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Recent advances in extraction and stabilization of natural food colorants

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Abstract
Natural food colorants are gaining increasing importance in the modern food industry because of growing consumer awareness regarding food safety, health, sustainability, and clean-label products. Natural pigments obtained from fruits, vegetables, flowers, algae, microorganisms, and other biological sources provide alternatives to synthetic food colours. However, their industrial application is often limited by poor stability against light, temperature, oxygen, pH variations, and processing conditions. Recent advances in extraction technologies, encapsulation, nanotechnology, fermentation, and innovative stabilization methods have created new opportunities for improving the quality and functionality of natural food colorants. Technologies such as ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction, and supercritical fluid extraction can improve pigment recovery and reduce the use of conventional solvents. Encapsulation techniques, including spray drying, freeze drying, liposomal delivery, and biopolymer-based systems, can protect pigments from environmental degradation. This article examines recent developments in the extraction and stabilization of natural food colorants, their applications, challenges, and future possibilities. It also presents illustrative tables to analyse technological developments, pigment stability, extraction methods, and consumer perceptions. The study adopts a descriptive and analytical methodology based on secondary literature and illustrative data. The article highlights the importance of sustainable extraction, improved pigment stability, regulatory compliance, and technological innovation in developing safe and commercially viable natural food colouring systems. Natural food colorants have gained increasing attention in the food industry due to growing consumer demand for clean-label products, health-oriented foods, and environmentally sustainable processing methods. These colorants are derived from natural sources such as fruits, vegetables, flowers, algae, and microorganisms, and include anthocyanins, carotenoids, betalains, chlorophylls, and curcumin. Recent advances in extraction technologies, including ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction, and enzyme-assisted extraction, have improved pigment recovery, reduced solvent consumption, and enhanced processing efficiency. However, the application of natural food colorants remains challenging because of their sensitivity to light, temperature, oxygen, pH, and other environmental factors. Innovative stabilization techniques, such as microencapsulation, nanoencapsulation, emulsification, liposomal delivery, and co-pigmentation, have been developed to improve pigment stability, shelf life, and bioavailability. Encapsulation using biopolymers, including maltodextrin, gum arabic, proteins, and polysaccharides, provides protection against degradation during food processing and storage. Emerging green extraction approaches emphasize the use of environmentally friendly solvents, including water and natural deep eutectic solvents, while reducing waste generation. This article examines recent developments in the extraction and stabilization of natural food colorants, focusing on technological innovations, functional properties, industrial applications, and existing challenges. The integration of advanced extraction methods with effective stabilization strategies offers significant potential for producing safe, attractive, sustainable, and high-quality food products. Continued research is necessary to improve cost-effectiveness, regulatory compliance, scalability, and long-term pigment stability for wider commercial applications.

Keywords: Natural Food Colorants, Pigment Extraction, Stabilization, Encapsulation, Food Technology

1. Introduction

Natural food colorants play an important role in the food processing industry by improving the visual appearance, acceptability, and market value of food products. Colour is one of the first sensory characteristics that consumers observe when selecting food. Traditionally, synthetic colourants have been widely used because of their strong colouring capacity, relatively low cost, and stability under specific processing conditions. However, concerns about consumer preferences, environmental sustainability, and the safety assess

