Review Article

Food additives from an organic chemistry perspective

Abstract

Food additives are an essential part of the contemporary food system, providing definite advantages in terms of people's way of life. Food additives have been used, investigated, regulated, and controlled all through history. Although many reports, books, monographs, articles, etc. are available on this topic, but only a few of them focus on catering primarily to an organic chemistry audience who has little or no prior exposure to systematic food additive chemistry. This report gives a brief historical and regulatory background followed by an overview of different types of food additives along with their properties and structures. The paper is roughly subdivided into the following categories: (a) introduction to food additives, (b) their brief historical background, (c) short introduction to the numbering and the approval process for additives, (d) a discussion of the categories of food additives from an organic chemists' perspective which forms the main bulk of the paper including, for example, categories such as acids, acidity regulators, antifoaming and anticaking agents, emulsifiers, flavors, etc., (e) comparison of organic vs synthetic foods and food safety issues, and (f) conclusion and future prospects.

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Paritosh Shukla, Akshay Sharma, Ashok Sharma
Dept of Chemistry, Birla Institute of Technology and Science (BITS), India

Correspondence: Paritosh Shukla, Department of Chemistry, Birla Institute of Technology and Science (BITS)-Pilani, Pilani-333031, Rajasthan, India, Tel: 91–1596–515688, Fax +91–1596–244183, Email shukla_p@pilani.bits-pilani.ac.in

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Introduction

Although different authorities have different ways to define food additives, but to give a working definition, "food additives are substances added to food to preserve flavor and/or enhance taste and/or appearance".[1,2] On a more scientific note, borrowing the definition from the European Commission on food safety regulation, food additives are defined as any substances 'not normally consumed as food itself' which are added to food to perform a specific technological purpose e.g. preservation.[3] In this document overall twenty-six categories of food additives have been outlined, which are roughly subdivided into the following topics: (i) regarding the safety as well as prevention of food degradation issues brought about by either bacterial infection, or chemical reactions, or oxidations, and (ii) regarding taste improvement, appearance, or mouth-feel of the final finished product.[4] The US FDA[5] lists the following items as food ingredients that may be legally added to food: anti-caking agents, color additives, dough strengtheners including conditioners, emulsifiers, enzymatic preparations, fat replacers, agents for firming, flavor enhancing agents, flavors and spices, humectants (moisture preservers), leavening agents, nutrients, pH control agents (including buffering agents), acidulants, preservatives, stabilizers along with thickeners, sweeteners, yeast nutrients, and gases.[6] Food additives become part of the finished food product either directly or indirectly and sometimes intentionally and unintentionally, during some stage of processing, storage, or packaging. Direct food additives are commonly those that have been deliberately added for some special function by the food processor (usually the company), while indirect additives are usually those that may have drifted into food products in minute quantities due to e.g. growing, processing, or packaging phase during the food production process. Interestingly, there is a difference between an ingredient and an additive which though self-explanatory is not immediately obvious. For example, salt is an ingredient and so is vinegar but the acid in vinegar namely, acetic acid, if used alone, must be classified as an additive.[7] Direct food additives have an important role to play in our foods e.g., to provide nutrition, often to maintain quality and freshness of the finished product, sometimes to help the practical handling, processing and preparation of foods, to make foods appealing, and so on.[8]

Let's begin: a little history of food chemistry

It is generally accepted that the only way the ancient people had of analyzing food was by organoleptic means, i.e. by the use of the senses of taste, smell, sight, touch, and possibly sound (when they heard their food cackle or bleat!). Lavoisier, regarded as the father of modern nutrition, was one of the first to demonstrate the process of metabolism that is so important for the digestion of food.[9] Justus von Liebig's analytical methods led to the growth of modern organic chemistry and the related techniques needed for the development of food chemistry, agricultural chemistry, and allied sciences. In the early nineteenth century, Frederick Accum (a German chemist) first applied scientific means to discover food adulteration by using the chemical analyses methods prevalent in those days and some of his interesting findings have been outlined in Table 1.[10] The practice of adding items to food is not a modern-day invention and in all likelihood the custom started when man first discovered that lighting a fire could also result in cooking his food and that the addition of say, salt could result in preservation of that food without cooking. The Egyptians have been known to use food colors, seasonings, spices, flavors, etc. and all these objects were regarded so invaluable so as to serve as items of trade and, at times, reason for waging war. The search for spices, again an important food additive even today, gave fillip to many a arduous explorations including those of Columbus who set forth seeking the spices of India but ended up discovering America instead. Incidentally, food additives were not an essential part of the austere lifestyle most Americans led in the late 1700's: it is a result of the modern day consumers' surging demand that food additives have found their present indomitable position in our food supply thus making our plates literally full.

Table 1 Food Adulterants Identified by Frederick Accum

Food	Adulterant
Red Cheese	Colored with red lead and mercury sulfide
Cayenne Pepper	Colored with red lead
Pickles	Colored with copper salts
Vinegar	Sharpened with Sulfuric acid and contained tin and lead
Confectionery	Red sweets colored with red mercury sulfide, green sweets contained copper salts including arsenate
Olive oil	Lead from presses.

Composition of food additives

Currently, more than 3000 food additives have been approved by the US FDA and an authentic list of all the various food additives used in the United States may be found at EAFUS[11] database maintained by the U.S. Food and Drug Administration.[12] From a food chemist's perspective, every additive in food (in fact, practically everything under the sun) regardless of its source or anticipated purpose, is composed of chemicals. That brings us face to face with the debate on natural vs synthetic chemicals. Majority of those chemicals synthesized in the chemical laboratory are also found naturally existing in foods. Chemicals are after all chemicals and the distinction between a "natural" and "synthetic" chemical is somewhat subjective. For example, the sugar in sugarcane (sucrose) is no different in chemical composition and function than the usual refined sugar added daily to our food. Similarly, the primary organic acid in a garden orange is vitamin c (ascorbic acid) which is the same vitamin c that is ″artificially″ added to canned beverages. Similarly, citric acid produced commercially in the lab by enzymatic action is the same naturally-occurring acid that gives lemons their natural tarty flavor. To say one chemical might be nutritionally safer than another because of its origin probably does not make much scientific sense.

