Table 16.1). One such group of "non-additives" are substances for which there is a prior history of use before 1958; these can be added to foods without regulatory oversight. Other substances not covered by food additives legislation are those with GRAS status (Burdock and Carabin 2004), color additives, dietary supplements, and drugs used for livestock treatments (Neltner et al. 2011).

1.4 Functional Classifications for Food Additives

There are currently 27 functional classes of food additives recognized as listed in Table 16.3 (Codex Alimentarius Commission 1989b). The

Table 16.3 Functional classification of food additives

CLASSES 1–14	CLASSES 15–27
1. Acidity regulator	15. Flour treatment agent
2. Anticaking agent	16. Foaming agent
3. Antifoaming agent	17. Gelling agent
4. Antioxidant	18. Glazing agent
5. Bleaching agent	19. Humectant
6. Bulking agent	20. Packaging gas
7. Carbonating agent	21. Preservative
8. Carrier	22. Propellant
9. Color	23. Raising agent
10. Color retention agent	24. Sequestrant
11. Emulsifier	25. Stabilizer
12. Emulsifying salt	26. Sweetener
13. Firming agent	27. Thickener
14. Flavor enhancer	

Adapted from Codex Alimentarius Commission (1989b) different category names are also used in the US (U.S. Food and Drug Administration 2014b) and internationally.

The World Health Organization is also behind the International Numbering System (INS) for food additives (Codex Alimentarius Commission 1989a). Accordingly, each additive is assigned a numerical identifier, which is useful for labeling purposes. The INS identifier comprises three digits – sometimes followed with a letter to differentiate closely related additives. The various classes of food additives are divided according to the function of different substances, and not according to structure. For example, very many different, unrelated, chemical entities may function as food colors, bulking agents, flavor enhancer etc. A comprehensive treatise on food additives, edited by Smith & Hong-Shum, covers 14 of the 27 classes in detail (Smith and Hong-Shum 2011).

Some of the technological functions performed by food additives are summarized in Fig. 16.1. The sensory additives can affect appearance (colors, bleaching agents, glazing agents), texture (bulking agents, anticaking agents for food powders and ingredients, stabilizers for food dispersions), and taste (sweeteners, acidity regulators). The nutritive food additives group covers vitamins, amino acids and minerals. Food additives which extend shelf life decrease the rate of spoilage involving, chemical, physical, biological or microbiological changes.

2 Additives Legislation

2.1 The 1958 Food Additive Act

Food additives are regulated by, the 1958 Food Additive Amendment to the Food & Drugs and Cosmetic Act of 1938. The 1958 act for food additives brought into effect the process of pre-market approval. Safety assessment for food additives involves a process of risk assessment. In general terms, all chemicals introduced after 1958 are presumed to be potentially hazardous. It is necessary to identify the types of adverse effects associated with a compound, and to establish the dose-adverse response characteristics. Ultimately, experts will establish the no effect level (NOEL) concentration below which no harm will befall the consumer. Toxicity testing is performed using animals (typically rodents) as models. Values for the NOEL are then adjusted (e.g. NOEL values for rats are divided by 100) to allow for the fact that tests were done with animals, and to allow for inter-person variations in responses (Hanlon et al. 2016). Ultimately, such analysis produces a safe-use level, or allowed daily intake (ADI) for an additive, which then passes into law.

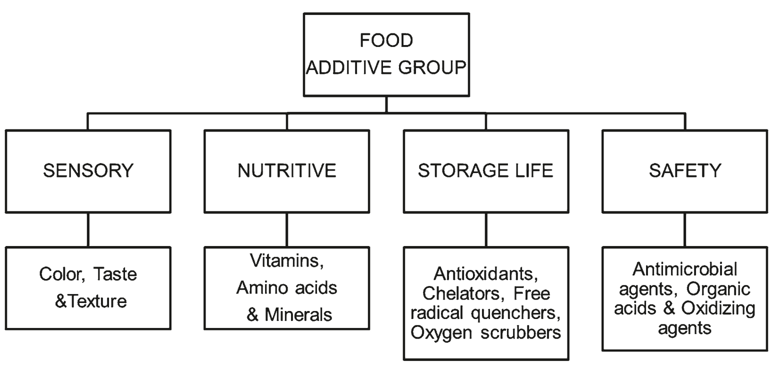

Fig. 16.1 Overview of food additives groupings (unofficial)

2.2 The Delaney Clause 1959

The Delaney Clause is named after US Representative James Delaney of New York, who introduced it into food legislation. The essence of the Delaney clause is that: "… *no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal*" (Lester and Staples 1996). The Delaney amendment was considered controversial perhaps because it opted to dismiss concerns about dosage (Hoyle 1996; Lester 1996; Picut and Parker 1992). Critics of the Delaney clause noted that all chemicals are toxic at high dosages; readers can find more detailed arguments for and against the Delaney clause in the following texts (Picut and Parker 1992; Weisburger 1996).

2.3 Gererally Recognized as Safe Compounds

Compounds previously established by the FDA as GRAS can be added legally to foods without classing them as food additives. GRAS substances are outside of the food additive framework (Burdock and Carabin 2004). Substances are considered for GRAS if they were used historically, without harm to consumers. In addition, new substances can be evaluated as GRAS, after a petition is submitted to the FDA. Completion of a GRAS certification may require several years because the supporting evidence includes a 2-year feeding study using two species of animals. Such studies must reveal no long-term and short-term adverse effects (Neltner et al. 2013).

2.4 Approved Lists for Additives

Approved food additives have well defined chemical identities with standards for quality, and limits for use. Currently, approved listings of food additives are available online (Food and Drug Administration (USDA) 2013) (Food and Agriculture Organization of the United Nations 2013) (Codex Alimentarius Commission 2015). A core list of approved food additives in the US is available from the Codes Of Federal Register 21 CFR 172 (U.S. Government Publishing Office 2014) (U.S. Government Publishing Office 2012) European lists of approved food additives can be found from the Eur-lex website (Eur-Lex 2011). International listing of approved food additives and conditions for their use have been compiled by the JEFCA, short for Joint FAO/WHO Expert Committee on Food Additives (JEFCA 2015; Joint FAO/WHO Expert Committee on Food Additives 2001).

Some basic requirements apply for all approved food additives and GRAS substances: (i) Intentional additives must perform their intended function. (ii) Additives must not deceive the consumer or conceal faulty ingredients or defects in manufacturing practices, (iii) Additives should not reduce the food's nutritional value. (iv) An additive cannot be used to achieve an effect that could be gained by good manufacturing practices and (v) A method of analysis must exist to monitor the use of the additive in foods or its incidental occurrence in foods (such as migration from a packaging material).

2.5 International Regulations for Food Additives

International regulations for food additives can be traced to JEFCA which, is a committee formed from international experts, nominated by the WHO and FAO. JECFA evaluated the safety of chemical substances added to foods since the 1950's. Currently, JECFA publishes authoritative data on the toxicity of additives, which is the basis for international regulations. Specifically, JECFA also produces unique identification numbers for different compounds and their standards of purity required for use in foods. The CAC standard CXS_192e available online (Codex Alimentarious Commission 1995, 11,917), provides details of international food additive regulations. The 475pp document contains a core of 15 pages setting out clear definitions for food additives, foods for which food additives can and cannot be used, key principles of food additive use and justifications. For example, food additive may be justified on the basis that their use is advantageous and poses no risk for the consumer.

Manufacturing foods for people with special dietary needs provides another justifiable use of food additives. Additives are also justified if they aide the in the achievement of established end-goals in the food system: processing and manufacturing, packaging, storage and distribution. By contrast, the use of additives will not be permitted if alternative economically practical ways exist to achieve the intended end goal. In accordance with principles of GMP, the use level for food additives should be the lowest level required to achieve the stated goals (Codex Alimentarious Commission 1995).

2.6 Labelling Requirements for Food Additives

The labeling requirements for food additives, when sold to food manufactures and caterers are as described in the appropriate CAC standards (Codex Alimentarius Commission 1981); In fact, the labeling requirements for food additives, when sold as such, are similar to these for other general food labels (Codex Alimentarius Commission 1981, 1985).

3 Sensory Additives

This section provides an overview of some major food additive classes. The reader is referred to several sources for more information (Armstrong 2009; Jackson 2009; Rulis and Levitt 2009; Smith and Hong-Shum 2011).

