

Natural food colorants from fruits: extraction and application in food industry— a review

Akath Singh and Ningthoujam Samarendra Singh

ICAR- Central Institute for Subtropical Horticulture, Rehmankhera, Lucknow, India

ABSTRACT

The food industry is traditionally dependent on synthetic colorants to enhance visual appeal and consumer's attraction. However, growing health concerns among consumers and regulatory restriction have possessed to identify safer natural alternatives from plants. Fruits serve a promising source of natural colorants with added health benefits due to presence of different bioactive pigments such as anthocyanins, carotenoids, betalains, and chlorophylls. These compounds not only enhance aesthetic value of food but also offer antioxidant, anti-inflammatory and other functional properties. However, challenges persist in their extraction, stability, and sustainability. Natural pigments are often sensitive to environmental factors such as light, temperature, and pH, limiting their commercial application. In response, recent research has focused on optimizing extraction and stabilization techniques to improve pigment yield and stability while maintaining their bioactivity. This review summarizes recent studies, highlighting advances in the identification, extraction and application of fruit-derived colorants in food systems. Emphasis is placed on their dual role as coloring agents and functional ingredients. Overall, fruit-based colorants signify a viable, health-conscious alternative to synthetic colours, though further innovation is needed to enhance their stability, bioavailability and commercial feasibility.

Key words: Functional foods, Fruits, Industrial use, Green extraction techniques, Pigment stability

Color plays a pivotal role in shaping consumer perception and acceptance of food products. Attributes such as size, shape, and especially colour are commonly used by consumers to assess the quality of food (Spence, 2022). The colour of food is often associated with characteristics like freshness, ripeness, and safety. Consequently, food colouring has become widely used to enhance the visual appeal and marketability of various food items (Wange *et al.*, 2019). Since colour forms the initial impression of any food item, manufacturers have adopted food colouring as a key marketing strategy. Food colorants can be categorized into four main types: inorganic, synthetic, nature-identical, and natural colors (Okafor *et al.*, 2016). Moreover, the food industry mostly relied on synthetic colourants due to their consistent vibrancy, cost-effectiveness, and stability throughout processing and storage (Martins *et al.*, 2016).

The majority of synthetic dyes with aromatic rings and azo functional groups may be harmful to human health, including hyperactivity, allergic responses, and asthma attacks, intestinal cancer, respiratory problems (Li *et al.*, 2014; Ntrallou *et al.*, 2020). Yet, growing consumer concerns over the potential adverse health effects of synthetic colours have prompted regulatory scrutiny and a shift toward natural alternatives. However, rising health concerns and regulatory restrictions have accelerated the search for safer, natural alternatives (Albuquerque *et al.*, 2020). Therefore, natural-food colorants have found their

niche for valuable food products.

Fruits, due to their vivid pigmentation and abundance of phytochemicals, are among the most viable sources for natural food colorants (Mazza, 2018; Martins *et al.*, 2016). These natural food colorants not only impart vibrant colour development, but also deliver functional benefits like antioxidant and anti-inflammatory properties being rich in bioactive compounds (Rodriguez-Amaya, 2016). These health-promoting qualities, along with rising consumer demand for clean-label and environmentally friendly products, have increased the popularity of natural colorants in the food industry. Moreover, the use of natural colourants can provide technological and bioactive functionalities to those foods in which they are applied, delivering additional value-added properties (Rodriguez-Amaya, 2016).

Nevertheless, natural pigments face many hurdles as they are often sensitive to environmental fluctuations including light, temperature, oxygen and pH resulting in colour fading, batch variability, and short shelf life (Fernandez-Lopez *et al.*, 2020). Per say, betalains extracted from vegetable peels degrade rapidly at ambient temperatures and are most stable under frozen conditions, restricting their application in processed foods. Moreover, the cost of natural pigments remains higher than synthetic dyes due to extraction complexity, variability in raw materials, and lower yield efficiency. To overcome these challenges, researchers are developing innovative extraction and stabilization methods. Encapsulation strategies, including micro-encapsulation

Corresponding author : akash2005@yahoo.co.in

or use of biopolymers, enhance pigment stability by protecting against degradation and thereby improving their bioavailability (Hidalgo *et al.*, 2018).

This review thus aims to synthesize recent advances in the use of fruit-derived colorants in food systems. It will examine major pigment classes viz. anthocyanins, carotenoids, betalains, and chlorophylls and their extraction and stabilization techniques, technological applications, and dual roles as colorants and functional ingredients. By bridging aesthetic appeal with health-conscious innovation, fruit-based colorants represent a viable alternative to synthetic dyes, though their successful adoption depends on overcoming stability, cost, and supply challenges.

