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Review Article

Food Pigments in Food Systems: Chemical Composition and Applications

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Abstract

Nature relies on a variety of compounds to impart colours to living organisms. The colours may be red, purple, orange, brown, yellow, green, blue or their various shades. In the case of raw unprocessed foods, these compounds or natural pigments that enhance their visual appeal to consumers who associate particular colours to foods associated with quality and freshness. These natural compounds are widespread in animals, plants and microorganisms including algae, fungi and yeasts. In all these organisms, these compounds display various shades of black, blue, brown, green, orange, pink, red or yellow colours. Although it is their visual appeal that first attracts the consumers attention to foods, these compounds also carry out a plethora of key functions in living organisms. In certain species, the compounds function as attractants or mating signals to gain the attention of their mates. In some cases, the colours provide camouflage against predators.

Some of the compounds like chlorophylls or carotenoids participate in metabolic processes in biosynthetic reactions and energy generation. Some others serve as antioxidants and protect vulnerable biomolecules from oxidative damage, while others play a role in vision or protect skins and membranes against damaging effects of sunlight, radiations and reactive oxygen species. Thus, it was not surprising that interest in these compounds extends beyond their visual appeal and consumer preferences in foods to also encompass other aspects like nutraceutical and functional benefits they provide. This review focuses on the natural and synthetic food pigments and their effect on human wellbeing.

Keywords: Natural food pigments, synthetic food pigments, carotenoids, anthocyanins, chlorophyll, betanins.

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Introduction

Pigments are responsible for the wide range of colours observed in everyday life, as they are present in organisms, plants and the surrounding environment [1]. They are chemical compounds that absorb light at specific wavelengths within the visible spectrum [2]. In the context of food, pigments are incorporated either through direct addition or indirectly via animal feed [3]. The perception and sensory acceptability of colour in food products are influenced by several factors, including cultural preferences, geographical location and socio- economic background. However, irrespective of regional dietary culture, consumers tend to have specific expectations regarding the colour of particular foods [4].

The increasing consumer awareness, sociological changes and technological advancements have significantly enhanced the demand for natural food colourants in the food processing industry. Natural pigments such as carotenoids, anthocyanins, annatto and paprika are widely used as alternatives to synthetic colourants, particularly in single-phase food systems such as baked products in solid phase and beverages in liquid phase [5].

Synthetic food colours, in contrast, are produced either through complete chemical synthesis or by modification of precursor compounds, whereas natural colourants are typically extracted and purified from plant, animal, or microbial sources. Synthetic colourants can be classified into azo dyes (Ex.: Tartrazine, sunset yellow FCF, azorubine, amaranth, ponceau 4R, allura red AC, brilliant black BN and brown HT), triarylmethane dyes (Ex.: patent blue, brilliant blue and green S), and other chemically related compounds such as Quinoline Yellow and Erythrosine. Additionally, synthetic food colours currently authorized in the European Union (EU) include beta-apo-8′-carotenal and indigo carmine [6].

Classification of food pigments: Pigments can be classified by their origin as natural and synthetic as shown in Figure 1. Natural pigments are produced by living organisms such as plants, animals, fungi and microorganisms. Synthetic pigments are obtained from laboratories. Natural and synthetic pigments are organic compounds [7]