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ment of food additives have increased interest in colourants derived from natural sources. Natural pigments such as anthocyanins, carotenoids, betalains, chlorophylls, and curcuminoids are obtained from plant materials, algae, microorganisms, and agricultural by-products. These compounds have different chemical structures and functional properties. Anthocyanins are commonly found in berries, purple vegetables, and coloured flowers. Carotenoids occur in sources such as carrots, tomatoes, and marigolds. Betalains are present in beetroot and selected plant species, while chlorophylls are responsible for the green colour of many plants. Curcuminoids are obtained primarily from turmeric. Despite their potential, natural colourants frequently experience degradation during food processing and storage. Temperature, oxygen, ultraviolet radiation, moisture, and pH can influence pigment stability and colour intensity. Consequently, researchers have developed advanced extraction and stabilization methods to improve pigment recovery, protect sensitive compounds, and increase their suitability for food applications. Modern approaches increasingly focus on green extraction, reduced solvent consumption, waste valorisation, and delivery systems that enhance pigment performance. The development of efficient extraction and stabilization technologies is relevant to sustainable food production and the advancement of functional food ingredients. By combining biotechnology, food chemistry, nanoscience, and process engineering, researchers are attempting to overcome the limitations of conventional natural pigment applications. Natural food colorants have gained increasing attention in the modern food industry because of growing consumer demand for safe, sustainable, and naturally derived food ingredients. Unlike synthetic colourants, natural pigments are obtained from plant, animal, algal, and microbial sources, including fruits, vegetables, flowers, spices, and agricultural by-products. Important natural pigments such as anthocyanins, carotenoids, betalains, chlorophylls, and curcuminoids provide diverse colours and may offer additional biological benefits. However, their application in food products is often limited by poor stability against light, temperature, oxygen, pH variations, and storage conditions. Recent advances in extraction and stabilization technologies aim to overcome these challenges and improve the efficiency, quality, and commercial usability of natural food colorants. Modern extraction techniques, including ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction, and supercritical fluid extraction, can improve pigment recovery while reducing solvent consumption and processing time. Similarly, stabilization approaches such as microencapsulation, nanoencapsulation, emulsification, co-pigmentation, and the use of natural protective agents help preserve pigment colour and functional properties. Sustainable extraction methods also promote the utilization of food-processing waste and agricultural residues, supporting circular economy principles. Therefore, research on advanced extraction and stabilization technologies plays an important role in developing stable, environmentally friendly, and commercially suitable natural food colourants for the future food industry.

2. Meaning of natural food colorants

Natural food colorants refer to colouring substances obtained from natural biological sources, including plants, animals, algae, fungi, and microorganisms, that are used to impart or restore colour in food products. These colourants may contain pigments such as anthocyanins, carotenoids, betalains, chlorophylls, and curcuminoids. Natural food colourants can be extracted through physical, chemical, enzymatic, or biotechnological processes. The extraction method depends on the pigment's chemical characteristics, its source material, and the intended food application. Extraction involves separating the desired colouring compounds from biological materials using suitable solvents, energy-assisted techniques, enzymes, or other processing methods. Stabilization refers to protecting extracted pigments from degradation caused by environmental and processing conditions. Recent stabilization approaches include encapsulation, emulsification, antioxidant protection, pH management, and the use of biopolymer-based delivery systems. The overall objective is to maintain colour intensity, improve storage stability, and support safe incorporation into food products. Natural colourants should not automatically be considered risk-free merely because they originate from natural sources. Their safety, purity, composition, allergenicity where relevant, and permitted food uses must be evaluated according to applicable regulations. Natural food colorants are colouring substances obtained from natural sources such as plants, fruits, vegetables, flowers, algae, microorganisms, and certain minerals. They are used in food and beverage products to improve visual appearance, enhance consumer acceptance, and restore colour lost during processing or storage. Unlike synthetic food colours, natural colorants are derived from biological or naturally occurring materials and are increasingly preferred because of growing consumer interest in clean-label, sustainable, and health-conscious food products. Common examples include anthocyanins from berries and purple cabbage, carotenoids from carrots and turmeric, chlorophyll from green plants, betalains from beetroot, and curcumin from turmeric. These pigments differ in their chemical composition, colour intensity, stability, and functional properties. However, natural food colorants may be sensitive to environmental factors such as temperature, light, oxygen, pH, and moisture, which can affect their colour stability and shelf life. Therefore, appropriate extraction, purification, and stabilization techniques are essential for their effective application in the food industry. Modern research focuses on advanced extraction methods, including ultrasound-assisted extraction, microwave-assisted extraction, and enzyme-assisted extraction, to improve pigment recovery and quality. Encapsulation, emulsification, and the use of protective agents are also explored to enhance stability. Thus, natural food colorants represent an important area of food science, combining aesthetic improvement, technological innovation, and sustainable approaches to food production.

3. Objectives of the study

1. To examine recent advances in the extraction of natural food colorants.
2. To analyse modern stabilization technologies used for protecting natural pigments.
3. To identify the major challenges associated with natural pigment extraction and application.
4. To examine the role of innovative technologies in improving pigment stability and food quality.
5. To analyse the potential applications of natural food colourants in the food processing industry.
6. To suggest strategies for sustainable extraction, improved stabilization, and future research.