Numbering

It is imperative for the scientific community as also for the authorities regulating the addition of items to food that each additive be designated a unique identity tag. Hence, each food additive is assigned a distinctive ″E″ number. This numbering system has now been accepted and extended by the Codex Alimentarius Commission, which is an arm of Food and Agricultural Organization (FAO) and World Health Organization (WHO), currently the byword in international food standards, and it regularly issues guidelines and codes of practice for safety and quality of food. The Codex has identified all additives[13] irrespective of whether they are approved by the concerned regulatory authorities for use or not. E numbers are all preceded by an "E", but non-European countries commonly use only the number (without the E), whether or not the additive is approved in Europe. For example, for products sold in Europe, acetic acid is designated as the chemical E260, but is simply identified as additive 260 in many other non-EU (non European Union) countries. Since 1987, Australia has had an official system of additives labelling in packaged foods. In the United States, 1961 onwards, Food and Drug Administration lists food additives as "Generally Recognized as Safe" or GRAS;[14] they are itemized both under their Chemical Abstract Services (CAS) number and under the US Code of Federal Regulations. Notably, there are two classes of food additives that are generally exempt from the testing and approval process: ″prior sanctioned″ and ″GRAS″ substances. ″Prior sanctioned" substances were approved by the FDA before the 1958 Food Additives Amendment came into force. GRAS additives, on the other hand, have been widely used in the past with no known harmful/toxic effect though these have been under constant review and surveillance since 1969 to insure their safety parameters.

Additive approval process

In the US, a person or proposer has to submit a food additive petition (FAP) and go through the following tentative steps (US FDA consumer updates) to seek approval for an intended food additive: (a) the proposer of the additive submits animal testing results to FDA as to whether or not the food is safe, (b) public notice is issued by FDA regarding the new food additive, (c) sometimes, if the FDA is not convinced, further testing may be required, and (d) when the FDA is convinced of its safety, a regulation is issued for its use. This regulation specifies the amount of substance permissible in foods, the categories of foods in which it is permitted, the usage, and any other particular labelling that may be required. A general rule applied by FDA in determining accepted levels of food additive use is the famed "Philosophy of the Minimum." First, the agency determines the lowest concentration limit for the desired effect and then the maximum concentration limit at which it does not exhibit deleterious effects, (similar to the "therapeutic window" for any drug). Having thus established the upper and lower effects limit, the permitted use level of the additive should then not exceed more than 1/100th of the "no effect" level of safety. Therefore, usually, there is a minimum 100-fold boundary of safety imposed on the additive,[15] which is quite reasonable even by conservative standards.[16] Has recently compiled a comparative study of the national (US) and international regulatory procedures for the safety and assessment of food additives.

Categories of food additives

Acids

As shown in Table 2, most of the food acids are tracked down to the fruits such as grapes, lemon, orange, berries, plums, etc. While the human metabolic system readily adjusts to most of the natural food acids, there are some acids that the human body does not naturally recognize and are unhealthy thus leading to irritation and inflammation.

Table 2 List of Food Acids: (foodadditivesworld.com)

Acid	Source
Citric Acid	Citrus fruits – Lemon, Orange
Malic Acid	Apple
Tartaric Acid	Grapes, Pineapples
Acetic Acid	Vinegar
Oxalic Acid	Tea, Pepper
Tannic Acid	Tea
Caffeotannic Acid	Coffee
Benzoic Acid	Cranberries, Plums
Butyric Acid	Decomposition of Butter
Lactic Acid	Butter Digestion

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Citric acid (IUPAC Name)

2-hydroxypropane-1, 2, 3-tricarboxylic acid): it is a weak organic acid with the chemical formula $C_6H_8O_7$. Its position is well established in the food industry as a natural preservative and additionally it gives a characteristic acidic or sour taste to food and drinks. When heated above 175°C, it undergoes decarboxylation i.e. loss of carbon dioxide. The acid strength of citric acid is somewhat higher than typical carboxylic acids. Applications: (a) citric acid is the acid of choice in the beverage industry and is used widely in carbonated beverages for its flavouring and buffering (pH maintaining) properties while its solubility properties make it a supreme additive for syrup concentrates; (b) It also increases the efficacy of anti-microbial (bacterial, fungal, etc.) preservatives. Citric acid (sometimes used as its citrate salt) is also used in non-carbonated beverages such as juices, thirst-quenchers, etc. (c) it is used in dry powder beverages, as also inartificially sweetened beverages. Citric acid helps add bulk and mouth-feel typically attributed to sucrose. In a recent paper the addition of citric acid showed reduced levels of the carcinogen acrylamide in cooked food[17] (Figure 1).

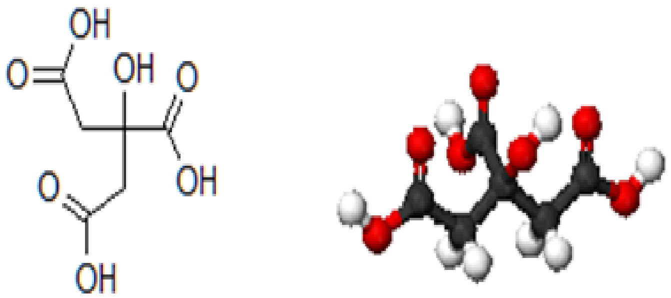

Figure 1 Structure of citric acid.

Tartaric acid (IUPAC Name)

2, 3-dihydroxybutanedioic acid): Tartaric acid is a white crystalline dicarboxylic aldaric acid with the formula $C_4H_6O_6$. It occurs naturally in many plants, e.g. grapes, bananas, and tamarinds. It functions as a leavening agent when added together with baking soda; is also routinely added to wine as the principal acidulant; is used as an antioxidant which makes it a more healthy alternative acid. Occasionally, tartaric acid is replaced by its salt i.e. tartarate. Chemically, it is a dihydroxy derivative of succinic acid which is itself used as a buffering agent in foods (Figure 2).

