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Natural and Synthetic Colours in the Food Industry: Uses, Benefits, Risks and Regulatory Considerations

A Narrative Review

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ABSTRACT

Food colourants are used to restore colour lost during processing and storage, standardize product appearance, reinforce expected flavour cues, and create distinctive product identities. Both naturally derived and synthetically manufactured colourants are used across beverages, confectionery, dairy products, bakery items, sauces, snacks and processed foods. Natural colourants including: Anthocyanins, carotenoids, betalains, chlorophylls, curcumin, annatto and phycocyanins can meet consumer demand for recognisable sources, but their performance may be limited by heat, light, oxygen, pH, cost, flavour carry-over and supply variability. Synthetic colourants often offer strong tinting power, reproducibility and processing stability, yet their use requires careful attention to permitted identity, purity specifications, maximum levels, exposure, labelling and possible intolerance in susceptible individuals. Neither "natural" nor "synthetic" alone establishes safety: Hazard depends on the specific substance, dose, purity, exposure and population. This narrative review summarizes principal colourant classes, food applications, technological advantages, safety concerns, and risk-management strategies, with particular attention to regulatory compliance and the Indian context. It recommends a substance-specific, evidence-led approach rather than a blanket preference for either source.

Key words: Food colourants; natural pigments; synthetic dyes; anthocyanins; carotenoids; food safety; regulation; India; exposure assessment.

1. Introduction

Colour is a major sensory cue that influences perceived flavour, freshness, ripeness, quality and product identity. Food colourants may compensate for colour loss during heating, drying, freezing, storage or exposure to light; reduce natural batch-to-batch variation; or add colour to products that otherwise appear pale. Colour can also help consumers identify a familiar flavour, although appearance should never be used to disguise spoilage or inferior quality [1,2].

Colour additives range from pigments extracted from plants, animals, algae and microorganisms to compounds produced by chemical synthesis. The terms "natural," "nature-identical" and "synthetic" are not used identically in every jurisdiction; legal classification and permitted applications must therefore be checked against the relevant food law. Natural origin does not guarantee freedom from contaminants or toxicity and synthetic origin does not by itself prove harm. Safety assessment considers chemical identity, specifications, intended use, dietary exposure and toxicological evidence [1,3].

2. Review approach

This narrative review is prepared from selected peer-reviewed reviews and regulatory information identified through literature searching. It is not a systematic review or meta-analysis and no pooled effect estimates are calculated. The included sources were selected for relevance to food-colour chemistry, industrial applications, safety and regulation. The discussion distinguishes established technological functions from health claims that require stronger evidence.

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3. Main classes of food colourants

3.1 Natural and biologically derived colourants

Natural colourants may be extracted from botanical materials, obtained from animals, or produced by microorganisms. Important groups include anthocyanins (red, purple and some blue hues), carotenoids (yellow, orange and red), betalains (beet red and yellow betaxanthins), chlorophylls (green), curcuminoids (yellow), annatto pigments (yellow-orange) and phycocyanin (blue). Caramel colour, produced by controlled heating of carbohydrate sources, is also widely used, although its classification and specifications vary by jurisdiction. Colour intensity and stability depend on extraction, purification, formulation, pH, oxygen, temperature, light and interactions with proteins, minerals and other ingredients [1,4,5].

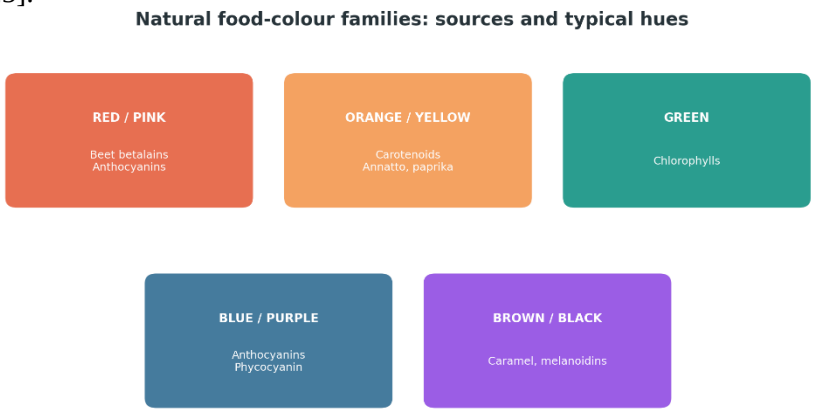


Figure 1. Examples of natural colourant families

3.2 Synthetic colourants

Synthetic colourants are manufactured to defined chemical specifications. Certain permitted dyes can provide intense, reproducible colour at relatively low use levels and can be easier to standardize across production lots. Depending on the molecule, they may be more stable than some natural pigments under heat, light, pH changes, or long storage. Examples used in some jurisdictions include tartrazine, sunset yellow, allura red, brilliant blue and indigotine; authorisation differs among countries and by food category. Only colourants permitted for the relevant product and market should be used, and they must meet purity and labelling requirements [1,2,3].