4. Hypotheses of the study

H01: Advanced extraction technologies do not significantly improve the recovery and quality of natural food pigments compared with conventional extraction methods.

H02: Advanced extraction technologies improve the recovery and quality of natural food pigments compared with conventional extraction methods.

H03: Stabilization techniques do not significantly improve the storage stability of natural food colourants.

H_{04}: Stabilization techniques improve the storage stability of natural food colourants.

H05: Technological innovation has no significant relationship with the potential commercial application of natural food colourants.

H06: Technological innovation has a positive relationship with the potential commercial application of natural food colourants.

5. Methodology of the study

The study adopts a descriptive and analytical research methodology to examine recent advances in the extraction and stabilization of natural food colorants. The research is primarily based on secondary information collected from scientific journal articles, review papers, academic

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publications, and research literature related to food chemistry, food processing, pigment extraction, and stabilization technologies. Recent literature on green extraction, encapsulation, nanotechnology, and non-thermal processing has been considered to understand emerging developments in the field. The descriptive approach explains the nature, classification, and characteristics of natural food pigments, while the analytical approach examines the advantages and limitations of extraction and stabilization methods. The study focuses on anthocyanins, carotenoids, betalains, chlorophylls, and curcuminoids. The analysis considers extraction efficiency, pigment stability, sustainability, processing conditions, and potential food applications. Four illustrative tables are presented to support a comparative understanding of technological developments. These tables contain hypothetical analytical values and are not based on an actual laboratory experiment or primary field survey. Percentages and scores should not be interpreted as experimentally validated results.

6. Recent advances in extraction technologies

Recent research has focused on improving the efficiency, selectivity, sustainability, and quality of natural pigment extraction. Conventional techniques such as maceration, solvent extraction, and Soxhlet extraction may require substantial time, energy, and solvent consumption. They can also expose sensitive pigments to conditions that promote degradation. Ultrasound-assisted extraction (UAE) uses ultrasonic energy to facilitate the disruption of plant tissues and improve mass transfer. This method may reduce extraction time and solvent requirements under suitable conditions. Microwave-assisted extraction (MAE) uses microwave energy to accelerate the release of pigments from biological materials. Its effectiveness depends on the characteristics of the raw material, solvent, temperature, and processing parameters. Enzyme-assisted extraction uses enzymes to break down cell-wall components and facilitate pigment release. Supercritical fluid extraction, particularly with carbon dioxide, is useful for selected compounds, especially relatively non-polar pigments such as carotenoids. Its suitability depends on the solubility and chemical characteristics of the target compound. Other emerging methods include pulsed electric field-assisted extraction, pressurized liquid extraction, and the use of natural deep eutectic solvents. These approaches are being studied for their potential to improve extraction efficiency and reduce environmental impacts. However, extraction performance depends on pigment chemistry and operating conditions, and no single technique is suitable for every natural colourant. Recent advances in extraction technologies have significantly improved the recovery, quality, and stability of natural food colorants from plant, microbial, and animal sources. Traditional extraction methods, such as maceration, soaking, and solvent extraction, often require considerable amounts of solvents, extended processing times, and high energy consumption. Modern techniques have been developed to overcome these limitations and promote sustainable food-colorant production. Ultrasound-Assisted Extraction (UAE) uses ultrasonic waves to disrupt plant cell walls, improving the release of pigments such as anthocyanins, carotenoids, and betalains. Microwave-Assisted Extraction (MAE) provides rapid heating and enhances pigment recovery while reducing extraction time. Supercritical Fluid Extraction (SFE), particularly using supercritical carbon dioxide, is an environmentally friendly approach for extracting lipid-soluble pigments, including carotenoids. Enzyme-Assisted Extraction (EAE) employs enzymes to break down cellular structures, facilitating the release of valuable color compounds. Emerging technologies, including pulsed electric field extraction, pressurized liquid extraction, and deep eutectic solvents, offer additional opportunities for improving extraction efficiency and reducing environmental impact. These advanced methods can help preserve pigment quality, minimize solvent usage, and increase industrial scalability. However, factors such as operating costs, solvent safety, pigment stability, and technological complexity must be carefully considered. Overall, innovative extraction technologies contribute to the development of safer, more efficient, and sustainable natural food-colorant production for modern food industries.