3.1 Colorants

Color additives can be categorized into three major types: natural, nature-identical, or synthetic. Natural colorants include the yellow from the annatto seed; green from chlorophyll; orange color from carotene; brown from caramelized sugar; and red from beets, tomatoes, and the cochineal insect. Natural colors are obtained from animal, vegetable, or mineral sources.

The term "nature-identical" applies to synthetic counterparts of colors and pigments that are derived from natural sources. These include the pure carotenoids such as canthaxanthin (red), apo-carotenal (orange-red), and beta-carotene (yellow-orange).

The synthetic color additives are of two types described as "Food Drugs and Cosmetics (FD&C) dyes and lakes. Dyes are water soluble and are available in powders, granules, liquids, blends, and pastes. GMP suggest that they not be used in amounts exceeding 300 ppm. The lakes are water-insoluble FD&C certified dyes on a substratum of aluminum hydrate or aluminum hydroxide. The color lakes are useful in foods that have very little water e.g. coloring oils, icings, fondant coatings, cake and doughnut mixes, hard candy, and gum products. They do not solubilize, as do dyes but impart color by dispersion rather than as solutions. In 1960, the Color Additive Amendments separated "color additives" from "food additives." Colors (which include black, white, and intermediate grays) no longer were to be classified as food additives.

Some compounds are not color additives but are used to produce a white color. Thus, oxidizing agents including benzoyl peroxide, chlorine dioxide, nitrosyl chloride, and chlorine are used as bleaching agents, and to whiten wheat flour, which is pale yellow in color if untreated. Titanium dioxide, on the other hand, is considered a color additive and may be added to some foods, such as artificial cream or coffee whiteners to add a white color (U.S. Food and Drug Administration 2014b).

3.2 Flavorings and Flavor Enhancers

3.2.1 Flavors

Flavorings are compounds, natural or synthetic, that are added to foods to produce flavors or to modify existing flavors. The variety of natural and synthetic flavorings available to the modern food technologist is very large. Essential oils provide a major source of flavorings. (Jelen 2011). Because of the large production of orange juice, quantities of essential oil of orange are produced as byproducts so there is little need for the production of synthetic orange flavoring.

Fruit extracts have been used as flavorings, but these are relatively weak when compared to essential oils and oleoresins. Synthetic flavorings are usually less expensive and more plentiful than natural flavorings. On the other hand, natural flavorings are often more acceptable, but they are quite complex and difficult to reproduce synthetically. Many artificial flavors, such as amyl acetate (artificial banana flavor), benzaldehyde (artificial cherry flavor), and ethyl caproate (artificial pineapple flavor), are added to confectioneries, baked products, soft drinks, and ice cream. These flavorings are added in very small amounts, often 0.03% or less.

3.2.2 Flavor Enhancers

Flavor enhancers, intensify flavors already present in a food, where the desirable flavors are relatively weak. Monosodium glutamate (MSG) is one of the best-known flavor enhancers (Schiffman 1998). MSG occurs naturally in many foods and in a certain seaweed that was used for centuries as a flavor enhancer. In the last hundred years, isolated MSG is used. Other flavor enhancers that also improve flavors are extremely powerful, effective in parts per million and even per billion. These compounds have been identified as nucleotides, including disodium inosinate and disodium GMP. Interestingly, there is a tendency to reference MSG to a new taste called UMAMI (Beauchamp 2009)

Several theories attempt to explain how MSG and other flavor enhancers work. One theory is that they increase the sensitivity of the taste buds. A second suggests that an increase in salivation as a result of the flavor enhancers will increase flavor perception. A third theory of intensified flavor perception is based on the observation that flavor enhancers produce certain physical sensations in the mouth such as coolness and heat (Beauchamp 2009).

3.3 Sweeteners

Sweetening agents are added to a large number of foods and beverages. Table sugar (sucrose) is the most commonly used sweetener. Sweeteners include other sugars, as well as an abundance of natural and synthetic agents of varying sweetening power and caloric values. Many sweeternes are intened to function as sugar subtitutes or sugar replacements (Struck et al. 2014; Van der Sman and Renzetti 2019).

3.3.1 Fructose

Fructose (also known as levulose), is the sweetest and most soluble of the natural sweeteners used in foods (nearly twice as sweet as table sugar, sucrose). Fructose functions as a humectant in baked goods to retard dehydration. Solutions of fructose have a low viscosity that results in lower "body" feel than sucrose but have greater flexibility of use over a wide range of temperatures. Fructose also does not crystallize out of solution, whereas sucrose will. Fructose (fruit sugar) occurs in many fruits and berries; It also occurs in honey, corn syrup, cane sugar, and beet sugar. Since glucose cannot be metabolized by people with diabetes, fructose may be a better substitute for sucrose for diabetics but there are also concerns that this sugar may promote increased energy intake and weight gain (Bantle 2009; Choo et al. 2018).

3.3.2 Molasses

Molasses is a byproduct of sugar production. The use of molasses as a sweetener in human foods is largely in baked goods that include bread, cookies, and cakes. In addition to sweetening, molasses adds flavor and acts as a humectant. It is also used in baked beans and in the production of rum and molasses alcohol. (The greatest use of molasses, however, is in the production of animal feed). Molasses comprises about 60% sucrose. Molasses is being evaluated as a health promoting food ingredient (Filipčev et al. 2010).

3.3.3 Honey

Honey, a natural viscous syrup, comprises mainly invert sugar. It is produced from the nectar of flowers, which is mainly sucrose, by the action of an invertase enzyme that is secreted by the honey bee. Honey is used as a direct sweetener, as an additive in a number of products, including baked goods, as well as in other ways. It is relatively expensive, e.g. Manuka honey used for therapeutic applications.

3.3.4 Maple Sugar

Maple sugar is produced from the sap of the sugar maple tree. It is comprised mainly of sucrose and small amounts of other sugars, including invert sugar. Maple sugar is used in the manufacture of candies, fudge, baked goods, and toppings. It is among the most expensive of sweeteners.

3.3.5 Lactose

Lactose the sugar component of mammalian milk, is less sweet and less water-soluble than sucrose. Although most babies and young children are able to metabolize this sugar, some are unable to do so. The ability to metabolize the sugar appears to decrease with age. When a person is unable to metabolize lactose, the ingestion of milk may cause intestinal discomfort, cramps, and diarrhea. The major source of lactose is whey, a cheese byproduct. Because lactose is not as sweet as sucrose, larger amounts can be used in those foods in which the texture benefits from a high solids content.

3.3.6 Maltose

Maltose or malt sugar, is produced during the malting process in brewing (enzyme conversion of starch). It is converted to alcohol by the action of yeasts through an intermediate conversion to dextrose. This sugar is much less sweet than sucrose, and it is used mainly in the manufacture of baked goods and infant foods.

3.4 Nutritive and Non-nutritive Sweeteners

Many substances are classified as nonnutritive sweeteners. Although this classification might imply a lack of nutritional value, the implication is correct only in a relative sense. For example, the caloric value of a nonnutritive sweetener such

Table 16.4 Some high-intensity tabletop sweeteners used in the US

Name[b]	Common names[b]	Sweetening effect[a]
Acylsulfame K	Sweet one	200
Advantame		20,000
Aspartame	Equal, Nutrasweet	200
Luo Han Guan extract	Nectresse, PureLo	100–250
Neotame	Neotame	7000–14,000
Saccharine	Sweet-N-Low	200–700
Steviol glycoside	Truvia	200–400
Sucralose	Splenda	600

Adapted from (U. S. Food and Drug Administration 2018), [a]Sweetening effect compared with an equal weight of sucrose. [b]Assume all names are trademarked registered trade names

as Aspartame is about 4 calories/g, which is the same as that for sugar. However, because it takes only 1 g of Aspartame to provide the same sweetness level as about 200 g of sugar (sucrose), it can be seen that the caloric contribution of Aspartame is only about 0.5% that of sucrose (Table 16.4). It is on this basis that a nonnutritive sweetener is classified as such (Butchko et al. 2002). According to the U.S. FDA, those tabletop sweeteners that contribute less than 2% of the caloric content of sucrose are referred as nonnutritive (U. S. Food and Drug Administration 2018).

