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A COLOURFUL FOOD PALETTE: HEALTH BENEFITS AND BEYOND

*Suchandra Dutta and Shreyasi Halder

Senior Research Fellow, Nutrition Research Division, Department of Home Science,
University of Calcutta, Kolkata-700027, India

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ABSTRACT

Plant compounds such as carotenoids, betalains, anthocyanins, anthoxanthin, chlorophylls or carminic acid present in fruits and vegetables as natural colorants have been well characterized to possess bioactive properties. The colouration of the food is a key factor in identifying its nutritional integrity and also gives an estimate about the level of processing it has undergone. For example, refined and processed food that has turned brown from extreme heat or high pressure is devoid of the colorful, magical phytonutrients which the natural whole food ingredients possess – and which a body needs to stay truly healthy. Phytonutrient study is one of the most appealing areas of nutritional research being undertaken today and is expanding our knowledge of the health benefits of food much beyond the macronutrients and micronutrients. Also, food security is a major area of concern worldwide. Amongst the many issues of food security, providing access to adequate nutritious food at nominal charges is a challenge yet to be fulfilled. Naturally pigmented foods with their multiple health benefits are a good fit for alleviating the food security scare.

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INTRODUCTION

Phytonutrients, also known as food pigments that give fresh foods their vibrant hues of red, green, purple, yellow and orange do more than just make a pretty meal. They are a great source of powerful antioxidants and therapeutic properties that can have a profound effect on complete human health^[1]. Approximately 1,500 coloured compounds have been isolated so far. Based on their chemical structure, these food pigments can be grouped in the following six classes: heme pigments, chlorophylls, carotenoids, flavonoids, betalains and miscellaneous pigments^[2]. Phytochemicals are particularly associated in protecting plants from diseases, insects, droughts, excessive heat, ultraviolet rays and pollutants in their air and soil. Basically, they are part of a plant's "immune system". In the human body, these non-nutritive compounds can stimulate the enzymes that assist in toxin removal, enhance immunity, contribute to cardiovascular and brain health and stimulate the death of cancer cells^[4]. Organoleptic characteristics largely determine food selection, acceptance and its subsequent consumption.

Therefore, food colorants are extremely important in the food industry. However, based on the latest findings related to the side effects and toxicity issues of some synthetic colorants, consumers worldwide have shown increasing interest in natural alternatives and this has led food industries to replace them with natural pigments^[5]. This paper is an attempt to summarize the various naturally occurring plant pigments in terms of their respective food sources, their medicinal significance on human health, focusing on their effective use as natural food colorants, functional ingredients and value-added food products.

THE CONCEPT OF NATURAL FOOD COLOURS:

Natural food colours or biological pigments originate from a wide range of sources like vegetables, fruits, plants, minerals and other edible natural sources. There are four families of plant pigments namely,

-) Chlorophyll (green)
-) Carotenoids (yellow, red, orange)
-) Flavonoids: anthocyanins + anthoxanthins (red, blue, purple)
-) Betalains (red, yellow, purple)

*Corresponding author: Suchandra Dutta

Senior Research Fellow, Nutrition Research Division, Department of Home Science, University of Calcutta, Kolkata-700027, India.

These can be extracted by physical and chemical extraction methods^[6]. Here we have categorized the plant pigments in terms of their primary colours.

GREEN: Chlorophyll, a water-insoluble plant pigment, primarily responsible for the green colour of all green vegetables and fruits like spinach, fenugreek leaves, coriander leaves, bell peppers, broccoli, green cabbage, celery, green beans, turnip greens, green chilies etc. ^[8]. By enabling plants to produce oxygen during photosynthesis, chlorophyll has made its place in modern medicine due to its numerous health benefits. In the food industry, chlorophyll is gaining importance as a natural food additive for its intense green colour and consumer's growing preference for natural foods. There are two main types of chlorophyll namely; chlorophyll-a (intense blue-green) and chlorophyll b (dull yellow-green)^[9].



Figure 1. Green coloured fruits and vegetables^[7]

Health benefits of “Green”

A study has been reported that chlorophyll-rich plant extracts like wheatgrass and other green vegetables can inhibit the cancer-causing effects of two mutagens (benzopyrene and methylcholanthrene) ^[10]. The structural resemblance of hemoglobin with chlorophyll makes it restore the RBCs and enhances their ability to carry more oxygen as well as eliminate the factors responsible for anaemia ^[11].

-) It also has been found that dietary chlorophyll and its derivatives prevalent in both fresh and processed foods have antioxidant and antimutagenic activities^[12]
-) ‘The Beginner’s Guide to Natural Living’ says chlorophyll stops bacterial growth in wounds, eliminates bad breath and body odor ^[13]
-) Chlorophyll also helps to remove heavy metals from the body that have accumulated due to the ingestion of contaminated food products ^[14]

BLUE/PURPLE

Anthocyanin is a water-soluble vacuolar pigment, whereas anthocyanidin is the sugar-free counterpart of anthocyanin, responsible for the attractive red, purple and blue colours of many flowers, fruits and vegetables ^[15]. They are sensitive to pH change, being reddest in strongly acidic conditions and become bluer as the pH rises.