Table 1. Comparative Analysis of Natural Pigment Extraction Technologies

Extraction Technology	Main Principle	Potential Advantages	Major Limitations
Conventional solvent extraction	Solvent-based pigment separation	Simple operation and established methods	Solvent use and longer processing time
Ultrasound-assisted extraction	Acoustic cavitation	Improved mass transfer and reduced extraction time	Requires optimization of energy and temperature
Microwave-assisted extraction	Microwave energy-assisted heating	Rapid extraction and potential solvent reduction	Excessive heating may degrade sensitive pigments
Enzyme-assisted extraction	Enzymatic cell-wall breakdown	Improved pigment release in suitable materials	Enzyme cost and process specificity
Supercritical fluid extraction	Supercritical fluid-based separation	Reduced solvent residues in appropriate applications	High equipment and operating costs
Pulsed electric field extraction	Electroporation of cell membranes	Non-thermal processing potential	Scale-up and process optimization challenges

Note: The table provides a qualitative comparison based on technological characteristics, not experimental measurements.

Table Analysis: The comparative assessment indicates that advanced extraction technologies offer different benefits depending on the pigment and raw material. Ultrasound and microwave methods may improve processing efficiency, whereas enzyme-assisted extraction can support pigment release from selected plant matrices. Supercritical fluid extraction provides opportunities for specialized applications but may require substantial investment. Pulsed electric field technology is an emerging option for non-thermal extraction. The selection of a method should consider extraction yield, pigment stability, solvent safety, energy use, and economic feasibility. The comparative assessment of advanced extraction technologies demonstrates that each method has specific advantages and limitations depending on the type of natural pigment, raw material composition, and intended food application. Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) have gained attention for their potential to improve extraction efficiency, reduce processing time, and minimize solvent consumption. These methods can support the recovery of valuable pigments from plant-based materials, although operating conditions must be carefully controlled to prevent pigment degradation caused by excessive heat or prolonged treatment. Enzyme-assisted extraction (EAE) facilitates the breakdown of plant cell walls, potentially improving pigment release and extraction yield from selected raw materials. Supercritical fluid extraction (SFE), particularly when using carbon dioxide, offers opportunities for obtaining specific pigment compounds with reduced conventional solvent residues, but its application may involve high equipment and operational costs. Pulsed electric field (PEF) technology represents an emerging non-thermal approach that can enhance cell membrane permeability and

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support the extraction of intracellular pigments. The selection of an appropriate extraction method should be based on extraction yield, pigment stability, solvent safety, energy consumption, environmental sustainability, scalability, and economic feasibility. Furthermore, the suitability of each technology depends on the chemical properties of the pigment and the characteristics of the raw material. Therefore, integrating technological efficiency with sustainable processing principles is essential for developing commercially viable natural food colorants.

7. Advances in stabilization of natural food colorants

Stabilization is an important stage in the development of natural food colourants because many pigments are sensitive to environmental and processing conditions. Anthocyanins may be affected by pH, temperature, oxygen, and light. Carotenoids can undergo oxidation and isomerization, while betalains are sensitive to heat and other environmental factors. Chlorophylls may experience colour changes during processing, particularly under unsuitable pH and temperature conditions. Recent stabilization strategies include microencapsulation, nanoencapsulation, liposomal delivery, co-pigmentation, emulsification, and antioxidant incorporation. Encapsulation involves surrounding pigment molecules or extracts with protective materials such as proteins, polysaccharides, and other food-compatible substances. These systems may reduce exposure to oxygen, light, and moisture. Spray drying is widely investigated for converting liquid pigment extracts into powders. Freeze drying can be useful for heat-sensitive compounds, although it may involve higher processing costs. Liposomes and other nanostructured systems are being studied to improve the protection and delivery of selected pigments. Co-pigmentation involves interactions between pigments and other compounds that may influence colour intensity and stability. The effectiveness of these strategies depends on the chemical nature of the pigment, the encapsulating material, food composition, and storage conditions. Recent reviews emphasize the importance of selecting stabilization systems according to the specific requirements of each pigment and food matrix.

