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Natural Food Pigments
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Abstract: Nature has endowed living organisms with different pigments for a plethora of functions. These include enhancing the visual appeal of the source material, a means for camouflage and concealments, as an index of food quality, and even as sex attractants. The interest in natural pigments as food-processing aids derives from the increasing consumer aversion to the use of chemicals and synthetic compounds in foods. The chapter provides information on the major types of natural food pigments and their major sources, their functions and uses in food, their health benefits, and their fate under various processing and storage conditions. The chapter also provides information on their relative advantages over their counterparts perceived as artificial food colorants.

INTRODUCTION
Nature relies on a variety of compounds to impart colors to living organisms and to carry out various functions. The colors may be red, purple, orange, brown, yellow, green, blue, or their various shades. In the case of raw unprocessed foods, these compounds or natural pigments enhance their visual appeal to consumers who associate the colors of food with quality and freshness. These natural compounds are widespread in animals, plants, and microorganisms (including algae, fungi, and yeasts). In all these organisms, these compounds display various shades of black, blue, brown, green, orange, pink, red, or yellow colors. Examples of fresh foods with dark or black colors are blackberries, grapes, black beans, black olives; those with brown colors include seaweeds (brown algae), mushroom, cocoa, coffee, and tea; some others with blue or purple colors include blueberries,
aubergines, raisins, currants, plums, pomegranates, and prunes; the kinds with green colors include asparagus, avocado, broccoli, Brussels sprouts, cabbage, celery, cucumber, green beans, green onion, kiwi fruit, lettuce, okra, spinach, and zucchini; examples of the types with orange or yellow colors are crustacea (crabs, lobster, scamps, and shrimps), salmonids (Arctic char, salmon, and trout), carrots, apricots, yellow peppers, mangoes, lemon, pumpkin, pineapple, squash; and the ones with shades of red colors include several fruits and vegetables (e.g., beets, cranberries, raspberries, red bell peppers, strawberries, tomatoes, and watermelon); meats (e.g., beef, hog, and poultry), and seaweeds (red algae).

Although it is their visual appeal that first attracts the consumers’ attention to foods, these compounds also carry out a plethora of key functions in living organisms. In certain species, the compounds function as attractants or mating signals to gain the attention of their mates; in some cases, the colors provide camouflage against predators; some of the compounds participate in metabolic processes (e.g., chlorophylls or carotenoids in biosynthetic reactions and energy generation); some others serve as antioxidants and protect vulnerable biomolecules from oxidative damage; some carry out a transport function (mioyoglobin (Mb) and hemoglobin (Hb) for oxygen (O2) transport and energy generation); while others play a role in vision or protect skins and membranes against the damaging effects of sunlight and radiation. Thus, it is not surprising that interest in these compounds extends beyond their visual appeal and consumer preferences in foods to also encompass other aspects such as the health benefits they provide. Each of these interests in itself can form the subject matter of an entire book; thus, the focus in this chapter will be on the major natural food pigments and their sources, structures and functions, properties and uses, and some of their important health benefits.

**THE MAJOR NATURAL PIGMENT TYPES**

For the purpose of this discourse, the term major natural food pigments is used to encompass the heme pigments (Mb and Hb), carotenoids, chlorophylls, anthocyanins, flavonoids, betalains, melanin, tannins, quinones, and xanthones. The heme pigments are the major pigments found in meats; they are water-soluble red, purplish or brownish compounds and they perform O2 transport and energy generations functions in animal tissues; the carotenoids are bright red, orange, and yellow fat-soluble and water-insoluble pigments widespread in plants, animals, and microorganisms; the chlorophyll pigments tend to occur with the carotenoids and are found in the plastids of photosynthetic organisms (i.e., plants, algae, and certain bacteria); the anthocyanins are water-soluble red, blue, and violet pigments found in several plants (fruits and vegetables) and microorganisms; flavonoids (also known as anthoxanthins) are water-soluble pigments ranging from colorless to yellowish and are found in plant and microbial sources; the betalains are red and yellow water-soluble pigments found extensively in plants; melanins are shades of brown to dark colored pigments formed by the enzymatic oxidation of polyphenolic compounds and are responsible for the dark colorations in animals, plants, and microorganisms; tannins are colorless to yellow or brown colored pigments found in the barks of certain trees like the oak or sumac; the quinones are a group of pale yellow to dark brown or black pigments also found in plants and microorganisms; and xanthones are yellow-colored compounds found mostly in the plant families of Bonnetiaceae, Clusiaceae, and Podostemaceae.

**THE HEME PIGMENTS (MB AND HB)**

**Structures and Functions**

The two main heme pigments of interest in foods are Mb and Hb. They are responsible for the red color of meats. The principal function of these two pigments in animal tissues is O2 transport for the purpose of energy generation. Mb comprises a single polypeptide chain called globin with a molecular weight of approximately 16.4 kDa. This single protein chain is bound to an essential nonprotein four-member ring compound known as porphyrin (or tetrapyrole) through a central iron (Fe) atom. The Fe can exist in two oxidation states, the ferrous (Fe2+), and the ferric (Fe3+) forms. Both of these forms have a coordination number of six, giving heme the capacity to bind or accept up to six ligands (Fig. 37.1). In both heme pigments (Mb and Hb), the central Fe atom uses four (4) of its coordination positions to bind with the four nitrogen (N) atoms in the porphyrin ring, and its fifth coordination site to bind with a N atom of one of the porphyrin rings.
Muscle cells as a complex known as oxymyoglobin (MbO$_2$) tend to range from white to gray. With regards to the physical fresh beef tends to be bright red in color, pork is pinkish, veal all influence the Mb levels (and the color) of meat. For example, type, other factors like species, age, sex, and physical activity of activity for only brief periods of time. In addition to muscle and relies on glycogen as the source of energy for rapid spurts meat, on the other hand, has muscle types with lesser Mb content of energy to carry out activities over protracted periods. White Mb content varies in cells; the higher the Mb content, the more white meats based on the muscle type and the Mb content. The