Figure 2. Purple coloured fruits and vegetables ^[16]

Delphinidin, which is one of the derivatives of anthocyanidin is primarily responsible for the particular blue colouration in fruits and vegetables. Malvidin and Petunidin, both derivatives of anthocyanidin are responsible for the purple violet colouration ^[17]. Blackberries, blueberries, purple grapes, plums, purple cabbage, eggplant are some of the richest sources of blue or purple pigmented fruits and vegetables^[18].

Blue/Purple as the ‘nutritious colour

-) Blue and purplish pigmented foods possess important anti-angiogenic properties which are helpful for the prevention and treatment of cancer, protection against liver injuries and improvement of eyesight^[19].
-) It has been reported that Delphinidin is the most potent inhibitor of osteoclast differentiation and will be an effective agent for preventing bone loss in postmenopausal osteoporosis ^[20]
-) Delphinidin has various pharmacological activities such as antioxidant, antimutagenesis, anti-inflammatory and antiangiogenic^[21].
-) Delphinidin can also suppress the growth of human tumor cells^[22].
-) It has been observed that berry anthocyanins can trigger genetic signaling in promoting human health and disease prevention^[23].

RED

Betalains maintain their colour appearance over a broader pH range from 3 to 7 being particularly suitable for coloring weakly acidic to neutral food red ^[24]. The betalains consist of two sub-groups, red-violet (betacyanin) and yellow to orange (betaxanthin) pigments. Carotenoids (lycopene, canthaxanthin, and astaxanthin), anthocyanins, and betacyanins are natural red pigments found in fruits and vegetables like tomatoes, guava, red grapefruit, papaya, rosehips, and watermelon indicate the presence of lycopene^[26]. Cranberry, beet, watermelon, tomato, strawberry, pomegranate are some of the most commonly available red plant foods. Red wine is produced from red grapes contains anthocyanins primarily resveratrol, a heart-healthy antioxidant. Red potatoes (*Solanum tuberosum* and *S. stenotomum*) were evaluated as potential sources for natural red colorants ^[27].



Figure 3. Red coloured fruits and vegetables [25]

Red is healthy, let's find how:

-) It has been found that anthocyanins are powerful antioxidants and help boost the immune system, maintain health and prevent diseases [28].
-) Resveratrol, a phytoalexin antioxidant found in red grapes have both chemopreventive and therapeutic effects against many diseases [29].
-) Certain laboratory studies have shown red coloured apples containing a variety of **phytochemicals**, including quercetin, catechin, phloridzin and chlorogenic acid have strong antioxidant activity, inhibited cancer cell proliferation, decreased lipid oxidation, and lowered cholesterol [30].
-) Studies have shown that **lycopene** in the diet can help to increase the breakdown of low-density lipoproteins in the body. **Anthocyanins** are now being studied for DNA protection, fighting estrogen-dependent diseases, anti-inflammatory response stimulation and their role in immune system regulation.
-) Red beet products used regularly in the diet may protect against certain oxidative stress-related disorders in humans [31].
-) It has also been reported that **resveratrol** has several neuroprotective roles in various neurodegenerative impairments, such as Alzheimer's, Huntington's, Parkinson's diseases, amyotrophic lateral sclerosis and alcohol-induced neurodegenerative disorders. [32]

YELLOW/ORANGE: Carotene absorbs blue and indigo hues, and that provides rich yellows and oranges to different foods. This pigment is important to our diet, as the human body breaks down each carotene molecule to produce two vitamin A molecules. Apricots, mangoes, nectarines, peaches, papaya, oranges, grapefruit, pineapple, passion fruit, carrots, sweet potatoes, butternut squash, pumpkin, yellow and orange peppers, sweetcorn are some of the many yellow/orange foods commonly found in the world [34].



Figure 4. Yellow coloured fruits and vegetables [33]

Health Benefits of "Orange"

-) Three of the most common carotenoids – alpha-carotene, beta carotene and beta-cryptoxanthin – can be converted from foods into vitamin A in the body.
-) Vitamin A is needed for good vision in dim light, normal growth and development, a strong immune system and to keep the skin and cells that line the airways, digestive tract and urinary tract healthy [35].
-) There's also evidence to suggest that carotenoids – and especially beta carotene, might help to reduce the risk of heart disease and certain cancers, especially lung cancer [36].
-) Citrus fruits and their juices are also packed with the phytochemical hesperidin, (protect against heart disease) and tangeritin (may prevent cancer of the head and neck).
-) It has been found that the zest of yellow citrus fruits is also a good source of limonene, a phytochemical that helps keep lungs healthy [37].