Table 2. Illustrative Analysis of Stabilization Methods

Stabilization Method	Primary Purpose	Expected Benefit	Key Consideration
Spray drying	Conversion of extracts into protective powders	Improved handling and storage potential	Drying temperature and carrier material
Freeze drying	Low-temperature moisture removal	Protection of selected heat-sensitive compounds	Processing cost and moisture control
Microencapsulation	Protective coating around pigment	Reduced exposure to environmental factors	Encapsulating material and release properties
Nanoencapsulation	Nanoscale delivery systems	Potential improvement in dispersion and protection	Safety assessment and regulatory compliance
Co-pigmentation	Pigment–compound interactions	Potential enhancement of colour stability	Compatibility and sensory effects
Antioxidant incorporation	Reduction of oxidative degradation	Protection of oxidation-sensitive pigments	Food compatibility and permitted use

Table Analysis: The illustrative comparison shows that stabilization technologies address different aspects of pigment protection. Spray drying and freeze drying are useful for producing pigment powders, while microencapsulation and nanoencapsulation focus on protective delivery systems. Co-pigmentation and antioxidants may offer additional chemical protection in suitable formulations. Nevertheless, the actual effectiveness of each method must be established through controlled experiments measuring pigment retention, colour characteristics, and storage stability. The stabilization of natural food colorants is an important aspect of maintaining pigment quality, colour intensity, and functional performance during food processing and storage. The illustrative comparison indicates that different stabilization technologies address specific challenges associated with pigment protection. Spray drying and freeze drying are widely considered useful approaches for converting liquid pigment extracts into stable powder forms, facilitating handling, transportation, and incorporation into food products. Microencapsulation and nanoencapsulation provide protective systems that may improve pigment stability against environmental factors such as light, oxygen, moisture, and temperature. Similarly, co-pigmentation can enhance colour stability in selected pigment systems, while antioxidants may help reduce oxidative degradation. However, the suitability of these technologies depends on pigment characteristics, encapsulating materials, processing conditions, and intended food applications. The selection of an appropriate stabilization method should consider pigment retention, colour intensity, solubility, bioavailability, production cost, and industrial scalability. Although these technologies demonstrate considerable potential, their actual effectiveness must be established through controlled laboratory and industrial experiments. Such investigations should measure pigment retention, colour parameters, antioxidant activity, and storage stability under different environmental conditions. Therefore, integrated research combining extraction efficiency with stabilization performance is essential for developing safe, economical, and commercially viable natural food colourants.

8. Sustainable extraction and waste valorisation

Sustainable extraction has become an important area of research in natural food colourant production. Agricultural and food-processing residues, including fruit peels, vegetable leaves, seeds, and other by-products, may contain valuable pigments. Their utilization can support waste reduction and the development of value-added food ingredients. Green extraction methods aim to reduce environmental impacts through improved solvent selection, efficient energy use, and reduced waste generation. Water, ethanol-based systems, supercritical fluids, and natural deep eutectic solvents are among the approaches investigated for selected pigment applications. However, the environmental performance of a process must be evaluated across its complete production cycle, including solvent preparation, energy consumption, purification, and waste management. Food waste valorisation requires careful assessment of raw material quality, seasonal variation, contamination risks, and pigment composition. By-products may also contain undesirable compounds, so suitable purification and safety controls are necessary. The use of food-grade solvents and appropriately validated processing conditions is essential for food applications. Recent literature has highlighted the potential of food residues as pigment sources and the use of green extraction and encapsulation approaches to improve their utilization.

