Natural Plants Pigments as Potential Antioxidant Sources and Food Grade Biocolorants in Traditional Cuisines: An Overview Study in Vietnam

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Summary

Due to the possible harm that man-made food dyes may do to human health, natural pigments have gradually taken the place of artificial colorants in Vietnam and the world. The food sector is being forced to move away from the use of artificial colorants and toward organically based alternatives because of rising customer demand for meals that are more nutrient-dense, components that are sourced naturally and with cleaner labeling. With a focus on plant sources, the industry is actively looking for sources of more stable colorants in this situation. 150 surveys were conducted to find the common plant being applied to traditional foods in Vietnam. The survey indicated that a lot of species could be utilized as natural food pigments. However, there are seven colorant plants that are primarily used in traditional Vietnamese cuisine and have their detailed information documented. This review focusses on crops that have a great deal of promise for use as sources of colorants in traditional foods. Some of these sources have received substantial research, while others have only recently attracted interest.

Key words

natural, colorant, antioxidant, food product, utilization

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Introduction

Due to its impact on perception and senses, color is a vital component of life (Sigurdson et al., 2017). Food and beverage color can affect how strongly an odor is detected, the identity of a flavor, how sweet something tastes, as well as the general approval of a product. In order for food products to be attractive to the consumer, the food industry frequently uses food colorants and pigments. However, due to potential health risks, customers have been turning away from foods with artificial colors in recent years. As a result, natural colorants have taken their position in the food industry, so that the use of natural colors in personal care, pharmaceuticals and food is becoming more popular globally. Moreover, the production of natural food colorings has been the focus of much research by the food industry and nutritional specialists. The outcomes demonstrate the numerous advantages of employing natural colorants. Renewable-sourced and natural, food colorings do not present a health risk. The usage of several synthetic colors, such as tartrazine and carmoisine, which are often used in food preparation and have been linked to harmful effects like impaired liver function and oxidative stress, has been questioned. The pursuit of natural pigments has gained tremendous momentum.

Several natural dyes are utilized as both food coloring and as medicines to keep people healthy and happy by fending off illness. The usage of natural colorants also does not impart any harmful qualities (Kumar and Sinha, 2004). Even when they are used extensively in their respective nation of origin, recognizing new sources of pigment as "new" food colorants typically necessitates a thorough assessment of food safety.. All nations have implemented stringent laws limiting the kinds of colors that may be added to food since they are thought to be hazardous but formerly were regarded as preventive measures that are health-related or even harmless. (Kapoor, 2006). Countries with a wide variety of plants, like Vietnam, have a unique chance to capitalize on these emerging consumer demands and the limitations of currently available naturally occurring pigments. In this overview, plants of natural origins that could be used to produce pigment for industrial uses are discussed. This review paper covers the knowledge on colorant plants and their sources that are frequently employed in the culinary tradition of ethnic communities in Vietnam.

Materials and Methods

The study collected real-life random interviews (n = 150) and literature references that were published in national or international journals. A database containing questions about the local knowledge of the use of colorant plants in traditional food culture was compiled through participants' observation and semi-structured interviews. Microsoft Excel was used to process the data using a simple mathematical procedure.

The findings of the survey indicate that there are over 40 species, spread over 30 groups that produce food coloring pigments. Traditional foods are dyed by indigenous people using well-known plants. Ten of the species are used to produce the hues red/orange, yellow and black, among others. Additionally, we noted seven colorant plants frequently ingested in Vietnam out of the potential plants' colorant, according to survey data (Fig. 1).

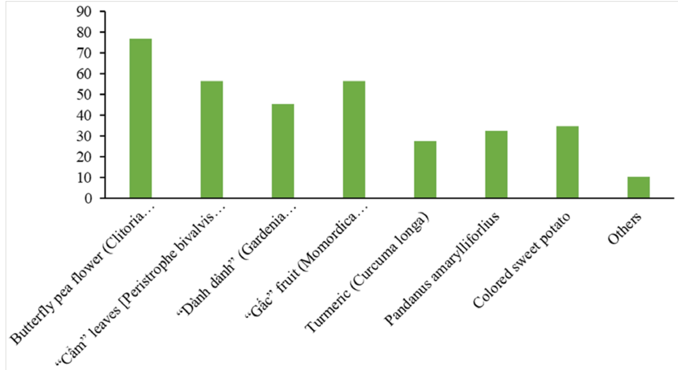

Figure 1. Percentage of colorant plants used in foods (Data was collected from survey)

Potential of antioxidants and recent application of selected plants in traditional food

From the survey, seven selected plants were chosen: butterfly pea flower, "Cẩm" leaves, "Dành dành", "Gấc" fruit, tumeric, panda leaves and colored sweet potato are further explored in this summary.

