An Overview on the Molecular Aspects of Food Additives
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Abstract: A food additive is a substance (or a mixture of substances) which is added to food and is involved in its production, processing, packaging and/or storage without being a major ingredient. Food additives are used for the enhancement of nutritive, sensory, shelf life and practical value of foods. The use of additives is regulated by Food and Drug or Health and Welfare administrations in most countries. Whereas foods used to be preserved for commercial reasons, toxicological findings have recently become additional reason for preservation. Since concentrations of various food additives vary among foods, it may give rise to adverse effects when taken in large amounts, but it does not mean that its proper use will effect a hazard to man by consideration of toxicity of the additives. An overview on the molecular aspects in the light of physicochemical phenomena of food additives is emphasized in this review.

Keywords: Food additives, food value, mineral, vitamin, Sequesterants

Introduction

A food additive is a substance (or a mixture of substances) which is added to food and is involved in its production, processing, packaging and/or storage without being a major ingredient. Additives or their degradation products generally remain in food, but in some cases they may be removed during processing. The following examples illustrate and support the use of additives to enhance the below mentioned values [1].

1. Nutritive Value of Food
Additives such as vitamins, minerals, amino acids and amino acid derivatives are utilized to increase the nutritive value of food. A particular diet may also require the use of thickening agents, emulsifiers, sweeteners, etc.

2. Sensory Value of Food
Color, odor, taste, consistency and texture, which are important for the sensory value of food, may decrease during processing and storage. Such decreases can be corrected or readjusted by additives such as pigments, aroma compounds or flavor enhancers. Development of “off-flavor”, for instance, derived from fat or oil oxidation, can be suppressed by antioxidants. Food texture can be stabilized by adding minerals or polysaccharides, and by many other means.

3. Shelf Life of Food
The current forms of food production and distribution have increased the demand for longer shelf life. Furthermore, the world food supply situation requires preservation by avoiding deterioration as much as possible. The extension of shelf life involves protection against microbial spoilage, for example, by using antimicrobial additives and by using active agents which suppress and retard undesired chemical and physical changes in food. The latter is achieved by stabilization of pH using buffering additives or stabilization of texture with thickening or gelling agents, which are polysaccharides.

4. Practical Value
The common trend towards foods which are easy and quick to prepare (convenience foods) can also necessitate the increasing use of additives.

It is implicitly understood that food additives and their degradation products should be non-toxic at their recommended levels of use. This applies equally to acute and to chronic toxicity, particularly the potential carcinogenic, teratogenic (causing a malformed fetus) and mutagenic effects. It is generally recognized that additives are applied only when required for the nutritive or sensory value of food, or for its processing or handling. The use of additives is regulated by Food and Drug or Health and Welfare administrations in most...
countries. The regulations differ in part from country to country but there are endeavors under way to harmonize them on the basis of both current toxicological knowledge and the requirements of modern food technology. The present report summarizes the chemical and molecular aspects of various significant food additives used over the last two decades.

**Discussion**

**Important group of food additives**

1. **Vitamins**

Many food products are enriched or fortified with vitamins to adjust for processing losses or to increase the nutritive value. Such enrichment is important, particularly for fruit juices, canned vegetables, flour and bread, milk, margarine and infant food formulations. Table 1 provides an overview of vitamin enrichment of food. Several vitamins have some desirable additional effects. Ascorbic acid is a dough improver, but can play a role similar to tocopherol as an antioxidant. Carotenoids and riboflavin are used as coloring pigments, while niacin improves the color stability of fresh and cured and pickled meat [1].

**Table.1:** Examples of vitamin fortification of food

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Food Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_1</td>
<td>Cocoa powder and its products, beverages and concentrates, confectionary and other baked products</td>
</tr>
<tr>
<td>B_2</td>
<td>Baked products, beverages</td>
</tr>
<tr>
<td>B_3</td>
<td>Baked and pasta products</td>
</tr>
<tr>
<td>B_6</td>
<td>Beverages</td>
</tr>
<tr>
<td>Pantothentic acid</td>
<td>Baked products</td>
</tr>
<tr>
<td>Folic acid</td>
<td>Cereals</td>
</tr>
<tr>
<td>C</td>
<td>Milk, milk powder etc</td>
</tr>
<tr>
<td>A</td>
<td>Various food products, e.g. margarine</td>
</tr>
</tbody>
</table>

2. **Amino acids**

The daily requirement of humans for essential amino acids is of immense importance. The biological value of a protein (g protein formed in the body/100 g food protein) is determined by the absolute content of essential amino acids, by their ratios to nonessential amino acids and by factors such as digestibility and availability. The most important (more or less expensive) *in vivo* and *in vitro* methods for determining the biological valence are based on the following principles:

- Replacement of endogenous protein after protein depletion.
- Utilization of protein for growth
- Maintenance of the N balance.
- Plasma concentration of amino acids.

