Abstract

Purpose of the review: In addition to colouring foods, natural plant pigments are medically active. Different colours appearing in different parts of the plant indicate the presence of various secondary metabolites. The intensity of the colour is directly proportional to the quantity of the secondary metabolites, which are known for their considerable medicinal value. The present review focuses on the different plant pigments known for their pharmacological significance and their recently-documented postharvest practices.

Main findings: It is desirable to maintain the colour of medicinal plants until they reach the point of consumption. Good postharvest practices can maintain the colours in medicinal plants.

Direction for further research: Conventional plant breeding, agronomic practices or genetic manipulation of these plants can be used in conjunction with postharvest practices to optimise the production of the medicinally active colour and pigments.

Keywords: Medicinal plants; colour and pigments; postharvest practices

Introduction

Colour is an important organoleptic characteristic that determines the quality of most of the drugs and foods that we consume. It may be defined as the individual’s response to the visual signals generated by the light on a product. These colours are mostly derived from natural sources, especially plants in the form of pigments. Pigments are present in all living matter, provide attractive colours and play basic roles in the development of organisms. Humans, like most animals, come in contact with their surroundings through colour, and things may be accepted or rejected based on their colour [1**].

Different pigments, present in different parts of the plant, are responsible for the variation of colour. Natural plant pigments (e.g., xanthophylls, carotenoids, anthocyanins) are medically active and have been found to play an important role in the treatment of human ailments. Biological studies have shown that a rich variety of nutrients, energy-rich sugars and pharmacologically-active compounds are abundant in colourful fruits and vegetables.
Different tissues of plants exhibit different colours, which vary from time to time as plants mature. Pigment stability/retention is obviously a challenge for postharvest technologist. The use of natural pigments will enable us to minimise the use of potentially hazardous artificial pigments. Postharvest practices become crucial for the processing of medicinal plants containing colour and pigments. Several factors, both in the pre- and postharvest stages, influence colour and pigment formation in medicinal plants. In general, juice is concentrated under vacuum until it comprises around 60-65% of total solids, while freeze-dried products tend to contain about 0.3-1.0% pigment. A higher level of pigment concentration in juice and powder products can be obtained through the fermentation process. For example, powders obtained after fermentation of beet juice contain five to seven times higher betacyanin compared with unfermented ones.

Botanical pigments hold a complex blend of attractions for human beings. Indeed, vivid colouration suggests more than delicious ripe fruit. Deeply pigmented varieties often possess medicinal properties that help our body systems to work well and avoid diseases. The present review focuses on the postharvest handling of medicinal plants, which contain important colour and pigments, and their pharmacological uses.

Natural food colours
Natural food colour is any dye obtained from vegetable, animal or mineral sources that is capable of colouring food, drugs, cosmetics or any part of the human body. These natural colours can be obtained from a variety of sources such as seeds, fruits, vegetables, algae and insects. Depending on the application, a suitable natural colour can be achieved by keeping in mind factors such as pH, heat, light, storage and other ingredients.

According to the United States Food and Drug Administration, natural colours and pigments are exempt from certification. Thus, they do not carry any categorisation as natural or synthetic. The reason for this classification is that although the source may be natural, it may or may not be natural to the food it is added to. There are 26 permitted colours that can be used in food, whereas 28 are prescribed for cosmetics and pharmaceutical applications. Some important natural colours are: annatto extract, anthocyanins, β-carotene, β-AP0 β-carotenal, black currant, burnt sugar, cantaloupe, citronella, carotenoids, carmine, carmine blue, cyanogenic acid, carrot, chlorophyll, chlorophyllin, cochineal extract, copper-chlorophyllin, copper-chlorophyll, curcumin, curcumin/curcuminoid, grape, hibiscus, honeysuckle, mixed carotenoids, paprika, riboflavin, spinach, stinging nettle, titanium dioxide and turmeric. In addition to those mentioned above, herbs also have pharmacologically-active natural colouring pigments. Bioactive colouring constituents must be preserved very carefully to ensure their activity until they reach the commodity. Therefore, good postharvest technology has to be adopted for each and every part of the plant separately.

