PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(2): 1-8
https://doi.org/10.14719/pst.8125

HORIZON
e-Publishing Group
HePG

REVIEW ARTICLE

Edible floral pigments: Exploring flowers as natural biocolourants for food applications

Sumera Shaik[1], R Chitra[1*], M Ganga[1], A Ramalakshmi[2], P Meenakshi[3] & P Geetha[4]

[1]Department of Floriculture and Landscaping, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Department of Food Process Engineering, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[3]Department of Renewable Energy, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[4]Centre for Post Harvest Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: chitra.varadharaj@gmail.com

OPEN ACCESS

ARTICLE HISTORY
Received: 07 March 2025
Accepted: 25 March 2025
Available online
Version 1.0 : 14 April 2025
Version 2.0 : 23 April 2025

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Sumera S, Chitra R, Ganga M, Ramalakshmi A, Meenakshi P, Geetha P. Edible floral pigments: Exploring flowers as natural biocolourants for food applications. Plant Science Today. 2025; 12(2): 1-8. https://doi.org/10.14719/pst.8125

Abstract

Celebrated for their aesthetic appeal, ornamental flowers are rich sources of vibrant pigments with potential applications beyond visual enhancement. This review explores the extraction and characterization of these natural pigments, emphasizing their viability as eco-friendly alternatives to synthetic colorants in the food industry. With increasing consumer preference for clean-label and sustainable ingredients, natural pigments derived from flowers present an attractive option for food coloration. Their application extends to improving the visual appeal of food products, replacing artificial dyes and supporting the growing demand for plant-based and naturally derived formulations. The study highlights the functional properties of floral pigments, their stability under various processing conditions and their potential role in enhancing both the nutritional and sensory attributes of a food. Furthermore, as sustainability remains a key focus in modern food production, ornamental flowers emerge as a valuable and renewable source of natural colorants. Their integration into food systems aligns with the industry's shift toward environmentally responsible and health-conscious innovations. This review underscores the promising role of floral pigments in shaping the future of food colouring, offering an innovative approach that meets regulatory, environmental and consumer-driven requirements. By leveraging these botanical resources, the food industry can advance toward safer, more sustainable and visually appealing product formulations, reinforcing the ongoing transition to greener and healthier alternatives.

Keywords

bio colourants; extraction; food products; ornamental flowers; pigments

Introduction

Colour plays a vital role in psychological and cultural significance, shaping human perception, emotions and daily experiences (1) colours function as powerful communicators like red symbolizes power and love, blue conveys trust and peace, green signifies growth and white represents purity (2). Throughout history, colours have been integral to industries such as food, textiles, medicine and cosmetics (3). The discovery of synthetic dyes, beginning with William Henry Perkin's "mauve" in 1856, marked a transition from natural sources. However, growing concerns over the toxicological effects of synthetic dyes have fueled interest in safer and eco-friendly alternatives. Bio-derived colours, extracted from plants, algae, insects, fungi and animals, are gaining popularity in food, cosmetics and pharmaceuticals as sustainable and health-conscious options (4). Among natural sources, horticultural crops serve as valuable reservoirs of bio-pigments, widely utilized for commercial colour extraction. Flowers, in particular, offer a diverse palette of pigments that align with the increasing demand for sustainable and biodegradable colourants. This review explores the potential of floral pigments in industrial applications, emphasizing their role in promoting environmentally responsible coloration practices.

Natural pigments

A natural food colour, or "bio colour," is any dye or pigment derived from natural sources (5). Colour has been an essential part of food for centuries, with records of its use dating back to ancient times. Early Egyptians coloured candy and wine was tinted as early as 400 BC. Traditional colorants like saffron and turmeric have a long history, with butter being coloured yellow as far back as 1300 BC. The Romans used saffron and spices for vibrant yellow hues (6) while natural sources like parsley, pomegranates and beets added colour to food. Biocolourants, such as henna, date back to 2500 BC and saffron is even mentioned in the Bible. Japan's Nara period also records natural colouring in foods like soybean cakes. Various plant-based pigments contribute to a wide spectrum of colours, including chlorophyll (green), carotenoids (orange, yellow, red), anthocyanins (red, purple, blue), flavonoids (yellow, orange, pink) and phycobilins (blue, red, purple) (Fig. 1). Edible flowers are abundant in various phenolic compounds that possess antioxidant properties, helping to combat free radical damage. These components all have potential bioactive properties. These compounds demonstrate beneficial effects, including antimicrobial, antiviral antioxidant, anticarcinogenic and enzyme induction properties (7). These pigments can be extracted from flowers (Fig. 2), stem, leaves and even roots of the plants (Table 1). These pigments play a crucial role in food formulation, providing both aesthetic and functional advantages, aligning with the growing demand for natural, health-conscious and sustainable food ingredients (8).

Basic extraction procedure of pigments

The process of pigment extraction consists of three key stages: pre-extraction, extraction and post-extraction, each involving crucial unit operations (Fig. 3). The pre-extraction phase begins with drying, which removes water to extend the sample's shelf life and inhibit microbial growths. During extraction, the dried sample is combined with a solvent, often under conditions such as applied pressure, heat, or ultrasonic energy to enhance efficiency. Filtration follows, separating the pigment-rich solution from solid residues, typically using filter paper. Lastly, the solvent is eliminated through evaporation commonly via a rotary evaporator while carefully controlling temperature to preserve pigment quality. The extracted pigments have applications in the food, cosmetic and pharmaceutical industries.