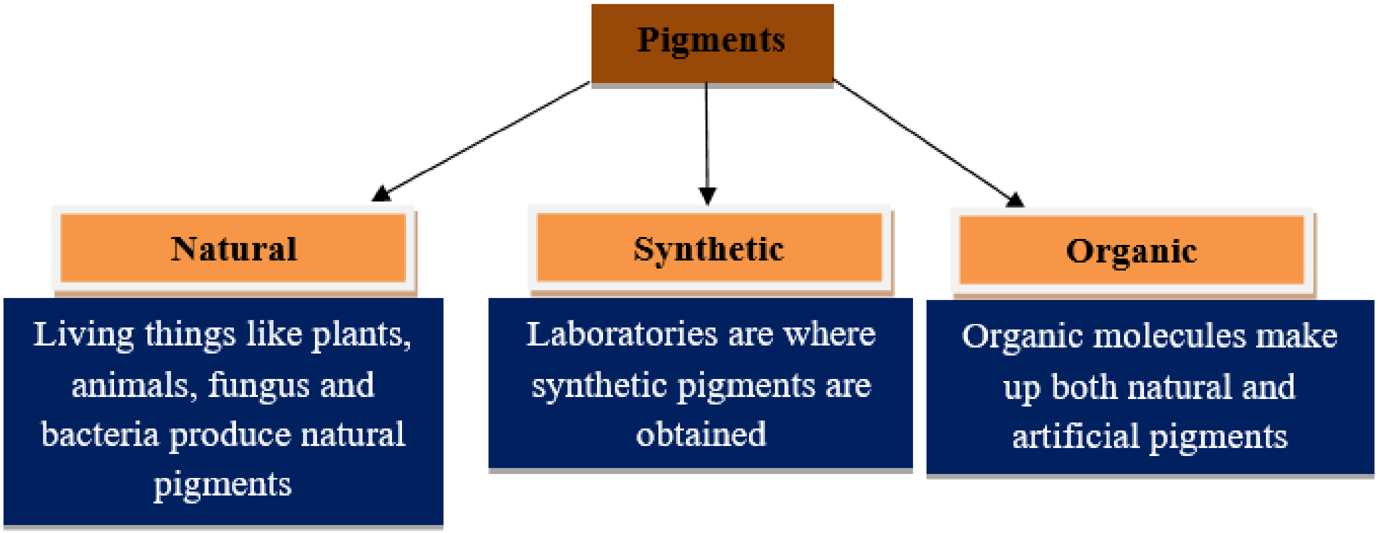

Figure 1. Classification of food pigments

Natural pigments: The natural colour of foods is primarily due to carotenoids, anthocyanins, betanin and chlorophylls either as inherent food constituents or as food or feed additives [3].

Carotenoids: Carotenoids are a class of compounds composed of eight isoprenoid units, whose arrangement can be modified at the molecular centre to yield a wide variety of structural forms. Structurally, all carotenoids may be considered derivatives of lycopene ($C_{40}H_{56}$), formed through reactions such as hydrogenation, dehydrogenation, cyclization, oxygenation, double bond migration, methyl migration and chain elongation or shortening [8].

Carotenoids represent the most widely distributed group of natural pigments. They have been identified in both photosynthetic and non-photosynthetic organisms including higher plants, algae, fungi, bacteria and at least one species from nearly every animal group. These pigments are responsible for the vivid red, orange and yellow colours observed in fruits, vegetables, flowers, fungi, birds, insects, crustaceans and fish such as trout [9].

More than 300 carotenoids had been identified by 1972, and this number increased to around 600 by 1992, with continued growth due to the discovery of new carotenoids, particularly from marine organisms [10]. The total natural production of carotenoids has been estimated at approximately 10^8 tons/year with a large proportion contributed by a few carotenoids like fucoxanthin in marine algae and lutein, violaxanthin and neoxanthin in green leaves [11].

Among the hundreds of naturally occurring carotenoids, only about 50 exhibit significant biological activity. These can be broadly classified into provitamin A and non-provitamin A carotenoids. Provitamin A carotenoids must contain at least one unsubstituted β-ionone ring and a polyene chain with a minimum of 11 carbon atoms [12].

In addition to their extensive use as natural colourants, carotenoids are widely utilized in food fortification due to their provitamin A activity and associated health benefits. These include enhancement of immune function, reduction in the risk of degenerative diseases, antioxidant properties, and potential anti-obesity or hypolipidemic effects [13]. Chemically, carotenoids are hydrophobic and lipophilic in nature, being insoluble in water but soluble in organic solvents such as acetone, alcohol, and chloroform. Their fat-soluble nature and strong colouring capacity contribute to their broad application across food and biological systems [14].

