Commercial Applications of Plant Pigments

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Abstract

Naturally occurring pigments in plants are responsible for giving eye capturing colors to them. The major groups of plant pigments like chlorophylls, carotenoids, betalains and flavonoids not only impart colors which attract pollinators but also have beneficial health effects when consumed in diet. Plant pigments have been used as impeccable natural source of color. A remarkable work has been done to understand the chemical and technological aspects of natural plant pigments, mainly anthocyanins, betalains, chlorophylls, and carotenoids. These plant pigments are related to a broad spectrum of health-promoting benefits. These natural compounds are also used as indispensable components in many pharmaceutical, medicinal and cosmetic product manufacturing industries. The wide range of biological usage of these pigmentsdemand further confirmation by performing cell culture, animal model research supported by human studies.

Keywords: *anthocyanins, betalains, carotenoids, plant pigments*

INTRODUCTION

Pigments are special chemical compound in plants that absorb different wavelengths of visible light and appear colorful. Plants can produce diverse pigments which attract pollinators due to their catchy colors and serve to disperse seeds as well as provide protection against various kinds of biotic and abiotic stresses.Chromophore component in the pigment is responsible for colorful appearance of the pigments. It captures energy and excites electrons from lower energy orbital to a higher orbital while non-absorbed energy is reflected and appears as a color to the naked eye [1]. Plants produce various kinds of natural pigments.

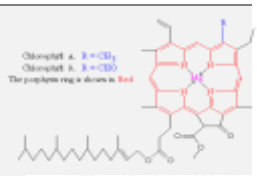
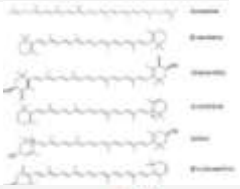
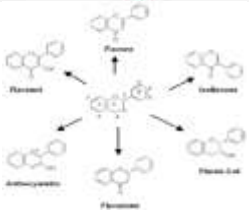
I. Carotenoids

Colorful lipid soluble pigments are called carotenoids that are found in fungi, bacteria and algae and are present in fruits, vegetables and fish[2]. More than 600 carotenoids have been identified in different plant species. A typical human diet contains about 40 carotenoids and human blood and tissues have been found to contain around 20 carotenoids. Carotenoids are C-40 based isoprenoids which are tetraterpenes family. On the basis of structural differences, carotenoids are divided into different groups e.g. carotenes, lycopenes, xanthophylls, etc. Red color in fruits and vegetables is due to a carotenoid called lycopene according to a report by European Food Information Council (EUFIC). And yellow orange color in the fruits and vegetables is imparted by α-carotene, β-carotene, xanthophylls (lutein, zeaxanthin and cryptoxanthin) [3, 4]. Human body and diet contains different kinds of carotenoids like β-carotene,α-carotene, lycopene, lutein and cryptoxanthin [5].

II. Flavonoids

Flavonoids are floral pigments and are found in almost all of the plants bearing flowers and give flower petals attractive colors which are visible in the light spectrum. Flavonoids are not only found in flowers but are also present in other parts of the plant as well and are responsible for attracting insects to the plants which are major pollinators of the plant world. They also help plant in protection against UV-B, signaling among plant microorganisms and also regulate auxin transport. Flavonoids have a chemical structure consisting of two phenyl rings connected by a bridge that constitutes a third ring or a phenylbenzopyran (Table.1). The degree of oxidation of the C-ring determines the color of the particular flavonoid. Since flavonoids are genetically and structurally related to each other, all the three sub-groups of flavonoids share a common chalcone precursor. Flavonoids (2-phenylbenzopyrans), neoflavonoids (4- benzopyrans) and isoflavonoids (3-benzopyrans) are the three subgroups. Onions and tea are major dietary sources of flavonols and flavones

Table 1: Major plant pigments

Pigment Group	*Types*	*Color*	*Structure [6]*
Chlorophylls	Chlorophylls *a, b*	Green	
Carotenoids	Carotenes, Xanthophylls	Yellow, Red, Orange	
Betalains	Betaxanthins Betacyanins	Yellow, Red	
Flavonoids	Chalcones Flavonols Anthocyanins	Cream, yellow, pink, red, blue, black	