3.4.1 Sugar Alcohols, Xylitol, Sorbitol and Mannitol

Xylitol, sorbitol and mannitol are the most common examples of sugar alcohols or polyols, suggested as low calorie sugar-replacers in a variety of products including baked products; sugar alcohols are used as sweeteners and bulking agent (Ghosh and Sudha 2012; Rice et al. 2020). The polyols have between 50–100% of the sweetening power of sucrose. Owing to their low metabolism, the caloric value ranges from 1.6–2.4 Cal/g (compared with 4 Cal/g for sucrose). Laterly polyols were used as sweetener in chewing gum, mainly because of their non-cariogenic property (they have not been found to cause tooth decay). Xylitol occurs naturally as a constituent of many fruits and vegetables, and is a normal intermediary product of carbohydrate metabolism in humans and in animals. Commercially, xylitol is produced by the hydrolysis of xylan (which is present in many plants) to xylose, which is then hydrogenated to produce xylitol.

Sorbitol occurs in red seaweed and in fruits (apples, cherries, peaches, pears, and prunes). It was first isolated from the sorb berries of the mountain ash, hence its name. Sorbitol is used as an additive for its humectant property and sweetening effect. Mannitol is a naturally occurring sweetener in many plants, algae, and mold. It occurs in the sap of the manna tree, an ash native to southern Italy, and can also be made by the reduction of the monosaccharides mannose or galactose.

Industrially, sugar alcohols can be produced by electrochemical reduction or catalytic hydrogenation methods. They are purified and crystallized. Xylitol imparts a sweet taste, which also appears to have a cooling effect.

3.4.2 High Intensity Sweeteners, Aspartame, Saccharine and Others

Aspartame is the common name for aspartylphenylalanine. It is a combination of the two amino acids. First produced in 1969, it is reputed to be about 200 times sweeter than sucrose. Unlike saccharin and cyclamate, Aspartame leaves no bitter aftertaste. (Butchko et al. 2002). Saccharin, the imide of o-benzosulfonic acid, is used as a sodium or calcium salt. It is about 300 times sweeter than sucrose (table sugar).

A new generation of high-intensity sweeteners are also approved for use in the US including products that are between 600-fold and 20,000–fold sweeter than sucrose (Table 16.4). Currently, Neotame™ and Advantame™ appear to be most sweetening of the commercial sweeteners. It was suggested that high-intensity sweetener may help reduce the intake of added sugar. A statement from the American Heart Association and also American Diabetic Association suggested that non-nutritive sweeteners might be useful for lowering health risks related with high intakes of added sugar, but that more studies were needed before more definite conclusions could be reached (Gardner et al. 2012)

3.5 Thickening Agents

3.5.1 Starches

Although starches differ from each other somewhat, depending on the plant from which they are extracted, they are sufficiently similar chemically to be often classified together. The properties of starch make it useful as a thickening agent. The major source of starch is corn, but some starch is also produced from sorghum, potatoes, and wheat (Eliasson 2004; BeMiller and Whistlerr 2009). Modified starches are used for thickener additives including those that are acid treated, heated, enzyme treated or chemically modified (Table 16.5).

3.5.2 Gums

Gums, a class of complex polysaccharides, are defined as materials that are dispersible in water and capable of making the water viscous. Many gums occur naturally in certain land and sea plants. Examples are gum Arabic and agar. Many gums, such as the cellulose derivatives, are modified or semisynthetic, and some gums, such as the vinyl polymers, are synthetic. Gums are used to stabilize ice cream and desserts, thicken certain beverages and preserves, stabilize foam in beer, emulsify salad dressings, and form protective coatings for meat, fish, and other products. A significant potential for the use of gums lies in the production of certain low-calorie foods. For example, the oil in salad dressing can be replaced with gums to result in a product with the normal appearance, texture, and taste but without the calories normally associated with the product.

3.5.3 Polyhydric Alcohols

In addition to their use as sweeteners, many polyhydric alcohols (sugar polyols, cf. Section 3.4) are used to improve texture and moisture retention because of their affinity for water. Many polyols occur in foods naturally, glycerine (glycerol) being the predominant one. However, only four of the many polyols are allowed as food additives. They are glycerin, sorbitol, mannitol (see above), and propylene glycol. All but the last have a moderately sweet taste although none is as sweet as sugar. Propylene glycol has a somewhat undesirable

Table 16.5 The major food additives used as thickeners or thickening agents

Name	Type	INS (¥)
Agar	Polysaccharide	406
Alginic acid	Polysaccharide	400
Alginate	Polysaccharide	402, 403, 404, 405
Arabinoglycan	Polysaccharide	409
Bakers yeast glycan	Polysaccharide	408
Beeswax	Lipid	901
Glycerol phosphate	Sugar	383
Candellilla wax	Lipid	802
Carob bean gum	Polysaccharide	410
Carrageenan	Polysaccharide	407
Cassia gum	Polysaccharide	427
CMC	Polysaccharide	468
Curdlan gum	Polysaccharide	427
Ethyl cellulose	Polysaccharide	462
Gelatin	Protein	428
Gellan gum	Polysaccharide	418
Guar gum	Polysaccharide	412
Gum Arabic	Polysaccharide	414
Gum ghatti	Polysaccharide	419
Hydroxypropyl cellulose	Polysaccharide	464 also 463 & 465
Cellulose (powdered)	Polysaccharide	460
Cellulose (microcrystalline)	Polysaccharide	460
Karaya gum	Polysaccharide	416
Konjac flour	Polysaccharide	425
Maltitols	Sugars	965
Pectins	Polysaccharide	440
Oat gums	Polysaccharide	411
Pullulan	Polysaccharide	1204
Soybean hemicellulose	Polysaccharide	426
Tannic acid	Polyphenol	181
Tara gum	Polysaccharide	417
Tragacanth gum	Polysaccharide	413
Xanthan gum	Polysaccharide	415
Xylitol	Sugar	967
Starch (acylated)	Polysaccharide	1422, 1414
Starch (acid treated)	Polysaccharide	1401
Starch (alkaline treated)	Polysaccharide	1402
Starch (roasted)	Polysaccharide	1400
Starch (bleached)	Polysaccharide	1403

Adapted from Codex Alimentarius Commission (1989a). (¥) Shows the international number system code for each additive

bitter taste, but is acceptable in small amounts. Polyols are used in the production of dietetic products including beverages, candy, gum, and ice cream to contribute to texture as well as to sweetness. They have less adverse effect on teeth than sugar, because they are not fermented as quickly as sugar and are usually washed away before being utilized by microorganisms.

3.6 Gelling Agents

Many polymer food additives function as gelling agents for controlling the water in foods. The compounds are usually large carbohydrate entities (polysaccharides) or proteins. Many of the gelling additives have additional functions at low concentrations where they form thickened solutions and function as thickeners. When applied to food surfaces, some gelling agents function as glazing agents to impart a shiny tint. The main classes of gelling food additives are shown in the table below (Table 16.6).

4 Nutrient Additives

The need for a balanced and ample nutrient intake by the human body is well known. Although nutrients are available in foods, losses of fractional amounts of some of them through processing and increasing frequency of improper dieting have led to the practice of adding minimum daily requirements or sizable fractions of minimum daily requirements of a number of nutrients to popular foods, such as breakfast cereals, baked goods, pasta products, and low-calorie breakfast drinks. Nutrient additives include mainly vitamins, proteins, and minerals.

4.1 Vitamins

Vitamin D is an exceptional example of the value of the food additive concept. The major source of vitamin D for humans is a precursor compound called 7-dehydrocholesterol which is produced in the liver. It circulates to an area just under the skin and is converted to previtamin D3 by the ultraviolet rays of sunlight. Previtamin D3 then goes through a number of steps and is converted to vitamin D3 and finally

Table 16.6 The major food additives used as gelling agents

Name	Type	INS[a]
Agar	Polysaccharide	406
Alginate	Polysaccharide	403
Alginic acid	Polysaccharide	400
Arabinogalactan	Polysaccharide	409
Carboxymethyl cellulose (CMC)	Polysaccharide	466
Carrageenan	Polysaccharide	407
Cassia gum	Polysaccharide	424
Curdlan	Polysaccharide	424
Euchema seaweed	Polysaccharide	407a
Gelatine	Protein	428
Konjac flour	Polysaccharide	425
Pectins	Polysaccharide	440
Tara gum	Polysaccharide	417
Yeast glycan	Polysaccharide	408

Adapted from Codex Alimentarius Commission (1989a). [a]Shows the international number system code for each additive to active vitamin D. However, in many cases, exposure to the sun is sporadic and insufficient, especially in areas where there is normally insufficient sunshine or in cases where sunlight exposure is of insufficient duration. Thus, vitamin D is added to nearly all commercial milk in a ration of 10 micrograms (as cholecalciferol). This is equivalent to the old 400 IU per quart (0.95 liter). Vitamins A and C and some of the B vitamins are also added to some foods.