Butterfly Pea Flower (*Clitoria ternatea* L.)

Butterfly pea, scientifically known as *Clitoria ternatea* L., also known as "đậu biếc" in Vietnam, is native to Maluku archipelago, Indonesia (Jain et al., 2003; Oguis et al., 2019). It grows widely in tropical areas including Southeast Asia (Suebkhampet and Sotthibandhu, 2012). It is a wild plant native to tropical and subtropical regions, found naturally in grasslands, open forests, scrublands and riparian vegetation. Butterfly pea is a perennial creeping or herbaceous plant (Chen et al., 2018) that has recently attracted a great deal of attention due to its potential for applications both in modern medicine and agriculture and as a source of natural food colorings and antioxidants (Oguis et al., 2019). Recently, as a natural blue color product, anthocyanins have been the most abundant compound in this material. The profile of anthocyanin components of butterfly pea flower cultivated at Southern part of Vietnam was recently identified by using Ultra Performance Liquid Chromatography/Ultraviolet Coupled to Mass Spectrometry (Thuy et al., 2021b). Five anthocyanins, including cyanidin 3-(6″-*p*-coumaroyl)-rutinoside, delphinidin 3-(*p*-coumaroyl) glucose in both cis- and trans-isomers, cyanidin 3-(*p*-coumaroyl-glucoside) and delphinidin 3-pyranoside, were found in the butterfly pea flower extract. The extraction method could lead to variations in the antioxidant properities of the extract. The conventional method was applied to extract the butterfly pea flower. Extracts with the highest DPPH antioxidant activity (575.10 mol TE L^{-1}) and FRAP (1093.83 mol TE L^{-1}) were produced after the extraction procedure, which was carried out at temperatures of 60 °C. Butterfly pea extracts with the highest FRAP power were obtained after 120 minutes of extraction. When the influence of extraction time on antioxidant activities of butterfly pea was considered, time range of 30-90 minutes led to the highest DPPH values. The drop in antioxidant activity was also caused by a decreasing solid-to-solvent ratio (Duy et al., 2020). However, another study showed that microwave assisted extraction and ultrasound assisted extraction improved anthocyanin yield of extract by 14.11% and 15.01%, respectively, compared with the tranditional method. Multiple regression analysis was performed to select the optimal parameters by ultrasound assisted extraction (74 °C for 56.88 minutes) with the highest concentration of anthocyanins (39.90 mg/l) in the extract (Thuy et al., 2021a). It can show the potential for application in nutraceutical foods. In addition to the antioxidative function, the butterfly pea flower extract, with its wide range of color based on pH, could be used as a natural colorant in foods. In Vietnam, the butterfly pea flower is applied to a wide range of foods such as steamed sticky rice, bread, noodle and beverage. A recent study by Thuy et al. (2022a) has shown the potential application of butterfly pea flower extract in traditional Vietnamese foods such as thin cakes (bánh bèo), rice ball with sweet soup (chè), fried meat stuffed rice ball, bread and drinking product. The study also showed that the antioxidant value remained within the appropriate amount in the product. The extract could also be processed into powder with high antioxidant activity by the foam-mat drying process (Thuy et al., 2023b), which could further be applied to bread, pasta products and beverage.

"Cẩm" Leaves (*Peristrophe bivalvis* L. Merr.)

"Cẩm" plant belongs to the *Acanthaceae* family. In Vietnam, it has a relatively wide distribution, scattered in most of the northern mountainous provinces such as Lang Son, Tuyen Quang, Ha Giang, Yen Bai, Lao Cai, Lai Chau, Hoa Binh (Thảo et al., 2009). Because it is a plant that is not difficult to grow, it is now widely distributed. According to the "List of Plant Species of Vietnam" (Bân, 2005), the genus *Peristrophe* has 4 species, while red and two types of purple cultivar are grown, but yellow brocade grows wild, so it is called wild "Cẩm". As shown in Table 1, the difference of varieties leads to different appearance and the color of the extract.