Common solvents

Plant pigments are usually extracted using solvents such as methanol, water, or ethanol, which facilitate the transfer of pigments from plant cells into the solvent. The efficiency of the process is influenced by factors like solubility and diffusivity, which help shorten extraction time. Many studies have pointed out the common use of polar solvents like ethanol, methanol and acidified water, which can include various inorganic and organic acids.

Deep eutectic solvents

Deep eutectic solvents (DESs) have gained considerable interest for their ability to extract bioactive compounds, including pigments from flowers and fruits (9). These solvents are formed by combining two or more components typically a hydrogen bond acceptor (Choline chloride, Lactic acid, Ascorbic acid) and a hydrogen bond donor (Urea, Glucose, Acetic acid, Ethylene glycol) to create a eutectic mixture with a lower melting point than the individual components. DESs are biodegradable, non-toxic and environmentally friendly, making them a sustainable alternative to conventional organic solvents. When used to extract pigments such as anthocyanins, flavonoids and carotenoids from natural sources, DESs demonstrate superior solubilizing capabilities, leading to higher extraction yields (10). Their adjustable properties, including viscosity and polarity, can be tailored by modifying their composition, enabling the selective extraction of specific pigments. Additionally, DESs operate under milder conditions, such as lower temperatures and

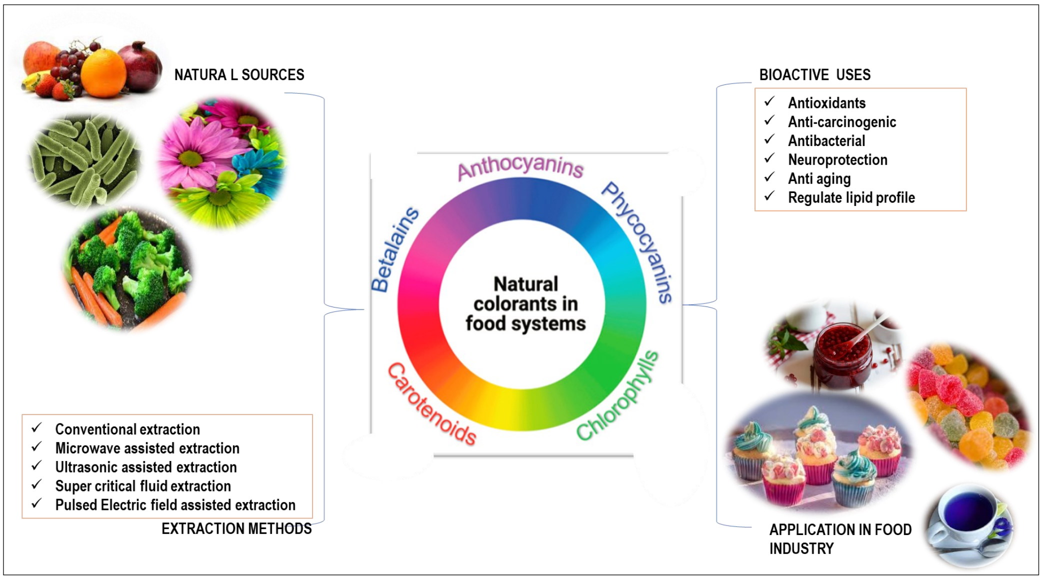

Fig. 1. Natural pigments and their bioactive uses.

