8 Pigments and Colors

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8.1 Introduction

Color is considered as one of the most delightful as well as impressive qualities of food products, which influences the eating desires of the consumers along with their preference and choice (Delgado-Vargas and Paredes-Lopez 2003). Food color is any dye, pigment, or substance which on addition to the food gives it color. Adding color elevates the look of the food and makes it more attractive and also influences our perception. Sometimes, the loss of color during processing is made up by adding food colors. Natural colors have been an important part of our diet. They are added to foods for good appeal as well as identity (Griffiths 2005). The trend is increasing in the markets to ensure expectations of consumers with more diverse food products with different textures, colors, and tastes are available (Ayala-Zavala et al. 2011).

Since the pre-historical era, human beings have left their identity in the nature that can be observed in painted images, whether it may be either simple handprints or fine artworks (Barnett et al. 2006). A pigment produces the colors which we observe in the leaves, flowers, fruits, and roots of the plants and is also present in the skin, hair, eyes, and other parts of the animals (Delgado-Vargas et al. 2000).

For decades, we have been associated with different colors of food products. The natural pigments have a very limited scope which is being permitted for use in foods, and they are under strict regulations (Clydesdale 1993).

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O. P. Chauhan (ed.), *Advances in Food Chemistry*,
https://doi.org/10.1007/978-981-19-4796-4_8

Structurally diversified natural food colorants which are widely distributed, are grouped into tetra-pyrrols, tetra-terpenoids, and flavonoids. Chlorophyll is the most important pigment, which is commonly found in leaves. Carotenoids are tetra-terpenoids that are responsible for the yellow, orange, and red color of many fruits and vegetables, whereas the red/purple shade of many fruits is due to the presence of anthocyanins. Other important classes of pigments are the anthraquinones found in carmine and madder, and the betalains found in beetroot.

8.2 Pigments

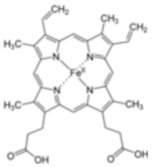
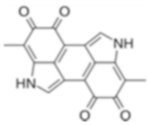
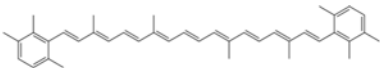
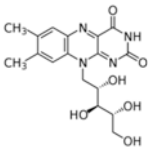
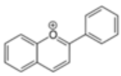
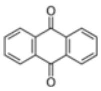
Pigments are the compounds which are generally responsible for the color of many products including food products. We observe various pigments in our day-to-day life since these compounds are widespread in every living organism. Among them, plants are the major principal producers (Delgado-Vargas et al. 2000). Hundreds of different structures can be found only in anthocyanin group. These compounds display various hues of colors like yellow, brown, blue, black, green, red, orange, pink, etc. Currently, pigments are used in various fields like food, medicine, cloths, cosmetics, furniture, and in other areas (Hari et al. 1994). However, along with imparting beauty to the products, pigments have also involved in most important functions of the living organism (Mortensen 2006). Quinones play a very significant role in the conversion of light energy into chemical energy. Since time immemorial, people used to distinguish the quality of the product by their color, especially in the case of meat (Koes et al. 1994; Mol et al. 1996).

Naturally occurring biological pigments are grouped as isoprenoids, tetrapyrroles, benzopyrans, quinines, metalloproteins, and N-heterocyclic compounds. Among them, carotenoids and chlorophylls are the most abundant pigments in nature. Plants, protozoa, and photosynthetic bacteria provide organic material, which is required for the growth of other animals (Hari et al. 1994). The pigments found in animals are presented in Table 8.1.

8.2.1 Classification of Pigments

1. **Natural Pigments**
   These are pigments produced mainly by plants, animals, and microorganisms and they have low stability and are found in low concentration (Hari et al. 1994).
2. **Synthetic Pigments**
   Synthetic pigments are produced by chemical reactions. They are highly stable and occur in high concentrations. Synthetic pigments can be separated into water-soluble and water-insoluble based on their solubility and they may be either organic or inorganic in nature (Amchova et al. 2015).

Table 8.1 Pigments in animals

Pigments	Distribution
Heme proteins 	Crustacea, Mollusks, Arachnida malacostraca, annelids
Melanins 	Wide distribution including crustacea, Echinoderms, insects, malacostraca
Carotenoids 	Mammals, birds, reptiles, fishes, amphibians, Echinoderms, insects, etc.
Riboflavin 	Reptiles, amphibians, fish
Flavonoids 	Crustacea, insects
Quinones 	Echinoderms, insects, and arachnida

8.2.2 Extraction of Pigments

The most common and easy method of coloring any food is to add strongly colored food to the product which needs to be colored. This approach is generally used in cooking, where spices may impart color along with flavor. However, for industrial food application, this approach shows problems like low concentration of pigments, provides unwanted flavors, and insoluble matter like peel and seed, which is unacceptable in beverages (Delgado-Vargas et al. 2000). Due to their low concentration, these pigments are extracted with organic solvents for fat-soluble pigments, and anthocyanins are extracted with water or alcohol (Mortensen 2006).

8.2.3 Major Classes of Natural Pigments

8.2.3.1 Chlorophylls

These are fat-soluble green pigments present in the plastids of plants, algae, and few bacteria. Chlorophylls are involved in the process of photosynthesis for the biosynthesis of complex substances from simpler ones like H_2O and CO_2. These pigments are widely distributed in all green leafy vegetables and green algae (Simpson et al. 2012). Among several chlorophylls, chlorophyll *a* and *b* are playing a very important role in food coloration as they are very common in green plants (Fig. 8.1).

Chlorophyll contains tetrapyrrole or porphyrin ring system which is very much similar to myoglobin (Mb) and hemoglobin (Hb) structures. The four pyrrole rings are connected together with the central Mg^{2+} ions to make a porphyrin ring. This porphyrin ring along with phytol makes the complete chlorophyll structure.

When chlorophyll-containing foods like vegetables and green leaves are cooked, chlorophyll can undergo changes with respect to the color and solubility. The color may be turned to dull green, brownish, or bright green. This color change is mainly due to changes or reactions of chlorophyll molecule, which may be due to the loss of the phytol side chain by the action of the enzymes called chlorophyllase and/or acidic conditions, or the removal of the central Mg^{2+} atom when exposed to heat treatment and acids (Patek 1936).