4. Uses in the food industry

Food sector	Common colour objectives	Illustrative colourant options*	Key formulation checks
Beverages and fruit drinks	Restore fruit-associated hues; improve batch consistency	Anthocyanins, carotenoids, permitted synthetic dyes	pH, clarity, light exposure, sedimentation
Confectionery and desserts	Bright, uniform, flavour-linked colours	Anthocyanins, beet betalains, curcumin, permitted synthetic dyes	Heat, acidity, water activity, migration
Dairy, yoghurt and frozen desserts	Fruit-style colour; compensate for ingredient variation	Annatto, carotenoids, beet colour, permitted dyes	Protein interactions, pH, freezing/thawing
Bakery and cereals	Golden, yellow, red or brown tones	Annatto, curcumin, caramel colour, permitted dyes	Baking temperature, moisture, browning
Sauces, dressings and savoury foods	Standardize appearance and product identity	Paprika, annatto, turmeric/curcumin, caramel colour	Oil/water partitioning, oxidation, pH
Plant-based foods	Support expected appearance of meat, fish or dairy analogues	Beet pigments, paprika, anthocyanins, chlorophylls	Protein matrix, cooking stability, flavour impact
Nutraceutical and specialty foods	Standardized appearance; sometimes co-delivery of pigments	Carotenoids, anthocyanins, phycocyanin	Bioavailability claims, stability, regulatory category

*Examples are not universal permissions. Confirm the additive's legal status and maximum permitted level for the exact food category and country.

5. Benefits and limitations

Attribute	Natural / biologically derived colours	Synthetic colours
Consumer perception	May align with demand for recognisable or plant-derived ingredients; "natural" can still be misleading if not legally defined	May be less preferred by some consumers, although preferences vary
Colour strength	Often variable; sometimes needs higher inclusion levels or carrier systems	Often high tinting strength and predictable shade
Stability	Many pigments are sensitive to heat, oxygen, light or pH; some are robust in suitable matrices	Many are stable and reproducible, but stability is compound-specific
Flavour / aroma	Extracts may contribute vegetal, earthy, bitter or other notes	Often little flavour at intended use levels, but formulation-specific
Supply and cost	Affected by crop, season, climate, extraction yield and purification	Often scalable and consistent; costs and supply still depend on manufacturing
Sustainability	Can valorize by-products, but land, water, solvents and extraction energy matter	Manufacturing footprint depends on feedstocks, process efficiency and waste treatment
Safety principle	Assess source, contaminants, extraction solvents, dose and specific toxicology	Assess identity, purity, dose, exposure, specific toxicology and susceptibility