**MB AND MEAT COLOR**

Meats are classified into two types, that is, red (or dark) versus white meats based on the muscle type and the Mb content. The Mb content varies in cells; the higher the Mb content, the more intense the red or dark color of the meat. Thus, red (or dark) meats have relatively higher content of Mb than white meats. This is because red or dark meat comprises muscles that require more uptake of O$_2$ to be able to generate a constant supply of energy to carry out activities over protracted periods. White meat, on the other hand, has muscle types with lesser Mb content and relies on glycogen as the source of energy for rapid spurts of activity for only brief periods of time. In addition to muscle type, other factors like species, age, sex, and physical activity all influence the Mb levels (and the color) of meat. For example, fresh beef tends to be bright red in color, pork is pinkish, veal is brownish pink, lamb and mutton are pale to brick red, poultry (chicken, ducks, and turkeys) are white to dull red, and most fish tend to range from white to gray. With regards to the physical state of the meat, the muscle protein in its native state imparts a reddish/purple color while the denatured form is pinkish to brownish. Furthermore, exercised muscles tend to be darker in color than nonexercised muscles. Thus, the color in the muscles of the same animal can vary depending on the state of activity of the animal. In terms of age, the Mb content tends to increase as the animal gets older (Kim et al. 2003), and the color of female foals were reported in a study to be darker than their male counterparts (Sarmiés and Beriain 2006), although Carrilho et al. (2009) found male rabbit meat to be more intensely colored than females rabbit meat. The diets of the animal also affect meat color. For example, cattle raised on pasture has a darker meat color than their counterparts raised on concentrates (Priolo et al. 2003), and there appears to be seasonal variations in meat color with the color being darker in the winter season than in the spring and autumn seasons (Kim et al. 2003). The color of meat also depends to a large extent on the oxidation state of the Fe present in the porphyrin ring, as well as on the nature of the ligand bound to the sixth coordination position of the central Fe atom. When meats are cooked, the color of Mb changes depending on the extent and/or intensity of the cooking. For example, Mb retains its native color when dark meats are cooked “rare.” However, medium cooking causes denaturation of the protein group (globin) and oxidation of the central Fe$^{2+}$ to the Fe$^{3+}$ form, and changes the meat to a tan-colored product known as hemichrome. When meats are “well done,” the amount of hemichrome formed increases and the meat acquires a darker brown hue. When white meat is cooked, it changes from a translucent pallor to an opaque or whitish color.

The interconversions between Mb, MbO$_2$, and MetMb are summarized in Figure 37.2. O$_2$ adds to purple colored Mb (Fe$^{2+}$) by oxygenation to form the bright red colored MbO$_2$ (with the central Fe atom still in the Fe$^{2+}$ form). MbO$_2$ thus formed may be deoxygenated to regenerate Mb, or oxidized via electron loss to form the brown-colored metmyoglobin (MetMb, Fe$^{3+}$). MetMb may then undergo reduction by electron gain to re-form Mb (Fig. 37.2).

![Figure 37.2. Intercalations between myoglobin (Mb), oxymyoglobin (MbO$_2$), and metmyoglobin (MetMb).](image-url)
**Discoloration of Meat**

The color of meats is important because it is used by consumers as an index of quality. In addition to the color changes ascribed previously to the chemical state of the central Fe atom, other factors may also influence the meat color. For example, pale, soft, and exudative (PSE) meats that are characterized by pale colors, soft textures and low water-holding capacities, tend to have considerably more moisture on their surfaces. This is caused by increased glycolysis and a rapid decline in muscle pH that denature meat proteins to adversely impact the texture. Unlike PSE meats, some meats may become dark, firm, and dry due to relatively higher pH levels (~6.0), which make the meat proteins bind water molecules more tenaciously and cause the meat surface to dry out, and reduce light absorption making the meat color to darken. The elevated pH also promotes meat spoilage from microbial proliferation and metabolism. An increase in microbial activity could enhance production of compounds such as amines (via deamination of amino acids) that can react with nitrates (used to “cure” meats) to form nitrosamines in the meats and/or impart a reddish color; or catalase negative bacteria (e.g., lactic acid bacteria) may produce H₂O₂ to give meats a greenish tinge. Exposure of meat to light may cause O₂ to dissociate readily to safeguard against stabilization of meat color. The use of nitrites to “cure” meats is primarily to retard the oxidation of Mb and/or MbO₂ to MetMb, and thereby prevent the yellow-orange colored compound ββ-carotene, which was first crystallized from carrot as far back as in the early 1830s. It is from this source material (carrot) that the name for the entire class of these compounds (carotenoids) is derived. Most carotenoids are water insoluble, but are fat or oil soluble and heat stable. They are found in fruits and vegetables like oranges, tomatoes, and carrots, in the yellow colors of many flowers, in animal species including crustacea (e.g., crab, lobster, scampi, shrimp), fishes (e.g., goldfish and salmonoids like Arctic char, salmon, trout) in birds (e.g., canaries, flamingos, and finches), and insects (plasmids, lady bird, and moths); in seaweeds (e.g., Undaria pinnatifida, Laminaria japonica), in yeasts (e.g., Rhodotorula rubra, Phaf- itu rhodectena); in algae (e.g., Xanthophyceae, Chlorophyceae); in fungi (e.g., Blakesleee, Xanthophyllomyces); and in bacte- ria (e.g., Corynebacterium auritutrospum, Rhodopseudomonas spheroides). Carotenoids may occur in the free form (e.g., fucoxanthin in seaweeds), or complexed with proteins to form the relatively more stable carotenoproteins as found in several invertebrates (e.g., crustacea). When complexed with proteins, the colors of carotenoids may be altered from orange, red, or yellow to blue, green, or purple. In general, carotenoids are present in low amounts in most organisms, but good sources of this class of pigments include algae and plants (the pre- dominant sources for humans), from fruits (cantaloupe, pum- kin, watermelon, pineapple, citrus fruits, red or yellow peppers, tomatoes, mangoes, papaya, and guava) and vegetables (car- rot, rhubarb, sweet potato, kale, parsley, cabbage, collards, and spinach).

**Heme Pigments and Health**

Red meats are a good source of Fe (by virtue of Fe being part of the heme). When Fe is deficient, it can cause a reduction in cognitive abilities particularly in children, or result in anemia (i.e., Fe deficiency anemia or IDA). The body requires Fe to synthesize red blood cells and to regulate body temperature, among other things. When a person has IDA, the red blood cell levels decline and the victim’s health suffers. People with IDA tend to feel cold on a continuing basis, because regulation of the body’s temperature is impaired. Because it is part of Hb and Mb, Fe-deficiency causes people to tire easily since their bodies have insufficient O₂ for both biosynthesis and energy generation.

**Measurement of Mb**

A number of procedures have been described in the literature for the measurements of Mb. These include the optical density method by atomic absorption spectroscopy (Weber et al. 1974), differential scanning calorimetry (Chow and Chen 2001), spectrophotometry (Tang et al. 2004), and NIR spectrophotometry (van Beck and Westerhof 1996).
Lycopene

Phytoene

β-Carotene

α-Carotene

γ-Carotene

Lutein

Astaxanthin

Figure 37.3. Structures of some common carotenoids (continued).