Colorant compounds from fruits

Among the compounds present in fruits that show coloring properties are anthocyanins, betalains, carotenoids, chlorophylls and other non-anthocyanin flavonoids. Anthocyanins have the widest range of colors presenting shades from blue to red; betalains, for red-violet, yellow-orange color, and mainly pink; carotenoids, range from red to yellow and chlorophylls, are mostly green but also can present blue tones. All these compounds, in addition to their colourant capacity, exhibit different bioactive properties evidencing health benefits with their consumption (Sigurdson *et al.*, 2017).

Anthocyanins

Anthocyanins is one of the largest groups of water-soluble plant pigments with more than 700 compounds have been identified in nature (Zhang *et al.*, 2019). Chemically, anthocyanins belong to the flavonoids group, a sub-class of the polyphenol family, contributing to the attractive orange, red, purple, violet, and blue colors of fruits. These compounds are secondary metabolites within the phenolic class (Nieto, 2020) and are responsible for the red, pink, violet, blue and even yellow colors ((Vidana Gamage *et al.*, 2021; Mazza, 2007). Among the 27 anthocyanidins

reported in nature, cyanidin, delphinidin, pelargonidin, peonidin, malvidin, and petunidin account for over 90% of those found in plants. Cyanidin-3-glucoside is the most abundant anthocyanin in the plant kingdom (Mattioli *et al.*, 2020; Zhang *et al.*, 2014; Li *et al.*, 2017). They absorb light around 500 nm and are commonly found in many fruits such as blackberries, blueberries, cranberries, strawberries, grapes, figs, pomegranate, jamun, karonda, plum etc (Khoo *et al.*, 2017; Wallace and Giusti, 2015). Anthocyanins have attracted significant interest due to their dual roles as natural colorants and bioactive compounds.

Beyond their coloring ability, anthocyanins have demonstrated multiple health benefits. Studies have linked them to anti-inflammatory, anti-oxidant, anti-tumor, anti-mutagenic, and anti-obesity effects (Sun and Li, 2018; You *et al.*, 2018). They are also associated with improved cardiovascular health through regulation of cholesterol and triglyceride levels, and possess anticoagulant properties. Furthermore, anthocyanins may support cognitive function and help prevent neurological disorders (Li *et al.*, 2017). Emerging evidence also points to their role in managing diabetes and offering protection against oxidative stress (Leong *et al.*, 2018; You *et al.*, 2018; Li *et al.*, 2017).

Anthocyanin production in plants can be influenced by environmental stress and pathogen attack, serving as part of the plant's defense system (Zhang *et al.*, 2014). Their widespread distribution in commonly consumed foods and their bioactive potential make them valuable compounds for both nutritional and industrial applications. Their use as natural alternatives to synthetic colorants is highly promising; however, their application is challenged by low stability. Factors such as pH, temperature, light, oxygen, metal ions, enzymes, and co-pigments can affect their structural integrity and color expression (Enaru *et al.*, 2021; Khoo *et al.*, 2017; Fan *et al.* 2019). Among these, pH is particularly critical, as the hue of anthocyanins shifts significantly with changes in acidity (Rodriguez Amaya

Table 1. Natural food pigments from fruits and their characteristics, solubility, and functional applications

Pigment Class	Source fruits	Color range	Solubility	Functional benefits	Reference
Anthocyanins	Berries, mulberries, black current, strawberries, pomegranate, jamun, karonda, plum etc.	Red to blue (pH-dependent)	Water	Antioxidant, pH indicator, health-promoting	Tiwari <i>et al.</i> (2009)
Carotenoids	Mango, guava, banana, papaya, citrus, peach, apricot etc.	Yellow to orange	Lipid	Pro-vitamin A, eye health, stable	Khoo <i>et al.</i> (2008)
Betalains	Beetroot, dragon fruit, Cactus, pear (prickly pear)	Red violet to yellow	Water	Antioxidant, vivid, limited pH stability	Sadowska-Bartosz and Bartosz (2021)
Chlorophylls	Green fruits	Green, red blue	Lipid / water	Functional pigments, limited uses	Dagnino-Leone <i>et al.</i> (2022)

2018).

Carotenoids

Carotenoids are a class of naturally occurring pigments responsible for the bright yellow, orange, and red coloration found in many fruits and vegetables (Nagarajan *et al.* 2017). These compounds are particularly abundant in tropical and subtropical fruits such as mango, papaya, peach, apricot, and citrus fruits, where they contribute not only to the fruit's visual appeal but also to its nutritional value (Maldonado-Celis *et al.* 2019; Zhou *et al.* 2020). Carotenoids such as β -carotene, lutein, and lycopene are among the most prominent and biologically significant members of this group (Rodriguez Amaya, 2016). The intense coloration of these pigments arises from their conjugated double-bond structures, which absorb visible light in the 400–550 nm range, thus producing hues that range from yellow to deep red (Saini and Keum, 2018).