4.2 Proteins and Amino Acids

The addition of protein concentrate (produced from fish or soybeans) to components of the diet of inhabitants of underdeveloped countries has been used successfully to remedy the high incidence of protein malnutrition. The range of applications for protein isolates, ingredients, and supplements have increased greatly for wellbeing and health, e.g. to deal with protein needs for the elderly, protein and weight management, and protein uses for sports nutrition (Hoffman and Falvo 2004; Michelfelder 2009; Hertzler et al. 2020).

4.3 Minerals

Among minerals, iron has received major attention as a food additive, mainly because of its role in preventing certain anemias. The addition of potassium chloride to foods is increasing as a replacement for table salt.

5 Processing Aides

5.1 Acidulants

From the root word, *acid,* in acidulants, one can conclude that this class of compounds tends to lower the pH of any food into which the compounds are incorporated. Acidulants also enhance desirable flavors, and in many cases, such as in pickled products, are the major taste component. Vinegar (acetic acid) is added to relishes, chili sauce, ketchup, and condiments as a flavor component and to aid in the preservation of these products. Because the microbial spoilage of food is inhibited as the pH is lowered, acidulants are used for that purpose in many cases. Many acidulants occur naturally in foods (e.g., citric acid in citrus fruits, malic acid in apples, acetic acid in vinegars; all three are contained in figs). Tartaric acid is widely used to lend tartness and enhance flavor. Citric acid is widely used in carbonated soft drinks. Phosphoric acid is one of the very few inorganic acids used as an acidulants in foods. It is widely used, comprising 25% of all the acidulants in foods. Citric acid accounts for 60% of all acidulants used in foods.

In addition to their preservative and flavor enhancing effects, acidulants are used to improve gelling properties and texture. Acidulants are also used as cleaners of dairy equipment. Acidulants may be used in the manufacture of processed cheese and cheese spreads for the purpose of emulsification as well as to provide a desirable tartness.

Acid salts may be added to soft drinks to provide a buffering action (buffers tend to prevent changes in pH) which will prevent excess tartness. In some cases, acid salts are used to inhibit mold growth (e.g., calcium propionate added to bread).

As has been pointed out, all microorganisms have a pH at which they grow best (See Chap. 7, Sect. 3), and a range of pH above or below which they will not grow. Generally, it is not possible to preserve all foods by adding acid to the point where microorganisms will not grow. Most foods would be too acid to be palatable. The amount of acid may be enough to inhibit the growth of microorganisms if such treatment is combined with some other method of preservation. Certain dairy products, such as sour cream, and fermented vegetables, such as sauerkraut, are preserved with lactic acid produced by the growth of bacteria. Addition of the acid, along with holding at refrigerator temperatures above freezing, in combination will prevent growth of pathogenic and spoilage organisms. When sauerkraut is canned, it is given a heat process sufficient to destroy all spoilage and disease microorganisms.

Pickles are preserved by the addition of some salt, some acid, and a heat process sufficient to raise the temperature of all parts of the food to or near 212 °F (100 °C). Pickled herring are preserved by the addition of some salt, some acetic acid (vinegar), and holding at refrigerator temperatures above freezing. In this case, the nonacid part of the acetic acid molecule has an inhibiting effect on the growth of microorganisms.

5.2 Alkaline Compounds

Alkaline compounds are compounds that raise the pH. Alkaline compounds, such as sodium hydroxide or potassium hydroxide, may be used to neutralize excess acid that can develop in natural or cultured fermented foods. Thus, the acid in cream may be partially neutralized prior to churning in the manufacture of butter. If this were not done, the excess acid would result in the development of undesirable flavors. Sodium carbonate and sodium bicarbonate are used to refine rendered fats. Alkaline compounds are also added to chlorinated drinking water to adjust the pH to high enough levels to control the corrosive effects of chlorine on pipes and equipment. Sodium carbonate is also used in conjunction with other compounds to reduce the amount of hardness in drinking water. Sodium hydroxide is used to modify starches and in the production of caramel. Sodium bicarbonate is used as an ingredient of baking powder, which is used in baked products. (It is also a common household item used in a variety of cooking recipes.) Its action is described in the "Leavening Agents" section of this chapter. Alkaline compounds are used in the production of chocolate and to adjust the acidity level in grape juice and other fruit juices that are to be fermented in the production of wine.

Itis important to note that some alkaline compounds, such as sodium bicarbonate, are relatively mild and safe to use, while others, such as sodium hydroxide and potassium hydroxide, are relatively powerful reagents and should not be handled by inexperienced people.

5.3 Enzymes

Enzymes occur naturally in foods, and their presence may be either beneficial or detrimental, depending on the particular enzyme. When the presence of enzymes is undesirable, steps are taken to inactivate them. When their presence is desirable, either the enzymes or sources of the enzymes are intentionally added to foods.

The use of enzymes as food additives presents no problem from the standpoint of safety, because enzymes occur naturally, are nontoxic, and easily inactivated, when desired. Enzymes applications in the food industry are too diverse to cover in the limited space available. A few examples of enzyme uses in food manufacturing are given in this section.

For baking (bread, cakes and biscuits); we find microbe derived proteases (usually) being used to modify dough properties. In the dairy industry – plant derived proteases and rennet substitutes are used for cheese manufacturing. In the meat and protein industry – papain and other proteases are used for tenderizing meat and for protein recovery. The brewing and beverage industry employs pectinases to reduce haze. The fruit and vegetable processors use pectinases for juice clarification and tomato juice manufacture. The starch and sugar sector uses starch degrading enzymes and others in the production of high fructose corn syrup. Lipases are used in modifying and producing specialty fats for confectionary applications and for degumming (Miguel et al. 2013; Whitehurst and Van Oort 2009; Novozyme 2014). Some other enzymes uses are described below.

5.3.1 Invertase

Certain enzymes, such as invertase, split disaccharides, such as sucrose (table sugar), to lower sugars (glucose and levulose). Invertase has many applications, and is used, for example, to prevent crystallization of the sucrose that is used in large amounts in the production of liqueurs. Without invertase, the liqueurs would appear cloudy.

5.3.2 Pectinase

Pectinases are enzymes that split pectin, a polysaccharide that occurs naturally in plant tissues, especially those of fruit. Pectin holds dispersed particles in suspension, as in tomato juice. Because it is desirable to keep the thick suspension in tomato juice, pectinases that occur naturally in it are inactivated by heat. On the other hand, products such as apple juice are customarily clear, and this is accomplished by adding commercial pectinase to the product, which degrades the pectin in the apple juice, resulting in the settling out of the suspended particles, which are then separated from the clear juice. In the manufacture of clear jellies from fruits, it is first necessary to add pectinase to destroy the naturally occurring pectin in order to clarify the juice. This pectinase must now be inactivated by heat. Then more pectin must be added to the clarified juice to produce the thick consistency of jelly. If the pectinase is not inactivated after clarification, the enzyme would also break down the newly added pectin required to produce the thick consistency.

5.3.3 Cellulases

Cellulases are enzymes that can break down cellulose, said to be the most abundant form of carbohydrate in nature. Cellulose, the principal structural material in plants, is insoluble in water and is indigestible by humans and many animals. Ruminants are able to digest cellulose because of a cellulase (produced by microorganisms in the large stomach) contained in their gastric juice. Commercial applications of cellulases are not widespread at present. Cellulases are used for tenderizing fibrous vegetables and other indigestible plant material for the production of foods or animal feed.

5.3.4 Proteases

Proteases are enzymes that break down proteins, polypeptides, and peptides. Peptides are the structural units of which polypeptides consist, and polypeptides are larger structural units that make up the protein. There is a large number of specific proteases, and each attacks protein molecules at different sites, producing a variety of end products. Proteases are used to manufacture soy sauce from roasted soybeans, cheese from milk, and bread dough from flour. They are also used to tenderize meat and chill-proof beer, which, if untreated, develops an undesirable haze when chilled (see above).

5.3.5 Lipases

Lipases, the lipid (fat or oil) splitting enzymes, have commercial application (as mentioned above). Lipases prepared from microbial sources are used the production of certain cheeses and other dairy products, as well as lipase-treated butterfat used in the manufacture of candies, confections, and baked products. Lipases are also used to remove fat residuals from egg whites and in drain cleaner preparations.

