"BETACYANIN: A COMPREHENSIVE REVIEW ON OCCURRENCE, EXTRACTION TECHNIQUES, STABILITY, AND PHARMACOLOGICAL ACTIVITIES"

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Abstract

This review paper provides an in-depth investigation of betacyanins, nitrogenous vacuolar pigments found in various plant species, with a primary focus on the Chenopodiaceae family, including red beetroot (Beta vulgaris rubra) and Swiss chard (Beta vulgaris circle).This study explores the diverse bioactive substances in red beetroot, such as betalains, and their potential health benefits.The study delves into the classification of betacyanins, their solubility, stability under different conditions, and various extraction techniques, including UV-Visible spectroscopy and high-performance liquid chromatography.Furthermore, the study discusses the natural sources of betacyanins, including red dragon fruit (Hylocereus polyrhizus), cactus fruit (Opuntia elatior Mill.), and Celosia Argentina var. cristata.The botanical classification and biosynthetic pathways of Amaranthus betacyanins are also explored.The pharmacological activities of betacyanins, such as their antioxidant, antimicrobial, anticancer, and anti-inflammatory properties, were thoroughly examined.The potential benefits of betacyanins over synthetic dyes in various applications, including the food and pharmaceutical industries, are highlighted.Overall, this comprehensive review consolidates existing knowledge on betacyanins, offering valuable insights into their extraction, sources, and diverse pharmacological activities, paving the way for future research and applications in different fields.

Index Terms - Betacyanin, Beta vulgaris L., Chenopodiaceae Family , inflorescence Celosia , High-Performance Liquid Chromatography (HPLC), Hepatoprotective Properties , Natural Colorants .

I. Introduction

The Chenopodiaceae family includes Swiss chard (Beta vulgaris cicla, BVc) and red beetroot (Beta vulgaris rubra, BVr) [1]. A variety of bioactive substances found in red beetroot, such as betalains, ascorbic acid, flavonoids, carotenoids, polyphenols, saponins, and high nitrate levels, can have positive impacts on health [2]. One of the major vegetables, beetroot (Beta vulgaris L.), has a notable concentration of nutritive and bioactive substances. A subset of them are called natural pigments, or betalians, from which B. vulgaris root preparations contain 300–600 mg/kg betanin [3].A group of 13 families of plants contain betalains, which are nitrogenous vacuolar pigments that also accumulate in certain Basidiomycetes [4].Various plant organs contain betalains, which mostly accumulate in cell vacuoles in epidermal and subepidermal tissues [5].Betalains are phytochemicals that were recently categorized as antioxidants [6]. They have long been recognized as acceptable colorants for food and other industrial applications.Natural betalains have therapeutic qualities that help prevent disease in addition to being used as food coloring additives, pharmaceuticals, and cosmetics [7].When stored at 4°C and in the pH range of 4-6, betalains exhibit maximum stability. Therefore, these pigments may be used as food coloring agents in meals with a short shelf life, dairy products that are chilled, and frozen foods [8]. Water-soluble betalains are the secondary metabolites of Caryophyllales that are derived from ammonium derivatives of betalamic acid. They are classified into two groups: Yellow betaxanthin pigments and reddish-violet betacyanin pigments [9].Subgroups of betacyanins, including betanin-, gomphrenin-, amaranthin-, and bougainville- type pigments, can be further subdivided [10].

Red beet (Betavulgaris) betacyanins, which have been widely marketed as food colorings, are the most researched betacyanins [11].Yellow betaxan-thins and violet betacyanins are produced when betalamic acid spontaneously condenses with amines and/or their derivatives and with cyclo-DOPA or its glucosyl derivatives [12].A class of chromoalkaloids includes betaxanthins, or yellow pigments, and betacyanins, or reddish-violet pigments, referred to as betalains [13]. The secondary metabolite of the Caryophyllales genus, betalains are water-soluble chemicals derived from ammonium derivatives of betalamic acid.The most abundant betacyanin is called betanin (betanidin 5-O-β-D-glucoside), and it is the only pigment that the US Food and Drug Administration (FDA) has approved for use as a natural colorant in food goods [14].There are four types of betacyanins: 2-descarboxybetanin, gomphrenin, amaranthine, and

betanin [15]. Regardless of the solvent used, beetroot pulps, peels, and juice had the highest concentration of betalain compared with leaves and stems. The maximum amount of betalain (0.81 mg/g) was extracted from Peel using methanol (II) OEM as opposed to (I) IEM (methanol 0.39 mg/g) [16].