(e.g., flamingos and finches); cryptoxanthin, antheraxanthin, and zeaxanthin are the principal ones in maize; cryptoxanthin and zeaxanthin are also predominant in papaya and cantaloupe; red bell peppers have a high content of capsanthin; tomatoes have high levels of phytoene, lycopene, ββ-carotene, neurosporene, and phytofluene; and seaweed and many algae have fucoxanthin, fucoxanthinol, and lactucaxanthin as the major ones.

Unlike plants and microorganisms, animals do not synthesize carotenoid compounds de novo, and must derive these compounds from their diets for various processes, although animals may transform dietary carotenoids to other forms for various functions (Tanaka et al. 1976).

Carotenoids like α-carotene, β-carotene, zeaxanthin, and β-cryptoxanthin are important sources of dietary vitamin A. These molecules are cleaved by dioxygenase in the gastrointestinal tract to release, at least a molecule of retinal, which is subsequently reduced to retinol (or vitamin A); thus, such carotenoid compounds are classed as having provitamin A activity. Vitamin A or retinol is needed in the retina of the eye for vision. Other biological functions of carotenoids include their role in light-harvesting and energy transfer reactions in photosynthesis, and in photo-protection of tissues against the ravaging effects of oxidation by exposure to light. The antioxidant role of carotenoids is well known. As antioxidants, carotenoids protect membranes and tissues from oxidative damage and prevent or minimize serious illnesses such as cancer, heart disease, and nutritional blindness. The antioxidant capacity of carotenoids enables them to ward off degenerative diseases by “quenching” harmful free
radicals and reactive O₂ species such as singlet O₂ from causing damage to cells or tissues. Evidence for this behavior by carotenoids includes studies in men that showed that carotenoids could reduce the risks of heart attacks significantly. The same free radical “quenching” behavior of carotenoids enables them to act as anticarcinogens, whereby they act to lower the incidence of certain cancers (e.g., lycopene in tomatoes and prostate cancer). There is also evidence that carotenoids like lycopene suppress the oxidation of low-density lipoprotein (LDL) and helps to lower blood cholesterol levels. Thus, carotenoids play crucial roles in vision and are effective in slowing down age-related eye disorders, and inhibiting oxidation of LDL that promotes platelet formation and aggregation and cardiovascular diseases, as well as free radical scavenging to prevent certain cancers and membrane or tissues damage from light (Hadley et al. 2003). Carotenoids also boost the immune system by increasing the activities of lymphocytes, or protecting macrophages and the immune system from damage by ultraviolet (UV) light and X-rays. However, the efficacy of antioxidants like β-carotene in protecting against cancers has been questioned (Albanes et al. 1996), and it has even been suggested that it may actually increase the risk of lung cancer in heavy smokers, and cause a higher incidence of cardiovascular diseases as well as high mortalities (Albanes et al. 1996).
An oxygenated carotenoid pigment touted for its health benefits is fucoxanthin (Fig. 37.3) found in the brown algae (kelp). Fucoxanthin has a molecular formula of \( \text{C}_{40}\text{H}_{60}\text{O}_{6} \), a molecular weight of 658.9 Da, and studies have shown it to induce apoptosis and/or antiproliferative effects on certain cancer cells (Hosokawa et al. 2004, Kotake-Nara et al. 2005). For these and other reasons, there is intensive research afoot on the antioxidant effects of carotenoids, and their role as regulators of the immune system, and there is considerable interest in the production of carotenoids by biotechnological approaches to increase supplies for the demand for these compounds.

**Properties and Uses of Carotenoids**

The market for carotenoids is estimated at approximately a billion US$ per annum (Fraser and Bramley 2004). They are used as colorants (e.g., \( \beta \)-carotene, annatto) to impart colors to many processed foods (e.g., margarine, butter, dairy products, confectionery, and baked goods) beverages (e.g., soft drinks), drugs and cosmetics (Britton 1996). They are also used as nutritional supplements and in animal feeds, for example, as colorants for farmed animals (e.g., poultry eggs, salmon, trout, shrimp, and lobster) (Lorenz and Cysewski 2000). Carotenoids (e.g., astaxanthin, lycopene, and zeaxanthin) can reduce the adverse side effects such as inflammation and/or pain associated with administration of cyclooxygenase inhibitor drugs (Kearney et al. 2006).

**Health Benefits of Carotenoids**

The health benefits of carotenoids include protection against cardiovascular diseases (by inhibiting the oxidation of LDL cholesterol), certain cancers (e.g., cervical, gastrointestinal tract, lung, skin, uterine), and age-related macular degeneration and cataracts. Carotenoids inhibit the growth of unhealthy cells while promoting the growth of healthy cells to invigorate the body. Most are antioxidants and are able to absorb light/filter the UV rays of the sun to reduce photo-oxidation, and thereby act to protect cells and tissues against oxidative damage potentiated by free radicals and reactive \( \text{O}_2 \) species (Krisinsky and Johnson 2005, Dembinska-Kiec 2005).

**Methods for Measuring Carotenoid Pigments**

Carotenoid pigments (as astaxanthin) may be measured quantitatively by measuring the absorbance at 485 m in a spectrophotometer (Saito and Regier 1971). Other methods that have been used to study the molecular properties of carotenoids include field desorption mass spectrometry (Takaichi et al. 2003), thin layer chromatography and analysis by gas chromatography (Remstrom and Lianen-Jensen 1981); high-pressure liquid chromatography (HPLC) (Yuan et al. 1996), or by negative ion liquid chromatography-atmospheric pressure chemical ionization mass spectrometry (negative ion LC-[APC]-MS) (Breithaupt 2004). Other methods described for the measurement of carotenoids include reversed phase HPLC (Burri et al. 2003, Graça Dias et al. 2008), resonance Raman spectroscopy (Bernstein et al. 2004), and by UV/Vis and mass spectra chromatography (Meléndez-Martínez et al. 2007).