More than 650 different anthocyanins have been identified with various aliphatic and aromatic groups. The color of anthocyanins can range from different colors of orange, red, pink purple and blue and it is predominantly influenced by the acylation, pH, metal complexation and co-pigmentation with other phenolic compounds. Anthocyanin-rich foods such as blood orange, corn, blueberryand other foods engineered to be rich in anthocyanins endorse health [7, 8]. Based on the health benefits of anthocyanins and apprehensions associated with synthetic food pigments, there is an increasing interest in replacement of harmful synthetic dyes by natural anthocyanin colors [9].

III. Betalains

Betalains are vacuole associated pigments composed of a nitrogenous central structure, betalamic acid which condenses with imino compounds like cyclo-L-3,4-dihydroxy-phenylalanine, glucosyl derivatives or amino acid derivatives to form variety of colorful pigments (Table 1). About 75 betalains have been isolated from plants of about 17 families under the order Caryophyllales [10]. These pigments are predominantly water-soluble and betacyanins haveabsorbance positioned at wavelengths nearly 536 nm. Betacyanin's more complex pigment structures can be obtained by glycosylation and acylglycosylation of hydroxyl groups present on them. Betalains are usually present in eatable parts of the plants and can also be found in other parts of the plants like the leaves, flowers, stems and bracts [11]. While other anthocyanins are mainly present in dietry plants, betalains are predominantly found in in beets and opuntia cactus fruits. Due to its toxicological safety, user-friendliness, low cost, biodegradability, and possibly health benefits, the integration of betalains in food manufacturing and related industries could solve our current problems.

IV. Chlorophyll

The pigment employed by all higher plants which imparts green color to plants for photosynthesis is called chlorophyll. The name originates from the Greek words that translate into green and leaf. Chlorophyll is a cyclic tetrapyrrole with coordinated magnesium in the center (Table 1). It has two types which are present in the plants chlorophyll (*a* and *b*) which have a difference of substitution of the tetrapyrrole ring. It is mainly isolated from edible plants, nettle, grass, or alfalfa, silkworm droppings and mulberry leaves[12].