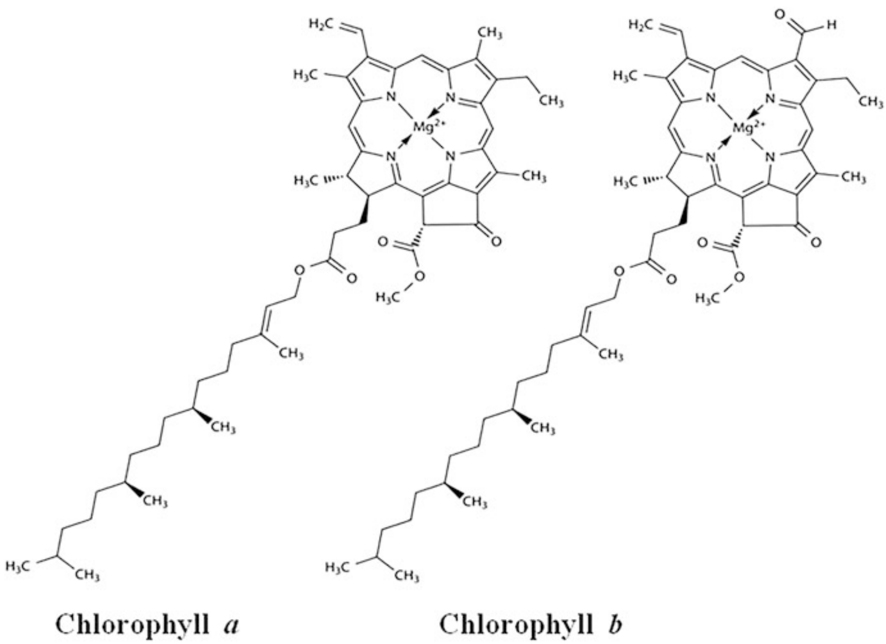


Fig. 8.1 The structure of chlorophyll *a* and Chlorophyll *b*

Chlorophyll exists in nature in various forms such as chlorophyll *a*, *b*, *c1*, *c2*, and *d*. Chlorophyll is generally extracted from plants like spinach, nettles or grass, and alfalfa using acetone and hexane in darkness to avoid degradation. Exposure to light, heat, extreme pH, and air cause adverse effect on its stability. The stability of chlorophyll increases when complexes with copper ion as well as by de-esterification (Colio and Babb 1948).

8.2.3.1.1 Chlorophyll Degradation

The degradation of chlorophyll is an important biochemical process which occurs during fruit ripening and also leaf senescence. Figure 8.2 shows the chlorophyll degradation pathway. During this process, the enzyme called chlorophyllase catalyzes the chlorophyll by removing the phytol group which results in the formation of the chlorophyllide. Jaques et al. (2001) reviewed the degradation of chlorophyll when green cellular tissues are subjected to various processing conditions. During heat treatment, freezing, and storage the chlorophyll degrades into pheophytin, which is having a color of olive brown. During processing, the duration of treatment, pH of the medium, temperature, and the release of acids speed up the chlorophyll degradation.

Maximum chlorophyll degradation takes place under longer and hotter processing conditions. For example, when a kiwifruit was exposed to the processing temperature of 100 °C for 5 min, chlorophylls were completely damaged (Robertson 1985). Chlorophyll is more stable at higher pH conditions. Hence, sodium bicarbonate is added to increase the pH of water during the cooking of peas and beans (Schwartz and Lorenzo 1990). Chlorophyll *a* is known to break down quickly than chlorophyll *b* during heat processing. But, reverse action happens during the storage of vegetables in flexible containers.

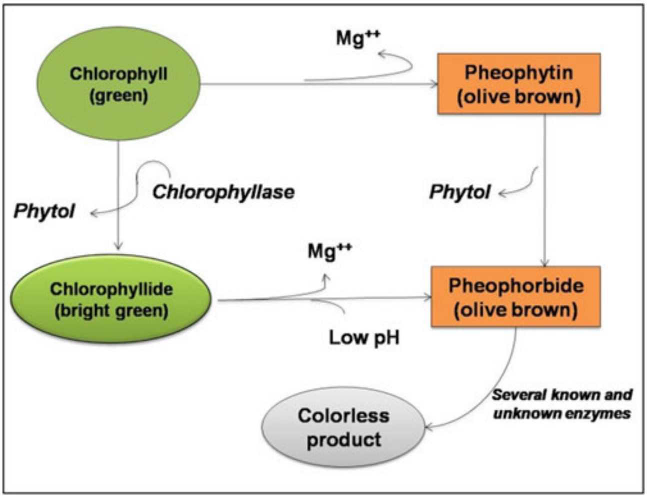


Fig. 8.2 Chlorophyll degradation pathway

8.2.3.1.2 Health Benefits

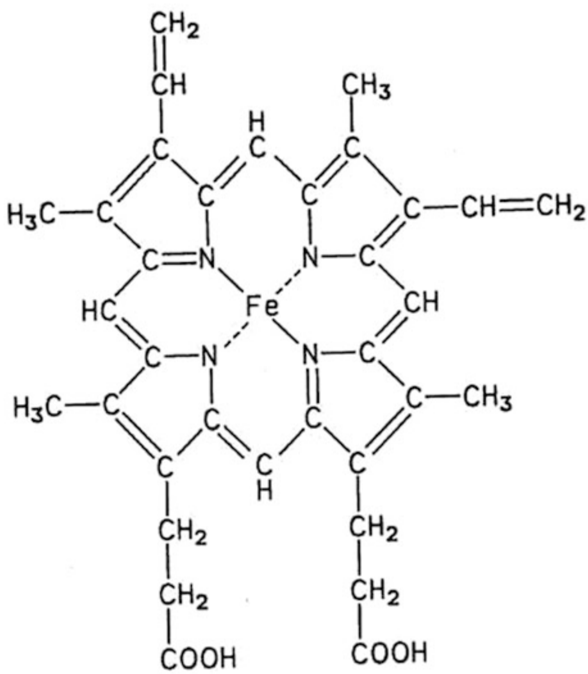
Chlorophyll has numerous health benefits for human beings. Firstly, they have been found capable of rebuilding the bloodstream without side effects when administrated in high doses through oral, intravenous, and intramuscular (Patek 1936). Chlorophyll also encourages the fertility rate by regulating sex hormones. They can also be used as antibacterial agents (Bowers 1947). They are capable to clean the deposition of drugs, deactivation of toxins in the body, reduce problem associated with blood sugar, and cleanses liver (Colio and Babb 1948). Chlorophyll also plays a major role in inhibiting oral bacterial infections in deodorizers, which promotes healing of rectal sores and reduces typhoid fever (Offenkrantz 1950).

8.2.3.2 Heme (blood) Pigments

Heme is a basic chemical (Fig. 8.3) responsible for the red coloration of hemoglobin and myoglobin. The color of the red meat is due to the presence of myoglobin. The other color compounds of muscles like vitamin B_2, cytochromes, and flavoproteins do not contribute much to red meat (Simpson et al. 2012).

The major function of heme pigments is the transportation of oxygen for generation of energy. The central Fe atom attaches to four nitrogen atoms in the porphyrin ring and the fifth coordinates to join with the nitrogen atom of histidine residue of globin (Weber et al. 1974). In terms of concentration, the major pigment of meat muscle is Mb, approximately 80%, and remaining 20% is Hb, which is common in the blood vessels for the transportation of oxygen (Kim et al. 2003).