- Calculation from the amino acid composition.
- Determination by enzymatic cleavage *in vitro.*

3. **Minerals**

Food is usually an abundant source of minerals. Fortification is considered for iron, which is often not fully available, and for calcium, magnesium, copper and zinc. Iodization of salt is of importance in iodine deficient areas.

4. **Aroma substances**

Aroma substances are volatile compounds which are perceived by the odor receptor sites of the smell organ, i.e. the olfactory tissue of the nasal cavity. They reach the receptors when drawn in through the nose (orthonasal detection) and via the throat after being released by chewing (retronasal detection). The concept of aroma substances, like the concept of taste substances, should be used loosely, since a compound might contribute to the typical odor or taste of one food, while in another food it might cause a faulty odor or taste, or both, resulting in an off-flavor.

**Table.2:** Examples of key odorants

<table>
<thead>
<tr>
<th>Compound</th>
<th>Aroma</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R)-Limonene</td>
<td>Citrus-like</td>
<td>Orange juice</td>
</tr>
<tr>
<td>(R)-1-p-Menthene-8-thiol</td>
<td>Grapefruit-like</td>
<td>Grapefruit juice</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>Bitter,</td>
<td>Almonds, cherries, plums</td>
</tr>
<tr>
<td>Neral/geranial</td>
<td>Lemon-like</td>
<td>Lemons</td>
</tr>
<tr>
<td>(R)-(−)-1-Octen-3-ol</td>
<td>Raspberry-like</td>
<td>Raspberries</td>
</tr>
<tr>
<td>(E,Z)-2,6-Nonadienal</td>
<td>Cucumber-like</td>
<td>Camembert cheese</td>
</tr>
<tr>
<td>Geosmin</td>
<td>Earthy</td>
<td>Beetroot</td>
</tr>
<tr>
<td>trans-5-Methyl-2-</td>
<td>Nut-like</td>
<td>Hazelnuts</td>
</tr>
<tr>
<td>hepten-4-one (fillbertone)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-Furfurylhithiol</td>
<td>Roasted</td>
<td>Coffee</td>
</tr>
<tr>
<td>4-Hydroxy-2,5-3(2H)-furane</td>
<td>Caramel-like</td>
<td>Biscuits, dark beer, coffee</td>
</tr>
<tr>
<td>2-Acetyl-1-pyrroline</td>
<td>Roasted</td>
<td>White-bread crust</td>
</tr>
</tbody>
</table>

5. **Flavor enhancers**

These are compounds that enhance the aroma of a food commodity, though they themselves have no distinct odor or taste in the concentrations used. An enhancer’s effect is apparent to the sense of “feeling”, “volume”, “body” or “freshness” (particularly in thermally processed food) of the aroma, and also by the speed of aroma perception (“time factor potentiator”) [2].
5.1. Monosodium glutamate (MSG): Glutamic acid was isolated by Ritthausen. In 1908 Ikeda found that MSG is the beneficial active component of the algae Laminaria japonica, used for a long time in Japan as a flavor improver of soup and similarly prepared food. The consumption of MSG in 1978 was 200,000 tonnes worldwide. The taste of MSG cannot be explained by a combination of sweet, salty, sour and bitter tastes. It is, as the fifth quality, of an elementary nature. This assumption, which was made as early as 1908 by a Japanese researcher to explain the special taste called umami, was confirmed by the identification of a taste receptor for MSG. MSG is one of the most important taste-bearing substances in meat (cf. 12.9) and cheese ripened for longer periods of time.

5.2. 5′-Nucleotides: 5′-Inosine monophosphate (IMP, disodium salt) and 5′-guanosine monophosphate (GMP, disodium salt) have properties similar to MSG but heightened by a factor of 10–20. Their flavor enhancing ability at 75–500 ppm is good in all food (e. g. soups, sauces, canned meat or tomato juice). However, some other specific effects, besides the “MSG effect”, have been described for nucleotides. For example, they imprint a sensation of higher viscosity in liquid food. The sensation is often expressed as “freshness” or “naturalness”, the expressions “body” and “mouthfeel” being more appropriate for soups.