**Chlorophylls**

**Structure and Functions**

Chlorophylls are fat and oil soluble green pigments that occur in the plastids of most plants, algae, and certain bacteria. In these organisms, chlorophylls participate in the biosynthesis of complex biomolecules (\( \text{C}_{100}\text{H}_{110}\text{O}_{16} \)) from simpler ones (\( \text{CO}_2 \) and \( \text{H}_2\text{O} \)) by the process of photosynthesis. They are the most widely distributed natural plant pigments and are present in all green leafy vegetables, and also occur abundantly in the green algae known as chlorophytes. The chemical structure of chlorophylls comprises a tetrapyrrole (or porphyrin) ring system similar to those of \( \text{Mb} \) and \( \text{Hb} \), except that the central atom of chlorophyll is \( \text{Mg} \), and the side chain is a 20 carbon hydrocarbon (phytol) group that is esterified to one of the pyrrole rings (while \( \text{Mb} \) or \( \text{Hb} \) has the protein, globin, bound to the fifth coordination position of the central \( \text{Fe} \) atom). Thus, four pyrrole groups are linked together by a central \( \text{Mg}^{2+} \) ion to form a porphyrin ring, which together with phytol (a 20-carbon hydrocarbon chain) makes the chlorophyll molecule (Fig. 37.4). When foods containing chlorophyll (e.g., vegetables) are cooked, the chlorophyll may undergo changes in color and/or solubility. The colors that form may be dull green, bright green, or brownish. These different colors are due to changes in the chlorophyll molecule such as loss of the phytol side chain, or the removal of the central \( \text{Mg}^{2+} \).
atom (Fig. 37.5). The phytol side chain may be removed by the action of enzymes (chlorophyllase) and/or acidic conditions, while Mg$^{2+}$ may be removed from exposure to acid and heat treatment. It is the 20 carbon hydrocarbon side chain (phytol) that makes chlorophylls nonpolar and water insoluble. So, its removal from the molecule renders the residual compound water soluble. Alkaline conditions and exposure to light can also induce changes in the chlorophyll molecule (Fig. 37.5).

Because of their light trapping and electron transfer roles in photosynthesis, chlorophyll pigments are considered as the basis of all plant life. Chlorophylls are synthesized via the formation of a porphyrin ring, and the initial steps in the biosynthesis pathway are similar to those of the heme pigments, Mb and Hb, described in Section “Structures and Functions.” Chlorophylls exist in nature in different forms (e.g., chlorophylls a, b, c1, c2, and d). The differences in these forms arise from subtle changes in either the tetrapyrrole ring itself or in the side chain groups. For example, chlorophylls a and b differ only in the substituent group on C7 of the molecule (i.e., $\text{CH}_3$ for chlorophyll a, and $\text{CH}_2\text{O}$ for chlorophyll b), while chlorophylls a and b both have $\text{CH}_2\text{O}$ group at the C3 position unlike chlorophyll d that has $\text{CH}_3$ group.

Chlorophyll is commonly extracted from plant species like spinach, alfalfa, nettles, or grass using organic solvents (e.g., acetone and hexane), preferably in dim light to minimize degradation of the pigment. Exposure to light, air, heat, and extreme pH all adversely affect its stability. Nevertheless, the stability of chlorophylls against degradation may be enhanced by de-esterification of the chlorophyll and complexation with copper ions.

**Properties, Sources, and Uses**

Chlorophylls are safe for human consumption and since ancient times humans have ingested chlorophylls in their fruits and vegetables. Commercial sources of chlorophylls include the green algae chlorella, the blue-green algae *Spirulina*, the string lettuce (*Enteromorpha*) and the sea lettuce (*Ulva*); all the sources mentioned previously are used as human food (Ayehunie et al. 1996) in salads and soups. Chlorophylls are used as food colorant and in this regard, can be safely added to several foods either in the pure form or complexed with copper. They are also used in several other applications including cosmetics (soaps, creams, and body lotions), oral hygiene products (mouthwash, toothpaste) as well as confectionary (gums and candies) because of their intense green color. Chlorophyll-colored products are best stored under dry conditions and protection from air, light, and heat to better retain the color. Certain countries have restrictions on the use of copper complexes of chlorophylls in foods and drugs because of the toxicity of copper.

Chlorophyll content in tissues and food materials may be measured spectrophotometrically by the AOCS (2004) official method AK 2-92.
**Chlorophylls and Health**

Chlorophylls also have several health benefits for humans. They have been shown to be capable of rebalancing the bloodstream (Page 1936), and to be nontoxic and without harmful side effects even when administered in large doses in various routes (intravenous, intramuscular, or oral). The high Mg content in chlorophyll promotes fertility by increasing the levels and activities of the enzymes that regulate sex hormones. Chlorophylls have antibacterial properties and can be used both inside and outside the body for this purpose (Bowers 1947). They are able to clean out drug deposits and deactivate toxins in the body, cleanse the liver, and reduce problems associated with blood sugar (Colos and Rabb 1948). They are also used in deodorizers, to inhibit oral bacterial infections, promote healing of rectal sores, and reduce typhoid fevers (Offenkrantz 1950).

**Anthocyanins and Anthocyanidins**

Anthocyanins are water-soluble, pH-sensitive, red, purple, and blue pigments found in higher plants. They impart the intrinsic colors to many flowers, fruits, and vegetables. They also occur in leaves, stems, and roots of plants particularly in the outer cells of these parts of the plant. They are found in almost all the plant families, and in fruits and vegetables the main sources include avocados, blackberries, black currants, blueberries, cherries, chokeberries, cranberries, grapes, prunes, oranges, mangoes, aubergines, olives, onions, and sweet potatoes. Anthocyanins (and anthocyanidins) may be considered as members of the flavonoid family of compounds (Section “Flavonoids”), but because of their importance and the extensive attention they have received, a separate section is devoted in this chapter to the discussion of these compounds.

The color of anthocyanins is influenced by acidity; they are red under acidic conditions and turn blue at neutral to alkaline pHs. On the basis of the chemical structures, two types are distinguished: the anthocyanidin aglycones (or anthocyanidins) that are devoid of sugar moieties, and the true anthocyanins are glycosides or sugar esters of the anthocyanidins. They all have a single basic core structure, the flavylium ion (Fig. 37.6) that has seven different side groups (denoted as R in the figure) that may be a hydroxyl (H) atom, a hydroxide (OH) group, or a methoxy (-OCH3) group. The sugars of anthocyanins are esterified to the different side groups, and because there are seven of these positions and several sugars (monosaccharides, disaccharides, and trisaccharides) in higher plants, it is to be expected that several different anthocyanins would occur in nature. Furthermore, the sugars may be acylated with the organic acids that are naturally present in plants (e.g., acetate, citrate, ascorbate, succinate, propionate, malate, and many others) to form acylated anthocyanins. The sugar residues may be monosaccharides, disaccharides, or trisaccharides. When there is only one monosaccharide residue esterified to the aglycone, the anthocyanin may be referred to as a monoside; where esterification is to either two monosaccharide units or one disaccharide unit, the product is known as a bioside; where there are three monosaccharides, or two disaccharides and one monosaccharide, or a single trisaccharide unit esterified, the compound is referred to as a triside.

Those without sugar molecules are known as aglycones. Some of the common anthocyanidins include: cyanidin, delphinidin, pelargonidin, malvidin, peonidin, and petunidin; and some of the known anthocyanin glycosides are: cyanidin-3-glucoside and pelargonidin-3-glucoside, as well as the glycosides and diglucosides of cyanidin, pelargonidin, delphinidin, and malvidin (Fig. 37.6). Their biological functions include their action as antioxidants whereby they protect plants against the damaging effects of reactive O2 species and UV radiation, and also serve as attractants for birds and insects to flowers for pollination.