A notable characteristic of carotenoids is their lipid solubility, which facilitates their incorporation into the fatty components of plant cells and makes them suitable for lipid-based formulations in food and cosmetic applications (Martins *et al.*, 2016). In addition, carotenoids are relatively stable under thermal processing, a property that enhances their utility in processed food products. However, their stability can still be influenced by factors such as light, oxygen, and pH, making proper storage and formulation essential to maintain their colour and bioactivity (Tharuka and Baojun, 2024). Recent studies have focused on improving carotenoid stability through encapsulation techniques and green extraction methods, including the use of deep eutectic solvents and nano-emulsions, to better preserve their structure and extend their shelf life during food processing and storage (Molina *et al.*, 2023; Gutierrez-Urbe *et al.*, 2022). Beyond their use as natural colourants, carotenoids are widely recognized for their health-promoting properties.

β -Carotene, for instance, is a well-established precursor of vitamin A and plays a vital role in maintaining healthy vision, immune function, and skin integrity (Rodriguez-Amaya *et al.*, 2021). Lutein, predominantly found in citrus peels, accumulates in the retina and macula of the eye, where it helps to filter harmful blue light and reduce the risk of age-related macular degeneration. Lycopene, a carotenoid pigment responsible for the red color in pink-fleshed fruits, is a potent anti-oxidant with demonstrated protective effects against oxidative stress, inflammation, and UV-induced skin damage (Crupi *et al.*, 2023). Exploring the use of carotenoid-rich by-products from fruit processing industries, such as mango and citrus peels, as sustainable sources of natural pigments for use in foods, supplements, and intelligent packaging systems is

new area for researchers (Rodriguez-Amaya *et al.*, 2023).

Betalains

Betalains are naturally occurring pigments found prominently in red dragon fruit, prickly pear, (Sadowska-Bartosz and Bartosz, 2021). These pigments fall into two chemical classes—betacyanins, which impart red violet colour, and betaxanthins, responsible for yellow orange coloration (Khan, 2016; Rodriguez Amaya, 2016). Betalains are notably stable across a pH range of roughly 3 to 7, which makes them suitable for low to mildly acidic food matrices (Martinez *et al.*, 2024). However, they are highly sensitive to heat and light: both betacyanins and betaxanthins degraded at elevated temperatures typically above 60°C for betacyanins and above 40°C for betaxanthins—leading to breakdown products such as betalamic acid, neobetalins, and colorless or yellow derivatives ((Martinez *et al.*, 2024)).

Kinetic analyses of betalains from pitaya (red dragon fruit) peel reveal first order degradation with temperature; stability is acceptable at or below 60°C, but degradation accelerates significantly at temperatures above 80°C, especially for betacyanins (Chew *et al.*, 2019). To mitigate these limitations, recent studies have explored encapsulation and co-pigmentation strategies: for instance, ionic gelation with calcium alginate or liposomal encapsulation greatly enhance heat and light tolerance, while co-pigmentation with black carrot anthocyanins significantly increases half life and reduces degradation under thermal and light stress (Martinez *et al.*, 2024). Different bioactivities have been related to betalains such as antioxidant, antibacterial, antifungal, antiprotozoal, and anticancer properties (Sadowska-Bartosz and Bartosz, 2021).

Chlorophylls

Among all pigments present in nature, chlorophylls are most abundant in the plant kingdom, responsible for the green color; however, they have been the least studied as natural colorants (Rodriguez-Amaya, 2016). Among different Chlorophylls, a, b, c, d and e; chlorophyll a and b are the most found in several plant tissues and in green fruits. Their vibrant green color and antioxidant properties have prompted their use in clean-label food products, cosmetics, and nutraceuticals (Yang *et al.*, 2025). However, chlorophylls exhibit significant sensitivity to environmental conditions. They degrade rapidly under acidic pH, elevated temperatures, light exposure, and enzymatic activity—environments that commonly arise during food processing and storage. Acidic conditions and heat can displace the central magnesium, forming olive-brown pheophytin, while enzymatic action by

chlorophyllase promotes breakdown into chlorophyllides (Pandiselvam *et al.*, 2023). Light and oxidative stress further exacerbate degradation, leading to fading and color loss (Tharuka and Baojun, 2024). Chlorophylls continue to be highly valued as natural green colorants, not only for their vibrant aesthetic contribution to food and cosmetic products but also for their functional and bioactive properties (Ebrahimi *et al.*, 2023). These include antioxidant activity, potential anti-inflammatory effects, and the ability to support detoxification processes, **anti-cancer**, and **anti-obesity**, all of which contribute to their growing appeal in health-conscious formulations (Masyita *et al.*, 2025).