Sustainable extraction and waste valorisation are emerging approaches in the production of natural food colorants, focusing on environmental protection, resource efficiency, and the utilization of agricultural and food-processing by-products. Conventional extraction methods may require large quantities of organic solvents, energy, and

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water, potentially generating environmental pollution. Sustainable extraction technologies, including ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction, and supercritical fluid extraction, help improve the recovery of bioactive pigments while reducing resource consumption. These techniques support the extraction of valuable colorants such as anthocyanins, carotenoids, betalains, and chlorophylls from natural sources. Waste valorisation involves converting food and agricultural waste into valuable products rather than discarding it. Fruit peels, vegetable residues, seeds, and processing by-products can serve as important sources of natural pigments. For example, grape skins, pomegranate peels, onion skins, and beetroot residues contain pigments with potential applications in the food industry. Recovering these compounds contributes to the circular economy by reducing waste generation and improving the economic value of agricultural resources. However, challenges such as pigment instability, seasonal availability, extraction costs, and food safety requirements must be addressed. Combining green extraction technologies with effective stabilization methods can support the development of safe, sustainable, and commercially viable natural food colorants.

Table 3. Illustrative Analysis of Pigment Sources and Applications

Natural Source	Major Pigment Group	Colour Range	Potential Food Applications
Purple sweet potato	Anthocyanins	Red to purple	Beverages, desserts, confectionery
Carrot	Carotenoids	Yellow to orange	Dairy products, sauces, beverages
Beetroot	Betalains	Red to violet	Bakery products, beverages
Spinach	Chlorophylls	Green	Sauces, pasta, selected beverages
Turmeric	Curcuminoids	Yellow	Mustard, sauces, prepared foods
Blue-green algae	Phycobiliproteins	Blue	Selected beverages and food formulations

Table Analysis: The table demonstrates the diversity of natural pigment sources and their potential food applications. Anthocyanins provide a range of red, purple, and blue shades depending on chemical and environmental conditions. Carotenoids and curcuminoids are relevant to yellow and orange colouring, while betalains offer red and related shades. Chlorophylls and phycobiliproteins provide opportunities for green and blue colouring. Application suitability depends on stability, sensory characteristics, permitted use, and compatibility with the food matrix. The table highlights the diversity of natural pigment sources and their significance in food colouring applications. Natural pigments obtained from fruits, vegetables, flowers, spices, algae, and other biological sources provide a wide range of colours that can be used as alternatives to synthetic food colourants. Anthocyanins are important pigments responsible for red, purple, and blue shades, with their colour influenced by pH, temperature, and storage conditions. Carotenoids and curcuminoids contribute yellow and orange colours and are widely relevant to food products such as beverages, dairy items, confectionery, and bakery products. Betalains offer red and violet shades, while chlorophylls provide green colouring potential. Phycobiliproteins, obtained primarily from certain algae, present opportunities for blue and related shades in specialised food applications. However, the practical use of these pigments depends on their stability against light, heat, oxygen, and changes in pH. Their effectiveness is also influenced by sensory characteristics, regulatory approval, extraction efficiency, and compatibility with different food matrices. Therefore, selecting an appropriate natural pigment requires consideration of both its colouring performance and technological stability. The table demonstrates that natural food pigments offer valuable opportunities for sustainable food innovation, although further research is needed to improve their stability, cost-effectiveness, and commercial application.

9. Industrial applications and technological challenges

Natural food colourants have potential applications in beverages, bakery products, dairy foods, confectionery, sauces, frozen foods, and other processed food categories. Their use can help manufacturers develop products aligned with demand for naturally sourced ingredients. However, natural pigments may differ in shade, strength, stability, and sensory characteristics from synthetic colourants. Industrial application requires reliable raw material supplies, standardized pigment concentrations, reproducible extraction processes, and appropriate quality control. Variations in agricultural conditions, storage, harvesting, and processing may affect pigment composition. The cost of extraction, purification, stabilization, and transportation can influence commercial feasibility. Another important issue is the interaction between pigments and food matrices. For example, pH-sensitive colourants may perform differently in acidic beverages and neutral food products. Encapsulation can improve handling and protection, but it may also influence colour release, texture, and bioavailability. Regulatory requirements must be considered before commercial application. Food colourants must comply with applicable legal provisions concerning permitted substances, purity, safety, labeling, and use levels. Advanced technologies should therefore be evaluated not only for technical performance but also for consumer safety, affordability, and regulatory suitability.

10. Consumer acceptance and future research directions

Consumer interest in naturally sourced food ingredients is one factor encouraging the development of natural food colourants. However, consumer acceptance is influenced by colour appearance, taste, product price, perceived safety, labeling, and familiarity with the ingredient. Natural origin alone does not guarantee consumer preference or technological suitability.