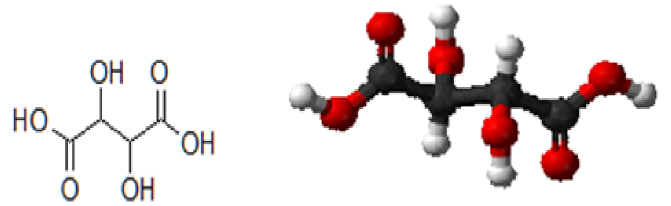

Figure 2 Structure of tartaric acid.

Malic acid (IUPAC Name)

2-hydroxybutanedioic acid): Malic acid is an organic compound with the formula HO2CCH2CHOHCO2H ($C_4H_6O_5$) and exists in its two stereoisomeric forms (L- and D-enantiomers), though only the L-isomer is found in nature. The salts of malic acid are known as malates. Applications: (a) low calorie beverages -its biggest advantage is that as compared to citric acid, the amount of malic acid required to be added to achieve the same level of sourness, is significantly lower.[18] Malic acid has an extended sourness i.e. its sourness stays longer and hence results in a more balanced taste. (b) Hard candy-It melts sooner than other food acids and hence can be assimilated easily into the molten hard candy without adding any extra water thus leading to increased shelf-life. (c) Chewing gum-For good chewing gum, it is important that it lead to profuse secretion of saliva and to achieve it, a combination of saccharin and food acid is often used. Blends of malic acid with other food acids having different miscibilities results in a progressive release of the acid creating sustained juiciness and flavor during chewing. (d) Desserts - it enhances fruit flavor in sherbets and water ices. In gelled desserts, addition of controlled amounts of malic acid leads to enhanced fruit flavor and pH control (Figure 3).

Fumaric acid (IUPAC Name)

(E)-butenedioic acid): Fumaric acid is the chemical compound with the formula HO2CCH=CHCO2H. Among all the food acids we have discussed up to now, this is the only acid having a double bond in its structure and it is therefore classified as an unsaturated acid. This white crystalline acid is one of the two isomeric unsaturated dicarboxylic acids, the other being maleic acid (the cis-isomer). Fumaric acid has a natural fruity taste and its salts and esters are called fumarates. Incidentally, dimethyl fumarate reduces disability progression in multiple sclerosis[19] (Figure 4).

Applications

As a food additive, this acid is mainly used as an acidity regulator. Fumaric acid is a food acidulent[20] used since 1946. It is usually a good alternative acid for tartaric acid and sometimes of citric acid. When used as a replacement for citric acid, it is added at a rate of 1.36 g of citric acid to every 0.91 grams of fumaric acid. It is also the acid of choice as a coagulant in stovetop pudding mixes.

Lactic acid (IUPAC Name)

(2-hydroxypropanoic acid): lactic acid, (obtained from milk and hence termed as "milk acid"), is an important chemical compound that plays a crucial role in various biochemical processes. Lactic acid is a α-hydroxy carboxylic acid with the chemical formula $C_3H_6O_3$. It exists in two enantiomeric forms: L (+)-lactic acid and D (-)-lactic acid, the former being the enantiomer that is primarily involved in human metabolism.[21] In early 1960's, the presence of D-lactic acid in infant milk formulas was found to lead to infant acidosis.[22] Applications: Being widely prevalent in natural foods, it is extant in many foodstuffs. Natural fermentation of mainly milk-based products e.g. cheese, yogurt, soy sauce, , meat products, etc yields lactic acid and hence it is widely used in food applications such as confectionery, bakery products, meat products, beverages, dairy products, salads, dressings, ready to-eat meals, etc. Lactic acid when used as a food additive mainly serves as a pH regulator or a preservative. Sometimes, it is also used as a flavoring agent. Among its many uses[23] are: (a) Meat, Poultry and Fish: in the form of its salts sodium or potassium lactate, it is employed to extend shelf life, control disease-causing bacteria (thus improving the safety and nutritional value of food), enhance (and protect) meat flavor, and improve water binding/retention capacity. (b) Pickled Vegetables: here again the natural preservative action of lactic acid is employed in preventing the damage of olives, gherkins, pearl onions (pearl onions closely resemble leek and are sweeter than common onions), and other vegetables preserved in brine. (c) Salads and Dressings: addition of lactic acid provides a relatively milder

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flavor to food products while maintaining natural microbial stability and safety. (d) Baked Goods: Sourdough is a type of bread made by prolonged fermentation of dough with lactic acid[24] where the latter is used directly for acidification in the production process. (e) Savory Flavors: Lactic acid does not just enhance the usual flavors, but it also enhances a broad range of savory flavors (also called umami flavors)[25,26] (Figure 5 & 6).

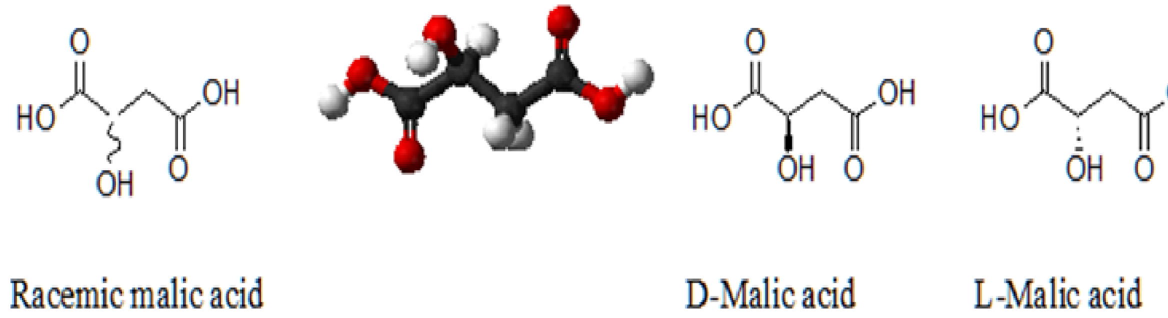

Figure 3 Structures of malic acids.

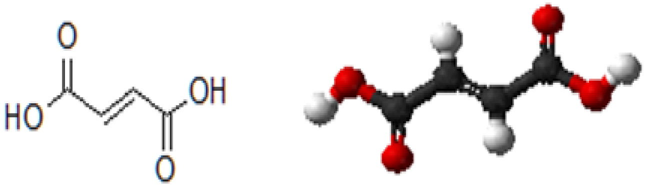

Figure 4 Structure of fumaric acid.