Fig. 8.3 Structure of heme



8.2.3.2.1 Health Benefits

Red meats are abundant in iron, which is very much essential for the human body to produce red blood cells as well as to regulate the temperature of the body. If a person is having Iron deficiency, it may lead to a decline in cognitive abilities, predominantly in children.

8.2.3.3 Anthocyanins

These pigments belong to the flavonoid family. These groups of reddish water-soluble pigments are present in flowers, fruits, and vegetables. Anthocyanin color mainly depends on pH condition. Anthocyanins are in red color under acidic condition; whereas, they appear blue and purple under basic and neutral pH, respectively (Solymosi et al. 2015).

Anthocyanins commonly occur in fruits, especially berries, nuts, vegetables, roots, grains, and flowers (De Brito et al. 2007; Einbond et al. 2004). Major sources are purple, raspberry, strawberry, cherry, blueberry, plum, red cabbage, etc. Based on the chemical structures, they are classified into two types, i.e., anthocyanidin aglycones and true anthocyanins, presented in Fig. 8.4.

Various factors such as cultivar or variety (Lee and Finn 2007), maturity (Ahmadiani et al. 2014), growing area, season, cultivation practices (Kovacevic et al. 2015), and storage conditions may affect the composition of anthocyanins. The effect of processing and storage on the stability of anthocyanins has been studied and it was found that effect of processing conditions and storage on the polyphenol content is negligible.

Anthocyanins are commonly used to color food products like jams, jellies, drinks, pastries, and confectionaries since they impart blue or red colors. However, they are vulnerable to pH changes. Molecules in the anthocyanin may get some protection against degradation due to the presence of sugar under ambient conditions. The harmful effects can be reduced by storing at low temperature (Simpson et al. 2012).

8.2.3.3.1 Health Benefits

The toxicity of anthocyanins has not been reported but it is believed that anthocyanins are nontoxic at high temperature. They are potential antioxidants and play various health benefits like improved visual perception, coronary heart disease, antiviral activity, etc. The anthocyanins like delphinidin, petunidin, and malvidin enhance the activity of glutamate decarboxylase, the enzyme that acts as a catalyst in

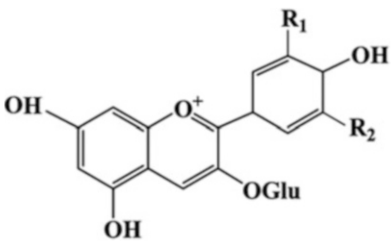


Fig. 8.4 Structure of anthocyanin

the decarboxylation of glutamic acid to gamma amino benzoic acid (Simpson et al. 2012).

8.2.3.4 Carotenoids

Carotenoids are commonly present in fruits and vegetables, yellow-colored flowers, animal species like crustaceans, birds, fishes, insects, and seaweeds (Britton 1996). Ripening in many fruits like citrus fruits, apricots, and tomatoes is mainly associated with the accumulation of carotenoids and the disappearance of chlorophyll. The oxygenated carotenoid counterparts like lutein, astaxanthin, cryptoxanthin, canthoxanthin, and zeaxanthin are formed by hydroxylation (Tanaka et al. 1976) (Fig. 8.5).

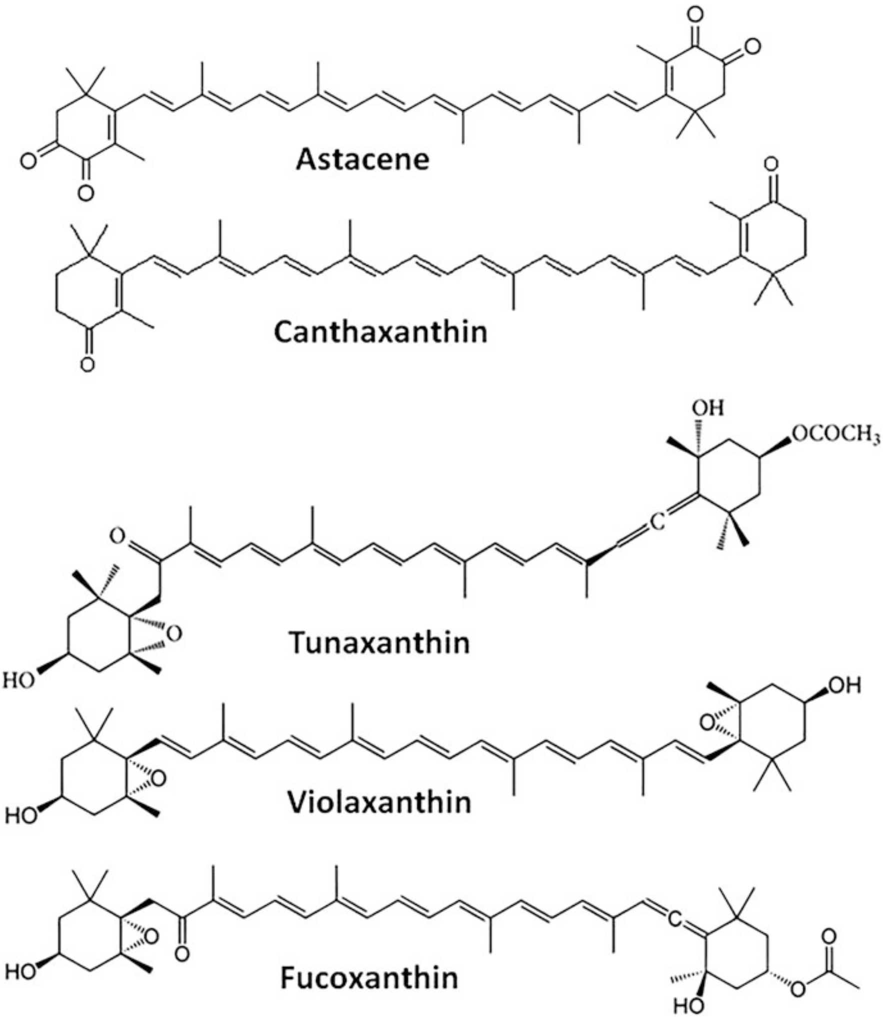


Fig. 8.5 Chemical structure of some common carotenoids

8.2.3.4.1 Health Benefits

Carotenoids are very important and most essential in the retina of the eye for vision and are eye disorders (Krinsky and Johnson 2005; Dembinska-Kiec 2005). Carotenoids also inhibit oxidation of low-density lipoprotein and cardiovascular diseases (Hadley et al. 2003). Carotenoids boost the immune system and also reduce the adverse side effects of cyclooxygenase inhibitor drugs (Kearney et al. 2006).