"Cẩm" plant is not only a medicinal plant, but also a promising source of natural purple pigments (Thảo et al., 2009). Its leaf extract has been considered as a good source of food coloring agent in Vietnam and some Asian countries (Thuy et al., 2012). In Vietnam, the leaves have long been used as dyes for fabrics, chopsticks, etc. In addition, the purple color extracted from the branches and leaves is completely non-toxic, soluble in water, and adheres to food quickly. Therefore, we can use it to color some foods such as ice cream, candy, soft drinks, colored wine, jelly, sticky rice and pills. Besides that, Thảo et al. (2009) show that purple pigments in "Cẩm" leaves are mainly distributed in leaves and the main chemical components of purple products extracted from mallow are anthocyanins, including substances with two main types of frameworks, perlagonidin and pyranopeonidin. In particular, the climatic and soil conditions in the highlands are very suitable for the growth, development and accumulation of pigments (anthocyanins) in "Cẩm". Hương and Thủy (2015) published that the optimal temperature for extracting pigments from "Cẩm" leaves in water was 85-90 °C. Quan et al. (2016) studied the types of "Cẩm" in the north of Vietnam and determined the total polyphenol content and the total flavonoid content of the 5 types of "Cẩm" water and organic solvent extracts in the north of Vietnam. Tân et al. (2018) studied and showed that pigments from "Cẩm" leaves could be extracted at a temperature of 85 °C for 25 minutes, water/material ratio of 25/1 and pH of 3.5. The extract was supplemented with 15% maltodextrin and evaporated at 80 °C for 60 minutes. The best quality color solution was obtained, with anthocyanin content of 72.022 mg CE 100 g^{-1} DM, total acid (according to citric acid) 0.324 g L^{-1} and total soluble solid content of 58%, brightness (L*) of 38.21, red value (a*) of 7.76, total color difference (ΔE) of 55.27. Cang et al. (2020) studied and optimized the extraction conditions for anthocyanins from the leaves of "Cẩm", showing the optimal conditions for extracting anthocyanins from the leaves at the laboratory scale to be solvent/material ratio of 40/1 (mL g^{-1}), temperature of 43.5 °C, and a time of 63 minutes.

"Dành Dành" (*Gardenia jasminoides* Ellis)

Gardenia fruit is known as a traditional medicine with many uses in prevention and treatment of diseases. This material is also known to contain many valuable biologically active compounds such as the crocin compounds. As a superior natural coloring material, it has excellent water solubility and may provide health benefits due to its strong antioxidant and non-toxic properties (Pham et al., 2000). Accordingly, it has been widely used in East Asian countries to color soft drinks, cakes, sweets, and noodles (Chen et al., 2020). Thuy et al. (2022c) produced the powder from its extract, with natural yellow color and high antioxidant activities. Crocin and its derivatives extracted from gardenia fruits have been identified as having low toxicity, low allergenic potential, and environmentally friendly (Hong et al., 2015). Crocin and crocetin are originally found in the stamens of the saffron (*Crocus sativus* L.) and have many uses, especially for the dye and pharmaceutical industries. They also have pharmacological effects in several conditions such as helping with weight loss, curing physiological disorders and premenstrual syndrome (Hausenblas et al., 2015). Currently, crocins are being studied by many scientists because of their remarkable biological activities.