Extraction and Stabilization process

The extraction and stabilization of natural pigments such as chlorophylls, anthocyanins, carotenoids, and betalains are essential for their effective application in food, pharmaceutical, and nutraceutical products (Nabi *et al.*, 2023). Conventional methods rely mainly on solvent extraction using ethanol, methanol, acetone, hexane, or water, depending on pigment solubility (Mungwari *et al.*, 2025). Chlorophylls and carotenoids, being lipid-soluble, are typically extracted with organic solvents such as acetone or hexane, while anthocyanins and betalains, which are water-soluble, are efficiently extracted with aqueous or hydroalcoholic solvents (Jiang *et al.* 2024). However, these methods often pose challenges such as solvent residues, low selectivity, and susceptibility of pigments to degradation.

To overcome these limitations, advanced extraction techniques have been developed, including ultrasound-assisted extraction, microwave-assisted extraction, and supercritical fluid extraction with CO₂ (Bhadange *et al.*, 2024). These approaches improve efficiency, reduce solvent use, and minimize thermal damage, thereby preserving pigment integrity and bioactivity. Once extracted, stabilization becomes critical since all natural pigments are sensitive to environmental stressors such as heat, light, oxygen, and pH. A variety of stabilization strategies are employed across pigment classes. Copigmentation with organic acids or polyphenols enhances anthocyanin stability by strengthening pigment-cofactor complexes, thereby improving color intensity and resistance to degradation. Microencapsulation using carriers such as maltodextrin, gums, or biopolymers protects chlorophylls, carotenoids, and betalains from oxidation and environmental stress, ensuring longer shelf-life (Laureanti *et al.*, 2023). The addition of natural antioxidants, such as ascorbic acid or tocopherols, further prevents oxidative degradation and enhances pigment stability during storage.

Specific modifications are also applied for certain pigments, such as conversion of chlorophyll into more stable chlorophyllins, or emulsification of carotenoids to improve dispersibility and protect against oxidative loss. Together, the integration of conventional and advanced extraction techniques with tailored stabilization strategies enables the recovery and preservation of these bioactive pigments (Mungwari *et al.*, 2025). Such approaches not only retain their vivid natural colors but also maintain their functional properties, including antioxidant, anti-inflammatory, and health-promoting effects. These advancements significantly expand the industrial potential of chlorophylls, anthocyanins, carotenoids, and betalains as sustainable and safe alternatives to synthetic colorants in modern food and nutraceutical systems.

Conventional methods

Conventional methods for pigment extraction largely rely on solvent-based techniques using ethanol, methanol, acetone, hexane, or water, depending on the solubility of the target compound (Lee *et al.*, 2024). For instance, anthocyanins and betalains, being water-soluble, are commonly extracted with aqueous or hydroalcoholic solutions, while lipid-soluble pigments such as chlorophylls and carotenoids are typically extracted using organic solvents like ethanol, acetone, or hexane (Taghavi *et al.*, 2023). These methods are simple, cost-effective, and widely applied in both research and industrial settings, making them the most established approach for natural pigment recovery. However, solvent extraction has limitations, including potential solvent residues, pigment degradation under heat or light, and relatively low selectivity, which can lead to co-extraction of unwanted compounds (Shawky *et al.*, 2025). Despite these drawbacks, conventional solvent extraction remains a baseline technique due to its accessibility, ease of operation, and suitability for initial screening or large-scale pigment isolation when carefully optimized.

Advanced extraction techniques for natural pigments

Advanced extraction techniques have been developed to overcome the limitations of conventional solvent-based methods and to ensure higher efficiency, selectivity, and preservation of pigment quality. Ultrasound-assisted extraction (UAE) employs acoustic cavitation to disrupt plant cell walls, enhancing solvent penetration and facilitating the release of pigments such as anthocyanins, chlorophylls, and carotenoids, while reducing extraction time and solvent use (Das *et al.*, 2022). Supercritical fluid extraction (SFE), particularly with supercritical carbon dioxide (CO₂), is highly effective for lipid-soluble

pigments like carotenoids and chlorophylls, offering the advantage of being solvent-free, environmentally friendly, and capable of producing high-purity extracts (Morcelli *et al.* 2021). Microwave-assisted extraction (MAE) utilizes microwave energy to rapidly heat plant tissues and solvents, causing cell rupture and accelerating pigment release with minimal thermal degradation when carefully controlled (Lozano Pérez *et al.*, 2024).

Collectively, these advanced techniques not only improve yield and stability but also align with sustainable and green chemistry practices, making them increasingly attractive for industrial applications in food, nutraceutical, and pharmaceutical sectors. Advanced extraction techniques represent a significant shift toward greener, more sustainable practices in natural pigment recovery (Putra *et al.*, 2023). Compared to conventional solvent-based methods, they offer enhanced selectivity, shorter processing times, and reduced solvent consumption, which are particularly important for preserving the integrity of heat and light-sensitive pigments such as anthocyanins and betalains (Irianto *et al.*, 2025). Despite their benefits, advanced techniques also present certain limitations that must be addressed before large-scale industrial adoption.