8.2.3.5 Flavonoids

Flavonoids are water-soluble compounds that exhibit shades of yellow to colorless appearance. They are removed very fast from the body which leads to inadequate absorption and low bioavailability. Isoflavones are the most bioavailable pigment while the flavanols are the least bioavailable among different flavonoids (Manach et al. 2005). Few flavonoids are esterified and occur in plants and foodstuffs. The major flavanols are catechin, epicatechin, epigallocatechin, epicatechin gallate, epigallocatechin gallate, and teaflavins. Flavanones are butin, hesperidin, hesperetin, naringenin, and naringin (Fig. 8.6) (Simpson et al. 2012).

8.2.3.6 Betalains

Betalains are water-soluble pigments and they are classified into two classes, betacyanin and betaxanthin. Betacyanins exhibit reddish to violet color, which includes amaranthine, isoamaranthine, betalain, isobetalain, phyllocactin, and isophyllocactin. Betaxanthin exhibit yellow to orange color, which comprises dopaxanthin, miraxanthin, indicaxanthin, portulaxanthin, portulacaxanthin, and vulgaxanthin (Fig. 8.7) (Simpson et al. 2012).

8.2.3.6.1 Health Benefits of Betalains

Betalain extracts are used as food colorant in wines and juices. The red beetroot is the most common source of betalain-based food colorant. Betalains are very less resistant to light and temperature. Hence, color may change from red to yellow color, based on the surrounding environment.

8.2.3.7 Astaxanthin

It is an orange-red colored keto-carotenoid produced and accumulated in few red algae, green algae, and bacteria. The most common astaxanthin accumulated in animal parts are flamingo feathers and crustacean shells. Astaxanthin is most commonly used in animal feed, in marine aquaculture including ornamental fish. It is also ideal in dietary supplements such as tablets, capsules, syrups, and soft gels (Solymosi et al. 2015).

8.2.3.8 Lycopene

Lycopene is an expensive pigment and is highly prone to oxidative degradation and is found in plants containing β carotene, in low concentration since lycopene act as a

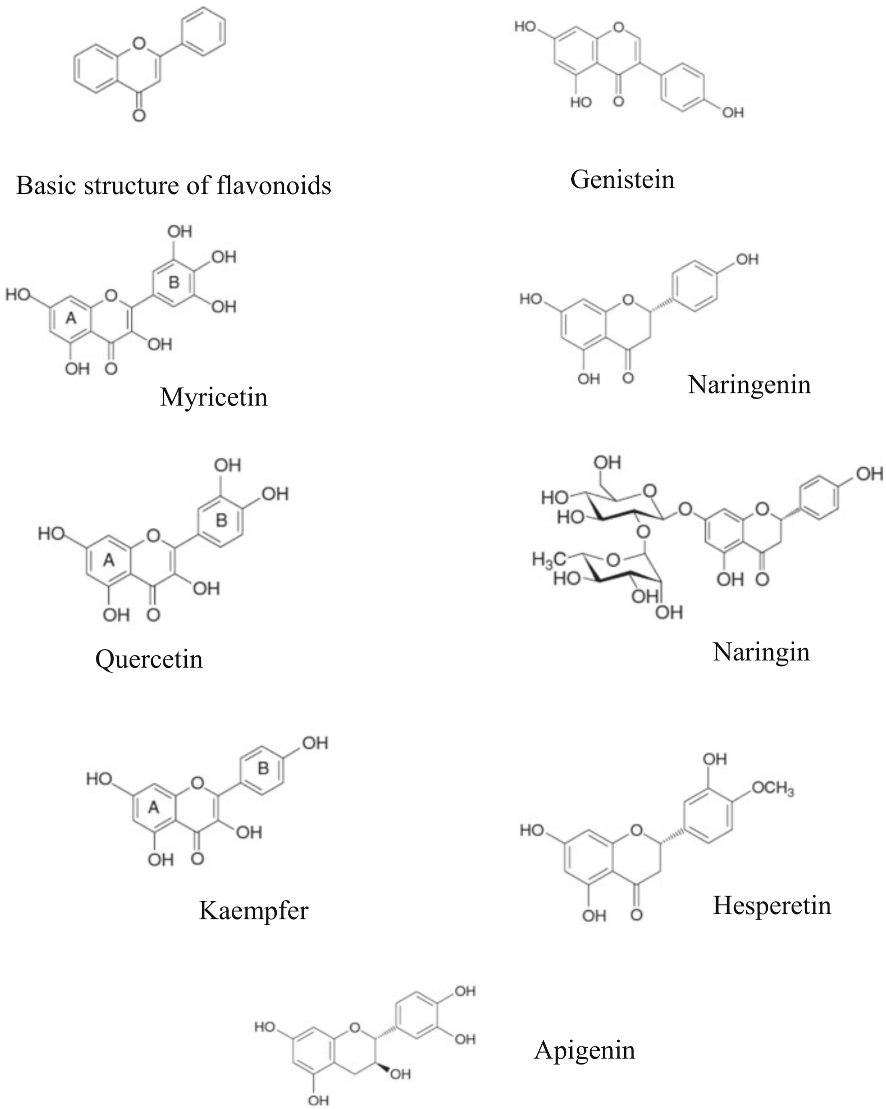


Fig. 8.6 Chemical structure of common flavonoids

precursor in the synthesis of β carotene. Lycopene is very common in tomatoes, watermelon, grapes, etc. It is a powerful antioxidant which reduces the risk of prostate cancer and ischaemic heart disease (Solymosi et al. 2015).

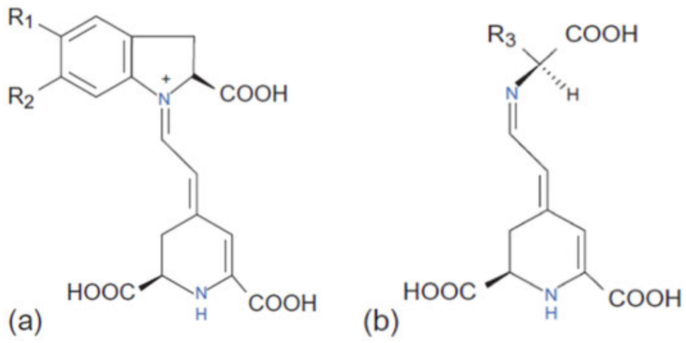


Fig. 8.7 Structure of (**a**) Betalain (**b**) Betacyanins

8.3 Food Colors

There are varieties of foods available in nature and each of them is recognized by its own taste, texture, smell, and color. Among these, food color is one of the major factor which influences consumers' attention. Color makes food items very attractive and appealing to taste. The reality is that most of the color pigments of any food product are unstable. Hence, whenever the food is exposed to harsh conditions during processing, color pigments can be destroyed (Kumari and Meghwal 2016).