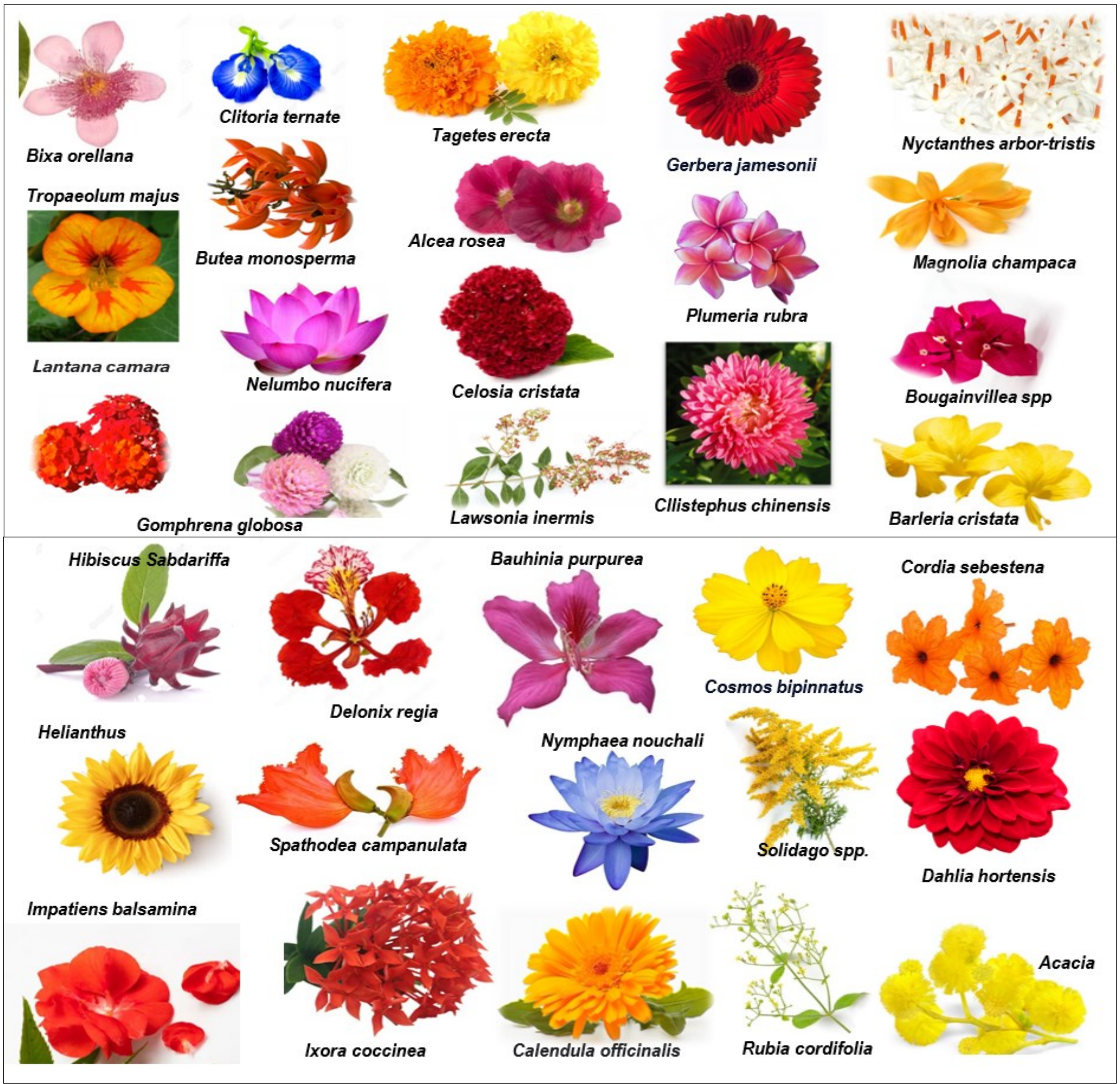

Fig. 2. Ornamental flowers as source of pigment extraction.

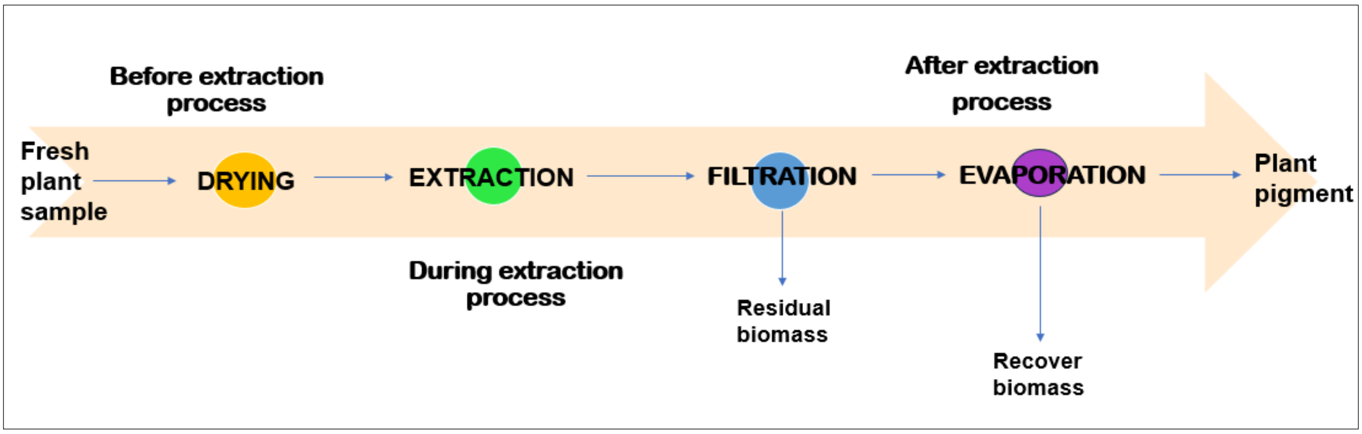

Fig. 3. Basic procedure for extraction of pigments.

pressures, compared to traditional solvents, helping to maintain the bioactivity and stability of the extracted compounds. The adoption of DESs in pigment extraction not only minimizes environmental impact but also aligns with green chemistry principles, making them a promising solution for industries seeking natural colorants in food, pharmaceuticals and cosmetics.

Methods of pigment extraction

Conventional extraction: Conventional extraction methods, including traditional techniques that use distilled water and solvent extraction, represent historical practices in the field. Research has shown that methanol, used alone, was significantly more effective, extracting 20 % to 73 % more anthocyanins than other solvents. Traditional extraction methods like percolation, maceration and reflux extraction often require large amounts of organic solvents and can be time-consuming. Other Suitable operating methods include Microwave-Aided Extraction, ultrasonic-assisted extraction, supercritical fluid extraction and Pulsed Electric Field extraction (Table 2).