Ultrasound and microwave-assisted extractions may involve high equipment costs and require careful

optimization to prevent thermal degradation of sensitive compounds (Niari *et al.* 2025). Supercritical CO₂ extraction, although highly efficient for non-polar pigments, often requires co-solvents such as ethanol for effective recovery of polar compounds, which can increase complexity and cost (Niari *et al.* 2025). Furthermore, scalability remains a challenge, as the energy requirements and equipment design for continuous large-scale processing are still under development. Nevertheless, the integration of advanced extraction techniques with emerging technologies holds great promise for improving both the efficiency and sustainability of pigment recovery.

Stabilization approaches for natural pigments

Natural pigments, including anthocyanins, carotenoids, betalains, and chlorophylls, are widely valued in food, pharmaceutical, and cosmetic applications for their vibrant colors and health-promoting properties (Nabi *et al.* 2023). One widely studied method is co-pigmentation, in which pigments form reversible complexes with organic acids (e.g., citric, tartaric, or caffeic acid) or polyphenols such as flavonoids, tannins, or phenolic acids (Enaru *et al.*, 2021). This molecular interaction stabilizes the chromophore by preventing hydration and structural breakdown, thereby enhancing both the intensity and

Table 2. Extraction strategies for plant-derived pigments: Principles, applications, and limitations

Extraction Method	Principle	Pigments Targeted	Advantages	Limitations	References
Conventional Solvent Extraction	Dissolution of pigments in solvents (ethanol, methanol, acetone, hexane, or water) based on solubility	Water-soluble: Anthocyanins, Betalains; Lipid-soluble: Chlorophylls, Carotenoids	Simple, low-cost, widely available, suitable for lab-scale and large-scale processes	Low selectivity, potential solvent residues, thermal/light degradation, co-extraction of unwanted compounds	Mungwari <i>et al.</i> (2025)
Ultrasound-Assisted Extraction (UAE)	Acoustic cavitation disrupts plant cells, enhancing solvent penetration and pigment release	Anthocyanins, Chlorophylls, Carotenoids	Higher yield, shorter time, lower solvent use, operates at low temperatures (protects heat-sensitive pigments)	Equipment cost, requires optimization to prevent pigment degradation	Das <i>et al.</i> (2022); Bhadange <i>et al.</i> (2024)
Microwave-Assisted Extraction (MAE)	Microwave energy rapidly heats solvent and plant matrix, causing cell rupture and pigment release	Anthocyanins, Carotenoids, Chlorophylls	Fast extraction, high efficiency, reduced solvent usage, good for heat-stable pigments	Risk of thermal degradation if not controlled, scalability challenges	Shawky <i>et al.</i> (2025)
Supercritical Fluid Extraction (SFE, CO ₂)	Supercritical CO ₂ acts as a solvent; often combined with co-solvents like ethanol for polar pigments	Carotenoids, Chlorophylls (lipid-soluble pigments)	Solvent-free, eco-friendly, high purity, good for sensitive bioactives	High equipment cost, less effective for polar pigments without co-solvent, complex operation.	Morcelli <i>et al.</i> (2021)
Hybrid Approaches (e.g., UAE + MAE, Enzyme + SFE)	Combination of physical/biochemical processes for enhanced pigment release and preservation	Applicable to all pigment classes (tailored methods)	Maximizes yield and stability, reduces processing time/energy use, more sustainable	Still in research stage, limited industrial-scale application, high setup cost.	Bhadange <i>et al.</i> (2024)

persistence of color (Yang *et al.*, 2025). Co-pigmentation is particularly effective for anthocyanins, which otherwise exhibit rapid fading in food systems (Yang *et al.*, 2025). For example, the addition of phenolic compounds has been shown to improve anthocyanin stability in berry-based beverages, extending both color retention and antioxidant activity (Estupiñan *et al.*, 2011). Another important technique is micro-encapsulation, where pigments are entrapped within a protective matrix, typically using wall materials such as maltodextrin, gum arabic, cyclodextrins, or biopolymers (Laureanti *et al.*, 2023). Encapsulation provides a physical barrier against oxygen, heat, and UV light, thereby preventing oxidation and pigment breakdown (Xu *et al.*, 2024). For instance, carotenoids encapsulated in maltodextrin-based carriers demonstrate enhanced stability and shelf-life in fortified food products (Sereti *et al.*, 2025). Spray-drying and freeze-drying are common encapsulation methods that convert liquid pigment extracts into stable powders with improved handling, dispersibility, and resistance to environmental stressors (Júnior *et al.*, 2023). More advanced encapsulation systems, including nanoemulsions and liposome-based carriers, are being developed to further improve pigment bioavailability and controlled release in functional foods and nutraceuticals (Zhu *et al.*, 2025). A complementary stabilization strategy involves the addition of antioxidants, which act as protective agents against oxidative damage. Natural antioxidants such as ascorbic acid, tocopherols (vitamin E), rosemary extract, and polyphenolic compounds are commonly incorporated into pigment formulations to reduce the formation of reactive oxygen species and free radicals that cause degradation (Gulcin, 2025). For example, the co-application of ascorbic acid with carotenoids or betalains has been shown to significantly reduce color fading during storage. Thus, stabilization strategies remain a cornerstone in advancing the use of natural pigments as safe, sustainable, and effective alternatives to synthetic colorants.