**Uses of Anthocyanins**

Anthocyanins are used as food colorant in drinks, food spreads (jams and jellies), jellies, pastries, and confectioneries because of their intense blue or red colorations. There are, however, some drawbacks in the use of anthocyanins in foods. This is due to their high solubility in water and vulnerability to pH changes. Thus, red cabbage may exhibit a deep reddish color or a purplish or bluish color depending on the pH of the milieu. Other factors such as exposure to high temperature, oxidizing agents (tocopherols, peroxides, and quinones), air, or light are detrimental to the stability of and colors imparted by anthocyanins. Although the sugars in anthocyanins may provide some protection for the molecule against degradation under ambient conditions, the same sugar moieties could elicit browning reactions in food products when the latter are exposed to high temperatures and/or light. The detrimental effects of temperature and air may be slowed down by low temperature storage, with protection from light and air/O2.

**Anthocyanins and Health**

The toxicity of the anthocyanins is not well documented. But they are believed to be nontoxic even at high concentrations. The compounds are potent antioxidants and have been associated with health benefits such as reduced risk of coronary heart disease, improved visual acuity, and antiviral activity. Studies with pelargonidin and delphinidin (both anthocyanins) have shown both of them to be capable of inhibiting aldolase, the enzyme that converts glucose into fructose and sorbitol (Varma and Kinoshita 1976). Inhibition of this enzyme is desirable in preventing complications from diabetes because without the inhibition, the sorbitol and fructose formed could diffuse into the myelin sheath along with fluid (by osmotic action) to cause edema of the myelin sheath in nerves (Levin et al. 1980). Thus, substances like pelargonidin and delphinidin that can inhibit the aldolase enzyme would be useful in reducing this type of complications for diabetics. The anthocyanins petunidin, delphinidin, and malvidin have also shown to enhance the activity of glutamate decarboxylase (GAD), the enzyme that catalyzes the decarboxylation of glutamic acid (HOOCC-CH=CH-NH2-COOH) to y-amino benzoic acid (HOOCC-CH=CH-NH-COOH) or GABA (short). GABA is an important neurotransmitter in the brain, and an
increase in the level of GAD is useful not only because of the formation of GABA, but also because it can maintain insulin production in people with type 1 diabetes (Ludvigsson et al. 2008). Petunidin, delphinidin, and malvidin can also inhibit glycerol dehydrogenase, a key enzyme in glycerolipid metabolism (Carpenter et al. 1967), and malate dehydrogenase that participate in both the tricarboxylic acid (TCA) cycle (i.e., the dehydrogenation of malate to oxaloacetate) and in gluconeogenesis (i.e., the synthesis of glucose from noncarbohydrate carbon sources) (Carpenter et al. 1967). Thus, by inhibiting malate dehydrogenase, antioxidants also act indirectly to regulate gluconeogenesis.

**Measurement of Anthocyanins**

Several methods have been reported for the measurement of anthocyanins in samples. These include spectrophotometric procedures for measuring anthocyanins in wines (Cliff et al. 2007), and the use of HPLC and ultra-performance liquid chromatography to measure the pigment levels in food samples (Hosseinian and Li 2008). Other procedures for measuring anthocyanins include pH-differential measurements (Giusti and Wrolstad 2001) and FTIR (Soriano et al. 2007).

**Flavonoids**

**Properties, Structures, and Functions**

The term flavonoids is used here to refer to a family of compounds produced by plants that are sometimes referred to as anthoxanthins. They are water soluble but have lower coloring power compared to the anthocyanins or anthocyanidins; they range in color from colorless to shades of yellow, and they...
have a common core structure, the benzopyrone ring (Fig. 37.7), which bears a structural resemblance to the flavylum ion of anthocyanins or anthocyanidins (Fig. 37.6). Flavonoids are subdivided into five sub-classes: the flavanols, the flavanones, the flavonols, the flavones, and the isoflavones. These five groups of compounds exhibit subtle differences in structure, such as degree of saturation or unsaturation, and/or position of substituent groups (Fig. 37.7). Examples of the flavanols are catechin, epicatechin, epigallocatechin, epicatechin gallate, epigallocatechin gallate, and theaflavins; examples of the flavanones are butin, hesperidin, hesperetin, naringenin and naringin; the flavonols include azaleatin, quercitin, kaempferol, myricetin, morin, and rhamnetin; members of the flavones family include apigenin, baicalein, chrysin, luteolin, tangeritin, and wogonin; and the isoflavones are typified by daidzein, genistein, and glycitein. The flavonoids have lower coloring power compared with the
anthocyanins or anthocyanidins and range from colorless to shades of yellow. Some common food sources at flavonoids are apples, broccoli, citrus fruits, chocolate, cocoa, grapes, green tea, oolong tea, parsley, red peppers, white tea, yellow onions, celery, soybeans, and thyme.

Like anthocyanins, some flavonoids are esterified with one or more sugar residues. Apart from flavonoids (catechins and proanthocyanidins), the other known flavonoids appear to occur in plants and foodstuffs in the esterified forms. A lot of these flavonoid glycosides appear to survive the cooking process, as well as the preliminary digestion steps in the mouth and stomach. However, in the small intestines, it appears only the aglycone forms and the flavonoid glucosides are absorbed and metabolized to form various secondary metabolites; and colon bacteria metabolize flavonoids to facilitate absorption (Manach et al. 2004). Nevertheless, the flavonoids have low bioavailability due to inadequate absorption and their fast removal from the body. Of the flavonoids, the isoflavones are said to be the most bioavailable while the flavans are the least bioavailable (Manach et al. 2005).

**Biological Functions and Uses**

Flavonoids also have antioxidant properties and are effective free radical scavengers (Chun et al. 2003). However, most circulating flavonoids are believed to be metabolized intermediates or by-products that have relatively lower antioxidant capacity than the parent flavonoid compounds. Thus, the relative contribution of dietary flavonoids to antioxidant behavior in the body is suggested to be miniscule (Lotito and Frei 2006). By virtue of their polyphenolic nature, flavonoids are also able to act as metal ion chelators to stop ions such as Cu$^{2+}$ or Ca$^{2+}$ and Fe$^{2+}$/Fe$^{3+}$ from promoting the formation and release of free radicals (Mira et al. 2002). The chelating behavior of flavonoids could also adversely affect intestinal absorption of Fe, thus it is recommended for Fe supplements not to be taken together with beverages high in flavonoids or flavonoid supplements (Zijp et al. 2000).