Black

Black / deep purple coloured foods like black beans, black raspberries, and black tea are packed with anthocyanins, the pigment that lends these foods with their dark hues. Black foods have more antioxidants than light-coloured foods because of their high pigment content says Cy Lee (2011) [38].



Figure 5. Black coloured fruits and vegetables [39]

Black is the new super colour, the reasons are

-) It has been observed that black garlic (an aged version of garlic) has twice the antioxidants of regular garlic [40].
-) Squid ink gives black pasta its striking colour. Squid ink has been shown to stop the growth of new blood vessels which is believed to slow the growth of cancer [41].
-) Black sesame seeds are high in calcium and make for a great appetizer.
-) Different types of black forest mushrooms contain a compound that stimulates the immune system and can help prevent premature aging and cancer.
-) Figs are a delicious summer fruit that are very high in fiber, potassium, manganese, and calcium [42].
-) According to a study presented at the American Chemical Society (ACS), one spoonful of black rice bran contains more anthocyanin antioxidants than a spoonful of blueberries. Black rice offers more fiber, vitamin E and less sugar [43].
-) Black rice contains anthocyanin pigments with notable antioxidant and anti-inflammatory properties for potential use in nutraceuticals or functional food formulations [44].

WHITE

A group of pigments called anthoxanthin is responsible for shades of white to yellow in many fruits and vegetables. Anthoxanthin is a phytochemical belonging to the family of antioxidant flavonoid. Cauliflower, garlic, ginger, mushrooms, onion, turnip, potato are commonly found white pigmented vegetables in the market ^[45].



Figure 6 . White coloured fruits and vegetables ^[46]

Beneficial health effects of White

-) Some white vegetables contain potent phytochemicals like allicin in garlic and onion that enhances the effectiveness of anthoxanthin and also helps in lowering blood cholesterol level ^[47].
-) White foods like potatoes and bananas are good sources of potassium needed for nerve and muscle functioning ^[48].
-) Regular consumption of flavonoid-rich white foods reduces the risk of several chronic diseases, including cancer, CVD and neurodegenerative disorders ^[49].
-) Flavonoids exhibit anti-allergenic, antiviral, anti-inflammatory and vasodilating actions ^[50].
-) Flavonoid compounds exhibit lipid-lowering effects and have anti-inflammatory and anti-atherogenic properties ^[51].
-) Eating high levels of flavonoids (anthocyanins) could offer protection from type 2 diabetes by lowering insulin resistance and improving blood glucose regulation ^[52].
-) It has been found that cauliflower and turnips contain rich amounts of compounds known as glucosinolates, which may provide some protection against cancer.
-) White beans are valuable sources of protein and fiber, as well as B-vitamins, potassium and iron ^[53].

Colour extraction, a brief overview: Total anthocyanin pigment content and indices for polymeric colour and browning are easily measured with simple spectrophotometric methods. Once individual pigments are identified, their changes can be monitored by High-Performance Liquid Chromatography (HPLC) ^[54]. Solvent extraction is a conventional method that is usually followed to extract colours from plant materials. Anthocyanin and betalain, the two water-soluble pigments are extracted from raw materials with water and sometimes with aqueous methanol. For carotenoid extraction, hexane is the solvent of choice and acetone is a good choice of solvent for the initial extraction of pigment

from the plant material. The current advanced techniques that are followed in colour extraction are:

- i. High Hydrostatic Pressure (HHP), ii. Pulsed Electric Field (PEF), iii. Sonication-assisted Extraction, iv. Gamma Irradiation, v. Enzymatic Extraction, vi. Membrane Technology ^[37].

CONCLUSION

Scientists have confirmed that plant pigments not only protect plants from external damages, they also have a great impact on human health due to its curative and healing properties. The very first pigment, chlorophyll is a water-insoluble plant pigment that has antioxidant, antimutagenic, anti-cancer and antimicrobial properties. Water-soluble vacuolar pigment anthocyanin is responsible for the blue and purple colouration of fruits and vegetables. It can cure liver injuries, improves eyesight and also can suppress tumor growth. Carotenoids, betalains and anthocyanins responsible for red colouration, possess antioxidant, anticancer and CVD preventing properties. Yellow and orange pigmented carotenoids can be converted into vitamin A, which is essential for growth, immune functioning and eye health.

Anthocyanin and anthoxanthin are respectively responsible for giving black and white colouration to foodstuffs. These plant pigments can be extracted by applying high Hydrostatic Pressure, Pulsed Electric Field, Sonication-assisted Extraction for further commercial purposes. Even though most phytonutrients are officially considered 'non-essential nutrients' and their consumption is not needed for survival but still they are essential for deep-seated good health, wellbeing, immunity – and definitely, longevity.

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