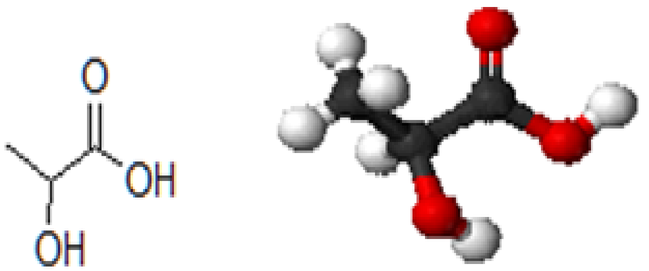

Figure 5 Structure of lactic acid.

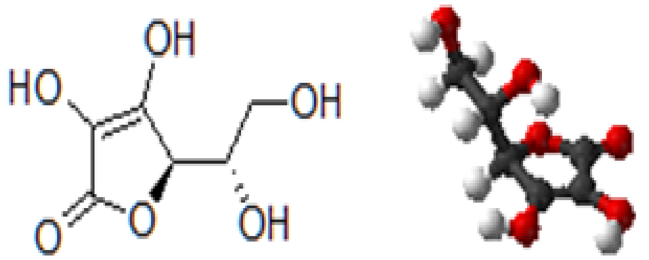

Figure 6 The structure of the antioxidant vitamin ascorbic acid (vitamin C).

Acidity regulators

Acidity regulators are required to maintain a balance between an extreme acid flavor and an extreme alkaline flavor. For instance, citrus fruits, juices, or yogurt are some commonly used acid foods while egg white and baking soda exemplify alkaline foods. Acidity regulators can be organic acids (e.g. acetic acid) or mineral acids (e.g. hydrochloric acid), bases (again organic or inorganic), neutralizing agents, or buffering agents (pH regulators). Of the most widely used acidity regulators are citric acid, acetic acid, and lactic acid. Notably in Europe, acidity regulators are controlled by strict EU (European Union) laws specifying authorisation, use, and labelling of all acidty rgulators.[27]

Anti caking agent

Anti-caking agents inhibit lump formation in food items thereby facilitating food products′ transport. Examples of anticaking agents are starch, magnesium carbonate ($MgCO_3$), and silica. These are added to fine-particle solid food products, like table salt, flours, coffee, and sugar. Anticaking agents may be water soluble (hydrophilic) or soluble in organic solvents like alcohol (hydrophobic) and consequently they function either by adsorbing excess moisture (hydrophilic property), or by creating a coating on the particles and making them water repellent (hydrophobic property). Calcium silicate ($CaSiO_3$), a commonly used anti-caking agent generously added to table salt, tends to absorb both water and oil indicating its amphiphilic proclivities. Some common anti-caking agents are: Aluminium silicate (Al_2 (SiO_3)3), Bentonite (a type of clay like montmorillonite), Calcium aluminosilicates (mainly $CaAl_2Si_2O_8$), Calcium ferrocyanide ($Ca_2[(Fe(CN)_6])$), Stearic acid (a long chain fatty acid of the formula CH_3 (CH2)16CO2H, Talcum powder, Tricalcium Phosphate (also referred to as bone ash having formula Ca_3 $(PO4)_2$), etc. Anticaking additives are also used to prevent the humidification of vitamin C[28] (Figure 7).

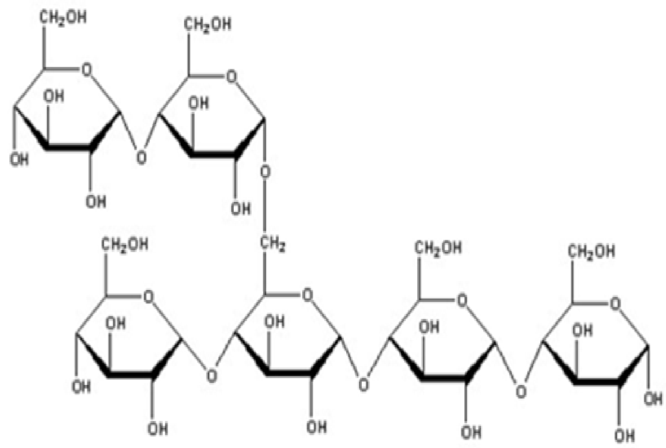

Figure 7 Structure of Starch.

Antifoaming agents

As a very general functional definition, an anti-foaming agent (also called a defoamer) is, as its name implies, a chemical additive that reduces and/or hinders the formation of foam (froth) in industrial process liquids. A variety of chemicals are available to prevent

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formation of foams[29] and these can be classified as: oil based, powder based, water based, silicone based, etc. When used as a food additive, antifoaming agents reduce outflow (effervescence) in a preparation or serving. These agents are found in various foods such as chicken nuggets in the form of polydimethylsiloxane which is a type of silicone polymer. Silicone oil is also added to commercial cooking oil to inhibit excessive frothing while deep-frying foods.

Antioxidants

An antioxidant is a molecule that inhibits or prevents the oxidation of other molecules. Traditionally, antioxidants are compounds that are believed to promote health by removing reactive chemical species that cause harmful effects when metabolized in the body.[30] Oxidation is a chemical reaction resulting in addition of oxygen to, or removal of hydrogen from, or removal of electrons from a substance. From a nutritional perspective, oxidations can result in the formation of free radicals which are chemical species having unpaired electrons that make them very unstable and therefore highly reactive. One of the common free radicals is the infamous reactive oxygen species (ROS). The latter can initiate uncontrolled chain reactions in the biological cells ultimately leading to damage or death of the cell. The function of antioxidants is to terminate these harmful chain reactions by taking out the dangerous free radical intermediates, hence resulting in the inhibition of further oxidations. Apart from their nutritional value, antioxidants also have varied industrial uses, such as their application as food and cosmetics preservative and to thwart the degradation of rubber and gasoline.[31] Antioxidants are subdivided based on their solubility in water (hydrophilicity) or their solubility in lipids (hydrophobicity). Applications: As detailed earlier, the use of antioxidants as food additives is primarily attributed to their ability to help guard against food deterioration. Now, it is well known that in refrigerated or even frozen foods, oxidation reactions do not stop and therefore food degradation keeps occurring. This degradation is surprising in that bacterial or fungal decomposition usually stops at subzero temperatures. Hence, the addition of antioxidants is virtually inadvertent in common foods that require shelf life. Some dietary additives e.g. vitamin C (ascorbic acid), tocopherols (vitamin E), carotenoids, polyphenolics, etc. can obliterate the danger of ROS free radicals. Such food products based on high antioxidant benefits include: whole foods and beverages (e.g. green tea, now much in vogue) or some chemically isolated substances available in the market as dietary supplements (e.g., vitamin C, lycopene, selenium, etc.).[32] Some synthetic (chemically prepared) compounds are also used as antioxidants such as tertiary butyl hydroquinone (TBHQ), propyl gallate (PG), butylated hydroxytoluene (BHT), and butylated hydroxyanisole (BHA) etc.[33] One of the reasons why fats (margarine or butter etc.) should not be wrapped in aluminum foil or stored in metal containers is that oxidation is often catalysed by metals. Antioxidant additives are also included in fat-based cosmetics such as lipstick (which sometimes gets into food), moisturizers, etc. to prevent their rancidity.