Solubility- A class of water-soluble pigments called betacyanins is responsible for the color found in a large range of fruits and flowers [17].Common polar solvents such as water, ethanol, and methanol, as well as their combinations, readily dissolve bethaneins [18].However, unlike anthocyanins, betacyanins can be added to foods with low acidity because they are less vulnerable to hydrolytic cleavage. This allows them to remain visible throughout a wide pH range, from 3 to 7, with pH ranges of 5-7 being optimal for their stability [19].

Stability- pH, temperature, oxygen content, light intensity, and water activity all had a significant impact on the stability of betacyanins from red beet and A. tricolor [20].

II. TECHNIQUES FOR BETACYANIN EXTRACTION

Generally, UV-Visible spectroscopy and high-performance liquid chromatography have been used to determine the betalain analysis of the sample.Whereas betaxanthins absorb at kma´x = 480 nm, betacyanins absorb at approximately Kma´x = 540 nm [21]. Using particular buffer solutions as the reference, the Beckman Model-25 spectrophotometer was used to measure the visible spectra of amaranthine in solution at different pH levels.[22]. UV-Vis. A Jasco U-530 UV-vis spectrophotometer was used to measure the total betacyanin concentration and UV-vis absorption spectrum in the 200–700 nm range [23].Column chromatography on highly acid Exchange resin was used to isolate the acylated betacyanins, which were then separated by chromatography on polyamide powder. Similar to the methods outlined for amaranthin and betanin [24].

HIGH-PERFORMANCE LIQUID CHROMATOGRAPHY (HPLC)

All LC separations were performed at room temperature. Double-distilled water was used to prepare buffers, and precise-grade reagents and solvents were used [25]. High-performance liquid chromatography (HPLC), as outlined by Schwartz and von Elbe (1980), was used to assess the betacyanin content of each sample [26]. An HPLC system with an L-7200 auto sampler, a D-7000 interface module, an L-7100 pump, an L-7350 column oven with a Peltier cooling module, and an L-7450A diode-array detector was used to analyze all samples [27].At a constant temperature of 25—C and a flow rate of 1 mL/min, the optimal separation of anthocyanins and betalains was achieved on an insightful scale (250 × 3 mm i.d.) using a LUNA C18(2)-reversed phase column with a particle size of 5 lm (Phenomenex, Torrance, CA) fitted with a security guard C18 ODS (4 · 3.0 mm i.d.) [28].A UV-visible 490 variable wavelength detector, a U6K injector with a 20 p, L injector loop, two 510 A and B pumps, a 680 solvent programmer, and a Hitachi D 2000 computing integrator comprised the detailed equipment (Waters Associates) [29].The compounds were separated using a Gemini C18 3 µm 50 × 0.5 mm column (Phenomenex, Torrance, CA, USA) at 45 °C and a flow rate of 25 µL/min, following the injection of aliquots (5µL) of sample solutions into HPLC systems [30].Two solutions were used in the gradient of elution for HPLC, which used a C18 reversed-phase column with a particle size of 5 µm. Whereas solution B includes 100% acetonitrile, solution A comprises 100% water and 0.1% (v/v) TFA [31].1% formic acid in water that has been double-distilled. A consistent flow rate of 0.5 mL/min was maintained with an injection volume of 10 µL. Typically, detection was carried out at λ = 538 nm using a diode array detection (DAD) device at 505, 480, and 310 nm with a UV-Vis detector. A constant 35 °C was maintained in the column.[32].The solvents were (A) water/acetonitrile/glacial acetic acid/phosphoric acid, 50:48.5:1.0:0.5 (v/v/v/v), and (B) 0.5% aqueous phosphoric acid (v/v). % B, start, 20%; 26 min, 60%; 30 min, 20; 35 min, 20% (run time 35 min) was the solvent gradient [33].