***β*-Carotene**: It is a thermolabile orange pigment that is light and oxygen sensitive with protection against heart disease and cancers to a certain extent. Still, the oxidation of LDL-cholesterol is a crucial factor for the atherosclerosis development and *β*-carotene can inhibit the lipoprotein oxidation in the body which otherwise results in the formation of plagues [14].

The red-orange coloured organic pigment, mostly extracted from the β-carotene rich algae, *Dunaliella salina*. The production of β-carotene through fermentation of *Blakeslea trispora* produces a pigment equivalent to pigments produced through a chemical process and is an accepted colouring agent [15]. It is used in a variety of food items ranging from red to yellow in colour. The human body converts β-carotene to vitamin A via body tissues as opposed to liver thus avoiding a buildup of toxins in the liver. Vitamin A is essential for the human body as it assists the body's immune system and helps battle eye diseases, like cataracts and night blindness, various skin ailments such as acne, signs of aging and certain forms of cancer [16].

Lycopene: Lycopene is a pigment belonging to the subgroup of non-oxygenated carotenoids, characterized by a symmetrical structure with 11 conjugated double bonds [17]. Owing to this unique chemical structure, lycopene is considered one of the most potent biological quenchers of free radicals. Among various carotenoids, it exhibits exceptional antioxidant activity by donating electrons to neutralize singlet oxygen and other reactive oxidative species before they can damage cellular components. Notably, lycopene demonstrates approximately twice the antioxidant capacity of β-carotene [18].

Clinical and epidemiological studies have shown that diets rich in lycopene are associated with a reduced risk of several cancers, including prostate, lung, and ovarian cancers, as well as a lower incidence of chronic degenerative and cardiovascular diseases [19]. Interestingly, more recent findings suggest that lycopene consumed through whole foods, particularly tomatoes, may be more effective in preventing certain types of cancer than purified lycopene administered in capsule form, possibly due to synergistic interactions with other bioactive compounds present in the food matrix [20].

Lutein and Zeaxanthin: Lutein and zeaxanthin were carotenoids stored in our body in the retina and lens eyes [14]. Some studies have shown that high lutein and zeaxanthin intake, particularly from foods rich in xanthophylls like spinach, broccoli and eggs are related with significant reduction of eye problems for over 20.0% and macular degeneration related to age for over 40.0% [21].

Astaxanthin: Astaxanthin is a pigment found in aquatic animals, such as lobster, crab and shrimp. A growing interest in the use of astaxanthin for poultry and fish-farming as this pigment is not synthesized by animals and must be added to the diets in order to obtain a colour attractive to consumers [22]. This xanthophyll has antioxidant potential 10 times greater than β-carotene and 500 times higher than vitamin E [23]. In addition, this pigment has been important in treatment of degenerative diseases and prevention and antitumor properties due to protection against free radical formation and lipid peroxidation, oxidative damage to LDL-cholesterol and essential polyunsaturated fatty acids along with UV light effect on cell membranes and tissues [24]. The incorporation of astaxanthin in feed for aquaculture is effective for salmonids and crustacean pigmentation [25]. It was observed that there was increase of colour intensity in salmons and shrimps respectively using diets with astaxanthin in the diet for beneficial effects [22; 26].

Anthocyanins: Anthocyanins are water-soluble pigments that provide blue, purple and red colour for various parts of plants, especially in fruits and blooms and are also involved in plant adaptability to environmental factors. They belong to a large subgroup of polyphenols, known as flavonoids. Chemically, anthocyanins are glycosides whose aglycones are polyhydroxy or polymethoxy derivatives of 2-phenylbenzopyrylium salts [27].