Bulking agents

Bulking agents increase the bulk or volume of a food without altering its taste or its available energy e.g. starch is a popular bulking agent. Starch or amylum is a member of the carbohydrate family (a chemical group of compounds made up of C, H, and O only and having the empirical formula CH_2O) consisting of a number of glucose units. Since it contains large number of glucose units joined together it is classified as a polysaccharide and interestingly, it is synthesised by all green plants as an energy storage source. Majority of the staple foods consumed by humans today comprises of rice, wheat, potatoes, maize (corn), etc., all containing starch. Pure starch which is insoluble in cold water or alcohol is a white, tasteless and odourless powder. When dissolved in warm water, it gives wheat paste, which can be used as a thickening, stiffening, or gluing agent (remember those poster campaigns in colleges?). The industrial processing of starch is commercially important as it gives rise to many of the sugars found in processed foods. The bulk of the starchy food intake worldwide comprises of cereals or grains most prominent among them are: wheat, corn, paddy (rice), barley, and sorghum which is a type of grass. Many starchy foods are characteristically grown only in specific climates, including acorns, arrowroot, taro, bananas, millet, oats, sago, sweet potatoes, rye, chestnuts, yams, beans (of various types e.g. mung, peas, lentils, etc.).[34] Popular everyday foods and delicacies consisting of starchy food are e.g. noodles, breads, pancakes, pasta, etc. Starch as such is not that easy to digest but when cooked, its digestibility is increased. Consequently, for our prehistoric human ancestors eating grains would not have been a lucrative way to obtain energy.

Food coloring

Any additive which may be in the form of a dye, pigment, or a chemical compound, that imparts color to the food can be termed as a color additive.[35] Usually, addition of colors can make the food look more attractive and it can also influence the observed flavour e.g. launching of the green ketchup by Heinz in 2000.The reasons for adding color to food could be various; such as to compensate for the loss of color due to atmospheric exposure to light, air, extreme temperatures, etc. FDA authorizes colors to be classified as allowable either with certification or exempt from certification. In either case, stringent safety standards are applied before these colors are officially endorsed and allowed to be added.[36] Certified colors are man-made and used widely because of their versatility and cheapness. Color additives are broadly categorized in the following three types: straight colors i.e. pure pigments that are not mixed or modified by other chemicals; lakes which are formed by mixing or reacting straight colors with other substances and; mixtures which are usually formed by mixing two different color additives. In the US, the following nine color additives are permitted: FD & C Blue No. 1, FD & C Blue No. 2, FD & C Green No. 3, FD & C Red No. 3, FD & C Red No. 40, FD & C Yellow No. 5, FD & C Yellow No. 6, Citrus Red No. 2, and Orange B where FD & C stands for Food Drug And Cosmetic. Notably, the latter two colors are permitted only for coloring the skins of oranges and casings of frankfurters and sausages, respectively.[37] Colorants of natural origin such as from vegetables, minerals, or animals are generally exempt from certification but may be more expensive than certified colors. Some examples of exempt colors can be found in the list shown below. According to the Centre for Science in the Public Interest,[38] since addition of colors is widely prevalent in foods having low nutritional value e.g. candy, soda pop, gelatin desserts, etc., one is advised to avoid all artificially colored foods. Colorings have been reported to cause hyperactivity (which is a part of the larger group of diseases called Attention Deficit and Hyperactivity Disorder, ADHD) in some sensitive children. As a thumb-rule, if colors are used in food it usually is a good indicator that fruit or other natural ingredient has not been used for that preparation (CSPI). As a passing remark, the most common pigments of red, blue, and yellow colors obtained from natural sources as a general rule belong to the polyphenols and carotenoid family.[39] Some examples of natural food dyes[40] are:

a. Caramel coloring - made from caramelized sugar i.e. by heating solid or dissolved sugar at high temperatures
b. Annatto (Bixa orellana) - a reddish-orange pigment obtained from the seed of the achiote plant.
c. Chlorophyllin - Chlorophyllin is a semi-synthetic mixture of water-soluble sodium copper salts derived from chlorophyll; a green dye made from chlorella algae
d. Cochineal (Dactylopius coccus)- the name of both crimson or carmine dye derived from the cochineal scaly insect
e. Betanin -a glycosidic red dye extracted from beets; generally used for short shelf-life food items
f. Turmeric.-. the active ingredient of which is curcumin, a phenolic compound, is often used as a much cheaper replacement of saffron
g. Saffron. (Crocus sativus) one of the most expensive natural spices; imparts rich golden-yellow hue
h. Paprika (Capsicum annum) obtained from a member of the capsicum family
i. Lycopene: red dye from tomatoes; is a type of carotenoid pigment
j. Elderberry juice: elderberry plant, also called Sambucus nigra, gives colors ranging from peach to strawberry to magenta
k. Pandan leaves (Pandanus odoratissimus) - imparts green coloration to food
l. Butterfly pea (Clitoria ternatea)-its blue flowers are used as a blue dye for foods e.g. in Malay cooking, the flowers are added to glutinous rice to give a tinge of blue color
m. An inventory of all allowed food colorants can be found at the FDA website.[41] The color additives are purified and then added as a formulation in solid or liquid form. The solvents present in these formulation could be hexane, acetone, ether, ethyl acetate, etc. that facilitate the extraction of the colorants. These solvent etc. residues may be found in the finished edible product but luckily these need not be declared as they form a group of chemicals called "carry-over ingredients". The food colorants could sometimes be hazardous e.g. annatto (of plant origin, for providing orange or bright yellow color to food), cochineal (of insect origin, imparts crimson color to food), caramine (similar to cochineal, giving natural red color), etc.[42]