III. NATURAL SOURCES OF BETACYANIN

In terms of color, betacyanins and anthocyanins are extremely comparable, whereas betacyanins have a greater ability to color [34].Betanin-type betacyanins are the most prevalent form and are mostly found in red beetroot (Beta vulgaris L.) and the Cactaceae family (e.g., Hylocereus polyrhizus and Opuntiaficus-indica L.), whereas amaranthin- and gomphrenin-type betacyanins are also present. The primary betacyanins in the Amaranthaceae family, such as those found in Gomphrenaglobosa L. and Amaranthustricolor L., are betacyanins [35].Within the betacyanin category, amaranthin - I was derived from Amaranthus tricolor, betanin from Beta vulgaris, and gomphrenin- I from Gomphrena globosa.(36) Taxanthines, which provide yellowish hues, and betacyanin compounds, which give reddish-violet colors [37]. In a number of places, including the southern United States, Mexico, Bolivia, Ecuador, and Argentina, amaranthus pigments have been used to color bread, beverages, and other delicacies [38].Thus, yogurt, sherbert, ice cream, frozen fruit desserts, sweets, frostings, puddings, bacon, sausage, drinks, and canned fruit are among the possible uses. The use of amaranthus pigments in food applications has not received much attention in the literature [39].There are few sources of crops, such as fruits, vegetables, and flowers, that contain betacyanin [40].Beta vulgaris, a herbaceous biennial crop in the Chenopodiaceae family, is more often known as beetroot [41].Against nine strains of Gram-positive bacteria, the betacyanin fraction from red spinach (minimum inhibitory concentration [MIC] values: 0.78–3.13 mg/mL) showed a stronger antibacterial activity profile than that of red pitahaya (MIC values: 3.13–6.25 mg/mL) [42].

In the food and pharmaceutical industries, natural red pigments derived from plants are increasingly sought after as alternatives to synthetic red dyes [43].The botanical classification, uses, and biosynthetic pathways of Amaranthus betacyanins were examined in early research conducted in the 1960s and 1970s [44].

RED DRAGON FRUIT (HYLOCEREUS POLYRHIYUS)

A member of the Cactaceae family, dragon fruit belongs to the genera Hylocereus and Selenicereus. The Cactaceae family's Selenicereus genus is the basis for the classification of dragon fruit. The following is the classification of dragon fruit [45].

Division	Spermatohyta [45]
Class	Dicotyledonae [45]
Order	Caryophyllales [46]
Family	Cactaceae [46]
Sub family	Cactoidea [46]
Genus	Hylocereus [46]
Species	Hylocereus polyrhizus [46]

Table no.1 Red dragon fruit (Hylocereus polyrhiyus)

This plant was first domesticated in Mexico and Central America, but it is currently farmed extensively in Taiwan, Vietnam, and Malaysia. Generally speaking, Malaysia is home to two varieties of dragon fruit: Hylocereus Undatus, which has pink skin and white flesh, and Hylocereus Polyrhizus, which has pink skin and red flesh [47].The crop has a 20-year lifespan, begins to bear fruit two years after planting, and stabilizes its yield in three to five years [48].

Fig.1 Red dragon fruit (Hylocereus polyrhiyus)

Numerous health benefits of red pitaya have been reported, such as cancer chemoprevention, anti-inflammatory and antidiabetic effects, a lower risk of cardiovascular disease mortality, and antioxidative qualities due to the presence of betacyanin [49]. A betacyanin found in red dragon fruit other than betanin is called isobetanin [50].One reddish-violet pigment found in red-fleshed dragon fruit is betacyanin. A class of molecules with radical scavenging and antioxidant properties are betalachins, which are linked to N-heterocyclic compounds. In many tropical and subtropical nations, betalacyanin improves fruit value and makes it a viable substitute crop for betacyanin [51].The pigment betacyanin is accountable for giving the fruit its reddish-purple hue [52].

BEETROOT (BETA VULGARIS L.)

The family Chenopodiaceae includes beetroot (Beta vulgaris L.), which has its origins in both Asia and Europe [53] . There are various types of beetroot, which range in bulk color from yellow to red, and it is a blooming plant that is either a genuine biennial or a rare perennial. B. vulgaris ssp. Maritima, B. vulgaris ssp. Vulgaris, B. vulgaris ssp. Adanensis, B. macrocarpa, B. macrocarpa Guss., B. patula, B. patula Ait., B. intermedia, B. intermedia Bunge, B. macrorhiza, B. macrorhiza Stev., B. trygina, B. corolliflora, B. corolliflora Zoss., B. Patellaris, B. patellaris Moq., B. procumbens, B. procumbens B. transzschel, B. lomatogona F., B. trigyna W., Chr. Sm., B. webbiana, B. Webbiana Moq. and B. nana Boiss [54].