Applications in Food Industry

The use of natural colorant by food industry has been increasing due to their multifaceted beneficial effects on food preservation, sensory characterization, health association (Albuquerque *et al.* 2020).

Bakery products

Natural colorants derived from fruits are increasingly being incorporated into bakery products to enhance visual appeal, improve nutritional value, and meet clean-label demands. These colorants not only provide attractive crust and crumb coloration but also impart potential health benefits, particularly due to their antioxidant properties.

Table 3. Application of natural colorants in common food products

Natural pigments	Food products
Anthocyanins	Bakery, frozen desserts, dairy products, beverages, smoothies, juices, and carbonated drinks
Carotenoids	Meat products, butter and vegetable oils, pasta, cheese,
Betalains	Yoghurt, cake mix, gummies, candies, jellies, ice cream, beverages, health drinks
Chlorophylls	Mix beverages, puddings, ice cream, cakes, muffins, bread

Applications span a range of bakery items, including bread, cakes, cookies, and biscuits. Common examples include turmeric for yellow hues in bread and cakes, and beet juice for imparting red tones to cookies, with minimal sensory disruption. Purified pigments and plant extracts have been shown to enhance the nutritional profile of bakery products without significantly affecting taste or texture. For instance, tomato waste, rich in lycopene, was successfully incorporated into cakes and cookies, contributing to increased product volume, enhanced DPPH radical scavenging activity, and brighter crumb color.

However, only formulations with 5% lycopene content showed a significant volume increase compared to controls (Eletr *et al.*, 2017). Further innovations include the use of jaboticaba (*Myrciaria jaboticaba*) peel extract, rich in anthocyanins, as a natural colorant for French macarons. Heat- and ultrasound-assisted extraction optimized pigment yield and stability, resulting in vibrant coloration without adverse sensory effects (Albuquerque *et al.*, 2020). Additionally, flours made from purple-fleshed sweet potatoes have been utilized to color biscuits, offering both appealing coloration and added health benefits due to their high anthocyanin content (Aziz *et al.*, 2018). Beyond aesthetics, many of these pigments (e.g., betalains, lycopene) confer antioxidant and even antimicrobial benefits, adding functional value to bakery products (Novais *et al.*, 2020)

Beverages

Colour is a critical sensory attribute in beverages, significantly influencing consumer perception, product appeal, and overall acceptability. During food processing, particularly thermal treatments, pH adjustments, and exposure to light significant colour degradation can occur. Therefore, colorants are often added to restore or enhance visual appeal. While synthetic dyes have been used for long for this purpose, increasing consumer awareness and regulatory pressure which have shifted the beverage industry toward natural, plant-derived colourants that offer both functionality and cleaner labels (FDA, 2025).

Natural colourants are now applied across a wide range of beverages, including fruit juices, flavoured waters, sports drinks, dairy-based beverages, and carbonated drinks. Among the most widely used natural sources are beetroot, turmeric, spirulina, sweet potato, marigold, jabuticaba skins, and gardenia, each offering pigments with distinct hues and stability profiles.

For example, beet juice, rich in betalains, is frequently used to impart red tones in fruit-based beverages due to its water solubility and relatively broad pH stability. Similarly, spirulina extract, containing phycocyanin, is a popular natural blue pigment used in sports and energy drinks (Petruzzi et al. 2017). The yellow colour in beverages is represented by carotenoids (bixin, lutein, and crocin), flavonoids (carthamin), and curcuminoids (curcumin). Riboflavin also imparts a yellow colour and serves as a vitamin, adding nutritional value. A comprehensive study by Cerreti et al. (2020) evaluated several natural yellow pigments including annatto (*Bixa orellana*), gardenia yellow (*Gardenia jasminoides*), lutein (*Tagetes erecta*), curcumin (*Curcuma longa*), and carthamin (*Carthamus tinctorius*) in beverage model systems, highlighting their varied stability under different storage and pH conditions.