Emulsifiers

Food emulsifiers must be surface active, possess a capacity to create foam and of course, be edible. Sometimes the term HLB (hydrophilic/liphophilic balance)[43] is used to quantify an emulsifying agent. An emulsifier (sometimes referred to as an "emulgent") is a species that helps stabilize an emulsion by increasing its kinetic (as opposed to its thermodynamic) stability. Examples of food emulsifiers are: (a) lecithin: Lecithos, which in Greek means egg yolk, is the major emulgent in the form of lecithin, (b) Proteins: especially those containing both hydrophilic and hydrophobic functional groups, e.g. milk proteins, legume proteins, etc. (c) Mustard: the chemicals in its seed are mainly responsible for its emulsifying action, (d) Sodium Stearoyl Lactylate: it is an ester having a long hydrophobic chain in its structure, (e) DATEM (diacetyl tartaric acid ester of monoglycerides and diglycerides)): also an ester majorly used in baking. Uses of Emulsifiers: Chemically, emulsifiers are molecules usually having two ends: one of which is hydrophobic (water repelling) and the other hydrophilic (water loving). Emulsions where oil is dispersed in water are common in food, e.g.: (a) Crema (i.e. the foam) in espresso -coffee oil dispersed in water it is an unstable emulsion, (b) Mayonnaise and Hollandaise sauce -also oil-in-water emulsions (c) Homogenized milk-it is raw milk mechanically churned to give it a homogeneous and smooth texture where the proteins and fats are broken down to give a smooth feel.

Flavours

Flavour is mainly a sensory response to the stimulation of taste buds and olfactory organs when food strikes them and it is possible to alter the flavor of the food to affect the senses.[44] Interestingly, food, drinks, or other dietary objects are identified mainly by the senses of smell (olfactory) and sight (visual), not taste (Small 2008). Hence, the main element of a food item's flavor is its smell although we have to consider sympathetically the case of people suffering from anosmia i.e. odor blindness. It is commonly accepted that the main attributes of flavor are the following: sweet, sour, bitter, salty, and then there is the recently recognized fifth one 'umami' ("oo-mommy" or savory/pleasant), followed by pungent or piquant, and finally metallic, the seven basic tastes. Natural flavor extracts are not abundantly available and extracting flavorants from them requires heavy spending, hence most of the commercially employed flavorants are chemically synthesized and are branded as ″nature-identical″, i.e. they can be considered as chemically comparable to the original natural flavors. There are three major types of flavouring additive substances used in foods: (a) natural; obtained from plants or animals by physically, microbiologically, or enzymatically manipulating the ingredients present in the respective original source, (b) Nature-Identical; as aforementioned, these may be made by chemical synthesis or isolated by chemical means, and (c) Artificial; flavouring substances not found in any natural product and are obtained by chemical manipulation of say, crude oil, coal tar, etc.[45] The extraction of flavorants from their natural sources maybe accomplished by solvent extraction (i.e. by selectively dissolving one of them in a mixture of solvents), distillation (based on differential boiling points of the ingredients), or using force or pressure to squeeze it out. After further purification, the extracts are then added to the desired foods. Many flavor additives consist of esters (chemicals formed by the reaction of a carboxylic acid and an alcohol), which have a characteristic "fruity" odour. Some important chemicals and their characteristic odours have been tabulated in Table 3. Discussed below are two of the most important factors responsible for flavors: (a) Taste: when it comes to taste, the Umami or "savory" or ″pleasant″ flavorants are now fairly common flavor additives and are primarily based on amino acids and nucleotides (nucleotides consist of a base, a sugar, and a phosphate unit). Although, in a purely technical sense, sugar and salt also constitute taste flavorants but in gastronomy, it is those additives that lead to an enhancement of umami or other secondary flavors that are regarded as the taste flavorants. Artificial sweeteners though are all technically regarded as flavorants. Umami flavorants recognized and lawfully allowed by the European Union include the ones shown in Table 3.[46] (b) Color: as we have seen earlier the natural color of food coupled with the color additives can affect its overall flavor. It interesting to note that the color of the food served in front of you sets up an expectation of the flavor: e.g. greens from the green vegetables give a feeling of freshness; reds from the red fruits give a perception of ripeness; and purple of the meats sometimes give an impression of being perfectly cooked.[47] From: More recently, natural pigments and dyes for use in food are being sourced from e.g. plants, insects, and microorganisms.[48] It is pertinent to mention that the classic example of the influence of cooking on flavor as well color of the cooked food is the Maillard reaction which occurs between the amino acids and the reducing sugars that are present in the cooked food. This non enzymatic reaction is mainly responsible for the browning of food when cooked at around 140°C or above. It has also been shown by research that the Maillard reaction products may be responsible for the inhibition of microbial growth in food[49] (Table 4).

Table 3 Some chemicals and their characteristic odors

Chemical	Odor
Diacetyl	Buttery
Isoamyl Acetate	Banana
Benzaldehyde	Bitter Almond
Cinnamic Aldehyde	Cinnamon
Ethyl Propionate	Fruity
Methyl Anthranilate	Grape
Limonene	Orange
Ethyl Decadienoate	Pear
Allyl Hexanoate	Pineapple
Ethyl Maltol	Sugar, Cotton Candy
Ethylvanilin	Vanilla
Methyl Salicylate	Whitegreen

Table 4 Some umami flovorants recognized by EU

Acid	Description
Acetic acid	Gives vinegar its sour taste and distinctive smell.
Ascorbic acid	Found in oranges and green peppers and gives a crisp, slightly sour taste. Better known as vitamin C.
Citric acid	Found in citrus fruits and gives them their sour taste.
Fumaric acid	Not found in fruits, used as a substitute for citric and tartaric acid.
Lactic acid	Found in various milk or fermented products and give them a rich tartness.
Malic acid	Found in apples and gives them their sour/tart taste.
Phosphoric acid	Used in all Cola drinks to give an acid taste.
Tartaric acid	Found in grapes and wines and gives them a tart taste.