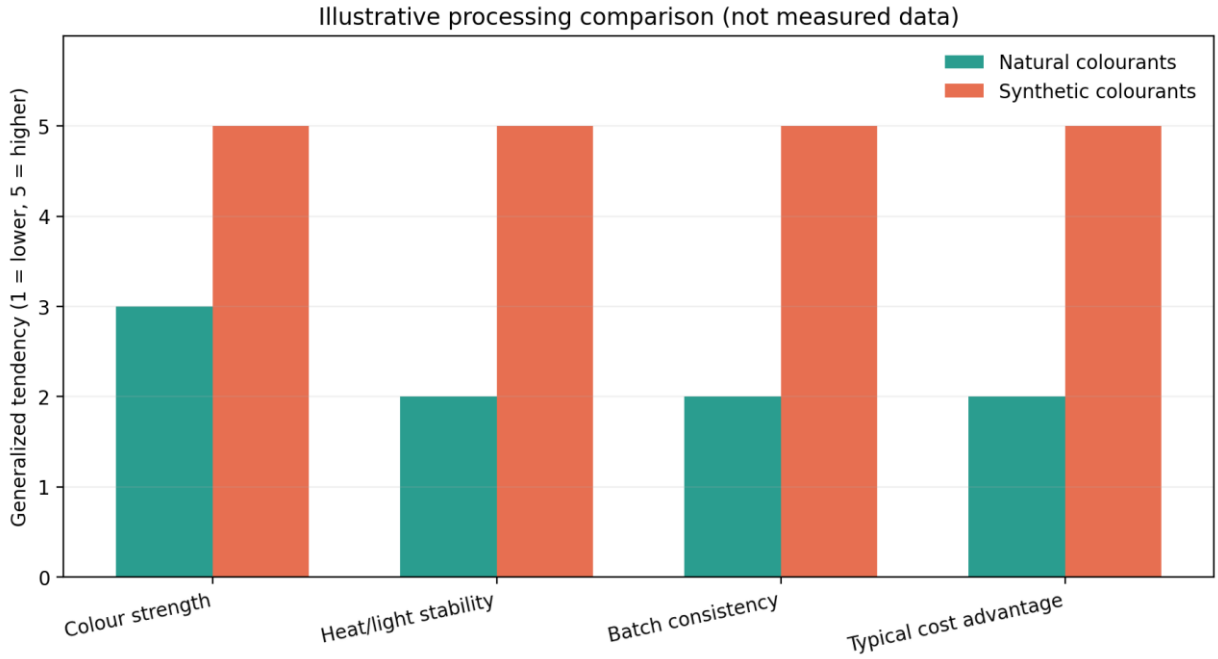


Figure 2. Qualitative illustration of commonly reported operational tendencies; this is not experimental data and should not be interpreted as a quantitative ranking.

6. Safety and potential risks

6.1 Natural colourants: Risks are source- and process-dependent

Natural extracts can contain unwanted plant constituents, pesticides, heavy metals, microbial contaminants, residual extraction solvents, or adulterants if sourcing and processing controls are inadequate. A pigment's biological activity in laboratory studies does not automatically establish a health benefit at the amount used as a colour additive. Some natural pigments degrade during storage or processing, changing shade or generating breakdown products; formulation and shelf-life studies are therefore necessary. Allergenicity or intolerance may occur with particular ingredients, and animal-derived colourants may raise dietary, cultural, or ethical considerations for some consumers [1,4,5].

6.2 Synthetic colourants: Exposure and susceptibility matter

Authorised synthetic colourants undergo jurisdiction-specific evaluation, but permitted use is not a reason to ignore intake or individual susceptibility. Some colours can cause intolerance or hypersensitivity-like reactions in a minority of consumers. Research on associations between certain synthetic colours and activity or attention in children has produced regulatory caution and labelling measures in some jurisdictions; findings should not be generalized to every dye or treated as proof that all synthetic colours cause behavioural effects. Risk assessment must identify the exact colourant, dose, total dietary exposure, study quality, and relevant population [2,3,6].

A distinct and serious issue is illegal use of non-permitted industrial dyes or colourants in foods, sometimes to intensify the appearance of spices, oils, or other commodities. This is not equivalent to use of an authorised food additive. Surveillance, analytical testing, traceability, and enforcement are central to preventing such adulteration [3].

6.3 Dose, exposure and vulnerable groups

Safety cannot be inferred from a colourant's source alone. A sound assessment considers hazard identification, dose-response data, estimated intake from all relevant foods, body weight, frequency of consumption, and high-consumption groups such as children. An acceptable daily intake (ADI), where established, is a health-based guidance value for lifetime daily exposure and is not a recommended target. Compliance with maximum use levels and good manufacturing practice reduces avoidable exposure, but the applicable rules differ by jurisdiction.

7. Regulatory landscape and Indian context

International and national frameworks differ in approved substances, food categories, permitted levels, purity criteria, and label declarations. In the European Union, authorised additives are identified by names and/or E numbers and are subject to safety evaluation and use conditions. In the United States, colour additives fall under specific FDA rules, with some subject to batch certification and others exempt from certification. These systems should not be assumed to be interchangeable [1,2].

In India, food colour use is governed by the Food Safety and Standards Authority of India (FSSAI) framework, including applicable regulations on food products, additives, standards and labelling. Food businesses should consult the latest consolidated regulations, amendments, and category-specific permissions rather than relying solely on older review articles. Varghese and Ramamoorthy [7] discuss the Indian market, regulatory context, and research gaps, including the need for stronger monitoring and population-specific evidence.

8. Testing, quality assurance and risk management

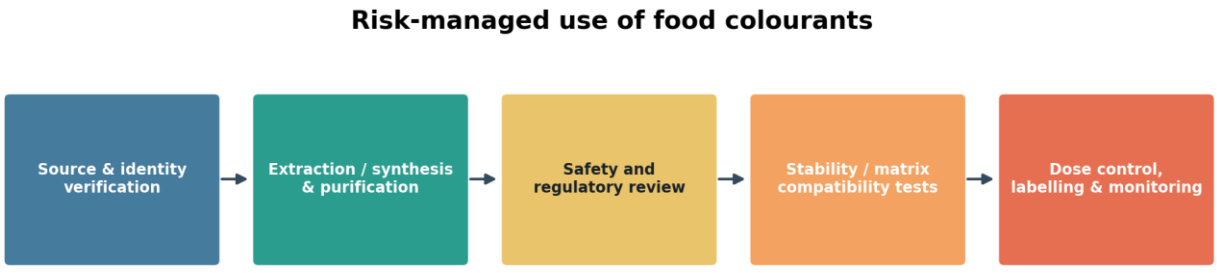


Figure 3. A practical quality and risk-management sequence for colourant use.