Microwave-Aided Extraction : Microwave-aided extraction has been developed to assess anthocyanins, allowing for the simultaneous processing of multiple samples. This method enables monitoring of anthocyanin content during ripening with fewer samples and shorter processing times (11). When designing extraction procedures, factors such as microwave power, temperature, sample size and solvent volume must also be considered, as understanding these elements can optimize extraction efficiency. MAE offers several advantages over traditional methods like solid-liquid extraction and supercritical fluid extraction, including greater effectiveness, reduced solvent use and higher quality yields at lower costs (12). Recent studies have expanded the application of MAE to extract various natural products, including ginseng saponins, artemisinin (13) and anthocyanins (14), highlighting its versatility in natural product extraction. Five anthocyanins were isolated from the Iris flower (cyanidin, delphinidin, petunidin, malvidin and pelargonidin)

Ultrasonic-Assisted Extraction: A study on the bioactive components in herbal extracts using ultrasonic-assisted extraction (UAE) revealed significant improvements in extractive values for various herbs. For fennel, marigold and mint, UAE enhanced extraction values compared to traditional methods with water and ethanol, showing increases of 34 %, 18 %, 2 % and 34 %, respectively (6). UAE presents significant advantages over traditional heating methods in terms of time efficiency, extraction yield and enables the recycling of by-products through biorefining, resulting in high-quality, safe products (3). UAE has gained recognition as a viable industrial technique especially for heat-sensitive bioactive compounds, since UAE operates at lower temperatures. Additionally, the mechanical properties of ultrasound improve solvent penetration into cellular materials, facilitating cell wall breakdown and enhancing the release of their contents.

Supercritical Fluid Extraction : The use of supercritical technology with carbon dioxide (CO_2) near its critical point as a solvent for extracting compounds like carotenoids has emerged as a viable alternative for the food and pharmaceutical industries. This method eliminates toxic waste, removes the need for additional processing to eliminate solvents from extracts and prevents thermal degradation of the extracted compounds. In an SFE study of rose fruit (Rosa canina), carotenoid extraction was optimized at pressures ranging from 15 to 45 MPa, temperatures from 40 to 80 °C and a CO_2 flow rate of 2 to 4 mL/min (15). The main carotenoids identified in the extracts included lycopene (1.18-14.37 mg/g), β-carotene (0.154-1.017 mg/g) and lutein (1.26-16.84 mg/g). A separate study on the solubility of lycopene and astaxanthin in supercritical CO_2, as a function of temperature (40 to 60 °C) and pressure (10 to 42 MPa), found that both carotenoids exhibited higher solubility with increased pressure and temperature (16).

Pulsed Electric Field Extraction: Pulsed Electric Fields (PEF) is a non-thermal, eco-friendly technique commonly used for treating biological tissues and biomaterials. In food systems, PEF technology is employed to recover phytochemical compounds from plant matrices, inactivate microbes and enzymes, facilitate dehydration and freezing, concentrate bioactive compounds and enhance the physicochemical, rheological and structural properties of food products. The use of PEF in extraction processes has been widely researched due to its ability to induce electroporation, which improves the mass transfer of intracellular components from the plant matrix, leading to more efficient extraction of valuable compounds (17). The electric field treatment disrupts the bilipid cell membrane, increasing permeability and promoting better contact between the solvent and the desired intracellular components. This results in higher extraction yields, as more targeted compounds are effectively extracted from the plant material (18). When extracting colour compounds, it's crucial to preserve their chemical and physical stability using gentler process conditions. PEF offer a gentler extraction process that helps maintain the integrity of colouring compounds (19).

Flower derived colourants in the food sector

Common flower-derived bio colourants include anthocyanins from hibiscus, elderberry and purple corn, which impart red, purple and blue colours used in beverages, jams, confectionery and dairy products (20) (Fig. 4). Additionally, beta cyanins and betaxanthins are utilized in juices, soups and sauces, while carotenoids from marigold, saffron and calendula are found in bakery products and snacks. Flavonoids from chamomile, acacia and pansies serve as natural colorants in teas and desserts, while phycobilins and anthoxanthins enhance beverages and dairy products, respectively. Single-layered clitoria blue flowers possess high anthocyanin used as for making the tea and blue rice compared to double layered flowers (21). Hibiscus petals are mostly used for preparation of tea, squash and jam (22).

Tannins from roses are also used in teas, wines and confections. Research has explored the dual benefits of adding iron as a fortifier and Roselle calyces extract as an antioxidant in pizzas. The study found that pizzas enriched with Roselle extract had higher iron concentrations, ranging from 1.05 to 1.97 mg g^{-1}, compared to the control (23). This indicates a potential for nutritional enhancement alongside antioxidant properties. Hibiscus petals, rich in antioxidants, flavonoids and phenols, were used to create Hibiscus squash. The nutritional qualities of the squash were analyzed analyzed over 90 days, assessing properties like total soluble solids (TSS), pH, acidity and antioxidant activity. In another study, noni beverages, including ready-to-serve (RTS) juice and squash, were evaluated for sensory acceptability, with the RTS containing 10 % juice and 14 % brix being particularly favored (24). The use of flower derived bio colourants in the food industry resonates well with consumer preferences for clean labels and natural ingredients. These natural pigments not only provide appealing colours but also bring potential health benefits associated with the bioactive compounds found in flowers. Notably, anthocyanins are recognized for their health-promoting properties, which can enhance the overall quality of food products and facilitate the development of innovative natural offerings with greater market appeal (25).