5.3. Maltol: Maltol (3-hydroxy-2-methyl-4-pyrone) has a caramel-like odor (melting point 162–164 °C). It enhances the perception of sweetness in carbohydrate-rich food (e. g. fruit juices, marmalades, fruit jelly). Addition of 5–75 ppm maltol allows a decrease of sugar content by about 15%, while retaining the sweetness intensity.

5. Sugar substitute

Sugar substitutes are those compounds that are used like sugars (sucrose, glucose) for sweetening, but are metabolized without the influence of insulin. Important sugar substitutes are the sugar alcohols, sorbitol, xylitol and mannitol and, to a certain extent, fructose.

7. Sweeteners

Sweeteners are natural or synthetic compounds which imprint a sweet sensation and possess no or negligible nutritional value ("nonnutritive sweeteners") in relation to the extent of sweetness [3]. There is considerable interest in new sweeteners. The rise in obesity in industrialized countries has established a trend for calorie-reduced nutrition. Also, there is an increased discussion about the safety of saccharin and cyclamate, the two sweeteners which were predominant for a long time. The search for new sweeteners is complicated by the fact that the relationship between chemical structure and sweetness perception is not yet satisfactorily resolved. In addition, the safety of suitable compounds has to be certain. Some other criteria must also be met, for example, the compound must be adequately soluble and stable over a wide pH and temperature range, have a clean sweet taste without side or post-flavor effects, and provide a sweetening effect as cost-effectively as does sucrose. At present, some new sweeteners are on the market (e. g., acesulfame and aspartame). It has been shown with numerous compounds that as the hydrophobicity and the space-filling properties of hydrophobic groups increase, the sweetening strength increases, passes through a maximum, and finally reaches a limit beyond which the sweet taste is either quenched or changes into a bitter taste [4,5].

7.1 Synergism: In mixtures of sweet tasting substances, synergistic intensification of taste occurs, i. e., the sweetness intensity is higher than the calculated value. An example is the intensification of sweetness in acesulfame-aspartame mixtures.

7.2 Saccharin: Saccharin is an important sweetener and is mostly used in the form of the water-soluble Na salt, which is not so sweet. At higher concentrations, this compound has a slightly metallic to bitter aftertaste. The synthesis of saccharin usually starts with toluene (Renssen/ Fahlberg process,) or sometimes with the methyl ester of anthranilic acid (Maumee process).

7.3 Monellin: The pulp of Dioscoreophyllum cumminsi fruit contains monellin, a sweet protein with a molecular weight of 11.5 kdal. It consists of two peptide chains, which are not covalently bound.

7.4 Curculin and Miraculin: Curculin is a sweet protein of known sequence. It occurs in the fruit of Curculigo latifolia. The sweet taste induced by this protein disappears after a few minutes, only to reappear with the same intensity on rinsing with water. It is assumed that Ca2+ and/or Mg2+ ions in the saliva suppress the sweet taste. Rinsing with citric acid (0.02mol/l) considerably enhances the impression of sweetness. Thus, like miraculin, curculin acts as a taste modifier.
8. Food colors

A number of natural colors are available and used to adjust or correct food discoloration or color change during processing or storage [6]. Carotenoids are used the most, followed by red beet pigment and brown colored caramels. The number of approved synthetic dyes is low. Yellow and red colors are used the most. Food products which are often colored are confections, beverages, dessert powders, cereals, ice creams and dairy products.

9. Acids

The acid taste is caused only by the H ion. The intensity depends on the potential and not on the actual H ion concentration, which indicates the pH. Consequently, the solution of a weak acid, which is not completely dissociated, tastes as sour as the solution of a strong acid of the same concentration. Therefore, the first step in the detection of an acid is comparable with an acid–base titration, the receptor for the sour taste functioning as the base. Apart from the taste effect and antimicrobial activities, acids have a number of other functions in foods.

9.1. Citric acid: Citric acid (pK = 3.09; pK2 = 4.74; pK3 = 5.41) is utilized in candy production, fruit juice, ice cream, marmalade and jelly manufacturing, in vegetable canning and in dairy products such as processed cheese and buttermilk (aroma improver). It is also used to suppress browning in fruits and vegetables and as a synergetic compound for antioxidants. Its production is based on microbial fermentation of molasses by Aspergillus niger.