**Medicinal properties of different plant pigments**

**Anthocyanins**
Anthocyanins are probably the best-known natural pigments. Francis listed pigment profiles and methods of extraction from more than 40 potential plant sources [2*, 3*], and also listed 49 patents on anthocyanin sources [4*]. Anthocyanins, in addition to their Colourful characteristics, possess antioxidant properties [5]. No doubt, the antioxidant activities of anthocyanins account for some of the beneficial effects against cardiovascular and other diseases, derived from consumption of fruits and vegetables high in anthocyanins. Olukemi et al. [6**] suggested hot and cold postharvest extraction procedures for anthocyanins, as well as quantification of anthocyanins by spectrophotometry, for natural colours such as Hibiscus sabdariffa, Sorgum bicolor. They authors found that the cold extract of S. bicolor contained 18% anthocyanin, which was about four times greater than that in the hot extract of H. sabdariffa (5%). The hot extract of H. sabdariffa contained the second highest concentration of anthocyanins (31%). Heat aided the extraction of the anthocyanins in H. sabdariffa, despite their susceptibility to rapid loss of colour because of the acidified methanol used for extraction. Spectroscopic analysis showed that the hot extract of S. bicolor had the highest quantity of anthocyanins (46%). Colour is one of the important quality attributes in products that usually deteriorate during storage. Anthocyanins readily degrade and form colourless or brown-coloured compounds [7**].

Berries are rich in anthocyanins, a group of botanical pigments that impart the brilliant reds, blues and purples to many flowers and fruits. Traditional therapies have made use of the diverse spectrum of activities associated with berries including their including laxative, astringent, anti-inflammatory and expectorant actions. Elderberry is used as a restorative cordial, buckthorn berry to relieve constipation, bilberry extracts to relieve sore throat and mild inflammation of the oral mucosa, and cranberry to provide natural support for urinary tract health. The potent antioxidant properties of berries offer enormous potential in areas of disease prevention and treatment, and a wealth of new research is being conducted in a variety of fields including tumour suppression; antimicrobial actions; prevention of hypertension, cardiac enlargement, atherosclerosis and gastric ulcers; and protection against large bowel cancer, cataracts and diabetes. Studies have shown that the discoulouration of anthocyanins in ethanol solutions occurs faster than in aqueous solutions [8*]. Hernández-Gutiérrez [9**] reported that an increase in ethanol concentration reduces the extent of copigmentation of anthocyanin in ethanolic solution kept at constant pH and releases more flavylum cations.

**Carotenoids**
Carotenoids are responsible for the attractive yellow, orange or red colour of many foods. The role of some of these compounds as provitamins has been known for years. Other bene-
ficial effects on human health, which have been more recently attributed to carotenoids, include enhancement of the immune response and reduction of the risk of degenerative diseases such as cancer, cardiovascular disorders, cataract and macular degeneration [10**]. Thus, the consumption of carotenoid-rich foods is widely recommended. The principal carotenoids of foods are β-carotene, β-cryptoxanthin, lycopene, lutein and violaxanthin. Except for violaxanthin, these are also the principal carotenoids found in the human plasma, and together with zeaxanthin, are the carotenoids mostly studied in terms of human health. β-carotene and β-cryptoxanthin are provitamin A. Lycopene is vitamin A inactive but is a more efficient antioxidant than β-carotene [11**]. It has been linked with the reduction of the risk of cancer, especially lung, stomach and prostate cancers.

Today, a wealth of new research has revealed the health benefits of the colourful and abundant carotenoids, a diverse group of fat-soluble pigments found in nutritional foods such as broccoli, spinach, carrots and tomatoes. Along with fibre, valuable trace minerals and essential vitamins, carotenoid-rich substances offer an array of protective benefits. An abundance of newly published data suggests that carotenoids confer cardiac and prostate protection, maintenance of eye health, potent antioxidant support and even potential anticancer effects [12**, 13**, 14**]. In a study published in the September 2004 issue of *Free Radical Biology and Medicine*, researchers reported that β-carotene confers protection against matrix metalloproteinases – chemical mediators involved in skin damage and aging due to sun exposure [15*]. Antioxidant activity is a key to this protection, as β-carotene neutralises the harmful effects of unpaired electrons, commonly referred to as free radicals, a reference to their highly reactive and destructive nature.