Color is one of the important selection criteria for food preference. Recent studies show their importance and role in selection of colors might modify among the population over a period of time (Clydesdale 1993). Color is the first noticeable characteristic of the food and helps to predetermine our expectation regarding that particular food, either taste or flavor. For example, the consumer perceives that yellow indicates the lemon flavor and pink goes with the grapefruit (Griffiths 2005). In our daily life, consumers get the opportunity to inspect any kind of food visually before tasting and buying (Spence 2015). Studies have found that by changing the intensity or hue of the color, food items can make use of a drastic impact on consumers' expectation and sensory attributes (Clydesdale and Walford 1984).

Food coloring is defined as any dye, pigment, or substance which is added to food items, either solid or liquid, to impart the required color. A food coloring agent exists in various forms like solid powders, liquids, gel or pastes, etc. Other than food industry, food colorants are used in cosmetics, pharmaceuticals, medical devices, etc. The global turnover of food colorants is about 8000 tons per year and in that India accounts for only 2% of output (Solymosi et al. 2015). There are set of laws and regulations given by the FDA and other regulatory organizations regarding the use of food color.

The natural color of plant-origin foods is mainly due to four groups of pigments such as green-colored chlorophylls, yellow-red-orange of carotenoids, red-blue-purple of anthocyanins, and red-colored betacyanin. Due to the health benefits of natural colorants, consumers prefer them over artificial food dyes. However, natural colorants are less stable and high cost when compared to synthetic dyes, besides having limited range of hues (Rodriguez-Amaya 2018). The usage of synthetic colors in the food industry has been started in the 1800s for decorative purposes as well as to mask low-quality food products (Sulz 1888).

8.4 Major Classification of Colors

Colorants are divided into two groups based on their source as natural and synthetic (Demirag and Uysal 2006).

8.4.1 Natural Color

Natural food color is any pigment extracted from plants, animals, or any other natural sources capable of coloring food. There are reports that in Europe food colorants were used during the Bronze age (Lakshmi 2014). Natural food colorants are safer than synthetic colorants and they are accepted worldwide due to their health benefits and biological potential along with their reliability as well as functionality (Martins et al. 2016). The natural colorants from beetroot, carrot, grape, paprika, and cabbage are very popular and safe. Apart from chinoides, flavonoids, betalains, isoprenoids, and porphyrins, there are few natural pigments such as curcumin and caramel, which are equally significant and commonly used in many food products (Solymosi et al. 2015).

8.4.1.1 Organic Natural Colors

Anatto: It is yellow-orange color food additive which is widely used in cosmetics and food industries like beverages, bakery, and dairy products. Recently, usage of nitrile in sausage is being replaced by Annato powder (Wrolstad and Culver 2012).

Carotenes: The main coloring chemical of carotene is β-carotene. These are highly preferred in various food products with more fatty acid content (Solymosi et al. 2015).

Caramel: Caramel accounts for more than 80% of all food colorants. Here, Class I has the lightest shade, whereas Class IV has the darkest shade (Sengar and Sharma 2014).

Carmine (Natural Red 4): It is a red dye extracted from insects like *Kermes vermilii*, *Porphyrophora polonica*, *Dactylopius coccus*, etc. (Mortensen 2006). At low pH, carmine is orange color at low pH and violet at alkaline pH.

Curcumin (Turmeric): In Turmeric, curcumin basically exists in 1,3-di-keto and enol forms, but also in the form of demethoxy curcumin, bis-demethoxycurcumin and cyclo-curcumin. The potential of curcumin is very high, because of its antioxidative and anti-inflammatory properties (Nielsen and Holst 2002).

Lycopene: The color of lycopene depends upon its concentration. It is red when accumulated in high concentration and orange in a dilute form. It is a very powerful antioxidant that reduces the risk of prostate cancer and ischaemic heart disease (Solymosi et al. 2015).

Marennine: It is a very popular natural color with a blue pigment and exhibits an anti-proliferative effect and presents antiviral and anticoagulant properties.

Melanins: Melanins are extensively distributed in animals, fungi, bacteria and play an important role in the protection against environmental stresses (Solymosi et al. 2015).

Riboflavin: It is a most effective natural yellow water-soluble colorant for powdered and solid food applications. It is being extracted from the fungi *Eremothecium ashbyii*. Its major drawback is that it is sensitive to light and vulnerable to oxidation thus resulting in limited applications (Solymosi et al. 2015).

8.4.1.2 Inorganic Natural Color

Silver gray colored Aluminium dust, red and brown colored iron oxide, gold, titanium dioxide and calcium carbonate are the main inorganic natural colorants. These inorganic colorants are commonly used in chocolate, bread, confectionery, etc. (Emerton and Choi 2008).

8.4.2 Nature-Identical Color

Nature-identical colors are synthetic chemicals and certification is not required from FDA. They are identical in chemical and functional properties when compared with natural colors.

8.4.3 Synthetic Colors

These are produced by chemical synthesis and do not occur in nature. Synthetic food coloring was originally manufactured from coal tar. People have started using synthetic food colors, though there are many natural colors in nature. Cost is a very big reason to go with synthetic color. Artificial food dyes are highly stable than natural ones of same color and there is a limitation for the application of natural colors as food dye (Andrade et al. 2014). In India, at present, eight synthetic colors, i.e., Sunset Yellow FCF, Tartrazine, Ponceau 4R, Carmosine, Erythrosine, Brilliant blue FCF, Fast Green FCF, and Indigo carmine are permitted to add in food items (FSSAI). The maximum permissible limit of all food colors is 100 ppm, which can be either individual or in combination.

Synthetic food colors are extensively used in many food products and in many instances they exceed the permissible level (Andrade et al. 2014; Kiseleva et al. 2003). Synthetic dyes such as Sunset Yellow, Tartrazine, Amaranth, and Brilliant Blue are vastly used in beverages (Al-Degs 2009). Many synthetic food colors are injurious to human health because they have azo group, which is known for genotoxicity (Lopez-de-Alba et al. 2001; Combes and Haveland-Smith 1982).

8.4.3.1 Water-Soluble Synthetic Colors

Allura Red AC: It is generally obtained from insects and used in the manufacture of various food products, viz., wine, soups, sauces, gums, snacks, carbonated drinks, etc. European Union permitted it, while many countries like Australia, Denmark, France, Switzerland, Norway, Belgium, and Sweden have banned it (Pandey and Upadhyay 2012).

Amaranth: This synthetic color is reddish-brown in color with water-soluble properties (Demirag and Uysal 2006).

Sunset Yellow: This synthetic chemical is orange-red in color and commonly used in drinks, beverages, sweet powders, ice cream, cereals, snacks, etc. (Branen and Haggaerty 2001).

Brilliant Blue FCF: This granular form synthetic color is water soluble with blue and black colors. It is used in different products like beverages, cheese, wine, sauce, etc. (Martins et al. 2016).

Tartrazine: It is a yellow colored synthetic chemical used to color cream, bread, cereal, beverages, confectionery, ice cream, peanuts, and canned food (FDA and US 2010).