9.2. Fumaric acid: Fumaric acid (pK1 = 3.00; pK2 = 4.52) increases the shelf life of some dehydrated food products (e.g., pudding and jelly powders). It is also used to lower the pH, usually together with food preservatives (e.g., benzoic acid), and as an additive promoting gel setting. Fumaric acid is synthesized via maleic acid anhydride which is obtained by catalytic oxidation of butene or benzene or is produced from molasses by fermentation using Rhizopus spp.

9.3. Maleic acid: Maleic acid (pK1 = 3.89; pK2 = 5.87) is an amino acid which is utilized in the production of starch and in the preparation of synthetic rubber. Maleic acid is used in the food industry as a crosslinking agent and as a preservative in the form of maleic acid anhydride. Maleic acid is also used as a flavor enhancer in the food industry.

9.4. Tartaric acid: Tartaric acid (pK1 = 3.81; pK2 = 6.43) is a dicarboxylic acid which is used in the production of starch and in the preparation of synthetic rubber. Tartaric acid is used in the food industry as a crosslinking agent and as a preservative in the form of tartaric acid anhydride. Tartaric acid is also used as a flavor enhancer in the food industry.

9.5. Malic acid: Malic acid (pK1 = 2.64; pK2 = 4.13) is a dicarboxylic acid which is used in the production of starch and in the preparation of synthetic rubber. Malic acid is used in the food industry as a crosslinking agent and as a preservative in the form of malic acid anhydride. Malic acid is also used as a flavor enhancer in the food industry.

9.6. Fumaric acid: Fumaric acid (pK1 = 3.00; pK2 = 4.52) increases the shelf life of some dehydrated food products (e.g., pudding and jelly powders). It is also used to lower the pH, usually together with food preservatives (e.g., benzoic acid), and as an additive promoting gel setting. Fumaric acid is synthesized via maleic acid anhydride which is obtained by catalytic oxidation of butene or benzene or is produced from molasses by fermentation using Rhizopus spp.

10. Bases

NaOH and a number of alkaline salts, such as NaHCO3, Na2CO3, MgCO3, MgO, Ca(OH)2, Na2HPO4 and Na-citrate, are used in food processing for various purposes, for example: Ripe olives are treated with 0.25-2% NaOH to eliminate the bitter flavor and to develop the desired dark fruit color. In alkalai-baked goods (bread and cakes that keep) molded dough pieces are dipped into 1.25% NaOH at 85-88 °C or, in the case of larger fresh alkali-baked goods, into 3.5% NaOH at room temperature in the baking process in order to form the typical smooth, light to dark brown surface. In chocolate manufacturing, NaHCO3 enhances the Maillard reaction, providing dark bitter chocolates.

11. Antimicrobial agents

Elimination of microflora by physical methods is not always possible; therefore, antimicrobial agents are needed. The spectrum of compounds used for this purpose has hardly changed for a long time. It is not easy to find new compounds with wider biological activity, negligible toxicity for mammals and acceptable cost. In the use of weak acids as preservatives, their pKa value and the pH value of the food are very important for the application because only the undisassociated molecule can penetrate into the inside of the microbial cell. Accordingly, weak acids like benzoic acid, sorbic acid, acetic acid etc. are suitable preferably for acidic foods.

12. Chelating agents (Sequesterants)

Chelating agents have acquired greater importance in food processing. Their ability to bind metal ions has contributed significantly to stabilization of food color, aroma and texture. Many natural constituents of food can act as chelating agents, e.g., carboxylic acids (oxalic, succinic), hydroxy acids (lactic, malic, tartaric, citric), polyphosphoric acids (ATP, pyrophosphates), amino acids, peptides, proteins and porphyrins. In the production of herb and spice extracts, the combination of an antioxidant and a chelating agent provides an improved extract quality. Chelating agents are also used in dairy products, wherein their disaggregating activity for the casein complexes is often utilized; in blood recovery processes to prevent clotting; and in the sugar industry to facilitate sucrose crystallization, a process which is otherwise retarded by sucrose-metal complexes.
Emulsifier

Emulsions in food are mixtures of oil and water. These normally do not mix and will separate if left without an emulsifier. Roll over the photograph of the mayonnaise to see the effects when the emulsifier is not added. Mayonnaise contains oil and water. The emulsifier keeps these mixed and without it the oil and water separate. Emulsifiers are molecules that have two distinct ends. One end likes to be in water (hydrophilic) and the other end likes to be in oil (lipophilic). This means that they will coat the surface of oil droplets in an oil-in-water emulsion and effectively ‘insulate’ the oil droplets from the water. It keeps them evenly dispersed throughout the emulsion and stops them from clumping together to form their own, separate layer. In a water-in-oil emulsion, the emulsifier coats the water droplets to stop them from separating from the oil. This property makes emulsifiers indispensable in the modern food industry where foams, suspensions (particles of solid dispersed evenly through a liquid) and emulsions are often used [7]. The activity of ionic and non-polar emulsifier is shown in Figure 1. Milk is a natural emulsion. It is a mixture of fat droplets in water. Proteins in the milk help to coat the fat droplets and allow them to stay dispersed in the water of the milk.