**Effects of processing and storage**

Many carotenogenic foods are seasonal and preservation at peak harvest is required to minimise losses, make the products available all year round and permit transportation to places other than the site of production. Processing and storage of foods should, however, be optimised to prevent carotenoid losses. Although industrial processing is often focussed, losses during home preparation of foods can be, at times, even more considerable. Retention or loss of carotenoids during processing and storage of food has been reported in numerous papers [16**]. The following is a list of factors to take into consideration during the storage of carotenoid-containing foods.

- The tropical climate enhances carotenoid biosynthesis.

- On the other hand, the same ambient conditions may hasten destruction of carotenoids during postharvest handling and storage.

- Carotenoid biosynthesis may continue after harvest, increasing the carotenoid content in fruits, vegetables and root crops, provided they are kept intact and not treated in any way that would inactivate the enzymes responsible for carotenogenesis. In leaves and other vegetables, postharvest degradation of carotenoids appears to prevail, especially at high storage temperature.

- Carotenoids are naturally protected in plant tissues; cutting, shredding, chopping and pulping of fruits and vegetables, and increased exposure to oxygen brings carotenoids in contact with enzymes that catalyse carotenoid oxidation.

- The stability of carotenoids differs in different foods, although the same processing and storage conditions are used. Thus, optimum conditions for carotenoid retention during preparation/processing differ from one food to another.

- Carotenoids have different susceptibilities to degradation.

- The major cause of carotenoid destruction during processing and storage of foods is enzymatic or non-enzymatic oxidation. Isomerisation of *trans* carotenoids to *cis* isomers, during heat treatment, alters their biological activity and discolours foods. Enzymatic degradation of carotenoids may be a more serious problem than thermal decomposition in many foods.

- During home preparation, losses of carotenoids generally increase in the following order: microwave > steaming > boiling > sautéing. Deep-frying, prolonged cooking, a combination of preparation and cooking methods, baking and pickling all result in substantial losses of carotenoids.

- Whatever the processing method chosen, retention of carotenoid decreases with longer processing time, higher processing temperature and cutting or puréeing of the food. Reducing processing time and temperature, and the time lag between peeling, cutting or puréeing and processing improves retention significantly. High temperature, short time processing is a good alternative.

- The heat treatment in blanching may result in some losses of carotenoids, but the inactivation of oxidative enzymes will prevent further and greater losses during holding before thermal processing, slow processing and storage.

- Freezing and frozen storage generally preserve carotenoids, but slow thawing can cause deterioration, particularly when the product has not been properly blanched.

- Peeling and juicing result in substantial losses of carotenoids, often surpassing those of heat treatment.

- Traditional sun drying, although the cheapest and most accessible means of food preservation in some regions, causes considerable carotenoid destruction. Solar drying can appreciably reduce losses although the process is simple and inexpensive. Protecting the food from direct sunlight also has a positive effect [12**].

**Lycopene**

Lycopene is a primary red carotenoid found in tomato products including ketchup and tomato juice, and in several red-fruits such as grapefruit and watermelon. Evidence suggests that lycopene protects the heart by reducing the incidence of stroke and heart attack, as well as certain other car-
diovascular risk factors. Lycopene is a potent antioxidant, but new research shows that it might diminish cholesterol production in the body, enhance cellular communication and inhibit inflammatory processes [15*, 17**]. In addition to promoting a healthy cardiovascular system, lycopene may offer a dual benefit. Research suggests that diets rich in lycopene help to maintain healthy prostate tissue. Lycopene also has strong protective effects against lung and stomach cancers. Promising benefits also have been noted in preventing cancers of the pancreas, colon, rectum, oesophagus, oral cavity, breast and cervix. Incorporating more deeply coloured products into our daily diets prevents age-related eye disease, cardiovascular disease, obesity and cancer [15*].