Future research should focus on developing extraction methods that combine high pigment recovery with low environmental impact. Further work is needed to optimize natural solvent systems, improve process scalability, and reduce energy consumption. Research on encapsulation and other stabilization technologies should assess long-term storage stability, pigment release, bioaccessibility, and performance in real food products. Advanced analytical techniques can support pigment identification and quality control. Spectrophotometry, chromatography, and other analytical approaches may be used to evaluate pigment concentration, degradation products, and colour changes. Computational modelling and process optimization may also help researchers identify suitable extraction conditions. The future of natural food colourants is likely to involve integrated approaches that combine sustainable extraction, targeted stabilization, improved quality control, and food-matrix-specific formulation. The practical success of these developments will depend on scientific validation, safety evaluation, and industrial feasibility.

11. Illustrative analysis of research findings

The following table presents hypothetical assessment scores for selected technological considerations. The values are included only to demonstrate a possible analytical framework and do not represent actual experimental findings.

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Table 4. Illustrative Assessment of Technological Priorities

Technological Factor	Illustrative Score (out of 5)	Interpretation
Pigment stability	4.5	High research priority
Extraction efficiency	4.4	High research priority
Sustainability	4.3	Important development objective
Industrial scalability	4.1	Significant challenge
Consumer acceptance	4.0	Important market consideration
Cost reduction	4.2	Relevant commercial objective

Table Analysis: The illustrative scores indicate that pigment stability and extraction efficiency could be considered important priorities in the development of natural food colourants. Sustainability and cost reduction are also relevant to industrial adoption. Scalability remains a significant consideration because laboratory-level performance does not necessarily translate directly into commercial production. Consumer acceptance depends on product quality, safety, price, and sensory characteristics. These hypothetical values demonstrate how future studies could organize and compare research priorities; they do not establish measured differences or statistical relationships. The illustrative scores indicate that pigment stability and extraction efficiency are important priorities in the development and commercialization of natural food colourants. Pigment stability plays a crucial role in maintaining colour quality during food processing, storage, and distribution, while efficient extraction methods can improve pigment recovery and reduce resource consumption. Sustainability and cost reduction are also essential considerations for promoting the industrial application of natural colourants. Environmentally friendly extraction techniques, reduced energy consumption, and the effective utilization of agricultural and food-processing waste can support sustainable production practices. Scalability remains a significant challenge, as successful laboratory-level extraction methods may require further technological improvements before large-scale commercial implementation. In addition, consumer acceptance depends on several factors, including product safety, colour appearance, sensory characteristics, affordability, and perceived health benefits. Manufacturers must therefore focus on developing colourants that combine functional performance with economic and environmental advantages. The illustrative values provide a framework for organizing and comparing potential research priorities in natural food colourant development. However, these hypothetical scores do not represent actual field measurements, experimental findings, or statistically established relationships. Future research should employ laboratory experiments, industrial trials, and consumer surveys to validate these priorities and identify practical strategies for improving the stability, efficiency, sustainability, and market acceptance of natural food colourants.

12. Findings of the study

The review identifies several important findings concerning the extraction and stabilization of natural food colorants.

1. **Advanced extraction technologies:** Ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction, and pulsed electric field methods offer potential benefits in improving pigment recovery and processing efficiency.
2. **Importance of pigment stability:** Natural pigments are sensitive to environmental conditions such as temperature, light, oxygen, and pH. Their stability varies according to chemical structure and food composition.
3. **Role of encapsulation:** Microencapsulation, nanoencapsulation, and other delivery systems may protect pigments from degradation and improve their suitability for selected food applications.
4. **Sustainable production:** Food-processing residues and agricultural by-products represent potential sources of natural pigments. Green extraction can support resource efficiency when appropriate solvents and processing conditions are selected.
5. **Industrial challenges:** Cost, scale-up, raw material variation, regulatory compliance, and storage stability remain important considerations in commercial natural colourant production.
6. **Need for integrated research:** Combining extraction optimization, stabilization, analytical testing, and food-matrix evaluation may help develop more reliable natural colourant systems.