**Flavonoids and Health**

Although various suggestions have been made to the effect that high intakes of flavonoids from plant sources do not elicit adverse effects in humans due to their low bioavailability and rapid metabolism and removal from the body, there are some reports indicating that high doses of some flavonoids can cause adverse health effects in some people. For example, some flavonoids like quercetin have been reported to induce nausea, headaches and/or tingling sensations in some people, or renal toxicity or vomiting, sweating, flushing, and dyspnea in certain cancer patients (Ferry et al. 1996, Shokes et al. 1999). Other reports attribute liver toxicity, abdominal pain, diarrhea, insomnia, tremors, dizziness, and confusion sometimes observed from intake of caffeinated green tea extracts to the flavonoids present in tea (Jato et al. 2003, Bonkowsky 2006). The flavonoids quercetin and naringenin have also been reported to inhibit cytochrome P450 that is involved in the oxidation of various biomolecules such as lipids, hormones, and xenobiotics (drugs) (Bailey and Dresser 2004). They are also known to inhibit the enzyme 3-hydroxy-3-methylglutaryl-coenzyme A reductase (HMGC-CoA reductase), the regulatory enzyme in the mevalonic acid pathway that leads to the formation of isoprenoid compounds, for example, carotenoids, cholesterol, and steroids. The effects of these compounds on drug metabolism have been shown to affect the bioavailability and toxicity of drugs such as amiodarone, atorvastatin, cyclosporine, saquinavir, and sildenafil (Bailey and Dresser 2004, Dahan and Altman 2004). It is partly for this reason that patients are cautioned to avoid taking grapefruit juice when they are on some of these drugs, as grapefruit juice has high levels of quercetin and naringenin, as well as furanocoumarins. Copious consumption of purple grape juice has also been found to inhibit platelet aggregation, and the inhibition has been attributed to the high levels of flavonoids in the juice (Polagruto et al. 2003). On the basis of this, it has been speculated that high intake of some of these flavonoids in conjunction with anticoagulants could make some patients more prone to bleeding (Polagruto et al. 2003).

**Betalains**

The name betalain is derived from beet vegetable (Beta vulgaris) from which it was first extracted. They are red or violet and yellow or orange water-soluble aromatic indole pigments found in plants and fungi (Basidiomycetes). Betalains are subdivided into two categories based on their colors as betacyanins (reddish to violet) and betaxanthins (yellowish to orange). Examples of the betacyanins are amaranthine, isosamaranthine, betanin, isobetanin, yphylococcin, and iso-yphylococcin; and representatives of betaxanthins include dopaxanthin, miraxanthin, indicaxanthin, portulacaxanthin, portulaxanthin, and vulgaxanthin. The betalains are synthesized from tyrosine via several routes. The amino acid tyrosine may be converted to betalains via either dihydroxyphenylalanine (DOPA) or dopaquinone; or through spontaneous combination with betalamic acid to an intermediate portulaca xanthin II (Tanaka et al. 2008). The structures of betanin and vulgaxanthin are shown in Figure 37.8. The betalains are most stable within the pH range of 3.5 and 7.0, but they are susceptible to light, heat and air.

**Uses of Betalains**

Extracts from betalains have been used to color foods since time immemorial, and beetroot extract is currently approved for use as food color in many countries to impart color to juices and wines. In addition, different varieties of beet have been used as a source of sugar (sugar beet), as vegetable (beetroot), and fodder (fodder beet). Beetroot tuber is cooked and eaten like potatoes, and it is pickled and used in salads.

Because of their high solubility in water and susceptibility to light and heat, the use of betalains to color food may be limited, although the dried form of betanin is quite stable. High sugar content has also been shown to impart protection to betalains, thus they are used in soft drink powders, frozen dairy products, and in confectioneries. Gentile et al. (2004) reported that...
Betanin have anticancer properties by virtue of their antioxidant and free radical scavenging behavior. They have been shown to inhibit redox state alteration induced by cytokines to protect the endothelium layer that line the internal surfaces of blood vessels. The content of betalains in samples may be measured by the HPLC and LC-MS/MS analyses (Stintzing et al. 2006).

**Melanins**

**Properties and Functions**

Melanins are dark brown and black pigments found in plants, animals, and microorganisms. They are formed via the enzymatic oxidation of phenolic compounds, for example, tyrosine, through several intermediates like DOPA and quinones, followed by polymerization to form the large molecular weight melanins. The enzymes catalyzing the oxidation of the phenolic compounds are polyphenoloxidases, also known as phenolases or tyrosinases. In animals and humans, melanins occur in the eyes, hair, skins, and peritoneal lining where they protect tissues from the detrimental effects of factors like light or UV radiation from the sun’s rays. Damage from UV radiation is potentiated in various ways such as dimerization of thymine in DNA molecules, or by the effects of reactive O2 species (e.g., singlet O2 and superoxide radicals (Jagger 1985, Tyrell 1991). Examples of melanins are eumelanin and pheomelanin. Pheomelanin is dark red-brown in color and is thought to be responsible for red hair and freckles in humans, while eumelanin imparts black and brown coloring to skin and hair (Meredith and Riesz 2004).

Microorganisms synthesize melanins as part of their normal metabolism, from where they are passed along the food chain to higher forms of life. In crustacea, the formation of melanins is sometimes referred to as melanosis or “blackspot” formation, and connotes spoilage to consumers—mainly due to their lack of visual appeal. The “blackspot” phenomenon has been extensively studied to develop strategies to control this undesirable effect and products such as glucose oxidase, glucose, catalase mixes, or 4-hexyl resorcinol were found to be effective in controlling blackspot formation in raw shrimp (Ogawa et al. 1984, Ferrer et al. 1989, Yan et al. 1989, Chen et al. 1993, Benjakul et al. 2005). Nevertheless, these same compounds are desirable in other situations, such as protecting against UV radiation from sunlight to prevent damage to the skin and also to minimize glare in the eyes. This feature of melanin has been exploited by Photoprotective Technologies (United States) in making a variety of eye wear that filter out colors to reduce the risks of macular degeneration and cataracts (Anon 2005). Melanin has also been incorporated in a hair dye, Melancor-NH, for darkening gray hair in humans.

**Melanins and Health**

Melanin deficiency in humans has been linked with certain abnormalities and diseases. Examples include oculocutaneous albinism that is characterized by reduced levels of the pigment in the eyes, hair, and skin, and ocular albinism that affects both eye pigmentation and visual acuity (Peracha et al. 2008). Melanin deficiency has also been linked to deafness (Cable et al. 1994) and Parkinson’s disease (Nicolaus 2005).