5.3.6 Glucose Oxidase

Glucose oxidase is an enzyme that specifically catalyzes the oxidation of glucose to gluconic acid. This reaction is important in preventing nonenzymatic browning, because glucose is a reactant in the undesirable browning reaction. The most important application of this enzyme is in the treatment of egg products, especially egg whites, prior to drying. Eggs treated with this enzyme before they are dried do not undergo nonenzymatic browning during storage, because the sugar has been removed. In some cases, the enzyme is added to remove traces of oxygen to prevent oxidative degradation of quality. Examples of this type of application are mayonnaise and bottled and canned beverages (especially beer and citrus drinks).

5.3.7 Catalase

Catalases are used to break down hydrogen peroxide to water and oxygen. Therefore, catalases are used when the presence of hydrogen peroxide is undesirable or when hydrogen peroxide is used for specific purposes, such as in bleaching, but then must be removed from the system. Examples of the latter case are the uses of hydrogen peroxide for preserving milk in areas where heat pasteurization and refrigeration are unavailable and in the manufacture of cheese from unpasteurized milk.

5.4 Surface-Active Agents and Emulsifiers

Surface-active agents affect physical forces at interfaces of surfaces. Commonly called surfactants or emulsifies, they are present in all natural foods, because by their nature they play a role in the growth process of plants and animals. They are defined as organic compounds that affect surface activities of certain materials. They act as wetting agents, lubricants, dispersing agents, detergents, emulsifiers, solubilizes, and so forth. Emulsifiers, such as lecithin, mono- and diglycerides, and wetting agents, such as "tweens," may be added to bakery products (to improve volume and texture of the finished products and the working properties of the dough and to prevent staling of the crumb), cake mixes, ice cream, and frozen desserts (to improve whipping properties). Except for the tweens, the chemicals cited above are natural components of certain foods (Goecmen 1993; Schuster and Adams 1984; Stampfli and Nersten 1995).

5.5 Leavening Agents

Leavening agents are used to enhance the rising of dough in the manufacture of baked products. Inorganic salts, especially ammonium and phosphate salts, favor the growth of yeasts, which produce the carbon dioxide gas that causes dough to rise. Chemical reagents that react to form carbon dioxide are also used in baked goods. When sodium bicarbonate, ammonium carbonate, or ammonium bicarbonate is reacted with potassium acid tartrate, sodium aluminum tartrate, and sodium aluminum phosphate, or tartaric acid, carbon dioxide is produced. Baking powder is a common household leavining agent that contains a mixture of chemical compounds that react to form carbon dioxide, producing the leavining effect. Baking powder can be either single acting or double acting, giving the desired leavining effect in different products. The carbon dioxide gas is liberated when sodium bicarbonate (the base) reacts with potassium acid tartrate (the potassium salt of tartaric acid).

The double-acting baking powder has two acid-reacting ingredients (monocalcium phosphate monohydrate and sodium aluminum sulfate). The hydrated form of monocalcium phosphate reacts with sodium bicarbonate to release some carbon dioxide during mixing a batter or dough. The remaining sodium bicarbonate will react with sulfuric acid that is produced from the sodium aluminum sulfate; the major portion of carbon dioxide is released whilst the product is heated in the oven.

6 Chemical Preservatives

6.1 Antioxidants

Antioxidants are food additives used, since about 1947, to stabilize foods that by their composition would otherwise undergo significant loss in quality in the presence of oxygen (Finley and Given 1986). Oxidative quality changes in foods include: (i) the development of rancidity from the oxidation of unsaturated fats resulting in off-odors and off-flavors and (ii) discoloration from oxidation of pigments or other components of the food.

There is a large number of antioxidants, and although they may function in different ways, the purpose of each is to prevent, delay, or minimize the oxidation of the food to which they are added. One of the ways by which some antioxidants function involves their combination with oxygen. Others prevent oxygen from reacting with components of the food. When only a limited amount of oxygen is present, as in a hermetically sealed container, it is possible for some antioxidants to use up all of the available free oxygen, because they have a relatively great affinity for it. Some antioxidants lose their effectiveness when they combine with oxygen; therefore, there is no advantage to using this type of antioxidant unless the food is enclosed in a system from which oxygen or air can be excluded. With the use of antioxidants, it should be noted that other precautions are necessary to minimize oxidation, because heat, light, and metals are prooxidants, that is, their presence favors oxidative reactions.

6.1.1 Natural Antioxidants

Many of the antioxidants used commercially occur naturally (e.g., vitamin C, Vitamin E, citric acid, and certain phenolic compounds). However, the amines and the phenolic compounds can be toxic to humans in low concentrations; therefore, their use and that of synthetic antioxidants require strict regulation. It should be pointed out that the potency of the naturally occurring antioxidants is not as great as that of the commonly used synthetic antioxidants.

6.1.2 Synthetic Antioxidants

Fats and shortenings, especially those used in bakery goods and fried foods, are subject to oxidation and the development of rancidity after cooking. To prevent this, chemical antioxidants in concentrations up to 0.02% of the weight of the fat component may be added. The main synthetic antioxidants and most widely used are butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and propylgallate. These are generally used in formulations that contain combinations of two or all three of them, and often in combination with a fourth component, frequently citric acid. The main purpose of adding citric acid is that it serves as a chelator or sequestrant (a chelator ties up metals, thereby preventing metal catalysis of oxidative reactions).

The use of antioxidants is regulated by the FDA and is subject to other regulations, such as the Meat Inspection Act and the Poultry Inspection Act. Their use is limited so that the maximum amount that can be added is generally 0.02% of the fat content of the food; however, there are some exceptions to, and variations of, that rule.

6.1.3 Benzoates

The benzoates and para-benzoates have been used as preservatives mainly in fruit juices, syrups (especially chocolate syrup), candied fruit peel, pie fillings, pickled vegetables, relishes, horseradish, and some cheeses. The probable reason that the benzoates and the related para-benzoates have been allowed as additives to food is that benzoic acid is present in cranberries as a natural component in concentrations that are higher than 0.1%. The benzoates are most effective in acid foods in which the pH is as low as 4.0 or below where compound exists as benzoic acid. The para-benzoates are said to be more effective than the benzoates over a wider range of pH (Del Olmo et al. 2017).

6.1.4 Sequestrants

Because metals catalyze oxidative reactions, a sequestrant can be considered to have antioxidant properties. The role of sequestrants is to combine with metals, forming complexes with them and making them unavailable for other reactions. Sequestrants, like many other additives used for enhancing specific properties of foods, occur naturally in foods. Many sequestrants have other properties; for example, citric, malic, and tartaric acids are acidulants but they also have sequestering properties.

Thus, they stabilize foods against oxidative rancidity and oxidative discoloration. Sequestrant antioxidants protect vitamins, which are unstable when exposed to metal catalyzed oxidation. Sequestrants are used to stabilize the color of many canned products e.g. color and lipids in canned fish and shellfish, which have high concentrations of metal and poor color stability. Sequestrants are also used to stabilize the flavors and odors in dairy products and the color in meat products.

6.2 Antimicrobial Agents

The practice of preserving food by the addition of chemical is quite old, Many chemical substances used in the preservation of foods occur naturally. When they are used with the proper intent, they can be used to preserve foods that cannot be easily preserved by other means. To preserve food, it is necessary either to destroy all of the spoilage microorganisms that contaminate it or to create and maintain conditions that prevent the microbes from carrying out their ordinary life processes. There are additive free methods for food preservation including food drying, freezing and refrigeration.

6.2.1 Antibiotics

Conventional antibiotics can be used as feed additives, growth promoters or for treatment of animal diseases. The use of antibiotics in the food system has led to concerns with antimicrobial resistant strains (CDC 2020).

6.2.2 Fatty Acids

The salts of certain short chain fatty acids have an inhibitory effect on the growth of microorganisms. Thus, sodium diacetate (a mixture of sodium acetate and acetic acid) and sodium or calcium propionate are added to bread and other bakery products to prevent mold growth, as well as the development of a slimy condition known as "ropiness," which results from the growth of certain aerobic, spore-forming bacteria (see Chap. 3 for the definition of spore forming bacteria). Caprylic acid, CH3CH2-CH2-CH2-COOH, or its salts or the salts of other fatty acids may be used in cheese to prevent the growth of mold.