Manufacturers should qualify suppliers, verify food-grade identity and purity, document traceability, and test the finished product under realistic processing and storage conditions. Analytical methods such as UV-visible spectrophotometry, high-performance liquid chromatography (HPLC), and liquid

chromatography–mass spectrometry (LC–MS) may be used according to the target compound and purpose. Screening and confirmatory methods should be validated for the matrix, detection limits, recovery, and likely interferences. Risk controls should also address undeclared colourants, cross-contamination, dosage accuracy, label compliance, and complaint investigation [3].

9. Practical decision framework for manufacturers

Decision step	Questions to resolve	Evidence / control
1. Define the function	Is colour restoration, standardization, or a specific visual identity needed?	Product specification and consumer-use context
2. Check legal permission	Is the exact colourant allowed in this food category and destination market?	Current regulations, positive lists, maximum levels
3. Compare options	Can a natural pigment meet hue, stability, flavour and cost requirements?	Bench trials and sensory evaluation
4. Evaluate exposure and safety	What is expected intake and are there source-specific hazards?	Specifications, toxicology and exposure assessment
5. Validate processing	Does the colour survive heating, light, oxygen and shelf life?	Accelerated and real-time stability tests
6. Verify and communicate	Are dosage, batch records and label declarations correct?	QA release, supplier certificates, label review

10. Research gaps and future directions

Priority areas include better comparative life-cycle assessments, improved extraction and purification with lower solvent and energy use, more stable natural blue and green colour systems, microencapsulation and emulsion-based delivery, and robust studies of pigment interactions in complex food matrices. Fermentation and precision biotechnology may improve consistency and reduce dependence on seasonal crops, but production strains, residuals, allergenicity, and regulatory status require case-by-case assessment. Research should also strengthen surveillance of illegal dyes and estimate exposure using realistic food-consumption data, especially in children and other high-consumption groups [1,3,4,7].

11. Conclusions

Natural and synthetic colourants both have useful roles in modern food manufacture, but they differ in source, processing behaviour, cost, stability, and consumer perception. Natural pigments can support clean-label strategies and may offer useful functional chemistry, yet they are not automatically safer or more sustainable. Synthetic colours can provide predictable and stable shades, but they must be selected and used within the relevant regulatory limits and with attention to exposure and susceptible consumers. The appropriate choice is product-specific: verified identity and purity, lawful use, dose control, stability testing, transparent labelling, and ongoing surveillance are more reliable indicators of responsible practice than a simple natural-versus-synthetic distinction.

Declaration, Conflict of Interest, Funding, and Other Statements

Use of Artificial Intelligence (AI): Artificial intelligence (AI) tools were used in preparing this narrative review to assist with organizing the subject matter, developing the manuscript structure, refining scientific explanations and improving the clarity and presentation of the text. AI assistance was used in discussing natural and synthetic food colourants, their industrial applications, technological benefits, potential risks and relevant regulatory considerations. The author is responsible for reviewing and verifying the scientific content, checking the accuracy of references and DOI information, ensuring the appropriate interpretation of published evidence and maintaining the scientific integrity of the final manuscript.

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Data Availability: No new datasets were generated or analyzed during the preparation of this review. The information discussed is derived from previously published literature and other sources cited in the manuscript.

Author Note

The manuscript entitled *"Natural and Synthetic Colours in the Food Industry: Uses, Benefits, Risks, and Regulatory Considerations: A Narrative Review"* provides an overview of the use of natural and synthetic colourants in food processing and manufacturing. It discusses their principal sources, chemical characteristics, technological functions, industrial applications, potential safety concerns and regulatory requirements.
The review examines the role of food colourants in improving or standardizing product appearance, restoring colour lost during processing and storage, and meeting product-specific visual requirements. It also considers the technological limitations of natural colourants, including sensitivity to heat, light, oxygen and pH, alongside the advantages and limitations of synthetic colourants in terms of colour intensity, stability, consistency and consumer acceptance.
Particular attention is given to the distinction between hazard and risk, the importance of exposure levels and individual susceptibility, the quality and purity of colour additives, the possibility of contamination or adulteration and compliance with applicable food safety regulations. The review also highlights the importance of evidence-based colourant selection, appropriate labelling, analytical testing and effective quality-control practices, including considerations relevant to the Indian food industry.
This manuscript is intended for academic, educational and scientific purposes. It aims to provide a balanced perspective on the benefits and potential risks of natural and synthetic food colourants without assuming that either category is inherently safer in all circumstances. The review is based on previously published literature and does not report new experimental findings.

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Selected regulatory resources

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https://www.efsa.europa.eu/en/topics/topic/food-colours

Food Safety and Standards Authority of India (FSSAI). Consult the current official regulations and amendments on food additives, product standards and labelling at https://www.fssai.gov.in/

U.S. Food and Drug Administration (FDA). Consult current colour additive regulations and permitted-use conditions at https://www.fda.gov/