Anthocyanins, abundant in many fruits, are also widely used, though they present challenges due to their pH sensitivity. Gomes Rocha et al. (2019) formulated whey-based protein beverages incorporating anthocyanin-rich extracts from jabuticaba skins. The study identified delphinidin-3-O-glucoside and cyanidin-3-glucoside (C3G) in the extract. Higher whey concentrations (4.0–6.0% w/v) yielded beverages with a stable and visually dominant red hue, though differences in chroma and redness (a^*) were minimal, suggesting good pigment integration in the matrix. In another case, Tensiska et al. (2017) developed jelly beverages using encapsulated anthocyanins from purple sweet potato cv. Ayamurasaki. The encapsulated pigments retained high anthocyanin content and redness for up to 30 days of storage, emphasizing the benefits of encapsulation techniques for maintaining colour stability in beverage applications. Importantly, beverages have become a strategic platform to enhance fruit and vegetable intake, which remains below recommended levels in many populations. Fortification with natural colourants often co-delivering phytonutrients serves both functional and aesthetic purposes (Petruzzi et al. 2017). Additionally, natural colourants help in preventing colour loss during pasteurization and other thermal processes, preserving both appearance and perceived freshness. Recent innovations, such as microencapsulation, copigmentation, and protein-pigment hybrid systems, are being applied to improve the heat, light, and pH stability of natural pigments in beverages (Magalhaes et al. 2024).

Dairy Products

Natural colorants play a pivotal role in enhancing the visual appeal and consistency of dairy products including yogurt, ice cream, and cheese. They can compensate for colour loss during processing or storage, intensify subtle hues, standardize batch appearance, and improve consumer acceptability (Martins et al. 2016). The complexity of dairy matrices, however, can introduce challenges such as color–texture interactions that must be carefully managed during formulation. Recent studies have advanced the use of natural pigments in the dairy sector. In yogurt-like soy models, betalain extracts from red beetroot and *Opuntia*, as well as anthocyanin extracts from hibiscus and red radish, were stabilized using nano-encapsulation in soy-lecithin systems.

Both encapsulated and non-encapsulated forms showed satisfactory colour retention over 21 days at 4°C, with the red radish extract imparting the most appealing pink hue, and encapsulated *Opuntia* delivering health benefits without compromising color quality (Dias et al. 2020). Emerging “blue” colourants from microalgae offer exciting opportunities for neutral-pH dairy products like ice cream. Phycocyanin from *Spirulina* demonstrated impressive color stability, with ΔE^* values significantly lower than controls after 182 days of storage, making it a promising natural blue shade (Hernández et al. 2022). Ice creams are popular dairy or dairy-like frozen desserts at neutral pH, sometimes formulated with milk fat, milk proteins, fruits, and flavours. The most common colourants used in ice cream are curcumin (intense lemon shade), *Carthamus* (bright yellow with slight greenish shade), carotenes (orange-yellow hues, preferred for vanilla-flavored products), annatto (yellow shades), beetroot (pink-red color), lycopene (red color), and chlorophylls or copper-chlorophylls (yellowish-green and bright green colors, respectively) (Krahl et al. 2016).

Aqueous and ethanolic/methanolic betacyanin extracts from red pitahaya (*Hylocereus polyrhizus*) were applied as a colourant in ice creams and found that betacyanin-supplemented ice creams exhibited the highest free radical scavenging activities (DPPH: 50–57%) (Gengatharan et al. 2020). Using colourants in cheese is also a common practice. Natural colourants are preferred mainly for their health benefits, providing additional properties such as antioxidant, antimicrobial, and surface-active activity to coloured cheese products (Rodriguez-Amaya, 2016). The main colourant used in cheese and butter is annatto, but for the cheese industry, the colorant is mainly composed of norbixin, responsible for imparting yellow/orange colour to cheddar cheese (Carter et al. 2017). Other usual colourants used in cheese are carminic

acid and anthocyanin, paprika oleoresin, chlorophylls and chlorophyllin, and curcumin (Sharma et al. 2020).

Other products

Natural colourants are widely used in pasta products to produce new ways of coloured pasta, especially the popular “vegetable-added pasta”. Dalla Costa et al. (2016) used 20% carrot flour as a substitute for-carotene for commercial dry wheat pasta and found 307% higher levels of carotenoids, 132% increased antioxidant capacity, and 608% higher total fiber compared to no carrot-added

pasta. Saffron enrichment (0.2–0.4% w/w) of wheat flour pasta (Armellini et al. 2018) decreased L^* but increased a^* and b^* values, higher antioxidant capacity compared to commercial pasta, and no textural parameters were affected. Cerezal Mezquita et al. (2019). Saffron and beetroot aqueous extracts were encapsulated in maltodextrin, gum arabic, modified starch, and chitosan and incorporated in a chewing gum system (Chranioti et al. 2015). Fruit-based extracts like *Clitoria ternatea* and freeze-dried blueberry juice have been shown to enhance both visual appeal and antioxidant content in gummy