**Measurement of Melanins**

Melanin measurements may be carried out by spectrophotometry (Rosenthal et al. 1973) by measuring the fluorescence induced by excitation at 410 nm and emission at 500 nm, or by spectrophotometric measurement of the rate of melanolchrome production from 5,6-dihydroxyindole-2-carboxylic acid and 5,6-dihydroxyindole systems at 540 and 500 nm (Blazirno et al. 1999). Melanin in tissues may also be measured based on spectrophotometry, HPLC, and electron spin resonance spectroscopy (Ito 2006, Hu et al. 1995).
TANNINS

PROPERTIES AND FUNCTIONS

Tannins are a heterogeneous group of water-soluble polyphenolic compounds present in many plants. The term “tannin” originated from the ancient practice of using plant extracts to “tan” leather, thus the name “tanning” is used to describe the process. This process makes use of the capacity of tannins to form cross-links with other biomolecules such as proteins or polysaccharides to “toughen” the textures of otherwise soft materials. Tannins occur mainly in tea, coffee, immature fruits, leaves, and the bark of trees where their function is believed to be one of defense. They have an astringent and bitter taste that is unpleasant to prospective consumers. The best known members of this family of compounds include tannic acid and its breakdown products (ellagic acid, gallic acid, and propyl gallate; Fig. 37.9). Tannic acid is used as a food additive. Foods known to be high in tannins include pomegranates, persimmons, cranberries, strawberries, blueberries, hazelnuts, walnuts, smoked meats and smoked fish, spices (e.g., cloves, tarragon, thyme, and cinnamon), most legumes, and beverages such as wine, cocoa, chocolate, and tea.

Tannins are classified into two main classes, (1) the hydrolyzable and (2) the condensed (nonhydrolyzable) tannins. The hydrolyzable tannins are those that on heating with dilute mineral acids or bases form carbohydrates and phenolic acids (i.e., gallic or ellagic acid). The condensed tannins form phlobaphenes (e.g., phloroglucinol) when heated with dilute acids or bases. It is the condensed tannins that are more important in alcoholic beverages such as wines.

Some tannins such as tannic acid and propyl gallate display antimicrobial activity toward foodborne bacteria, aquatic bacteria and off-flavor-producing microorganisms, e.g., tannic acid reduces staphylococcal activity (Akiyama et al. 2001). Thus, they can also be used in food processing to extend the shelf-life of some food products.

TANNINS AND HEALTH

Some of the health benefits of tannins include their anti-inflammatory, antiseptic, and astringent properties. They also are effective against diarrhea, irritable bowel syndrome, and skin disorders. However, tannins are metal ion chelators and their binding to metal ions make these mineral elements not readily bioavailable. High intake of tannins could hamper the absorption of minerals such as Fe to result in anemia. They can also cause protein precipitation to interfere with the uptake of nutrients in some ruminants. Foods with high levels of tannins are judged to be of poor nutritional value, because they reduce feed intake, protein digestibility, feed efficiency and growth rates, among other things (Chung et al. 1998). These observations have been linked to tannins decreasing the efficiency in converting absorbed nutrients into new body components (Chung et al. 1998). The intake of foods high in tannins such as herbal teas is also thought to increase the incidence of cancers (e.g., esophageal cancer) and this has led to the suggestion that these compounds may be carcinogenic, but other reports attribute the apparent carcinogenic activity observed to constituents associated with tannins and not the tannins per se (Chung et al. 1998).

Some of these observations contradict findings alluding to the anticarcinogenic behavior of tannins (Nepka 2009), or their capacity to reduce the mutagenicity of certain compounds (Chen and Chung 2000). The anticarcinogenic and antimutagenic activities of tannins and related compounds have been attributed to their polyphenolic nature that enables them to behave as antioxidants to check lipid peroxidation (Hong et al. 1995) and the damaging effects of reactive O2 species (Nakagawa and Yokozawa 2002) in biological tissues. Tannins are also reported to reduce blood clotting, blood pressure, and serum lipid levels (Akiyama et al. 2001). They also induce liver necrosis (Goel and Agrawal 1981), and modulate immunoresponses (Marzo et al. 1990).

QUINONES

PROPERTIES AND FUNCTIONS

Quinones are a class of heterocyclic organic compounds with structures like cyclic conjugated dienes. They have been described as secondary metabolites and are found in several organisms including flowering plants, bacteria, fungi, and to a small extent in animals like insects, sea urchins, corals, and other marine animals (Thompson 1991). The compounds display a plethora of colors from yellow to orange to intense purple to black. Examples of quinones include anthraquinone,
1,2-benzo- and 1,4-benzo-quinones and naphthoquinones (Fig. 37.10). Because of their high coloring power, quinones are used as dyes. Quinones are used for the commercial scale production of hydrogen peroxide ($\text{H}_2\text{O}_2$) by the hydrogenation of anthraquinones to hydroquinones, and subsequent transfer of hydrogen ($\text{H}_2$) to $\text{O}_2$ (Schreyer et al. 1972, Drelinkiewicz and Waksmundzka-Góra 2006). For example:

$$2\text{-ethyl-9,10-anthraquinone} + \text{H}_2 \rightarrow 2\text{-ethyl-9,10-anthrahydroquinone}$$

$$\text{dihydroanthraquinone} + \text{O}_2 \rightarrow \text{anthraquinone} + \text{H}_2\text{O}_2$$

Quinones can also react and form conjugates with amino acids, and the products formed can impact the flavor and color of foods (Bittner 2006).

In nature, some quinones serve as important constituents of biomolecules (e.g., vitamin K$_1$); some like ubiquinone and plastoquinone in mitochondria participate in electron transfer reactions in aerobic respiration, while plastoquinone in chloroplasts are involved in electron transfer reactions between photosystems 1 and 2 in photosynthesis.

**Quinones and Health**

Quinones and related compounds (e.g., tertiary butyl hydroquinone or TBHQ) have antioxidant properties and the terpenes of hydroquinone are thought to be more potent than the more common antioxidants such as $\alpha$-tocopherol (Delgado-Vargas and Paredes-López 2003). Some other quinones like the naphthoquinones have antibacterial activity and can inhibit various strains of aerobic and anaerobic microorganisms (Didry et al. 1986, Riffel et al. 2002). Some have also been shown to have anticancer or antitumor activities (Smith 1985). For example, dietary intake of certain quinone derivatives was reported to play a role in the prevention of breast cancer (Zhang et al. 2009). Ironically, certain quinones and their derivatives have also been shown to be mutagenic or carcinogenic (Zhang et al. 2009). In this regard, it is reported that extended exposure to some of these compounds increases the incidence of breast cancer. Some metabolite products of quinones are also known to be toxic, and the toxicity appears to arise from either the arylation of sulfhydryls compounds or the production of free radicals and/or reactive $\text{O}_2$ species (Smith 1985).