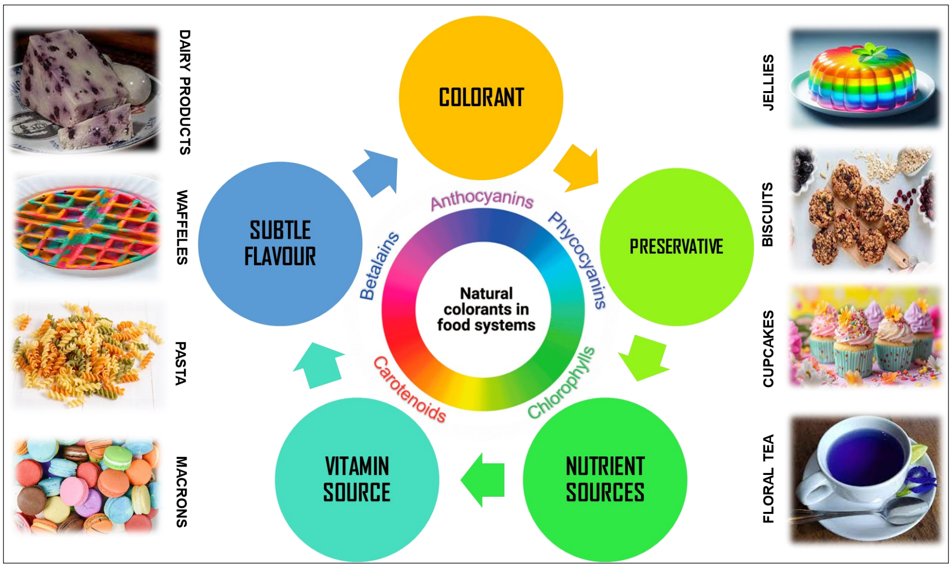

Fig. 4. Natural colourants used in food.

Table 1. Natural pigments present in various ornamentals and their health benefits

Name of the flowering plants & colour	Main pigment	Health benefits	References
Tagetes erecta (Yellow)	Lutein	Antioxidant Antibacterial agent	(26)
Calendula Officinalis (Yellow)	Carotenoids	Vitamin A Inhibit cancer cells Protect against sun burns	
Bixaorellana (Yellow)	Carotenoids	Vitamin A Inhibit cancer cells Protect against sun burns	(27)
Nyctanthes arbortristis (Yellow)	Carotenoids	Protect neural retina	
Tropaeolum majus (Yellow)	Carotenoids	Vitamin A Inhibit cancer cells Protect against sun burns	
Lantana camara (Yellow)	Anthocyanin	Antioxidant Avoid cardio diseases, antiviral	
Hibiscus rosasinensis (Red)	Anthocyanin		
Gerbera jamesonii (Red)	Anthocyanin	Bactericidal Protect against free radicals Avoid heart diseases Anti carcinogen	(28)
Ixora coccinea (Red)	Anthocyanin		
Nelumbo nucifera (Reddish Brown)	Proanthocyanidins	Avoid heart diseases Anti carcinogen	
Plumeria rubra (Yellow)	Quercetin	Antiviral	(29)
Lawsonia inermis (Yellow)	Quinonoid		
Butea monosperma (Yellow)	Isobitrin	Anti -depressant	(30)
Clitoria ternate (Blue)	Delphinidin		(31)
Indigofera tinctoria (Blue)	Indigotine		
Cllistephus chinensis (Pink)	Flavonoids	Decrease risk of cancer	
Magnolia champaca (Yellow)	Flavonoids		
Celosia cristata (Brown)	Betacyanins	Antioxidant and anti-inflammatory	(32)
Gomphrena globose (Purple)	Betacyanins		