Erythrosine: It is a xanthene-class colorant and added to flavored milk and pudding, ice cream, jelly, etc. (Karaali and Ozcelik 1993).

8.4.3.2 Fat-Soluble Synthetic Colors

These are soluble in oil or organic solvents and they are banned for food coloring as they have toxic properties. The Penso SX is an oil-soluble chemical used to color butter, whereas Yellow AB and Oil red XO are used in the coloring of orange peel (Demirag and Uysal 2006).

8.4.3.3 Lake Colors

These are water-insoluble precipitation of aluminum hydrate substrate and are produced in the form of fine powders. The color tone of the powder is decided based on dye content and particle size (Downham and Collins 2000). Since they are not soluble in water, oil, and other solvents, they are dispersed directly into food matrix to impart color. Lake colors are being used in cakes, biscuit fillings, confectionery, powder drinks, sweets, soups, and spice mixtures.

Today, most of the synthetic food colors are obtained from crude oil. The list of permitted and non-permitted synthetic colors is provided in Tables 8.2 and 8.3.

Table 8.2 Artificial food colors permitted in India as per FSSAI (2011)

S. No.	Color	Common name	Chemical class
1	Red	Panacea 4R	Azo
		Carmoisine	Azo
		Erythrosine	Xanthene
2	Yellow	Tartrazine	Pyrazolone
		Sunset yellow	Azo
3	Blue	Indigo caramine	Indigoid
		Brilliant blue	Triaryimethane
4	Green	Fast green FCF	Triaryimethane

Table 8.3 List of non-permitted synthetic food colors in India

S. No.	Color	Color index name	Application
1	Amaranth	C. I. Food Red 9	Crushed ice, cut and glazed fruits, jam and jellies, milk sweets
2	Fast Red E	C. I. Food Red 4	Hard-boiled sugar confectionery, crushed ice, sweetened supari
3	Metanil Yellow	C. I. Acid Yellow 36	Bakery products, savories, biryani, non-milk sweets, turmeric powder, dhokla
4	Orange II	C. I. Acid Orange 7	Milk sweets, non-milk sweets, bakery products, sugar toys, turmeric powder
5	Auramine	C. I. Basic Yellow 2	Non-milk sweets, sugar toys, savories
6	Blue VRS	C. I. Food Blue 3	Ice cream cones, glazed fruits, biryani, savories
7	Green S	C. I. Food Green 4	Milk sweets, non-milk sweets
8	Malachite green	C. I. Basic Green 4	Fresh vegetables, fresh coriander leaves, green peas, milk, and non milk sweets
9	Rhodamine B	C. I. Basic Violet 10	Milk-based and non milk-based sweets, confectionery, sugar toys, colored tamarind

8.5 Regulatory Status and Labeling

As per the inventory of colored eatables, more colored food products are common in the urban areas when compared to the rural areas (Tripathi et al. 2007). About 69% of colored food products are manufactured using permitted color while 31% of samples revealed the presence of non-permitted colors. The use of non-permitted colors was more in rural areas (38%) as compared to urban areas (25%). However, the permitted colors in food products were within the approved limit of 100 ppm in urban markets (73%) than in rural areas (50%) (Tripathi et al. 2007).

Nowadays, many synthetic colors which are meant for paper and textiles are being used in food products. In spite of regulatory supervision, the non-permitted synthetic colors are being used in some of the local food vendors or non-branded food products. In other instances, the permitted food colors are being used beyond the permissible limit. The disproportionate application of non-food grade colors needs to be regulated (Tripathi et al. 2007).

In spite of strict regulation for synthetic food colors, the uses, status, doses, acceptable daily intake (ADI), labeling requirements, and applications are continuously being reevaluated. Many recognized authorities have made regulations list of approved food color additives and limitations for use in food products. Many countries follow the specifications provided by the Codex Alimentarius or FAO for the usage of color additives and to set allowable doses in foods (Corradini 2018).

In the EU, the European Food Safety Authority (EFSA) established its ADI for the evaluation and safety of synthetic colors. According to EU regulations, stating either the name of synthetic color or its corresponding additive E number on the label is required. Additionally, if any of the six synthetic colors (Allura Red AC, Azorubin, Ponceau 4R, Quinoline yellow, Sunset Yellow FCF, and Tartrazine) is being added to any product, its label should include a warning. Within the EU, the RASFF (Rapid Alert System for Food and Feed) has been developed to assist the exchange of information on adulterated foods (Corradini 2018).

Permission for food colorants is stringently regulated by detailed laws at both national and international levels. The natural colorants permitted by FSSAI for use in India are carotene and carotenoids, chlorophyll, riboflavin, caramel, annatto, saffron, turmeric, or curcumin. The list of natural colors permitted in the US are listed in Table 8.4.

Table 8.4 Application limit for natural color as per US regulations

S. No.	Food product	Colorant	Maximum limit (ppm)
01	Breakfast cereals	Carminic acid Caramel color-III, Carotenes, Bixin, Norbixin, Capsanthin, Betanin, Anthocyanins	25–200
02	Butter	Carrot extract	NL
03	Malt bread	Caramel color (E150a–d)	NL
04	Chips (potato)	Curcumin, Turmeric	NL
05	Cheese	Carotenes, Bixin, Norbixin	1.5–50 for E160b
06	Margarine, emulsions of fat in water	Curcumin, Turmeric	10 for E160b
07	Vinegars	Caramel colors (E150a–d), Anthocyanins	NL
08	Bitter beverages	Curcumin, Turmeric, Riboflavin, Carminic acid	100 mg/L
09	Fruit and vegetable juices	Carotenes, Lycopene, β-apo-8-carotenal	NL
10	Beer and Cider	Caramel colors (E150a–d)	NL
11	Preserved vegetables	Riboflavin, Chlorophyll, Caramel colors (E150a–d), Chlorophyllins, carotenes, Anthocyanins	NL
12	Jams and Marmalade	Curcumin, Turmeric, Chlorophyll, Chlorophyllins, Capsanthin, Paprika, Lutein, Betanin, Anthocyanins, Carminic acid	100 only for synthetic colorants
13	Sausages, meat pastes, fish products	Curcumin, Turmeric, Riboflavin, Carminic acid, Caramel colors (Ea–d), Carotenes, Capsanthin, Paprika, Betanin	20–100
14	Hamburger	Carminic acid, Caramel colors (Ea–d)	100 only for E120

NL no limit specified

8.6 Health Benefits of Pigments

We consume a wide variety of foods which includes carotenoids, chlorophylls, and anthocyanins which are present in many colorful tubers, seeds, fruits, and vegetables. However, compared to synthetic food colors, consumers predominantly favor natural colors due to their health benefits and nutrition (Downham and Collins 2000). The findings of Southampton University confirmed a quantifiable change in diverse behavioral issues like hyperactivity and attention period when consumed food products spiked with food colors and preservatives (McCann et al. 2007; Bonan et al. 2013). Anthocyanin and their aglycones like cyanidin, delphinidin, malvin, and peonidin demonstrated anti-proliferative and proapoptotic activities in gastric adenocarcinoma (Duluc et al. 2014).