13. Results and Discussion

The analysis indicates that recent technological development in natural food colourants is moving beyond conventional extraction toward integrated systems involving green solvents, energy-assisted processing, stabilization, and advanced delivery technologies. Extraction and stabilization should be considered complementary stages because obtaining a high pigment yield does not necessarily ensure long-term colour retention or successful food application. The development of ultrasound-assisted and microwave-assisted extraction methods provides opportunities for improving processing efficiency under suitable conditions. However, the choice of extraction parameters is critical because excessive energy or temperature can negatively affect sensitive pigments. Similarly, green solvent systems may offer environmental advantages, but their safety, selectivity, recovery, and economic feasibility must be evaluated. Stabilization technologies provide opportunities to address the major limitations of natural colourants. Encapsulation can reduce the exposure of pigments to environmental factors, while co-pigmentation and other formulation approaches may improve colour performance in specific applications. Nevertheless, stabilization outcomes depend on the pigment, protective material, food matrix, and storage conditions. The analysis also suggests that food waste valorisation can contribute to sustainable pigment production. Fruit peels, vegetable leaves, and other by-products may serve as valuable raw materials. However, raw material quality, contamination control, seasonal availability, and extraction consistency require attention.

14. Conclusion

Natural food colorants have become an important area of research because of their potential applications in sustainable food production and the development of naturally sourced food ingredients. Pigments such as anthocyanins, carotenoids, betalains, chlorophylls, and curcuminoids provide diverse colour characteristics and can be obtained from a wide range of biological materials. However, their sensitivity to temperature, light, oxygen, pH, and other environmental factors continues to limit their practical application. Recent advances in ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction, pulsed electric field processing, and green solvent systems provide opportunities to improve pigment recovery and processing efficiency. Stabilization technologies, including encapsulation, emulsification, co-pigmentation, and protective delivery systems, offer potential strategies for maintaining colour quality during storage and food processing. The future development of natural food colourants requires a balanced approach that combines scientific innovation, sustainability, safety, economic feasibility, and consumer acceptance. Food-processing by-products may provide valuable sources of pigments, while advanced extraction and stabilization technologies can support their conversion into commercially useful ingredients. In conclusion, natural food colourants have considerable tech

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nological potential, but successful industrial application depends on pigment-specific research, validated processing conditions, regulatory compliance, and demonstrated stability in real food products**.** Continued collaboration between food scientists, biotechnology researchers, industry, and regulatory authorities can contribute to the development of safer, sustainable, and effective natural colouring systems.

References

1. Tzanova MT, Yaneva Z, *et al.* Green Solvents for Extraction of Natural Food Colorants from Plants: Selectivity and Stability Issues. Foods. 2024;13(4):605.
2. Irmadamayanti A, Herawati H, Raharjo B, *et al.* Green Technologies in Food Colorant Extraction: A Comprehensive Review. South African Journal of Chemical Engineering. 2025;51:22–34.
3. Cazón P, Sanches Silva A. Natural Pigments from Food Wastes: New Approaches for the Extraction and Encapsulation. Current Opinion in Green and Sustainable Chemistry. 2024;47:100929.
4. Wijesekara T, Xu B. A Critical Review on the Stability of Natural Food Pigments and Stabilization Techniques. Food Research International. 2024;179:114011.
5. Enhancing the Quality of Natural Food Colorants by Novel Extraction and Concentration Processes. Food Reviews International. 2024;40(10).
6. Pulsed Electric Field-Assisted Extraction of Natural Colorants: Principles and Applications. Food Bioscience. 2024;61:104746.
7. Singh A, Singh NS. Natural Food Colorants from Fruits: Extraction and Application in Food Industry—A Review. Current Horticulture. 2025;13(4):47–58.
8. Impact of Conventional and Advanced Techniques on Stability of Natural Food Colourants. Foods. 2025;14(18):3187.
9. Natural Food Colorant Applications in the Food Industry: Alternatives for Overcoming Stability Limitations. Colorants. 2026;5(3):27.
10. Green Extraction of Natural Colorants from Food Residues: Colorimetric Characterization and Nanostructuring for Enhanced Stability. Foods. 2024;13(6):962.

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