Table 1. Some characteristics of "Cẩm" varieties cultivated in Vietnam (Thảo et al., 2009)

Name of variety	Appearance	Color of extract
Red "Cẩm" (Chẳm thủ)	Leaves are oval, the base is slender, dark green, hairy, the upper surface is not white	Red
Purple "Cẩm" (Chẳm lai)	Leaves are large ovate, rounded base, light green, thin, hairless, large area bearing white spots along the veins	Purple
Purple "Cẩm" (Chẳm khâu)	Leaves are oval, rounded or tapered, dark green, thick, few hairs, rarely white spots along the veins	Purple
Yellow "Cẩm" (Chẳm hiên)	Leaves are ovate, the base is tapered, the tip is tapered, 2 sides are sparsely hairy, the leaf blade is often wrinkled, especially leaf margin	Yellow-green

In several human and animal studies, crocin and crocetin have been shown to have antioxidant, antihypertensive, anti-atherosclerotic, anti-inflammatory, neuroprotective and positive effects on sleep, reduced physical fatigue, and preventing retinal degeneration (Gao and Zhu, 2013). Thủy and Hiển (2006) investigated the method of extracting crocin from gardenia fruit and the durability of the pigment under different conditions. The carotenoid content was determined according to the description of Kotíková et al. (2011). The crocin content was determined by molecular absorption spectroscopy at 440 nm. The results showed gardenia as a potential source of crocin with a concentration of up to 16.04 mg g^{-1} for fresh ingredients and 14.63 mg g^{-1} for dry ingredients. The crocin extraction efficiency was highest with the solvent system ethanol:water [40:60 or 50:50 (v/v)]. The ratio of solvent:material, extraction conditions for fresh and dry materials, respectively, is 20 mL g^{-1} at 40 °C for 45 minutes; 25 mL g^{-1} at 70 °C for 60 minutes. Crocin is stable at temperatures below 100 °C for 140 minutes. In a different study, the extraction conditions of gardenia fruits were improved. The results showed that at temperatures of 55 °C and at extraction time of 57 min, 24% of the fruits in solvent and 56% ethanol were the optimal conditions for extraction (Thuy et al., 2022c). Besides, crocin is quite stable under weak acid, neutral and alkaline conditions. Vui et al. (2001) conducted a study on acute toxicity of gardenia extract, and the results also showed that at a dose of 6-12 g, it can be used for safe treatment.

A study to evaluate the crocin content and some food safety criteria of the gardenia extract by Lê (2018) has identified crocin as the main coloring ingredient, which accounted for 42.4% by weight of the extract powder. Besides, it consisted of crocin-1 with molecular weight 976 Dalton and crocin-2 with molecular weight 814 Dalton. In addition, the gardenia extract had antioxidant activity with an IC_{50} value of 0.33 g L^{-1} and no toxicity in rats at a high dose of 33.0 g kg^{-1}, but had an increasing effect on fish embryos over time. At a concentration of 4.9 g L^{-1}, the concentration of zebrafish embryos was not malformed at 0.1-1 g L^{-1}. The yellow powder from the extract of the gardenia was soluble in water, resistant to a wide pH range of 1-12, stable to high temperatures up to 100 °C, and able to retain 96% of its color after 12 months of storage at 4 °C. It met the food safety criteria, as target microorganisms (*Pseudomonas*, *E. coli*, Coliforms) were below the allowable lower limit value of 10^1 CFU g^{-1}, and heavy metals (lead, cadmium, arsenic) were not detected.

"Gấc" Fruit [*Momordica cochinchinensis*]

"Gấc"(*Momordica cochinchinensis* Spreng) or Gac is proven to be a safe and popular fruit in some Southeast Asian countries, especially Vietnam. As a native plant of Vietnam and some Asian countries such as Thailand, Cambodia, Laos, Malaysia, China, Japan, it is widely used in cuisine and medicine (Vuong et al., 2006). In Vietnam, "Gấc" tree is quite popular. The red membrane surrounding the seeds is the most used part and accounts for only 25 - 30% of the whole gac fruit. "Gấc" membrane is often used to color food, to create many sticky rice dishes and cakes with attractive red-orange colors or to extract "Gấc" oil (Vuong et al., 2006). According to published scientific studies, the total carotenoid content in "Gấc" fruit ranges from 3768.3 to 7516 μg/g (Thao, 2007). Carotenoids in "Gấc" fruit are compounds with strong antioxidant activity, have anti-aging capabilities, protect eyes, liver and prevent cancer risk (Aoki et al., 2002). β-carotene and lycopene are the two main carotenoids in "Gấc" fruit with very high content. The research has shown that the edible part of "Gấc" fruit contains 2 times the amount of β-carotene in cod liver oil and 10 times that of carrots (Aoki et al., 2002), while the lycopene content in gac membranes is 70 times higher than in tomato. (Vuong et al., 2006). The composition of carotenoids in "Gấc" membranes is quite diverse, including β-carotene, lycopene, zeaxanthin and β-crytoxanthin, but the main and highest contents are β-carotene and lycopene. By high performance liquid chromatography (HPLC) analysis, Vuong et al. (2006) published the content of the main carotenoids in the "Gấc" seed membrane, and compared them with the results from other published literature. In Vietnam, Gac has long been considered a nutritious fruit with many uses. "Gấc" membrane is mixed with a little alcohol, cooked with sticky rice to form "Gấc" sticky rice. In addition, "Gấc" membrane is also used to extract "Gấc" oil and other biologically active substances. Gac seeds contain a lot of oeanodic acid, diterpene columbin and chondrillasterol, which are ingredients with medicinal properties. In medicine, "Gấc" seeds soaked with alcohol are used to treat pain, boils, swelling, trauma, blood stasis and others (Kha et al., 2013).