There are many reports to link the adverse side effects like carcinogenicity, behavior problems like hyperactivity in children, allergy, asthma, etc., when food products with synthetic food colors are consumed (Hashem et al. 2010; Kobylewski and Jacobson 2010; Tripathi et al. 2007). Lycopene and lutein are associated with a reduced risk of prostate cancer because of their high antioxidant properties (Zhao et al. 2017; Jia et al. 2017; Akhtar and Bryan 2008; Aghajanpour et al. 2017; Li et al. 2018). The potential health risks are increasing due to the adulteration of wines and juices with synthetic food colors instead of using natural sources (Komissarchik and Nyanikova 2014; Kobylewski and Jacobson 2010). Consumption of synthetic food colors causes some potential adverse health effects like allergenicity, behavioral problems like hyperactivity syndrome in children, neurotoxicity, genotoxicity, and carcinogenicity. Recent studies show that adverse effects like allergy, asthma, hyperactivity, and even cancer can be linked to the intake of synthetic food dyes (Hashem et al. 2010; Kobylewski and Jacobson 2010; Tripathi et al. 2007; McCann et al. 2007).

8.7 Conclusion

In recent years, food additives which may be either natural or synthetic are used to preserve food products to improve their appearance, taste, texture, and color. Natural or synthetic food colors are used in many food products either to restore or substitute the color to reduce batch variation and to attract consumers. Natural food colors are in great demand because of their health benefits without any side effects when compared to synthetic food colors, which are identified for many side effects. There is a lot of scope and opportunity to explore new sources of natural colors and their application specific to the products as well as the processes involved. New technologies may overcome the short shelf life of natural food colors and to impart color stability along with their health-promoting activities of food products.

References

Aghajanpour M, Nazer MR, Obeidavi Z et al (2017) Functional foods and their role in cancer prevention and health promotion: a comprehensive review. Am J Cancer Res 7(4):740–769

Ahmadiani N, Robbins RJ, Collins TM et al (2014) Anthocyanins contents, profiles, and color characteristics of red cabbage extracts from different cultivars and maturity stages. J Agric Food Chem 62:7524–7531

Akhtar MH, Bryan M (2008) Extraction and quantification of major carotenoids in processed foods and supplements by liquid chromatography. Food Chem 111(1):255–261

Al-Degs YS (2009) Determination of three dyes in commercial soft drinks using HLA/GO and liquid chromatography. Food Chem 117(3):485–490

Amchova P, Kotolova H, Ruda-Kucerova J (2015) Health safety issues of synthetic food colorants. Regul Toxicol Pharmcol 73(3):914–922

Andrade FID, Guedes MIF, Vieira IGP et al (2014) Determination of synthetic food dyes in commercial soft drinks by TLC and ion-pair HPLC. Food Chem 157:193–198

Ayala-Zavala JFN, Vega-Vega V, Rosas-Domínguez C et al (2011) Agro-industrial potential of exotic fruit byproducts as a source of food additives. Int Food Res J 44(7):1866–1874

Barnett JR, Miller S, Pearce E (2006) Colour and art: a brief history of pigments. Opt Laser Technol 38(5):445–453

Bonan S, Fedrizzi G, Menotta S, Elisabetta C (2013) Simultaneous determination of synthetic dyes in foodstuffs and beverages by high-performance liquid chromatography coupled with diode-array detector. Dyes Pigments 99:36–40

Bowers WF (1947) Chlorophyll in wound healing and suppurative disease. Am J Surg 71:37–50

Branen AL, Haggaerty RJ (2001) Introduction to food additives. In: Branen AL, Davidson PM, Salminen S, Thorngate J (eds) Food additives. CRC Press, Boca Raton, FL, pp 1–11

Britton G (1996) Carotenoids. In: Hendry GAF, Houghton JD (eds) Natural food colorants, 2nd edn. Blackie Academic & Professional, London, pp 197–243

Clydesdale FM (1993) Color as a factor in food choice. Crit Rev Food Sci Nutr 33(1):83–101

Clydesdale FM, Walford J (eds) (1984) Developments in food colors–2. Elsevier Applied Sciences, London, UK, pp 75–112

Colio LG, Babb V (1948) Study of a new stimulatory growth factor. J Biol Chem 174:405–409

Combes RD, Haveland-Smith RB (1982) A review of the genotoxicity of food, drug and cosmetic colors and other azo, triphenylmethane and xanthene dyes. Mutat Res Rev Genet 98(2):101–243

Corradini MG (2018) Synthetic food colors. Reference module in food science, University of Massachusetts, Amherst, pp 291–296

De Brito ES, de Araujo MCP, Alves RE et al (2007) Anthocyanins present in selected tropical fruits: acerola, jambolao, jussara and guajiru. J Agric Food Chem 55:9389–9394

Delgado-Vargas F, Jimenez AR, Paredes-Lopez O (2000) Natural pigments: carotenoids, anthocyanins, and betalains - characteristics, biosynthesis, processing and stability. Crit Rev Food Sci Nutr 40(3):173–289

Delgado-Vargas, Paredes-Lopez (2003) Natural colorants for food and nutraceutical uses. CRC Press LLC

Dembinska-Kiec A (2005) Carotenoids: risk or benefit for health. Biochim Biophys Acta Mol basis Dis 1740(2):93–94

Demirag K, Uysal V (2006) Renklendiriciler. In: Altug T (ed) Gida katkımaddeleri. Meta Basim, Izmir, pp 169–191

Downham A, Collins P (2000) Coloring our foods in the last and next millennium. Int J Food Sci Technol 35:5–22

Duluc L, Jacques C, Soleti R et al (2014) Delphinidin inhibits VEGF induced-mitochondrial biogenesis and Akt activation in endothelial cells. Int J Biochem 53:9–14

Einbond LS, Reynertson KA, Luo XD et al (2004) Anthocyanin antioxidants from edible fruits. Food Chem 84:23–28

Emerton V, Choi E (2008) Essential guide to food additives, 4th edn. Leatherhead Publishing, Cambridge, UK

FDA (2010) Food and Drug Administration & US Department of Health and Human Services. Food ingredients and colors. International Food Information Council (IFIC) and US Food and Drug Administration, Washington, DC

FSSAI (Food Safety Standards Authority of India) (2011) Food Safety and Standards (contaminants, toxins and residues) regulations, 2011, available at: http://www.fssai.gov.in

Griffiths JC (2005) Coloring foods and beverages. Food Technol 59:38–44

Hadley CW, Clinton SK, Schwartz SJ (2003) The consumption of processed tomato products enhances plasma lycopene concentrations in association with reduced lipoprotein sensitivity to oxidative damage. J Nutr 133:727–732