6.2.3 Sequestrant Antimicrobial Agents

The high mineral requirement by microorganism allows the use of sequestrants or chelating agents (chemicals that tie up metals and prevent the catalytic action of metals) to function as antimicrobial agents. The compound EDTA and citric acid from lemon and citrus fruit are good chelating agents, alongside of many plant-derived chemicals – polyphenols.

6.2.4 Sodium Chloride (Salt)

When sufficient salt is added to food, it makes water unavailable to microorganisms. Because microorganisms require water to survive, they cannot exist when their water requirement is diminished by the addition of salt. We can reduce the amount of water available to microorganisms by lowering the water activity (A_W). (For more on A_W see Chap. 7 -Sect 3 & Chap. 14 -Sect. 1.3) Some precautions must be observed in the salting preservation of flesh-type foods, such as fish or meats. The usual procedure is to hold products under refrigeration at 40–60 °F (4–15 °C) during salting until there has been an adequate "take-up" of salt throughout the food. If, such, precautions are not observed, the growth of spoilage or even disease-causing bacteria may occur in some parts of the food before enough salt has diffused into the product to inhibit growth.

6.2.5 Sulfur Dioxide

Sulfur dioxide or a source of this compound such as sodium bisulfite (NaHS03) may be added to foods to inhibit a narrow range of microorganisms. Therefore sulfur dioxide is usually applied together with another chemical inhibitor to prevent the growth of undesirable yeasts or bacteria in fruit juices, which are stored prior to fermentation, in the production of wine or vinegar. For many years, sulfiting agents have been classified as GRAS substances by the FDA for use as food preservatives when used in accordance with GMP (good manufacturing practice). However, the GRAS status does not apply for sulfur dioxide uses in three scenarios; (i) use with meat, (ii) use with fruits and vegetable products served or sold as raw to the consumer and (iii) foods that are sources of thiamine (vitamin B1). Sulfites may still be used in foods that have not been excluded by the FDA, their presence must be declared on the label when their concentrations exceed 10 ppm (parts per million). Research has shown that in concentrations of 10 ppm or less, these agents should not cause adverse reactions in humans (U. S. Food and Drug Administration 2019).

6.2.6 Sorbic Acid

Sorbic acid inhibits the growth of both yeasts and molds. This compound is most effective at pH 5.0 or below. Humans can metabolize this compound, as can fatty acids, and hence it is generally recognized as safe. Sorbic acid is used in certain bakery products (not yeast-leavened products, because it inhibits yeast growth), in cheeses, and in some fruit drinks, especially for the purpose of preventing molding. It is believed to inhibit the metabolic enzymes required by certain microorganisms for growth and multiplication.

6.2.7 Sodium Nitrite

Sodium nitrite is added to some food products to inhibit bacterial growth (especially *Cl. botuli-*

num) and to enhance color (U. S. Food and Drug Administration 2015). It is added to most cured meats, including hams, bacon, cooked sausage (such as frankfurters, bologna, salami), and to some kinds of corned beef. Nitrite provides for the red or pink color of the cured and cooked sausages and of the other cured products after cooking. The nitrite combines with the reddish pigment of meat, the myoglobin, and prevents its oxidation. If the meat were not treated with nitrite, it would discolor to a brown color during cooking or during storage. When red meat is heated, as in cooking, the color turns from red to gray or brown because of the conversion of myoglobin to the oxidized form, metmyoglobin. With intense heating or exposure to light and oxygen, even the nitrited myoglobin may be oxidized to metmyoglobin, with the result that the red or pink color is lost (Cammack et al. 1999; Alahakoon et al. 2015).

In addition to stabilizing the color of cured or cured and cooked meats, nitrite acts as a preservative to prevent the germination of spores and subsequent toxin production by *Cl. botulinum* (Chap. 17, Sect. 4)

It is uncertain whether or not nitrites should be allowed in food in any concentration. At present, the maximum usage levels are 10 ppm (10 mg/kg) nitrite for cured/smoked tuna fish and 200 ppm nitrite for cured/smoked salmon and smoked whitefish e.g. shads and chubs (21 CFR 172.170). However, sodium or potassium nitrite may not be used for fresh meat or fresh fish sold as such. The level of nitrite used for cured meat is 200ppm or lower with or without 500 ppm nitrate (U. S. Food and Drug Administration, 2015). National survey results showed the average level of nitrite were 4.54-ppm together with 37.07-ppm nitrate across the entire range of processed meats (Bryan et al. 2015).

Nitrite-cured products, especially those cooked at high temperatures, such as bacon, may develop nitrosamines, which are known to be extremely carcinogenic or cancer promoting. It is clear that the amount of nitrites used must be minimized but the level must remain high enough to protect against botulism and other microbiologically based foodborne diseases (Hord et al. 2009).

The levels of nitrite occurring naturally in some vegetables is surprisingly high (Santamaria 1997; Ferysiuk and Wójciak 2020). Therefore, some vegetable powders (e.g. spinach, kale, Chinese cabbage etc.) were used as sources of nitrite or nitrate for processed meat products labelled as, “No Nitrate or Nitrite Added” or “uncured” by manufacturers (Pennisi et al. 2020; Yong et al. 2021). Following objections from US consumer groups (Porter et al. 2020), these alternatively cured or “indirectly cured” food may not in the future qualify as additives-free or clean-label products (Devenyns 2020; McCarthy 2020).

6.2.8 Oxidizing Agents

Oxidizing agents, such as chlorine, iodine, and hydrogen peroxide, are not ordinarily used in food, but they are used to sanitize food-processing equipment and apparatus and even the walls and floors of areas where food is processed (Lopes 1986). Furthermore, some sanitizers are used for the disinfection of fresh produce surfaces, e.g. poultry, fruits and vegetables (Bolder 1997; Gómez-López et al. 2009; Prado-Silva et al. 2015). Thus, there is no doubt that small residuals, especially of chlorine or iodine, can get into food.

Hydrogen peroxide may be used to destroy the natural bacterial flora of milk, prior to inoculation with cultures of known bacterial species, for producing specific dairy products. In such cases, all of the residual hydrogen peroxide must be removed by treatment with the enzyme catalase. This treatment with catalase must be carried out prior to the inoculation of milk with cultures of desirable bacteria; otherwise the hydrogen peroxide will destroy the added bacterial culture, the growth of which is the objective of culturing milk.

Oxidizing agents are believed to inhibit and destroy the growth of microorganisms by destroying certain parts of the enzymes essential to the metabolic processes of these organisms.

6.3 Ionizing Radiation

The Food Additives Amendment of 1958 included ionizing radiation as a food additive. Ionization radiation is considered an additive because the irradiation may induce changes in food. In this case, the FDA tests foods that have been irradiated and approves irradiation sources and maximum dosages.

Irradiation does not leave a residue in food and it does not make it radioactive (Institute of Food Science and Technology (IFST) 2015). The levels of irradiation allowed in food processing do not induce measurable radioactivity. Any radioactivity found in irradiated foods has been shown to be "background radiation" or that which is already present naturally. Irradiation does cause small chemical changes in the food, as do other methods of food processing (Fig. 16.2).

Foods that have been irradiated must be labeled with the green international logo (see Fig. 16.2) to inform the consumer that the food has been processed by ionizing radiation. The words "Treated with Radiation" or "Treated by Irradiation" must also appear and must be in the same print style as the product name and be no smaller than one-third the size of the largest letter in the product name.

Long-term effects of consumption of irradiated products have been discussed. The safety of irradiated foods has been tested in feeding studies for over 40 years. The studies include both animal and human subjects. Chemistry studies, feeding studies, and mutagenicity and teratogenicity studies have not revealed any confirmable negative evidence as to the wholesomeness of foods preserved by ionization radiation. Nutrient retention of irradiated foods is comparable to that of heat-processed foods. Irradiated foods may be more susceptible to oxidation but this can be controlled by use of low temperatures and elimination of oxygen.

Fig. 16.2 International radiation logo (green in color)

Food irradiation remains a polarizing topic. However, there are over 50 countries where the use of ionizing radiation to sanitize and disinfect selected types of food is allowed (Institute of Food Science and Technology (IFST) (2015); Parnes and Lichtenstein 2004; Mahapatra et al. 2005; Maherani et al. 2016; Munir and Federighi 2020). The following articles may provide some insights about current debates concerning food irradiation (Louria 2000; Thayer 2000).