Table 4: Challenges in using fruit-derived colorants in the food industry

Challenge	Details	Possible Solutions	Impact on Industry	Examples	References
Stability issues	Natural pigments (e.g. anthocyanins, carotenoids, betalains) are sensitive to pH, heat, light, and oxygen, leading to colour degradation during processing and storage	Encapsulation (spray-drying, liposomes, nanoencapsulation) - use of antioxidants like ascorbic acid - pH control through buffering agents	Inconsistent or fading color can lead to reduced shelf appeal, consumer distrust, and product reformulations	Purple grape anthocyanins fading in yogurt; encapsulated beet extract used in gummy candies to enhance stability	Novais <i>et al.</i> (2022)
Low yield and high cost	Fruit pigments are often present in low concentrations, and extraction is energy- and solvent-intensive, increasing cost	Valorization of fruit waste (e.g., peels, pomace) - Efficient extraction technologies like ultrasound-assisted extraction - cultivar selection for high pigment yield	Higher costs may limit use to premium products, reducing competitiveness with synthetic colorants	Pomegranate peel used for anthocyanin extraction in beverages; use of carrot pomace for natural orange coloring	Rodríguez-Mena <i>et al.</i> (2023)
Sensory interference	Some pigments impart undesirable flavors, odors, or astringency, especially in mildly flavored or dairy products	Use of purified concentrates - flavor masking agents - Formulation with complementary flavors	Alters taste perception and may require costly reformulation, affecting product development timelines	Elderberry anthocyanins adding bitterness to soft drinks; purified blueberry extract used in yogurt to avoid off-flavors	Reshna <i>et al.</i> (2023)
Regulatory hurdles	Approval and use of natural colorants vary by country. Limited safety data and lack of harmonized global regulations can restrict market access	Conduct toxicological evaluations - standardized documentation for food-grade certifications - Proactive engagement with food safety authorities	Can delay product launch, create trade barriers, and require multiple regional formulations	Anthocyanin use restricted in some Asian countries; companies like GNT Group navigating EU/US regulations for EXBERRY® colors	Varghese and Ramamoorthy (2023)
batch Variability	Natural pigments can show variability in color intensity due to differences in harvest time, growing conditions, or storage	Implement standardized sourcing and processing protocols - use of blending to achieve colour consistency	Inconsistent product color leads to branding issues and customer dissatisfaction	Seasonal variation in hibiscus extract leading to color shift in iced teas; blend standardization used by beverage companies	Ghosh <i>et al.</i> (2022)
Limited shelf life	Natural colorants often have a shorter shelf life compared to synthetic dyes due to oxidation or microbial degradation	Use of natural preservatives - vacuum-sealed or inert gas packaging - cold chain logistics	Limits distribution range and increases logistics and storage costs	Beet extract needing cold storage; microencapsulated fruit pigments with improved shelf life used in snack coatings	Dey and Nagababu (2022)

candies compared to conventional versions (Tarahi et al. 2024).

Recent work on “functional gummies” shows green-extracted berry anthocyanins withstand gelatin/pectin matrices and typical shelf conditions while elevating antioxidant capacity, supporting clean-label claims (Nima et al. 2024). In jelly candies, grape-juice anthocyanins survive cooking and storage with ~41% retention, and products remain sensorially accepted—evidence that real fruit pigments can deliver stable hue and consumer appeal (Yara et al. 2022). Betalains, though vivid, are heat- and pH-sensitive; encapsulating pitaya/dragon-fruit or prickly-pear pigments in maltodextrin/gum arabic or nanoliposomes markedly improves resistance to degradation in confectionery systems and enables brighter, longer-lasting reds/purples in gummies (Nurhadi et al. 2024).

Challenges and Limitations

While fruit-derived colourants offer a natural and health-conscious alternative to synthetic dyes, their adoption in large-scale food production presents several challenges and limitations (Novais et al. 2022). These obstacles span technical, economic, sensory, and regulatory domains and must be addressed for broader and more reliable use in the food industry.

CONCLUSION

Fruits remain one of the most underexploited yet powerful reservoirs of natural pigments. The pigments they contain are anthocyanins, carotenoids, betalains, and chlorophylls, serve as antioxidants, anti-inflammatory and disease-preventive compounds that can be transformed into healthy foods. Fruits represent a rich, renewable source of natural colorants with immense potential to replace synthetic dyes in food applications. Despite certain limitations, advancements in extraction technology and formulation strategies are making fruit-based colourants increasingly viable. Future research should focus on improving stability, reducing production costs, and ensuring regulatory compliance to fully harness the benefits of fruit-derived pigments in the global food industry.

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