Hari RK, Patel TR, Martin AM (1994) An overview of pigment production in biological systems: functions, biosynthesis, and applications in food industry. Food Rev Int 10(1):49–70

Hashem MM, Atta AH, Arbid MS et al (2010) Immunological studies on Amaranth, Sunset Yellow and Curcumin as food coloring agents in albino rats. Food Chem Toxicol 48(6):1581–1586

Jaques AG, Bortik K, Hau J et al (2001) Improved method to track chlorophyll degradation. J Agric Food Chem 49:1117–1122

Jia YP, Sun L, Yu HS et al (2017) The pharmacological effects of lutein and zeaxanthin on visual disorders and cognition diseases. Molecules 22(4):610

Karaali A, Ozcelik B (1993) Gıda Katkısı Olarak Dogal ve Sentetik Boyalar. GIDA 18(6):389–396

Kearney PM, Baigent C, Godwin J et al (2006) Do selective cyclo-oxygenase-2 inhibitors and traditional non-steroidal anti-inflammatory drugs increase the risk of atherothrombosis? Meta-analysis of randomized trials. BMJ 332(7553):1302–1308

Kim YS, Yoon SK, Song YH et al (2003) Effect of season on color of Hanwoo (Korean native cattle) beef. Meat Sci 63(4):509–513

Kiseleva MG, Pimenova VV, Eller KI (2003) Optimization of conditions for the HPLC determination of synthetic dyes in food. J Anal Chem 58(7):685–690

Kobylewski S, Jacobson MF (2010) Food dyes: a rainbow of risks. Centre for Science in the Public Interest, Washington, DC

Koes REK, Quattrocchio F, Mol JNM (1994) The flavonoid biosynthetic pathway in plants: function and evolution. BioEssays 16(2):123–132

Komissarchik S, Nyanikova G (2014) Test systems and a method for express detection of synthetic food dyes in drinks. LWT-Food Sci Techol 58(2):315–320

Kovacevic DB, Putnik P, Dragovic-Uzelac V et al (2015) Influences of organically and conventionally grown strawberry cultivars on anthocyanin content and color in purees and low-sugar jams. Food Chem 181:94–100

Krinsky NI, Johnson EJ (2005) Carotenoid actions and their relation to health and disease. Mol Asp Med 26(6):459–516

Kumari R, Meghwal M (2016) Benefits of food colors and safety in usage. Food 6:22–24

Lakshmi GC (2014) Food coloring: the natural way. Res J Chem Sci 4(2):87–96

Lee J, Finn CE (2007) Anthocyanin and other polyphenolics in American elderberry (Sambucus canadensis) and European elderberry (S. nigra) cultivars. J Sci Food Agric 87:2665–2675

Li X, Wang Z, Zhang G et al (2018) Improving lycopene production in Saccharomyces cerevisiae through optimizing pathway and chassis metabolism. Chem Eng Sci 193:364–369

Lopez-de-Alba PL, Lopez-Martinez L, Cerda V et al (2001) Simultaneous determination of tartrazine, sunset yellow and allura red in commercial soft drinks by multivariate spectral analysis. Quimica Analitica Bellaterra 20(2):63–72

Manach C, Williamson G, Morand C et al (2005) Bioavailability and bio-efficacy of polyphenols in humans. I. Review of 97 bioavailability studies. Am J Clin Nutr 81(1):230S–242S

Martins N, Roriz CL, Morales P et al (2016) Food colorants: challenges, opportunities and current desires of agro-industries to ensure consumer expectations and regulatory practices. Trend Food Sci 52:1–15

McCann D, Barrett A, Cooper A, Crumpler D et al (2007) Food additives and hyperactive behaviour in 3-year-old and 8/9-year-old children in the community: a randomised, double-blinded, placebo-controlled trial. Lancet 370(9598):1560–1567

Mol J, Jenkins G, Schäfer E et al (1996) Signal perception, transduction and gene expression involved in anthocyanin biosynthesis. Crit Rev Plant Sci 155(6):525–557

Mortensen A (2006) Carotenoids and other pigments as natural colorants. Pure Appl Chem 78(8): 1477–1491

Nielsen SR, Holst S (2002) Developments in natural colourings. In: MacDougall DB (ed) Color in food improving quality. Woodhead, Cambridge, UK, pp 331–352

Offenkrantz W (1950) Water-soluble chlorophyll in ulcers of long duration. Rev Gastroenterol 17: 359–367

Pandey RM, Upadhyay SK (2012) In: El-Samragy Y (ed) Food additive. Intech Open, London, pp 1–30

Patek A (1936) Chlorophyll and regeneration of blood. Arch Int Med 57:73–84

Robertson GL (1985) Changes in the chlorophyll and pheophytin concentrations of kiwifruit during processing and storage. Food Chem 17(1):25–32

Rodriguez-Amaya DB (2018) Natural food pigments and colorants. In: Bioactive molecules in food. Springer, Cham, pp 1–35

Schwartz SJ, Lorenzo TV (1990) Chlorophylls in foods. Crit Rev Food Sci Nutr 29:1–17

Sengar G, Sharma HK (2014) Food caramels: a review. J Food Sci Technol 51:1686–1696

Simpson BK, Benjakul S, Klomklao S (2012) Natural food pigments. In: Simpson BK, Nollet MLN, Toldra F et al (eds) Food biochemistry and food processing, 2nd edn. Wiley, Hoboken, NJ, pp 705–722

Solymosi K, Latruffe N, Morant-Manceau A et al (2015) Food color additives of natural origin. In: Color additives for foods and beverages. Woodhead, Cambridge, UK, pp 1–34

Spence C (2015) On the psychological impact of food color. Spence Flavour 4:1–16

Sulz CH (1888) A treatise on beverages, or, the complete practical bottler: Full Instructions for Laboratory Work with Original Practical Recipes for All Kinds of Carbonated Drinks, Mineral Waters, Flavorings, Extracts, Syrups. EtcDick & Fitzgerald Sulz & Co., New York

Tanaka Y, Matsuguchi H, Katayama T et al (1976) The biosynthesis of astaxanthin-XVI. The carotenoids in crustacea. Comp Biochem Physiol 54B:391–393

Tripathi M, Subhash K, Das KM (2007) Surveillance on use of synthetic colors in eatables vis a vis Prevention of Food Adulteration Act of India. Food Control 18:211–219

Weber RE, Hemmingsen EA, Johansen K (1974) Functional and biochemical studies of penguin myoglobin. Comp Biochem Physiol B Biochem Mol Biol 49(2):197–204

Wrolstad RE, Culver CA (2012) Alternatives to those artificial FDC food colorants. Annu Rev Food Sci Technol 3:59–77

Zhao L, Temelli F, Curtis JM et al (2017) Encapsulation of lutein in liposomes using supercritical carbon dioxide. Food Res Int 100:168–179