Table 2. Suitable operating parameters to extract bio colourants

Pigment	Location in plant	Extraction method	Operational parameters	Advantages & disadvantages	References
Chlorophylls (Green)	Plastids	Super critical fluid extraction	Temperature: 40 °C Pressure: 250 bar Solvent: CO_2 with 7.7 % (v/v) ethanol Flow rate: 2 g/min Time: 240 min	Operating temperatures can be controlled Pure product can be obtained	(33)
		Solvent extraction	Temperature: Room temperature Solvent: 90 % ethanol Solvent volume: 50 mL Time: 120 min		(34)
			Temperature: 50 °C Solvent: 80 % ethanol Solvent to sample ratio (mL/g): 200:1 Time: 30 min	It is not labour extensive Low-cost input	(35)
Anthocyanins (Red, Blue, Purple, Magenta, Violet)	Epidermal cells of petals Vacuoles	Solvent extraction	Temperature: 80 °C Solvent: Methanol Solvent volume: 200 mL Time: 300 min	Require more solvent Simple procedures to use	(36)
			Temperature: 80 °C Solvent: Ethanol Solvent volume: 200 mL Time: 300 min		(37)
Betalains (Red, Purple, Blue)	Vacuoles	Microwave assisted extraction	Solvent: 50 % (v/v) ethanol with 0.04-M ascorbic acid Solvent to sample ratio (mL/g): 250:1 Microwave power: 400 W Time: 3.50 min	Higher efficiency Require less time than conventional methods	(38)
		Solvent extraction	Temperature: 30 °C Solvent: McIlvaine buffer at pH 3.5 Solvent volume: 400 mL Time: 300 min	Solvents are easily available Long extraction time	(39)
Carotenoids (Yellow, Red, Orange)	Plastids	Super critical fluid extraction	Temperature: 40 °C Pressure: 505 bar Solvent: CO_2 Flow rate:600-750 mL/min Time: 60 min	No organic solvent is required It is non- destructive process	(40)
		Pulse electrified fluid extraction	Temperature: 60 °C Pressure: 300 bar Solvent: CO_2 Flow rate: 4.5 mmol/min Time: 180 min	High extraction efficiency Simple extraction protocol	(41)
		Microwave assisted extraction	Temperature: 58 °C Solvent: mixed solvent (50 % v/v hexane, 25 % v/v acetone, 25 % v/v ethanol) Solvent volume: 75 mL, Microwave power: 180 W Time: 3 min	Simple instrumentation Takes shorter time for extraction	(42)
Flavonoids (Pale yellow, Red, Blue, Purple)	In all tissues	Solvent extraction	Temperature: Room temperature Solvent: 90 % ethanol Solvent volume: 50 ml Time: 120 min	Economical Easy to operate	(43)
		Ultrasonic assisted extraction	Temperature: 70 °C Solvent: 50 % (v/v) ethanol Solvent to sample ratio (mL/g): 4.5:1 Time: 60 min	Useful for both industrial and laboratory scale Low consumption of solvent High initial cost	(44)

Conclusion

Integrating flower-derived pigments into industries promotes safer, eco-friendly colour solutions that meet consumer and regulatory demands. Extracting colours from flowers merges scientific innovation with sustainability and industry needs. Success in this field depends on interdisciplinary collaboration and a holistic approach. Advancing research and technology will maximize the potentials of flower-based natural colourants. This shift promises a more sustainable and aesthetically rich future.

Acknowledgements

I would like to express my sincere gratitude to my chairperson Dr. R Chitra and my Advisory Committee Dr. M Ganga, Dr. A Ramalakshmi, Dr. P Meenakshi and Dr. P Geetha for their invaluable guidance and support throughout this research. I am deeply indebted to them for suggesting the topic and providing technical expertise that greatly enhanced the quality of this work. Their meticulous review and correction of the manuscript have been instrumental in shaping the final version of this article. The Department of Floriculture and Landscape Architecture is acknowledged for providing the necessary financial resources required for the work. We would like to thank Farm manager Dr. S Karthikeyan for providing necessary field resources. While Dr. S Thamaraiselvi for her expertise in our research.