References

Alahakoon AU, Jayasena DD, Ramachandra S, Jo C (2015) Alternatives to nitrite in processed meat: up to date. Trends Food Sci Technol 45(1):37–49. https://www.sciencedirect.com/science/article/abs/pii/S0924224415001429

Armstrong DJ (2009) Food chemistry and U.S. food regulations. J Agric Food Chem 57(18):8180–8186

Bantle JP (2009) Dietary fructose and metabolic syndrome and diabetes. J Nutr 139(6):1263S–1268S

Beauchamp GK (2009) Sensory and receptor responses to umami: an overview of pioneering work. Am J Clin Nutr 90(3):723S–727S. https://doi.org/10.3945/ajcn.2009.27462E

BeMiller JN, Whistler RL (2009) Starch: chemistry and technology. Elsevier Science, 894pp. https://books.google.co.uk/books?id=Anbz_whRM2YC

Bolder NM (1997) Decontamination of meat and poultry carcasses. Trends Food Sci Technol 8(7):221–227

Bryan N, Osburn W, Keeton J, Hardin M (2015) A national survey of the nitrite/nitrate concentrations in cured meat products and non-meat foods available at retail, from https://www.nal.usda.gov/fsrio/research-projects/national-survey-nitritenitrate-concentrations-cured-meat-products-and-non-meat-foods-available

Burdock GA, Carabin IG (2004) Generally recognized as safe (GRAS): history and description. Toxicol Lett 150(1):3–18

Butchko HH, Stargel WW, Comer CP, Mayhew DA, Benninger C, Blackburn GL et al (2002) Aspartame: review of safety. Regul Toxicol Pharmacol 35(2):S1–S93. https://doi.org/10.1006/rtph.2002.1542

Cammack R, Joannou CL, Cui XY, Torres Martinez C, Maraj SR, Hughes MN (1999) Nitrite and nitrosyl

compounds in food preservation. Biochim Biophys Acta 1411(2-3):475–488. https://pubmed.ncbi.nlm.nih.gov/10320676/
CDC (2020) Antibiotic/antimicrobial resistance (AR/AMR). Retrieved from https://www.cdc.gov/drugresistance/index.html
Choo VL, Viguiliouk E, Blanco Mejia S, Cozma AI, Khan TA, Ha V et al (2018) Food sources of fructose-containing sugars and glycaemic control: systematic review and meta-analysis of controlled intervention studies. BMJ 363:k4644. https://doi.org/10.1136/bmj.k4644
Codex Alimentarious Commission (1995) General standard for food additives. Codex stan 192–1995. Adopted in 1995. Revision 1997, 1999, 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019. Retrieved from http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B192-1995%252FCXS_192e.pdf
Codex Alimentarius Commission (1981) Codex general standard for the labeling of food additives when sold as such: CODEX STAN 107–1981. Retrieved from http://www.fao.org/docrep/005/y2770e/y2770e03.htm#fn8
Codex Alimentarius Commission (1985) Codex general standard for the labeling of prepackaged foods: CODEX STAN 1–1985 (Rev. 1–1991)[1]. Retrieved from http://www.fao.org/docrep/005/y2770e/y2770e02.htm
Codex Alimentarius Commission (1989a, 2015) Class names and the international numbering system for food additives: CAC/GL 36-1989 Adopted in 1989. Revision: 2008. Amendment: 2015. Retrieved from http://www.fao.org/input/download/standards/13341/CXG_036e_2015.pdf
Codex Alimentarius Commission (1989b) Codex class names and the international numbering system for food additives CAC/GL 36-1989. Retrieved from http://www.codexalimentarius.org/input/download/standards/13341/CXG_036e.pdf
Codex Alimentarius Commission (2015) GSFA online: codex General Standard for Food Additives (GSFA) online database Retrieved from http://www.codexalimentarius.net/gsfaonline/index.html
David TJ (1988) Food additives. Arch Dis Child 63(6):582–583
Del Olmo A, Calzada J, Nunez M (2017) Benzoic acid and its derivatives as naturally occurring compounds in foods and as additives: uses, exposure, and controversy. Crit Rev Food Sci Nutr 57(14):3084–3103. https://doi.org/10.1080/10408398.2015.1087964
Devenyns J (2020) USDA plans to crack down on nitrate and nitrite labeling claims in meat. From https://www.fooddive.com/news/usda-plans-to-crack-down-on-nitrate-and-nitrite-labeling-claims-in-meat/592240
Eliasson AC (2004) Starch in food: structure, function and applications. Taylor Francis, 605pp
Eur-Lex (2011) Commission Regulation (EU) No 1130/2011 of 11 November 2011 amending Annex III to Regulation (EC) No 1333/2008 of the European Parliament and of the Council on food additives by establishing a Union list of food additives approved for use in food additives, food enzymes, food flavourings and nutrients Text with EEA relevance Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1410296955393&uri=CELEX:32011R1130
Europa (2014) Food additives and flavourings. Retrieved from http://ec.europa.eu/food/fs/sfp/flav_index_en.html
Fennema OR (1987) Food additives–an unending controversy. Am J Clin Nutr 46(1 Suppl):201–203. https://doi.org/10.1093/ajcn/46.1.201
Ferysiuk K, Wójciak KM (2020) Reduction of nitrite in meat products through the application of various plant-based ingredients. Antioxidants (Basel) 9(8):28pp. https://mdpi-res.com/d_attachment/antioxidants/antioxidants-09-00711/article_deploy/antioxidants-00709-00711-v00712.pdf
Filipčev B, Lević L, Bodroža-Solarov M, Mišljenović N, Koprivica G (2010) Quality characteristics and antioxidant properties of breads supplemented with sugar beet molasses-based ingredients. Int J Food Prop 13(5):1035–1053
Finley JW, Given P Jr (1986) Technological necessity of antioxidants in the food industry. Food Chem Toxicol 24(10–11):999–1006. https://doi.org/10.1016/0278-6915(86)90280-2
Food and Agriculture Organization of the United Nations (2013) Online edition: "combined compendium of food additive specifications". Retrieved from http://www.fao.org/food/food-safety-quality/scientific-advice/jecfa/jecfa-additives/en/
Food and Drug Administration (USDA) (2013) Everything added to food in the US (EAFUS). Retrieved from http://www.accessdata.fda.gov/scripts/fcn/fcnnavigation.cfm?rpt=eafuslisting&displayAll=true
Food and Drug Administration (USDA) (2015) Food ingredients and packaging terms. Retrieved from http://www.fda.gov/Food/IngredientsPackagingLabeling/Definitions/default.htm
Gardner C, Wylie-Rosett J, Gidding SS, Steffen LM, Johnson RK, Reader D, Lichtenstein AH (2012) Nonnutritive sweeteners: current use and health perspectives: a scientific statement from the American Heart Association and the American Diabetes Association. Circulation 126(4):509–519
Ghosh S, Sudha M (2012) A review on polyols: new frontiers for health-based bakery products. Int J Food Sci Nutr 63(3):372–379
Goecmen D (1993) The effect of flour and additives on bread quality and staling. Gida 18(5):325–331
Gómez-López VM, Rajkovic A, Ragaert P, Smigic N, Devlieghere F (2009) Chlorine dioxide for minimally processed produce preservation: a review. Trends Food Sci Technol 20(1):17–26
Hanlon P, Brorby GP, Krishan M (2016) A risk-based strategy for evaluating mitigation options for process-formed compounds in food: workshop proceedings. Int J Toxicol 35(3):358–370

Hertzler SR, Lieblein-Boff JC, Weiler M, Allgeier C (2020) Plant proteins: assessing their nutritional quality and effects on health and physical function. Nutrients 12(12).: 27pp. https://res.mdpi.com/d_attachment/nutrients/nutrients-12-03704/article_deploy/nutrients-03712-03704-v03703.pdf

Hoffman JR, Falvo MJ (2004) Protein - which is best? J Sports Sci Med 3(3):118–130. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3905294/pdf/jssm-3905203-3905118.pdf

Hord NG, Tang Y, Bryan NS (2009) Food sources of nitrates and nitrites: the physiologic context for potential health benefits. Am J Clin Nutr 90(1):1–10

Hoyle R (1996) Delaney clause knocked out by surprise compromise act. Nat Biotechnol 14(9):1056

Institute of Food Science and Technology (IFST) (2015) Food irradiation. Retrieved from https://www.ifst.org/resources/information-statements/food-irradiation