In addition to the above uses, the oil extracted from the "Gấc" membrane is also used as an additive to create a natural red-orange color, replacing chemical dyes. "Gấc" oil is proven to be safe and has many benefits for health such as: prevention and treatment of cirrhosis, precancerous lesions, treatment of eye diseases such as night blindness and dry eyes. "Gấc" oil also strengthens the immune system and heals infections. "Gấc" fruit is also used in cosmetics and pharmaceutical products such as lipsticks, ointments, functional capsules, etc. "Gấc" products in Vietnam are not diverse and not widely available to the people. Some products such as bottled "Gấc" oil, "Gấc" oil capsules, "Gấc" powder and especially "Gấc" juice were initially trusted and used by people of Vietnam (Kha et al., 2014). "Gấc" juice products on the market today contain gac membranes as the main ingredient without any added ingredients.

Turmeric (*Curcuma longa* L.)

A highly useful medicinal herb known as turmeric is used frequently in cooking and for several different medical conditions. Studies on the nutritional value of turmeric have revealed the presence of many beneficial compounds with a wide range of beneficial medicinal properties, such as anti-inflammatory, antidiabetic, hepatoprotective, neuroprotective, chemoprotective, anticancer, anti-allergic and antidermatophytic effects (Salehi et al., 2019). Furthermore, numerous studies have demonstrated the efficacy of turmeric in the treatment of a variety of conditions, including sinusitis, anorexia, coryza, rheumatism, biliary and hepatic problems, diabetic wounds, inflammation, cough (Nasri et al., 2014; Salehi et al., 2019). Due to these advantageous characteristics, turmeric is widely grown throughout Vietnam in areas like Lao Cai, Lang Son, Vinh Phuc, Hung Yen, Nghe An, and the Central Highlands, where it is a crop with significant economic value to farmers. It is essential to design and implement comprehensive plant-pathogen management techniques, including the control of plant-parasitic nematodes, in order to accomplish the sustainable development of turmeric in these areas (Luc et al., 2005). *Meloidogyne incognita* and *Rotylenchus reniformis* are two nematode species that have been linked to turmeric across the globe (Luc et al., 2005), and they are both well-known for their extensive distribution and ability to seriously harm turmeric crops. To the best of our knowledge, Vietnam has only conducted a relatively small number of studies on the infections linked to turmeric. This is particularly true for worms that parasitize plants. The only available research on the topic is *M. incognita* and *M. javanica* reports in Vietnamese turmeric (Nguyen et al., 2020).

Because of the advantages turmeric possesses in the production of food colorants, the interest in it has grown significantly over time (Aggarwal et al., 2003). Although it is frequently used in households as a yellow-flavored hot food, processing sweet meals with it is prohibited due to its unique flavor. Human health can be enhanced and protected by including turmeric in the diet regularly (Nishiyama et al., 2005). The primary coloring agent, curcumin, is extracted from the plant's zhizomes and utilized in place of synthetic colours in the food processing industry. According to Khurana and Ho (1988), the three main colorants that make turmeric yellow are curcumin, bisdemethoxycurcumin and demethoxycurcumin. Yellow curcumin is used as a food preservative and is highly valuable in the production of pharmaceuticals. Additionally, it has generated anti-microbial proofs (Egan et al., 2004; Dai et al., 2022).