Authors' contributions

SS collected and analyzed the literature, data and draft manuscript. RC reviewed and corrected the manuscript, while MG, AR, PM and PG provided valuable technical aspects and suggestions to enhance the manuscript's quality. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Bashir I, Pandey VK, Dar AH, Dash KK, Shams R, Mir SA, et al. Exploring sources, 184 extraction techniques and food applications: a review on biocolors as next-generation colorants. Phytochemistry Reviews. 2024:1-26. https://doi.org/10.1007/s11101-023-09908-6
2. Gogoi M, Hazarika B, Gogoi N. Flower-An incredible source of natural dye. 2019. https://doi.org/10.5958/2394-4471.2019.00014.5
3. Al-Dhabi NA, Ponmurugan K, Jeganathan PM. Development and validation of ultrasound- assisted solid-liquid extraction of phenolic compounds from waste spent coffee grounds. Ultrasonics Sonochemistry. 2017;34:206-13. https://doi.org/10.1016/j.ultsonch.2016.05.005
4. Singh T, Pandey VK, Dash KK, Zanwar S, Singh R. Natural bio-colorant and pigments: Sources and applications in food processing. Journal of Agriculture and Food Research. 2023; 12:100628. https://doi.org/10.1016/j.jafr.2023.100628
5. Chaitanya Lakshmi G. Food coloring: the natural way. Res J Chem Sci. 2014;2231(8):606X.
6. Chitra R. Effect of organic inputs on growth and herbage yield of Japanese mint (*Mentha arvensis*). 2023. https://doi.org/10.29321/MAJ.10.200727
7. Thamaraiselvi S, Karthikeyan S, Ganga M, Visalakshi M, Fernandaz CC, Sivakumar V, et al. Effects of drying and storage on anthocyanin content and antioxidant activity in hibiscus tea infusions. Journal of Advances in Biology & Biotechnology. 2025;28(1):748-58. https://doi.org/10.9734/jabb/2025/v28i11930
8. Mejía JJ, Sierra LJ, Ceballos JG, Martínez JR, Stashenko EE. Color, antioxidant capacity and flavonoid composition in *Hibiscus rosa-sinensis* cultivars. Molecules. 2023;28(4):1779. https://doi.org/10.3390/molecules28041779
9. Długosz O, Banach M. Green methods for obtaining deep eutectic solvents (DES). Journal of Cleaner Production. 2024; 434:139914. https://doi.org/10.1016/j.jclepro.2023.139914
10. Smith EL, Abbott AP, Ryder KS. Deep eutectic solvents (DESs) and their applications. Chemical Reviews. 2014;114(21):11060-82.
11. Liazid A, Guerrero R, Cantos E, Palma M, Barroso C. Microwave assisted extraction of anthocyanins from grape skins. Food chemistry. 2011;124(3):1238-43. https://doi.org/10.1016/j.foodchem.2010.07.053
12. Zheng X, Xu X, Liu C, Sun Y, Lin Z, Liu H. Extraction characteristics and optimal parameters of anthocyanin from blueberry powder under microwave-assisted extraction conditions. Separation and Purification Technology. 2013;104:17-25. https://doi.org/10.1016/j.seppur.2012.11.011
13. Hao J-y, Han W, Xue B-y, Deng X. Microwave-assisted extraction of artemisinin from *Artemisia annua* L. Separation and Purification Technology. 2002;28(3):191-6. https://doi.org/10.1016/S1383-5866(02)00043-6
14. Sun Y, Liao X, Wang Z, Hu X, Chen F. Optimization of microwave-assisted extraction of anthocyanins in red raspberries and identification of anthocyanin of extracts using high-performance liquid chromatography–mass spectrometry. European Food Research and Technology. 2007; 225:511-23. https://doi.org/10.1007/s00217-006-0447-1
15. Machado APDF, Pereira ALD, Barbero GF, Martínez J. Recovery of anthocyanins from residues of *Rubus fruticosus, Vaccinium myrtillus* and *Eugenia brasiliensis* by ultrasound assisted extraction, pressurized liquid extraction and their combination. Food Chemistry. 2017;231:1-10. https://doi.org/10.1016/j.foodchem.2017.03.060
16. Minjares-Fuentes R, Femenia A, Garau M, Meza-Velázquez J, Simal S, Rosselló C. Ultrasound-assisted extraction of pectins from grape pomace using citric acid: A response surface methodology approach. Carbohydrate polymers. 2014;106:179-89. https://doi.org/10.1016/j.carbpol.2014.02.013
17. Ferreira LF, Minuzzi NM, Rodrigues RF, Pauletto R, Rodrigues E, Emanuelli T, et al. Citric acid water-based solution for blueberry bagasse anthocyanins recovery: Optimization and comparisons with microwave-assisted extraction (MAE). Lwt. 2020; 133:110064. https://doi.org/10.1016/j.lwt.2020.110064
18. Andiku C, Shimelis H, Shayanowako AI, Gangashetty PI, Manyasa E. Genetic diversity analysis of East African sorghum (*Sorghum bicolor* [L.] Moench) germplasm collections for agronomic and nutritional quality traits. Heliyon. 2022;8(6).
19. Kale R, Sawate A, Kshirsagar R, Patil B, Mane R. Studies on evaluation of physical and chemical composition of beetroot (*Beta vulgaris* L.). International Journal of Chemical Studies. 2018;6(2):2977-9.
20. Wrolstad RE, Culver CA. Alternatives to those artificial FD&C food colorants. Annual Review of Food Science and Technology. 2012;3(1):59-77. https://doi.org/10.1146/annurev-food-022811-101118
21. Hujjatusnaini N, Marshanda UT, Nirmalasari R. Morphological

characteristics and evaluating bioactive compound extracts of *Isotoma longiflora* and *Clitoria ternatea* plants from central Kalimantan as therapeutic agents. Journal Agronomi Tanaman Tropika (Juatika). 2025;7(1):199–208. https://doi.org/10.36378/juatika.v7i1.3990

22. Pieracci Y, Pistelli L, Lari M, Iannone M, Marianelli A, Ascrizzi R, et al. *Hibiscus rosa-sinensis* as flavoring agent for alcoholic beverages. Applied Sciences. 2021;11(21):9864. https://doi.org/10.3390/app11219864

23. Daramola B, Asunni O. Nutrient composition and storage studies on roselle extract enriched deep-fat-fried snack food. African Journal of Biotechnology. 2006;5(19):1803.

24. Srivastava A, Rao LJM, Shivanandappa T. A novel cytoprotective antioxidant: 4-Hydroxyisophthalic acid. Food chemistry. 2012;132 (4):1959-65. https://doi.org/10.1016/j.foodchem.2011.12.032

25. Quan W, He W, Lu M, Yuan B, Zeng M, Gao D, et al. Anthocyanin composition and storage degradation kinetics of anthocyanins-based natural food colourant from purple-fleshed sweet potato. International Journal of Food Science & Technology. 2019;54 (8):2529-39. https://doi.org/10.1111/ijfs.14163

26. Razz SA. Comprehensive overview of microalgae-derived carotenoids and their applications in diverse industries. Algal Research. 2024:103422. https://doi.org/10.1016/j.algal.2024.103422

27. Samira O, Laila B, Moussa NA, Mohamed I, Devkota K, Abdelhakim B, et al. Recent advances in the extraction of bioactive compounds from plant matrices and their use as potential antioxidants for vegetable oils enrichment. Journal of Food Composition and Analysis. 2024:105995. https://doi.org/10.1016/j.jfca.2024.105995