Flour treatment agents

Also called bread improvers or improving agents are food additives pooled with flour to develop their baking functionality. Hence, these are generally used to increase the rapidity of dough rising and to improve the strength and workability of the dough. These falls into the following four main categories: oxidizing and reducing agents, enzymes, bleaching agents, and emulsifiers. Usually the addition of a small amount of these flour treatment species is enough to bring about the desired effect and hence they are sold mixed with soy flour base. Since freshly milled flour is yellowish, flour bleaching agents are mixed with flour to make it appear whiter. Oxidizing agents are used as treatment agents added to flour to help with the development of gluten which gives the flour its elasticity and chewiness. Common oxidizing agents thus added are: (a) Azodicarbonamide (biurea, also known as an improving agent), (b) Urea (NH_2CONH_2), and (c) Potassium Bromate ($KBrO_3$). Potassium bromate is well known oxidizing agent, and is completely used up in the bread baking process. However, if proper precautions are not taken to keep the amount of potassium bromate concentration under control, then even a residual amount remaining unused may be harmful if consumed[50] (Figure 8).

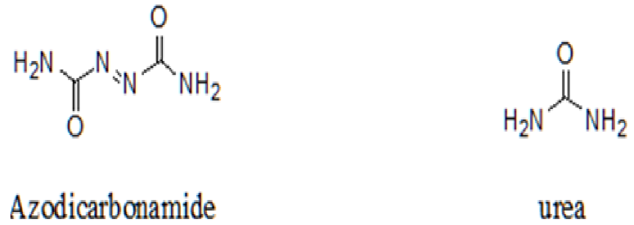

Figure 8 Structure of azodicarbonamide and urea.

Glazing agents

A glazing agent usually functions as a coating material to prevent water loss and provide other surface protection for the food some common galzing agents are beeswax (e.g. for coating of confectionary), lac: obtained from the lac insect from India (used in chocolates, candies, etc), mineral oil which is generally used to coat chewing gums, fresh vegetables, drug capsules, etc.

Preservatives

In a very general way, a preservative is a naturally or synthetically obtained substance that is added to products such as foods, pharmaceutical preparations, biological samples, etc. to prevent decomposition brought about by bacteriological growth, or by atmospheric degradation, or by adverse chemical changes.[51] Most preservatives can be categorized as: (a) those that help prevent bacterial or fungal growth, (b) those preventing oxidation, and (c) those that prevent the natural ripening of foods, vegetables, etc. Most preservatives that are added to food can be classified into class-I and class-II preservatives; the former are natural chemicals commonly found in the kitchen e.g. salt, sugar, alcohol, vinegar, etc. while the class-II preservatives are artificial compounds and are usually synthesised e.g. benzoates, sorbates, sulfites, etc. Lately, the benefit ensuing from these preservatives as against their safety issues is the subject of debate among academics and regulatory authorities.[52] The natural food preservatives and the natural ways of preserving foods are the traditional methods used for millenniums including grandma's recipes still used at home while making pickles, jams, and juices etc. Also included in this list are the established procedures of salting, freezing, boiling, smoking, etc.[53] For example, coffee powder and soups are dehydrated (i.e. all the moisture removed) and freeze-dried to preserve their quality and enhance shelf-life. The following is list of some commonly added chemical food preservatives[54] classified by their preservative action - antioxidant functionality: BHT, BHA, and citric acid; microorganism inhibitory: benzoates, sodium nitrate, and sodium nitrite; those that inhibit molds: calcium propionate and potassium sorbate; those that prevent discoloration: sulfur dioxide, etc.

Stabilizers

In chemistry, a stabilizer can be thought of as the antithesis of a catalyst. In food chemistry, the term can be applied to refer to a

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chemical or other additive that impedes separation of emulsions, suspensions, and foams. Food stabilizers are used to produce uniform texture of foods and to improve "mouth feel" especially in frozen desserts, jellies, etc. and may consist of gelatin, pectin, guar gum, carrageenan, xanthan gum, whey, etc (US FDA food ingredients). Some types of stabilizers are: (a) Sequestrants (metal chelators), (b) Antioxidants, (c) Ultraviolet stabilizers, and, (d) Emulsifiers and Surfactants.

Organic Vs synthetic food: the debate continues

Surprisingly, majority of people assume that organic foods taste better than those grown conventionally. However, there is not much real evidence to corroborate this statement. The term "natural" applies broadly to foods that are unprocessed or minimally processed and free of colors, artificial sweeteners, synthetic preservatives, other additives, and are even devoid of stabilizers, growth hormones, emulsifiers, etc.[55] Incidentally, the term "organic" when viewed from the standpoint of food science includes not just the food itself but also alludes to how the food was produced. Foods tagged as organic must be certified by the National Organic Program (NOP) of the United States Department of Agriculture. They must be grown and processed under strict laws using accepted organic farming methods that a) recycle the resources produced and b) promote biodiversity. The latter two are the vital elements of environmentally sustainable agriculture (US FDA Food Marketing Institute). Largely, one can find out whether the product is organic or natural by searching its PLU (price look up) code usually found on the sticky label (Table 5). On the other hand, synthetic foods sometimes also called artificial foods are mainly derived from chemically synthesized food substances. Synthetic food products usually mimic natural food products in appearance, taste, and odour. Some basic differences between organic and synthetic food have been outlined in Table 6.

Table 5 The PLU code example

Conventionally grown	Organically grown
4-digit code	5-digits starting with 9
e.g. banana: 4011	banana: 94011

Table 6 Some differences between organic and synthetic foods (Snitkjaer and others 2012)

Organic	Synthetic
Pesticides not used	Pesticides used
Grown with natural fertilizers	Grown with synthetic or chemical fertilizers
Weeds are controlled naturally	Weeds are controlled with chemical herbicides
Insects are controlled using natural methods	Insecticides are used to manage pests and disease.