Fig.2 Beetroot (Beta vulgaris L.)

The vegetable red beetroot is high in oil, carbs, vitamins, and components that have bioactive qualities. Among the bioactive components include betaine, water-soluble pigments called betalains, polyphenols, carotenoids, and flavonoid saponins [55]. Typically eaten as a side dish, red beetroot is one of the healthiest foods. Apart from its antioxidant qualities, red beetroot also possesses anti-inflammatory and detoxification characteristics. Owing to its many biological properties, the plant may be able to avert serious health issues including heart disease [56].Plants belonging to the genus Beta produce betalains, which are secondary metabolites, in addition to sucrose, primary metabolites, and other organic acids and vitamins. [57].Most of the phenolic chemicals are found in the outermost sections of the red beetroot's (Beta vulgaris) root. Peel, crown, and meat had the lowest levels of betanin (I) and total phenolic content among the different root sections [58]. Red betacyanins and yellow betaxanthins are the two primary categories of bettalains, which are excellent water-soluble nitrogenous pigments that may be extracted from beet root [59].Yellow betaxanthins and reddish-violet betacyanins are the two main types. Approximately 74.95% of beetroot's content is made up of betacyanins, whereas only 25.25% is betaxanthin. Betacyanins, specifically betanin and its isomerisoetarin, make up almost 80% of the pigments found in red beetroot [60].

INFLORESCENCE CELOSIA

Celosia Argentina var. cristata, often known as common cockscomb, is a herbaceous plant that belongs to the Amaranthaceae family.This annual plant has an inflorescence that, when fully formed, resembles the crest of a rooster or a convoluted brain [61].Two varieties of flowers are found in Celosia: the plume-type Celosia plumosa and the cockscomb-type Celosia Cristata [62].Celosia cristata is an annual herbaceous dicotyledon plant that is both decorative and therapeutic . It grows to a height of 5-2 feet. This plant is a member of the Magnoliopsid class and has bisexual flowers with pink or white, oblanceolate, curving, and crowded ovate bracteoles in terminal, elongated spikes measuring 2.5–15 2–2.5 cm. On top of the stems and branches, there is a cylindraceous or trophoformis inflorescence. [63,64].

Fig.3 Inflorescence Celosia

Under the Amaranthaceae (Caryophyllales) family, the genus Celosia of plants has about sixty species that are endemic to Africa, South America, and Southeast Asia's temperate and subtropical zones [65]. In some parts of the world like Africa, China, Indonesia, India, and other parts of Asia, its leaves and inflorescences are eaten as vegetables [66]. It has been observed that the genus Celosia exhibits hepatoprotective properties. In a prior chemical analysis, flavones, steroids, and saponins were identified in C. cristata; the latter two demonstrated hepatoprotective properties [67]. In China and other nations, seedlings, young leaves, and inflorescences are consumed as vegetables; in traditional Chinese medicine, dried leaves, inflorescences, and seeds are also utilized [68] .The seeds have been applied for a variety of conditions, including diarrhea, bleeding, dysentery, coughing, impaired vision, eye inflammation, strong light sensitivity, headaches, intestinal worms, and uncomfortable urination [69]. The dried red flowers are useful in treating osteoporosis, hemoptysis, hemorrhoid hemorrhage, leucorrhea, severe menstrual bleeding, and hematuria [70]. Betalains are found exclusively in plants belonging to the order Caryophyllales (formerly known as Centrospermae). This group contains the Amaranthaceae family, which comprises numerous significant genera, including Amaranthus and Celosia cristata, as well as the Nyctaginaceae family, which includes Bougainvillea spectabilis. Various parts of plants belonging to the Amaranthaceae family, such as stems, leaves, and inflorescences, have produced the isolation and identification of many betalians (16 red-violet betacyanins and 3 yellow betaxanthins[71].The existence of 2-descarboxy-betanidin was assessed through the extraction of betacyanins found in trace amounts in the yellow inflorescences of C. cristata and co-injection with a hairy root extract from yellow beets [72].

CACTUS FRUIT (OPUNTIA ELATIOR MILL.)