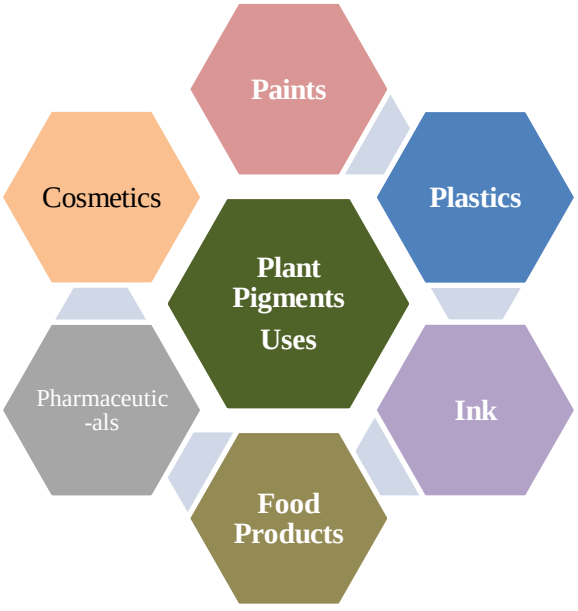


Figure 1. *Major applications of plant pigments in industry*

PHARMACEUTICAL IMPORTANCE OF PLANT PIGMENTS

The phytochemicals; lycopene, anthocyanins and betacyanins are responsible to give red coloration to the fruits and vegetables. These pigments are known as functional ingredients because of the protective roles for degenerative diseases like cancer and cardio-vascular diseases. These have antioxidant ability to scavenge free radicals which may cause oxidative damage and chronic diseases in human body. Oxidative stress is known to be the major deleterious factor resulting to onset of different chronic diseases**.** Carotenoids are known to have health-promoting benefits like prevention of dangerous human diseases such as cancer and age-related disorders. These are also recognized as a vital dietary source for vitamin A, mainly found as α-carotene and β-carotene (vitamin A precursors) [13]. A diet containing high carotenoid results in a reduced risk of breast, cervical, ovarian and colorectal cancers,cardio-vascular and different eye diseases [14]**.** Lycopene is claimed to have protective role against breast cancer, lung cancer, ovarian cancer, gastrointestinal cancer and pancreatic cancer [15]. The high intake of pigment lycopene has a positive effect for the preventing cardio-vascular diseases [16] and lung diseases [17]. A study has reported that lycopene, especially cis-lycopene implies a protective role in cases of human papillomavirus (HPV) infection. Lycopene has been reported to impart animproved visual function to the patients having tension glaucoma [18]

Flavonoids have shown major biochemical and antioxidant benefits associated with many diseases like cancer, Alzheimer's disease (AD) and atherosclerosis [19]. A high antioxidant activity is observed by both anthocyanins and anthocyanidins. Anti-obesity, low gain in body weight and better blood lipid profile in the rats induced with high-fat has been observed [20]. Anthocyanin possesses antimicrobial effects by damaging and then destroying cell wall, cell membrane and also the intercellular matrix [21]. Betalains have promising potential as therapeutic agents for promoting health issues and to prevent diseases like hypertension, dyslipidemia , cancer, and vascular stenosis[22].

PLANT PIGMENTS IN FOOD INDUSTRY

Natural pigments found in food materials are responsible to give color to the products. The additives in the form of pigments impart to deepen the color or to renew color of food product. These pigments can improve the taste of food and make its identification easier. Nowadays, many conscious consumers have demand for the food products which are colored using natural pigments. Artificial pigments are known as harmful and undesirably dangerous. Sixteen natural pigments are now permitted to be used in food. [23].

Betalains are oil-insoluble but water-soluble. Depending upon the pH of the environment, they take the tawny (pH > 8.5), blue-violet (6.5–8.0), red-purple (3.0–6.5) or red-violet color (pH < 3.0), but their highest stability is observed at the pH 4–5 range. They are used to color frozen food, ice-creams, flavored milk drinks, yoghurts, powdered desserts, gels, sauces, jams, jellies, candies[24, 25]. Betalains have been used as food colorants and as dietary supplements [26].

Anthocyanins also change color depending on the pH of the substance they are in. They may take red at pH value lower than 4, red-violet pH 4–6 or blue when the indicator pH is higher than 7. Anthocyanins were initially obtained from the pomace of red grapes, elder, red currant, purple carrot, as well as hibiscus flowers. Application of the group of flavonoids by the food industry is a common practice and they can be found in fruit, alcoholic and non-alcoholic drinks, sauces, cheeses, milk desserts, jellies, jams and candies [27]. Use of anthocyanins in food as colorants and also as functional ingredients is limited due to their low stability and interaction with other ingredients in the food matrix [28]. Carotenoids are resistant to heating, sterilization and freezing processes. They are well soluble in oils but insoluble in water. Color in food products because of carotenoids are produced by extraction from major natural sources such as annatto, paprika, saffron, tomato lycopene, marigold lutein. They are used in the production of butter, margarines, oils and fats, cheese spreads, non-alcoholic drinks, fruit juices, confectionery baked goods, ice-creams, yogurts, desserts, jams, creams, pastries and jellies [29].

Chlorophyll is obtained via extraction from plant leaves. It is obtained from peppermint, pistachio, common or stinging nettle. It shows the lowest stability of all the natural pigments and low resistance to a higher temperature, light activity, oxygenation and pH change. It hydrolyses in the acidic environment giving a brown coloring. Chlorophylls are used in beverages, sweets, chewing gums, soup concentrates, cheese spreads, preserves and vegetable pickles. Besides they show medicinal properties since they improve human metabolism, being a source of magnesium [24, 27, 30]. Practically use of chlorophyll was first boomed in the 1940s. Commercial products comprising of chlorophyll included bathroom tissue, diapers, chewing gum, bed sheets, toothpaste and other products of daily use. The major selling product was as an anti-odorant and also the one used in dental hygiene. Other applications of chlorophyll use in wound healing, germ killing, treatment of infections,

materials used against inflammations and in use of bandages, antiseptic ointments, and surgical dressings [31].