**XANTHONES**

**Properties and Functions**

Xanthones are a group of heat stable organic compounds with 9H-xanthen-9-one (xanthone) as the core structure (Fig. 37.11). Xanthones occur naturally in tropical plants and about two
hundred known compounds in this group have been identified. Well-known examples are α-mangostin, β-mangostin, garcinone B, and garcinone E from the pericarp of mangosteen fruit. Xanthones are said to enhance the body’s immune system and also impart other human health benefits such as promoting healthy cardiovascular or respiratory systems, supporting cartilage and joint function (Weecharangsan et al. 2006). Other health benefits attributed to xanthones include their capacity to reduce: allergies, cholesterol levels, inflammation, skin disorders and fatigue, and they also curb susceptibility to infections and help maintain gastrointestinal health (Weecharangsan et al. 2008). They have antioxidant properties and they do this by deactivating free radicals in the body. In this regard, they are said to be even more potent antioxidants than vitamins E and C.

Some applications of xanthones include their use as insecticide and it has been used in this regard against moth eggs and larvae. Xanthone in the form of xanthrol is also used to verify area levels in the blood.

OTHER PIGMENTS

Apart from the pigments described above, there are other lesser known natural pigments that are also found in various living organisms. Examples of these include the blue and red chromoproteins (phycocyanin and phycoerythrin) found in the blue-green algae and cyanobacteria. There are also other pigments such as flavins and pterins.

Phycocyanin and Phycoerythrin

Phycocyanin is blue pigment found in the blue-green algae and cyanobacteria, while phycoerythrin refers to red pigment found in the red algae commonly referred to as rhodophytes. These pigments are conjugated chromoproteins and they comprise of subunits each with a protein backbone that is covalently linked to open chain tetrapyrrole groups. Their molecular weights range from 44,000 daltons (monomers) to 260,000 daltons (hexamers) (Boussiba and Richmond 1979), and they function as light-absorbing substances together with chlorophyll in photosynthesis.

An example of useful red algae is the nori or Porphyra that is consumed as food and is used as wraps for sushi and in several other Japanese dishes. These pigments are produced commercially from Spirulina platensis. Spirulina are blue-green algae and they grow well in warm climates and alkaline waters. The two best known members of the Spirulina species are S. platensis and Spirulina maxima. S. platensis is cultivated in California while S. maxima are cultivated in Mexico. Phycocyanin and related compounds are thought to have antiviral and anticancer activities as well as immune system stimulatory ability. Phycocyanins also enhance the formation and development of red blood cells to reduce the incidence of anemia (Mathew et al. 1995, Jensen and Ginsberg 2000, Mani et al. 2000, Jensen et al. 2001, Samuels et al. 2002, Shih et al. 2003), and also thought to promote the development of healthy skins. Thus, it is used to treat eczema and psoriasis and some other skin disorders. These pigments occur together with carotenoids and chlorophylls in the blue-green and red algae. Phycoerythrin, in particular, is believed to facilitate red seaweed subsistence at greater depths in the ocean where hydrostatic pressures are high, unlike the other seaweed species (e.g., brown and green algae) that subsist in shallow waters.

The antioxidant, free radical scavenging, and anti-inflammatory properties of phycocyanin, as well as antiviral activity of the pigment have been demonstrated in studies with laboratory animals (Bhat and Madyastha 2000). Other studies have also revealed protective effects by phycocyanin against neuronal damage and oxidative damage to DNA (Bhat and Madyastha 2001, Piñero Estrada et al. 2001). Phycocyanin is used as a natural food-coloring agent in food products such as yogurts, milk shakes and ice creams, beverages, desserts, and also in cosmetic products. Phycoerythrin is used in medicine to facilitate selective destruction of atheroscrotic plaques or cancer cells by radiation with little or no damage to the surrounding cells or tissue (Morcos and Henry 1989), while phycoerythrin is used as fluorescent dyes for fluorescence activated cell scanning (Hardy 1986).

Other pigments include curcumin found in turmeric. Curcumin is an oil soluble pigment and tends to fade when exposed to light, but it is heat stable. It is used to impart lemon yellow colors in food products such as curry, soups, and conversationery. Riboflavin (or vitamin B2), is a water-soluble and heat stable compound with an intense yellow color. It is used to color and fortify foods like dairy products, cereals, and dessert mixes. Carmine (or carminic acid, C22H20O13) is a water-soluble pigment obtained from the female cochineal insect (Dactylopus coccus). It is stable to heat and light, and resistant to oxidation; and is used in alcoholic beverages and processed meat products. It is also used as an ant repellent.

SUMMARY/CONCLUDING REMARKS

For some time, interest in synthetic food colors was high because of the perceived disadvantages with natural pigments. These disadvantages include inconsistency in the product quality and yields from batch to batch, susceptibility to factors such as heat, pH, light, and air, as well as the high cost. However, pressure now seems to be increasing for less use of synthetic pigments as food colorants. Consumers are showing higher preference for natural pigments in foods for health safety reasons, and recent studies published in various scientific journals, including the Lancet, linked synthetic colors with hyperactivity in children (Harley et al. 1978, McCann et al. 2007). In addition, food regulations published in Europe are promoting the use of natural pigments in foods over their synthetic counterparts. And the United States Food and Drug Administration has been petitioned to ban the use of synthetic colors like Yellow 5 and 6, Red 3 and 40, Blue 1 and 2, Green 3, and Orange B in foods, and to require labels on foods that contain these dyes. In addition to their coloring power, some of these natural pigments have also been shown to have more potent antioxidant and free radical scavenging capabilities than the synthetic ones commonly used in foods (Frankel et al. 1996). It is estimated that the world market for food colors is in excess of a billion dollars (United States) annually, and natural
pigments account for about 30% of the market. It is predicted that the market share of natural pigments will continue to grow and surpass that of synthetic colors due to the increasing consumer concerns with the latter.

Thus, what needs to be done is more research to address the disadvantages with the commercial production and use of natural food pigments. Sources of the major food colors (red, blue, and yellow) must be identified; procedures to recover them efficiently and in purer and more stable forms, such as enzyme-assisted treatments (Kim et al. 2005) need to be developed; and treatments and/or conditions to stabilize them such as use in combination with antioxidants need to be exploited.

REFERENCES


Bhat VB, Madyastha KM. 2001. Scavenging of peroxynitrite by phycocyanin and phycocyanobilin from Spirulina platensis: protection against oxidative damage to DNA. Biochem Biophys Res Comm 286: 262–266.