Jackson LS (2009) Chemical food safety issues in the United States: past, present, and future. J Agric Food Chem 57(18):8161–8170. https://doi.org/10.1021/jf900628u

JEFCA (2015) Online edition: "combined compendium of food additive specifications". Retrieved from http://www.fao.org/ag/agn/jecfa-additives/index.html

Jelen H (2011) Food flavors. Chemical, sensory and technological properties. CRC Press, 504pp

Joint FAO/WHO Expert Committee on Food Additives (2001) Gellan gum (WHO Food Additives Series 28). Summary of Evaluations Performed by the JEFAC for gellan gum. Retrieved from http://www.inchem.org/documents/jecfa/jecmono/v28je17.htm

Lester SU (1996) Delaney is still the best protection. Environ Health Perspect 104(4):352

Lester SU, Staples RE (1996) Delaney still the best protection comment: teratogens and the Delaney Clause. Environ Health Perspect 104(4):352

Lewis C (2002) The 'Poison Squad' and the advent of food and drug regulation. FDA Consum 36(6):12–15

Lopes JA (1986) Evaluation of dairy and food plant sanitizers against *Salmonella typhimurium* and *Listeria monocytogenes*. J Dairy Sci 69(11):2791–2796

Louria DB (2000) Counterpoint on food irradiation. Int J Infect Dis 4(2):67–69. https://www.ncbi.nlm.nih.gov/pubmed/10737841

Maherani B, Hossain F, Criado P, Ben-Fadhel Y, Salmieri S, Lacroix M (2016) World market development and consumer acceptance of irradiation technology. Foods 5(4):21pp. https://res.mdpi.com/d_attachment/foods/foods-05-00079/article_deploy/foods-00005-00079.pdf

McCarthy R (2020) FSIS addresses 'nitrates/nitrites' meat product labeling. Food Business News: 2pp. https://www.foodbusinessnews.net/articles/17544-fsis-addresses-nitratesnitrites-meat-product-labeling

Michelfelder AJ (2009) Soy: a complete source of protein. Am Fam Physician 79(1):43–47

Miguel A, Martins-Meyer TS, Figueiredo EVDC, Lobo BWP, Dellamora-Ortiz GM (2013) Enzymes in bakery: current and future trends. Food industry: IntechOpen, pp 278–321. https://www.intechopen.com/chapters/41661

Munir MT, Federighi M (2020) Control of foodborne biological hazards by ionizing radiations. Foods 9(7):23pp. https://res.mdpi.com/d_attachment/foods/foods-09-00878/article_deploy/foods-00809-00878.pdf

Novozyme (2014) Enzymes at work. Retrieved from http://www.novozymes.com/en/about-us/brochures/Documents/Enzymes_at_work.pdf

Neltner TG, Kulkarni NR, Alger HM, Maffini MV, Bongard ED, Fortin ND, Olson ED (2011) Navigating the US food additive regulatory program. Compr Rev Food Sci Food Saf 10(6):342–368. https://doi.org/10.1111/j.1541-4337.2011.00166.x

Neltner TG, Alger HM, O'Reilly JT, Krimsky S, Bero LA, Maffini MV (2013) Conflicts of interest in approvals of additives to food determined to be generally recognized as safe: out of balance. JAMA Intern Med 173(22):2032–2036

Nicole W (2013) Secret ingredients: who knows what's in your food? Environ Health Perspect 121(4): a126–a133

Parnes RB, Lichtenstein AH (2004) Food irradiation: a safe and useful technology. Nutr Clin Care 7(4):149–155

Pennisi L, Verrocchi E, Paludi D, Vergara A (2020) Effects of vegetable powders as nitrite alternative in Italian dry fermented sausage. Ital J Food Saf 9(2):8422. https://www.pagepressjournals.org/index.php/ijfs/article/download/8422/8907

Picut CA, Parker GA (1992) Interpreting the Delaney Clause in the 21st century. Toxicol Pathol 20(4):617–627, discussion 628–619

Porter ES, Castles C, Laudon KG, Fries AN (2020) United States: consumer groups file petition urging the USDA to change meat labeling requirements. Mondaq.com: 4pp. https://www.mondaq.com/unitedstates/consumer-law/879964/consumer-groups-file-petition-urging-the-usda-to-change-meat-labeling-requirements

Prado-Silva L, Cadavez V, Gonzales-Barron U, Rezende AC, Sant'Ana AS (2015) Meta-analysis of the effects of sanitizing treatments on Salmonella, Escherichia coli O157:H7, and Listeria monocytogenes inactivation in fresh produce. Appl Environ Microbiol 81(23):8008–8021. https://doi.org/10.1128/AEM.02216-15

Rice T, Zannini E, Arendt EK, Coffey A (2020) A review of polyols–biotechnological production, food applications, regulation, labeling and health effects. Crit Rev Food Sci Nutr 60(12):2034–2051

Rulis AM, Levitt JA (2009) FDA'S food ingredient approval process: safety assurance based on scientific assessment. Regul Toxicol Pharm 53(1):20–31

Santamaria P (1997) Occurrence of nitrate and nitrite in vegetables and total dietary intakes. Industrie Alimentari 36(364):1329–1334

Schiffman SS (1998) Sensory enhancement of foods for the elderly with monosodium glutamate and flavors. Food Rev Intl 14(2–3):321–333

Schuster G, Adams WF (1984) Emulsifiers as additives in bread and fine baked products. Adv Cereal Sci Technol 6:139–287

Smith J, Hong-Shum L (2011) Food additives data book. Wiley, 1128 pages
Stampfli L, Nersten B (1995) Emulsifiers in bread making. Food Chem 52(4):353–360
Struck S, Jaros D, Brennan CS, Rohm H (2014) Sugar replacement in sweetened bakery goods. Int J Food Sci Technol 49(9):1963–1976
Thayer DW (2000) Are there valid concerns about food irradiation? Int J Infect Dis 4(4):232–234. author reply 234-235 https://www.ncbi.nlm.nih.gov/pubmed/11231191
U. S. Food and Drug Administration (2015) 21.CFR Part 172.175 sodium nitrite. Retrieved from https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=172.175
U. S. Food and Drug Administration (2018) Additional information about high-intensity sweeteners permitted for use in food in the United States. Retrieved from https://www.fda.gov/food/food-additives-petitions/additional-information-about-high-intensity-sweeteners-permitted-use-food-united-states
U. S. Food and Drug Administration (2019) CFR 21CFR182.3862. Substances Generally Recognized As Safe. Subpart D–Chemical Preservatives. Sec. 182.3862 Sulfur dioxide
U.S. Food and Drug Administration (2014a) Overview of food ingredients, additives & colors international food information council (IFIC) and U.S. Food and drug administration November 2004; revised April 2010. Retrieved from http://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm094211.htm
U.S. Food and Drug Administration (2014b) Overview of food ingredients, additives & colors. Retrieved from http://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm115326.htm
U.S. Government Publishing Office (2012) Code of Federal Regulations. Title 21–Food and Drugs; Chapter 1; Food and Drug Administration Department Of Health And Human Services, Subchapter B. Food for human consumption (continued). Part 172 Food additives permitted for direct addition to food for human consumption. Subpart I–Multipurpose additives Sec. 172.892 Food Starch-Modified. *21 CFR 172.892 – Modified Starch*. Retrieved from http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?fr=172.892
U.S. Government Publishing Office (2014) Electronic Code of Federal Regulations: Title 21: Food and Drugs Part 173—Secondary direct food additives permitted in food for human consumption. Retrieved from http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=761464347534256da7af5f3b0b73e700&h=L&mc=true&n=pt21.3.173&r=PART&ty=HTML
Van der Sman RGM, Renzetti S (2019) Understanding functionality of sucrose in biscuits for reformulation purposes. Crit Rev Food Sci Nutr 59(14):2225–2239
Weisburger JH (1996) Human protection against non-genotoxic carcinogens in the US without the Delaney Clause. Exp Toxicol Pathol 48(2–3):201–208
Whitehurst RJ, Van Oort M (2009) Enzymes in food technology. Wiley, 384pp. https://books.google.co.uk/books?id=GHQBMyTzJ-oC
Yong HI, Kim TK, Jang HW CHD, Jung S, Choi YS (2021) Clean label meat technology: pre-converted nitrite as a natural curing. Food Sci Anim Resour 41(2):173–184. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8115001/pdf/kosfa-8115041-8115002-8115173.pdf