A significant potent problem in the wide use of natural plant pigments is their instability, which is an important point in food industry. Different factors like pH, light, temperature, processing method, harvesting period, enzymes, sugars, oxygen and metal ions can drastically result the stability of the naturally occurring plant pigments [32].

PLANT PIGMENTS IN COSMETIC INDUSTRY

Due to side effects of prolonged usage of synthetic coloring compounds, the trend has been shifted towards the market of natural colors in the form of pigments used in cosmetics. Plant extracted pigments are mixed in dermatological products to transfer color to the skin or lips, hair etc. Due to the antimicrobial properties and radical scavenging activities, plant pigments have been beneficially used in cosmetics [33]. Henna or mehndi has been used as an agent for color and cosmetic for over thousand years. Its pigment; lawsone is remotely used in cosmetology due to its dyeing properties and is being used to color hair and nail. Lawsone due to its conditioning properties is being widely mixed in shampoos,hair rinse, and conditioners. Mehndi is applied to cover gray hair without adverse effects on hair and also for making temporary tattoos for decoration purposes on the skin [34]. Sappanwood extract due to its powerful antibacterial action is incorporated to cosmetic creams, gels and lotions which also maintains the integrity of formulations.

Caesalpinia sappan, the heartwood, when freshly cut is of yellow color, but it rapidly transfers its color to red. The color transition with pH, altering from yellow to red is used advantageously in production of lipsticks of beautiful colors [35]. The heartwood of red sandalwood tree or Red Sanders (*Pterocarpus santalinus* Linn.) is applied to make skin health better. Traditionally, sanders red mixed with turmeric is used to give healthy glow to skin. Red sandalwood extract is mixed in the formulation of lipstick and other color cosmetic compositions.

Beta Vulgaris extract (betalain pigments) is used to give red color to the hair and is used in formations of bleachingagents, facial moisturizer, anti-aging , acne treatment, toners, astringents, shampoo, defoliant/scrubs and lip balm etc. [36].The saffron has been used as a yellow colorant even before the 23rd century B.C. The carotenoid in saffron comprises of a simple sugar linked with basic chain, responsible for its water solubility. Saffron is being used for making beverages , cosmetics, and pharmaceutical products in limited amount due to its high cost [36].Turmeric (*Curcuma longa*) is being used as an environment friendly substance for giving color to both food and cloth. Turmeric pigment is recognized as the brightest of all naturally found yellow dyes and it is used as a powerful antiseptic for revitalizing skin [37].Examples of few other pigments are: berberinebased pigments (like palmatine, coptisane and limonene), hino kitiol, betel nut pigment, rutin, logwood pigments, henna tannin and catechin [38].

USE OF PLANT PIGMENTS IN INK

Natural pigments from different sources including plants have been discovered thousands of years ago and are being used ever since. Earlier, prehistoric people used these pigments for painting the walls of the caves in which they used to live. Madder (*Rubia tinctorium L.*) is used for red color, St John's wort (*Hypericum perforatum L.*) gives yellow brown color. Tall mallow (*Malva sylvestris L.*) gives yellow green color. Tansy (*Tanacetum vulgare L.*) is used for yellow color [39].

PLANT PIGMENTS USAGE IN SOLAR CELLS

Dye Sensitized Solar Cells (DSSC) are being the point of attention now due to simple designing and fabrication material which applies low cost. Use of metal complexes and organic dyes result in better efficiency and higher durability for DSSC. But the process to synthesize such dyes is laborious, too much costly and it involves usage of toxic materials. So the alternative approach is to use natural pigments (dyes) found in plants such as anthocyanin, carotenoid, chlorophyll, tannin, betalain and many others are as dyes in making of DSSCs. The source of these natural pigments are fruits, flowers, leaves, seeds, barks and other parts of plants. The prevailing benefits of using natural dyes are high absorption coefficients, pigments' high light harvesting efficiency, low cost extraction of pigments and also their low toxicity [40]

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