**Postharvest damage of lycopene**
Undesirable degradation of lycopene not only affects the sensory quality of the final products, but also the health benefit of tomato-based foods for the human body. Lycopene occurs in the all-trans configuration in fresh tomato fruits. The major causes of tomato lycopene degradation during processing are isomerisation and oxidation. Isomerisation converts all-trans isomers to cis isomers due to additional energy input, and results in an unstable, energy-rich situation. Determination of lycopene isomerisation during processing would provide a measure of the potential health benefits of tomato-based foods. Thermal processing such as bleaching, retorting, and freezing generally causes some loss of lycopene in tomato-based foods. Heat initiates isomerisation of the all-trans to cis forms thus, the cis isomers increase with temperature and processing time. In general, dehydrated and powdered tomatoes have poor lycopene stability unless carefully processed and promptly stored in a hermetically sealed and inert atmosphere. A significant increase in cis isomers, with a simultaneous decrease in the all-trans isomers, can be observed in tomato samples treated with different dehydration methods. Frozen and heat-sterilised foods exhibit excellent lycopene stability throughout their normal temperature storage shelf-life. Lycopene bioavailability (absorption) can be influenced by many factors. The bioavailability of cis isomers in food is higher than that of all-trans isomers and lycopene bioavailability in processed tomato products is higher than in unprocessed fresh tomatoes. Food processing may improve lycopene bioavailability by breaking down cell walls, which weakens the bonding forces between lycopene and the tissue matrix, thus making lycopene more available and enhancing the cis isomerisation. High-quality lycopene products that meet food safety regulations will offer potential benefits to the food industry [18*].

**Extraction procedure for lycopene and \( \beta \)-carotene**
Lycopene and \( \beta \)-carotene were extracted from tomato paste waste using supercritical carbon dioxide. To optimise the results of supercritical fluid extraction (SFE) for isolation of lycopene and \( \beta \)-carotene, a factorial designed experiment was studied. The factors studied were the temperature of the extractor (35, 45, 55 and 65°C), the pressure of the extraction fluid (200, 250 and 300 bar), cosolvent (5, 10 and 15% etha-

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Flavonoids
Flavonoids are an important group of polyphenols, widely distributed in plant flora. Over 4,000 flavonoids are known to exist, some of which are pigments in higher plants. Quercetin and kaempferol are common flavonoids. They are primarily recognised as the pigments responsible for autumnal burst of hues, and yellow, orange and red shades in flowers and fruits. Flavonoids have been shown to possess a variety of pharmacological activities in living organisms at nontoxic concentrations. Data from various in vivo and in vitro experimental and epidemiological studies have demonstrated the beneficial effects of dietary flavonoids. The mechanisms of their cardio-protective effect have been thought to be due to their free-radical scavenging, antioxidant, anti-thrombotic, anti-apoptotic and anti-hypertensive effects. Based on the results of clinical studies, it has been suggested that flavonoids could be promising cardioprotective agents [22**].
Curcumin
Curcumin, a yellow pigment from Curcuma longa, exhibits anti-inflammatory, anti-tumor, and antioxidative properties. Studies have shown that the chemopreventive action of curcumin might be due to its effect in inducing apoptosis (programmed cell death) in cancer cells. For the estimation of apoptosis due to curcumin, changes in cell morphology and flow cytometry analysis (DNA content and presence of the sub-G1 peak) were performed. Microscopic examination of the curcumin-treated cells (with concentrations above 100 μM) showed a characteristic morphology of apoptosis [23].

Betaxanthin
These are the colourants obtained from sources such as Celosia argentea. Lyophilised betaxanthin powders from yellow inflorescences of Celosia exhibited bright yellow colour and high colour purity and strong hygroscopicity [24]. The aqueous solutions containing these betaxanthins were bright yellow in the pH range of 2.2–7.0, and they were most stable at pH 5.5. The betaxanthins in a model system (buffer) were susceptible to heat, and found to be as unstable as red betacyanins (betanin and amaranthine) at high temperatures (>40°C), but more stable at 40°C with the exclusion of light and air. The betaxanthins had slightly higher pigment retention than amaranthine/isoamaranthine in crude extracts at 22°C, as verified by HPLC. Lyophilised betaxanthins had much better storage stability (mean 95.0% pigment retention) than corresponding aqueous solutions (14.8%) at 22°C after 20 weeks. Refrigeration (4°C) significantly increased pigment retention of aqueous betaxanthins to 75.5% [24].