28. Simionescu N, Petrovici AR. Enhancing the antioxidant potential of *Weissella confusa* PP29 probiotic media through incorporation of *Hibiscus sabdariffa* L. anthocyanin extract. Antioxidants. 2024;13(2):165. https://doi.org/10.3390/antiox13020165

29. Roy AV, Chan M, Banadyga L, He S, Zhu W, Chrétien M, et al. Quercetin inhibits SARS-CoV-2 infection and prevents syncytium formation by cells co-expressing the viral spike protein and human ACE2. Virology Journal. 2024;21(1):29. https://doi.org/10.1186/s12985-024-02299-w

30. van der Most MA, Bakker W, Wesseling S, van den Brink NW. Toxicokinetics of the antidepressant fluoxetine and its active metabolite norfluoxetine in *Caenorhabditis elegans* and their comparative potency. Environmental Science & Technology. 2024;58(7):3129-40.

31. Khairnar SJ, Ahire ED, Jagtap MR, Surana KR, Kshirsagar SJ, Keservani RK. Management and prevention of diseases by flavonoids. Advances in Flavonoids for Human Health and Prevention of Diseases: Apple Academic Press; 2024. p. 47-71.

32. Nirmal NP, Medhe S, Dahal M, Koirala P, Nirmal S, Al-Asmari F, et al. Betalains protect various body organs through antioxidant and anti-inflammatory pathways. Food Science and Human Wellness. 2024;13(3):1109-17. https://doi.org/10.26599/FSHW.2022.9250093

33. Guedes AC, Gião MS, Matias AA, Nunes AV, Pintado ME, Duarte CM, et al. Supercritical fluid extraction of carotenoids and chlorophylls a, b and c, from a wild strain of *Scenedesmus obliquus* for use in food processing. Journal of Food Engineering. 2013;116(2):478-82. https://doi.org/10.1016/j.jfoodeng.2012.12.015

34. Dahmoune F, Spigno G, Moussi K, Remini H, Cherbal A, Madani K. *Pistacia lentiscus* leaves as a source of phenolic compounds: Microwave-assisted extraction optimized and compared with ultrasound-assisted and conventional solvent extraction. Industrial Crops and Products. 2014;61:31-40. https://doi.org/10.1016/j.indcrop.2014.06.035

35. Paraíso CM, Dos Santos SS, Correa VG, Magon T, Peralta RM, Visentainer JV, et al. Ultrasound assisted extraction of hibiscus (*Hibiscus sabdariffa* L.) bioactive compounds for application as potential functional ingredient. Journal of Food Science and Technology. 2019;56:4667-77. https://doi.org/10.1007/s13197-019-03919-y

36. Vardanega R, Santos DT, Meireles MAA. Intensification of bioactive compounds extraction from medicinal plants using ultrasonic irradiation. Pharmacognosy reviews. 2014;8(16):88. https://doi.org/10.4103/0973-7847.134231

37. Cardoso-Ugarte G, Sosa-Morales M, Ballard T, Liceaga A, San Martín-González M. Microwave-assisted extraction of betalains from red beet (*Beta vulgaris*). LWT-Food Science and Technology. 2014;59(1):276-82. https://doi.org/10.1016/j.lwt.2014.05.025

38. Khan MI. Plant betalains: Safety, antioxidant activity, clinical efficacy and bioavailability. Comprehensive Reviews in Food Science and Food Safety. 2016;15(2):316-30. https://doi.org/10.1111/1541-4337.12185

39. Pazmiño-Durán EA, Giusti MM, Wrolstad RE, Glória MBA. Anthocyanins from Oxalis triangularis as potential food colorants. Food Chemistry. 2001;75(2):211-6. https://doi.org/10.1016/S0308-8146(01)00201-1

40. El-Raey MA, Ibrahim GE, Eldahshan OA. Lycopene and Lutein; A review for their Chemistry and Medicinal Uses. Journal of Pharmacognosy and Phytochemistry. 2013;2(1):245-54.

41. Tsibezov VV, Bashmakov YK, Pristenskiy DV, Zigangirova NA, Kostina LV, Chalyk NE, et al. Generation and application of monoclonal antibody against lycopene. Monoclonal Antibodies in Immunodiagnosis and Immunotherapy. 2017;36(2):62-7. https://doi.org/10.1089/mab.2016.0046

42. Dabiri M, Salimi S, Ghassempour A, Rassouli A, Talebi M. Optimization of microwave-assisted extraction for alizarin and purpurin in Rubiaceae plants and its comparison with conventional extraction methods. Journal of Separation Science. 2005;28(4):387-96. https://doi.org/10.1002/jssc.200400041

43. Mustafa A, Trevino LM, Turner C. Pressurized hot ethanol extraction of carotenoids from carrot by-products. Molecules. 2012;17(2):1809-18. https://doi.org/10.3390/molecules17021809

44. Kizil N, Basaran E, Yola ML, Soylak M. Deep eutectic solvent dispersive liquid–liquid microextraction methods for the analysis of chlorophyll natural colorant (E140) via microwave assisted sample preparation. Microchemical Journal. 2024;(1);196. https://doi.org/10.1016/j.microc.2023.109577