Approximately 200–300 species of xerophytic plants belong to the Opuntia subfamily of the Cactaceae family [74]. The cactus is known by several colloquial names in India, including Hathlo Thor and Chorhthlo (Gujarati); Haththathoira, Nagphana, and Nagphani (Hindi); Snuhi, Vajrakantaka, and Bahushala (Sanskrit); Nagadali and Nagakkali (Tamil); and Nagamulla and Nagajemudu (Telugu) [75].It became naturally occurring in a number of regions across the globe, such as the Middle East, South Africa, Australia, India, and the Mediterranean basin.This species' edible fruit, the prickly pear, is also grown in South Africa, the Mediterranean region, and South America [76].In terms of morphology, Opuntia elatior Mill reaches a height of 3 m or more and is a subarborescent or shrubby shrub with small, caduceus, and subulate leaves. It is a prickly shrub with fleshy stems that are articulated and flattened [77].

Kingdom	Plantae
Division	Magnoliophyta (Angiosperms)
Class	Magnoliopsida (Dicotyledons)
Sub-class	Archichlamydeae
Order	Caryophyllales (cactales)
Family	Cactaceae
Subfamily	Opuntiodeae
Tribe	Opuntieae
Genus	Opuntia
Species	Elatior Mill

Table no.2 Cactus fruit (Opuntia elatior Mill.) [73]

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IV. PHARMACOLOGICAL ACTIVITIES OF BETACYANIN

Potential sources of free radicals in nature include plants. According to epidemiological research, eating a diet rich in fruits and vegetables can help prevent a number of chronic diseases linked to aging, including cancer, heart disease, cataracts, immune system malfunction, and brain disorders [85] .Because betacyanin have a number of pharmacological properties that are significant for human health, including antioxidant, anticancer, antilipidemic, and antibacterial properties, more research has been done on them recently [86].

ANTIOXIDANT ACTIVITY

Natural antioxidants can be obtained from plants, and some species are important because they can be used to produce raw materials or preparations that include photochemicals that have strong antioxidant properties and health benefits [87]. Betalains biochemical characteristics have led to intriguing health possibilities in recent years.Many studies have shown that betalains are very active antioxidants in a variety of plants, including Celosia, pitahaya, prickly pears, beetroot, and garambullo [88].The chemoprotective properties of food colorings such betalains help the body balance its oxidants and antioxidants and fight oxidative stress [89].The antioxidant activity of betacyanins is often increased by acylation and decreased by glycosylation. If a hydroxyl group is present at the aglycone's C-5 position, betalains' antioxidant activity is boosted [90].

ANTIMICROBIAL ACTIVITY

One significant issue facing the food processing sector is microbial contamination. Food deterioration can jeopardize food safety by increasing the risk of foodborne illnesses and have a negative impact on food quality by causing waste and financial losses [91].Antimicrobial action against Staphylococcus aureus, Bacillus cereus, and Salmonella Typhimurium was established by betalains derived from beetroot pomace. At quantities less than or equal to 500 µg/mL, it was also observed that the red pitahaya's betacyanin fraction demonstrated a good antibacterial spectrum against molds, yeasts, and Gram-positive and Gram-negative bacteria. In this study, extracts and betacyanin fractions from the edible sections of red pitahaya and red spinach were tested for their ability to inhibit 16 human disease-causing bacterial species. Higher antibacterial activity is indicated by lower MIC values [92]. Strains of microorganisms were employed to evaluate antibacterial activity. The test bacterial cultures were placed in Müller-Hinton agar at 37°C for 20–24 hours before being moved to Müller-Hinton broth [93]. This review includes studies that looked at how betalains affected a range of microorganisms, including the multidrug-resistant and extremely virulent ESKAPE pathogens (Enterococcus spp., Pseudomonas aeruginosa, Acinetobacter baumannii, Staphylococcus aureus, and Enterobacter spp.).Biofilm-forming, Gram-positive, and Gram-negative bacteria, as well as fungi and the dengue virus, were all shown to exhibit antimicrobial action in in vitro testing employing betalains from different sources [94].