Chemical food and safety issues

Recently, food safety has acquired a broadening concept encompassing: (i) food quality (i.e. the composition of food); (ii) traceability (i.e. origin of food), and (iii) food safety (absence of allergens, pathogens, or other contaminants).[56] In addition, chemical food safety has attracted attention worldwide as a global issue affecting public health (Table 7) and international trade.

Table 7 Depicting some chemical hazards

Chemical Hazard	Subcategory of Chemical Hazard
Agrochemical	Pesticides, fungicides, fertilizers, herbicides, veterinary drugs
Environmental and Industrial Contaminants	Heavy Metals (lead, cadmium, mercury), PCBs (polychlorinated biphenyls), Dioxins, radionuclides, organic chemicals (benzene)
Toxins produced during processing and storage	Heat-produced chemical hazards (furan, lipid degradation products), chemical hazards produced during non-thermal processing and storage (benzene, ethyl carbamate)
Packing derived hazards	Monomers (vinyl chlorides, styrene, acrylonitrile), pigments (lead), plasticizers (phthalates)
Allergens	Major food allergens (milk, peanut, egg, soy)

Chemical hazards in food

This subject is emerging as a leading cause of international trade complications and disputes. Contamination in food may occur through various agencies like environmental pollution of the air, water, and soil (as usually occurs with toxic metals), or through the use of various chemicals, such as pesticides, other agrochemicals, veterinary drugs, etc.[57] It is likely that the next food safety crisis may be caused by toxins that are yet undiscovered or due to increased incidences of unintentional or intentional chemical contamination of human and animal food. Not just additives, but type or method of packaging food too can also be responsible for contamination brought about by human intervention. Food packaging and food safety issues are the Siamese twins of modern nutrition science and technology. In search for better food packaging materials, scientists are sizing up nanoscience materials whose safety has not yet been fully researched.[58] Plastics and other synthetically prepared polymers are the materials of choice for the modern food packaging industry. Mostly the packaging materials may be too heavy in terms of their molecular weight and therefore relatively unreactive or inert. Nevertheless, some lower molecular weight constituents may inadvertently be present e.g. comprising of residual plastic monomers or oligomers or other additives such as pigments, plasticizers added in the process of manufacture, antioxidants, color additives, etc. These latter components are liable to pass on to food and result in unwarranted human exposure. Hence, over the last three decades or so, there have been concerns, controversy, and at times public outcry over the safety contaminants caused by food packaging (US FDA food packaging). Consequently, these substances are frequently being controlled and regulated by the concerned authorities. The safety concerns arise mainly from the lack of proper scientific information on the effects of sustained exposure to these contaminants in humans. Let us end by taking a very recent example of Bisphenol A (BPA) which has been used profusely in food packaging materials since the 1960s. It is used as a buffer chemical layer to prevent direct mixing of the food with metal surface and finds use in polycarbonate beverage bottles, metal cans, etc. It has recently attracted much adverse public attention because this chemically synthesised compound is suspected of possessing endocrine-disrupting properties[59] and consequently BPA based materials in infant formula packaging, sippy cups, and baby bottles, etc. have been recently banned by FDA.

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Future prospects

The business of food additives is thriving and to cite some recent data, Global Industry Analysts Inc. (GIA) released a global report in 2010 on food additives market that underlines exciting prospects for the world market for food additives as it is projected to exceed $33.9 billion by the year 2015[60] and possibly may reach $45 billion by 2020. Perhaps the most significant trend driving growth in additives is a general increase in processed foods consumption across the world. From a food business perspective, the emerging markets of Asia and Latin America are becoming increasingly attractive for food additive industries and suppliers as the processes food demand in these regions is growing by leaps and bounds.[61] Research and Markets has announced the addition of the "Food Additives - Global Strategic Business Report" document to their offering and as expected, the United States and Europe once again continue to dominate the world food additives market.[62] Americans are particularly growing health conscious and cautiously counting calories such that low-calorie, low-fat foods are fast gaining popularity in the United States. More and more technology-driven research is now being undertaken that will allow the production of additives in newer and more sophisticated ways e.g. the increasing stress being laid on biotechnology as it uses simple organisms to produce additives that are the same as natural food constituents. In 1990, FDA approved the first bioengineered enzyme, rennin, extracted from calves' stomachs for use in cheese making industry.[63] It appears that some of the sectors likely to have better-performance may include segments such as colors and flavors that are naturally sourced, enzyme based foods, food hydrocolloids (which are foods similar to gums), and some of the functional food ingredients. As is evident from previous discussion, the inclination to spend more on naturally sourced and/or additive-free food and drinks is projected to continue in the short-term. This could be largely due to increasing end user concern over the safety of artificial ingredients. The role of food packaging in modern day food industry is also crucial and has huge economic impacts e.g.[64] have investigated the benefits of intelligent packaging systems to the quality and safety of food.

So, in looking toward the future, increases in overall population will definitely have a remarkable effect on the world's food supply. Statistically, although the level of food additives added to food vis-a-vis the total diet of an average customer is minor, the overall contribution does turn out be significant. Recently the FDA's Food Safety Modernization Act (FSMA), one of the boldest reforms of U.S. food security and health safety laws in more than 70 years, was made into law by President Obama on January 4, 2011. Its focus is to make sure the U.S. food supply is safe by aiming on prevention rather than response to food contamination. Ultimately, the responsibility of avoiding the risk of consuming unsafe food lies with us and herein the World Health Organization's rule-of-thumb guide says it all: keep the food clean; effort should be made to separate raw from cooked food; cook the food thoroughly; store the cooked/uncooked food at safe temperatures; and take precautions to use safe water and raw materials as far as possible.[65] With increasing public concern about food safety issues[66] eventually, there are four important players that will decide the future of food additives: law-makers, scientists, commercial enterprises, and finally the consumers themselves.[67] Hence, the use of food additives is vast; they are used from cold drinks to chips and as preservatives in pickles to coloring and sweetening agents in many food items. All these uses can be expanded with the help of further research. The report analyses the chemistry of food additives, their structures, and their chemical properties. The report can be used as a benchmark for further studies.[68–71]

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Conflict of interest

The author declares no conflicts of interest.

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