Pandan (*Pandanus amarylliforlius* Roxb.)

Pandan leaves ("Lá dứa") represent a very familiar ingredient, widely used in recipes to enhance flavor and create a beautiful color (Bhattacharjee et al., 2005). Pandan leaves also have many effects such as antipyretic, aiding digestion and detoxification of the body (Ooi et al., 2004). More importantly, quite a few studies have proven that pandan leaf extract has good antioxidant, antibacterial and antiviral properties, because the pandan leaf extract contains many important biological compounds such as tannins, alkaloids (Pandamarilactone-1, Pandamarilactonine-A-B-C, Pandamarine, Pandanamine), flavonoids and polyphenols (Ooi et al., 2004; Aini and Mardiyaningsih, 2016). The extraction efficiency of biological and antioxidant components present in pandan plant is influenced by extraction methods such as extraction temperature, extraction time, and especially the type of extraction solvent (Goli et al., 2005; Vuong et al., 2013). According to Al-Alwani et al. (2017), pandan plant may be a source of naturally occurring green pigment. Quercetin and other chemical components were found, which supported the existence of antioxidant properties (Miean and Mohamed, 2001; Nor et al., 2008). According to Wissgott and Bortlik (1996), *P. amaryllifolius* is a valuable source for making green pigments used in food processing.

Colored Sweet Potato (*Solanum tuberosum* L.)

The nightshade family's starchy, tuberous crop known as the sweet potato (*Solanum tuberosum*) comes in a variety of sizes, hues, and shapes. Sweet potato was first domesticated in South America, several thousand years ago. A wide range of wild species found in the Andes of Peru and Bolivia were brought into cultivation as a staple diet (Hawkes, 1992).

It is now grown in more than 100 nations and is the fourth-most significant crop in the world after rice, wheat and maize (Hawkes, 1992). Sweet potato is a delicious food with high nutritional value but also known for its diverse medicinal properties (polyphenols, anthocyanins, fiber, etc.). The medicinal properties of sweet potatoes include anticancer, antidiabetic, anti-inflammatory, antioxidant, antibacterial, antifungal, antiviral, hepatoprotective, wound healing and regulatory activities of immunity (Pham et al., 2019). Sweet potatoes are used for beverages, dough and alcoholic beverages and they act as a natural colorant (Thi Lan Khanh et al., 2018; Pham et al., 2019). Sweet potatoes can also be boiled, steamed, baked, fried, candied, canned, frozen, powdered and starched or processed into several other products (Phan et al., 2018; Thi Lan Khanh et al., 2018; Van Toan and Anh, 2018; Thuy et al., 2020; Thuy et al., 2022b; Thuy et al., 2023a). Many compounds present in sweet potatoes are important because they have health benefits. In addition, antioxidant compounds and antifree radical intermediates have been found in sweet potatoes to prevent degenerative processes or support the treatment of diseases such as cancer, heart disease and Alzheimer's disease (Thi Lan Khanh et al., 2018).

Conclusion and future direction

Although over forty species of colorant plants are edible, seven species are widely used in traditional Vietnamese cuisine and research on the pharmacological and bioactive qualities of their key bioactive components and extracts has been reported. Market trends suggest that natural colorants will remain popular, but their safety as well as the remaining color during processing and storage should be further considered. Even though artificial substitutes will continue to be an alluring option, the industry will continue to look for alternatives due to consumer demands for clean labels and healthier meals. The diversity of Vietnamese plant life offers exciting new potential to the food and cosmetic industries due to the availability of a wide range of colorant components. Further research is necessary to fully understand the behavior and potential of the pigments extracted from these interesting plants.

CRediT Authorship Contribution Statement

Le Thi Kim Loan: drafted the manuscript and collected the information. **Vo Thi Ngoc Tran**: drafted the manuscript and collected the information. **Vo Quang Minh:** contributed to the editing of the manuscript. **Nguyen Minh Thuy:** contributed to the editing of the manuscript and mainly supervised this work. **Ngo Van Tai:** drafted the manuscript, collected the information and co-supervised this work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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