Gel builders and stabilizers

A number of polysaccharides and their modified forms, even at low concentrations, are able to increase a system’s viscosity, to form gels and to stabilize emulsions, suspensions or foams. These compounds are also active as crystallization inhibitors (e.g. in confections, ice creams) and are suitable for aroma encapsulation, as is often needed for dehydrated food. These properties make polysaccharides important additives in food processing and storage. Among proteins, gelatin is an important gel-forming agent used widely in food products.

Humectants

Some polyols (1, 2-propanediol, glycerol, mannitol, sorbitol) have distinct hygroscopic properties and act as humectants, i.e. additives for retaining food moisture and softness and inhibiting crystallization. They are often required in a confectionery product. When glycerol or sorbitol is added to mashed vegetables or fruits or in the production of other powdered foods before the final drying stage, the dehydrated products have improved rehydration characteristics.

Anticaking Agents

Some food products, such as common salt, seasoning salt (e.g. a mixture of onion or garlic powder with common salt), dehydrated vegetable and fruit powders, soup and sauce powders and baking powder, tend to cake into a hard lump. Lumping can be avoided by using any of a number of compounds that either absorb water or provide protective hydrophobic films. Anticaking compounds include sodium, potassium and calcium hexacyanoferrate (II), calcium and magnesium silicate, tricalcium phosphate and magnesium carbonate.

Bleaching Agents

Bleaching is used primarily in flour production. The removal of yellow carotenoids by oxidation can be achieved by a number of compounds that, in addition to bleaching, improve the baking quality of flour. Examples of some approved common bleaching agents are Cl₂, ClO₂, NOCl, NO₂ and N₂O₄. Lipoxygenase enzyme also has an efficient bleaching activity.

Clarifying Agents

In some beverages, such as fruit juices, beer or wine, turbidity and sediment formation can occur with the involvement of phenolic compounds, pectins and proteins. These defects can be corrected by: (a) partial enzymatic degradation of pectins and proteins; (b) removal of phenolic compounds with the aid of gelatin, polyamide or polyvinyl pyrrolidone powders; and (c) by protein removal with bentonite or tannin. Bentonite consists of hydrous aluminium silicate changing amounts of iron, calcium and magnesium salts.

Propellants, Protective Gases

Food sensitive to oxidation and/or microbial spoilage can be stored in an atmosphere of protective gas or a gas mixture (N₂, CO₂, CO, etc.; modified or controlled atmosphere storage). This is
often a suitable method for lengthening the shelf life of food. Liquid food can be filled into pressurized containers and, when needed, using a propellant, discharged in the form of a cream or paste (e.g., cream cheese, ketchup), a foam (whipping cream) or a mist (herb or spice extracts in oil; liquid barbecue smoke). Propellants used are N\textsubscript{2}, N\textsubscript{2}O, and CO\textsubscript{2}. Due to its low solubility in water, fat and oil, N\textsubscript{2} is used preferentially as a propellant when foam formation is not desired (ketchup). On the other hand, gases such as N\textsubscript{2}O and CO\textsubscript{2} are preferred for foam formation (whipped cream) due to their good solubility in water.

Conclusion

Cereals, fruits and other foods of plant origin is available fresh only during a brief harvest periods. Consequently, since ancient time it has been necessary to keep supply to harvested fruit edible over relatively long spells. Recently, there has been a change of leaving habits and requirements in many countries in as much as people now we wish to enjoy foods. Although food preservation has now reached in high standard in developed countries, the quantity of foods still spoiled are astonishing. Whereas foods used to be preserved for commercial reasons, toxicological findings have recently become additional reason for preservation. Since concentrations of various food additives vary among foods, it may give rise to adverse effects when taken in large amounts, but it does not mean that its proper use will affect a hazard to man by consideration of toxicity of the additives [8]. Legal measures are designed to protect the public from the presence in a food supply of any additives that have not been recommended to be safe under the conditions of use.

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References


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