ANTICANCER ACTIVITY

The process by which a normal cell changes into a cancerous type is known as carcinogenesis [95]. Utilizing the MTT colorimetric test, the inhibitory effect of natural colors on cancer cell proliferation was assessed for each recovered pigment [96]. The use of beetroot products or its constituents as dietary supplements in cancer prevention has garnered significant attention recently due to its anticancer characteristics [97].Numerous research have been done to examine the potential anticancer effects of red beet extract betalains on human tumor cell lines, including those from the breast, lung, kidney, stomach, prostate, and colon. When beetroot betalains are applied to colon cancer cells, they cause apoptosis and decrease cell proliferation without harming healthy cells [98]. The original nutritional betacyanin, bethanin, promotes death in K562 human myeloid leukemia cells, faintly demonstrates epigenome-regulated gene expression in MCF-7 breast cancer cells, and effectively suppresses tumor cell development in the stomach, breast, lung, colon, and central nervous system.However, more research is needed to determine betaxanthins' possible proliferative, chemopreventive, and epigenetic effects [99].

ANTI-INFLAMMATORY ACTIVITY

When the immune system recognizes that something is bad, such a pathogen, damaged cells, poisonous chemicals, or radiation, it releases inflammation, which starts the healing process and eliminates the harmful stimulus [100]. Anti-inflammatory medication can stop early neoplastic growth and malignant conversion because inflammatory cells create a milieu that is conducive to tumor development, which explains why many malignancies arise at sites of inflammation. An inhibitory effect on cyclooxygenase (COX) enzymes is extremely desirable, as COXs convert arachidonic acid to prostaglandins, which in turn induce inflammation [101]. Reddy and colleagues conducted a study which shown that betanin inhibited 97% of the enzyme activity in cyclooxygenase-2 (COX-2). This suppression was on par with or even higher than that of numerous phenolic compounds and a number of anti-inflammatory medications, including Vioxx, Celebrex, and Ibuprofen [102].Furthermore, it has been demonstrated that betalains shield vascular endothelium cells from cytokine-induced redox state modification, a direct target of oxidative stress in inflammation [103].Extracts from beetroot and betalains have shown promise as powerful anti-inflammatory drugs. Their anti-inflammatory actions, which are summed up in, seem to be mediated in part by disrupting pro-inflammatory signaling cascades. The most significant of them is the nuclear factor-kappa B (NF-κB) cascade, which directly activates and transcribes the majority of gene targets (cytokines, chemokines, apoptotic and phagocytic cells) that control and magnify the inflammatory response [104].

V. BENEFITS OF BETACYNIN OVER SYNTHETICS DYES

Human health may be at risk from certain artificial food colorings made from minerals. As alternatives to synthetic colorants, natural colorants and plant-based sources are gaining popularity among food producers and consumers.The higher cost and lower stability of natural food coloring have drawn criticism [105].There is a growing trend in food technology to substitute safe synthetic food colorants with natural plant extracts that include betacyanin pigments [106]. It has been extensively utilized as a natural coloring agent in food, cosmetics, paintings, and ornamental arts. It has also been used as a medication to treat common ailments of the blood, heart, liver, pancreas, digestive system, and nervous system [107]. As a natural colorant, it is also extensively utilized in a variety of dairy goods, candies, beverages, and cattle products, including cooked, smoked, semi-dry, or fermented sausages [108]. Examples of these products include milk, ice creams, yogurt, and kefir.As an antioxidant, it scavenges and neutralizes the harmful oxidative chemicals that are present in our bodies [109].In comparison to red pitahaya (MIC values: 3.13–6.25 mg/mL), the betacyanin fraction from red spinach (MIC values: 0.78–3.13 mg/mL) showed a superior antibacterial activity profile against nine Gram-positive bacterial strains [100].One potential mechanism of betacyanin fractions' anti-biofilm effect against S. aureus and P. aeruginosa is their ability to inhibit the growth of biofilms on red spinach and pitahaya [111].

VI. CONCLUSION

In conclusion, this review provides a comprehensive overview of betacyanins, focusing on their presence in various plant sources such as beetroot, dragon fruit, celosia, and cactus fruit. Betacyanins, specifically betanin, have been extensively studied for their bioactive properties, including antioxidant, antimicrobial, anticancer, and anti-inflammatory activities.The stability and solubility of betacyanins under different conditions, such as pH and temperature, are highlighted, emphasizing their potential applications as natural colorants in the food industry.This study also delves into the various techniques employed for betacyanin extraction, including UV-Vis spectroscopy and high-performance liquid chromatography.The pharmacological activities of betacyanins, particularly their role as antioxidants and their potential benefits for human health, are discussed.Overall, the diverse sources and multifaceted properties of betacyanins make them promising candidates for various applications, from food coloring to potential therapeutic agents.

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