Postharvest processing and handling of colour- and pigments-containing medicinal plants
Most plant-derived colour and pigments are used directly from the fresh plant material or from dried plants. The dried material may be used in a chopped or ground form. Roots and wood may be chopped before use or dried. Leaves are usually picked and crushed by heavy, horse-drawn rollers. The resulting mass was ballied and air-dried. The wood balls were stable chemically, and could be stored and handled effectively compared with fresh material. Later, the balls were converted to powder, which was then packed and dispatched to the pigment houses for use. Indigofera and Polygonum tinctoria can be treated the same way. This treatment is unnecessary for indigo-containing plants if used fresh for dye. The problems arising from handling, storing, transporting, drying and other processing methods would need to be considered if large-scale production of plant-derived dyes was developed. Primary processing at the point of production to produce a concentrate of some sort may be possible. To make production as cheap as possible it would be desirable to transport as little water as possible, to use as little heat and space for drying as possible and to store as little material as possible. All needs to be achieved with the minimum use of labour. The production and collection of fresh material is usually seasonal, and the quality of the colourant is variable through the season and with the age of the material. The simplest solution is the storage of material by the producer or the user, although both options have cost and, possibly, quality and environmental implications.

Steps in postharvest handling of medicinal plants
Raw materials that are to be kept after harvesting have to be dried and stored properly to prevent deterioration and infestation. Therefore, harvesting and postharvest treatments have to be linked with the processing schedule and can vary from crop to crop. For example, the yields of essential oils obtained from aromatic plants will depend on the harvesting stage and postharvest treatment. Fruits and vegetables contain natural colour pigments, which may be used to colour foods. In fruits these pigments attract animals and birds, signalling that the fruit are ripe for consumption, thus facilitating distribution of the seeds. The stability of the pigments is affected by pH, light and heat. Freshly cut fruits, such as bananas, apples and peaches will discolor quickly in open air. This oxidation is called enzymic browning. This may be slowed down by the use of antioxidants or prevented by adding an acidic or sugary solution to the surface of the fruit or keeping it at cold temperatures or in water. A similar reaction also occurs in some vegetables, such as potatoes. The factors influencing vegetable colours are freezing or drying, and external factors like pH, temperature, humidity, packaging materials and storage.

Preservatives
Various preservation techniques have been practiced for vegetables and herbs. Some common techniques are pasteurisation, sterilisation, refrigeration and freezing dehydration, irradiation fermentation, salting and osmotic dehydration.

Postharvest physiology
The intensity of colour declines after harvest. The focus of current activities is to maintain rather than improve the quality of harvested materials. The expressions of colour in hydrated tissue are related to the compartmentalisation of the cells. The anthocyanins are located in the vacuole, which is expected to be highly acidic because of the proton gradient across the tonoplast that, amongst other things, drives the accumulation of organic acids [25, 26].

Dehydration may act to disrupt the compartments, increasing the permeability of the membranes, causing the pH of the vacuole to rise, and accelerating the oxidation of anthocyanins and other cell components. Postharvest processing of vegetables can reduce water content by a factor of 10 [27].

Packhouse operations and packing
Sorting, grading and packing are often carried out in a pack house or shed to protect workers and plant materials from the elements. Where shelter is not available, operations are best located in a cool, shady area. This is commonly practiced in Chiang, Thailand and other parts of Asia. Good manufacturing practices in the warehouse could reduce contamination during handling. Damaged parts need to be regularly removed
from the packing area to reduce the spread of spores. Modified packaging techniques such as vacuum packing and hypobaric packing also work as preservatives.

Conclusion

Bright coloured plants and their parts have excellent biological values. It is desirable to retain the colour quality to keep the medicinal activities of these plants active. Various pharmacological activities of colour- and pigments-containing medicinal plants, and the already documented postharvest practices, have been discussed. Secondary metabolites are responsible for the various biological activities that plants exert on living things. It can be concluded that good pre- and postharvest handling and storage of medicinal plants must be maintained or followed for achieving the desired quality and quantity of colour, and, in turn, the production of secondary metabolites of plant materials to preserve its medicinal values.

References

Papers of interest have been highlighted as:

*Marginal importance

**Essential reading