The consumption of dietary plants and fruits or products rich in anthocyanins can provide potent protective effects to human or animal brain, liver and kidney and moreover can prevent cardiovascular diseases, control obesity and in cancer therapy [28]. Many of these therapeutic effects are attributed to the radical scavenging and antioxidant activity of anthocyanins. However, it is suggested that these compounds can also exert an intracellular antioxidant action through modulation of cellular antioxidant defence systems [29].

Anthocyanins occur in all plant tissues, but an extensive amount of anthocyanins are produced in fruits and vegetables. The largest proportion of anthocyanins in human diet comes from berries which contain a particularly high number of anthocyanins. The amount and composition of anthocyanins may vary depending on the cultivar or the ripening stage and the synthesis in berries along with exposure to temperature and UV-B or light wavelength [30; 31].

Betanins: Beetroot [*Beta vulgaris* L.] is a vegetable presenting significant scientific interest mainly because it was a rich source of nitrate [NO^{3-}], a compound with beneficial cardiovascular health effects through the endogen production of nitric oxide [NO]. Moreover, beetroots are the main source of betalains, a heterocyclic compound and water-soluble nitrogen pigment which can be subdivided into two classes according to their chemical structure as betacyanins, such as betanin, prebetanin, isobetanin and neobetanin responsible for red-violet colouring, and betaxanthins responsible for orange-yellow colouring comprising Indica xanthin, vulgaxanthin I and II [32; 33].

Betalains are present in the tuberous part of beetroots conferring its red-purple colouration. Betanin [betanidin 5-O-β-D-glucoside] is the most abundant betacyanin and the only one approved for use as a natural colourant in food products, cosmetics and pharmaceuticals, under code EEC No. E 162 by the European Union and under Section 73.40 in Title 21 of the Code of Federal Regulations stipulated by the Food and Drug Administration in United States [34].

In the food industry, synthetic antioxidants are added to foods containing fat, especially meats with the purpose of delaying autooxidation resulting in undesirable sensorial changes, decreased shelf life and nutritional value and formation of secondary metabolites potentially harmful to health [35]. However, data in the literature has associated the synthetic antioxidants BHT [Butylated hydroxytoluene] and BHA [Butylated hydroxyanisole] with possible deleterious health effects like potential tumour promoters following the chronic administration of these compounds to animals [36]. This has motivated the replacement of synthetic antioxidants with natural antioxidants extracted from foodstuffs [37].

Betanin can be used as a powerful antioxidant in the food industry as extract or powder or natural pigment. Its antioxidant activity in biological lipid environments was reported in human macromolecules like low density lipoproteins, cell membranes and whole cells [38]. Furthermore, betanin has attracted attention due to its anti-inflammatory and hepatic protective functions in human cells. This compound was able to modulate redox-mediated signal transduction pathways involved in inflammation responses in cultured endothelia cells and has also displayed antiproliferative effects on human tumour cell lines [39].

In both healthy and tumoral human hepatic cell lines, betanin can induce the translocation of the erythroid 2-related factor 2 [Nrf2] antioxidant response element [ARE] from the cytosol to nuclear compartment, that controls the mRNA and protein levels of detoxifying/antioxidant enzymes, including GSTP, GSTM, GSTT, GSTA [glutathione S-transferases], NQO1 [NAD[P]H quinone dehydrogenase 1] and HO–(heme oxygenase-1) in these cells, exerting hepatoprotective and anticarcinogenic activity [40].

Chlorophyll: Chlorophyll is a green pigment found in most plants. Its name is derived from the Greek terms chloros (green) and phyllon (leaf) [41]. There are a few different forms of chlorophyll. Chlorophyll a, greenish-yellow in solution is the primary photosynthetic pigment in most green plants for the transfer of light energy to a chemical acceptor as absorbed light provides energy for photosynthesis. A green leaf absorbs blue light mostly at 430nm and red light mostly at 660 nm. It reflects the green wavelengths, appearing green to human eye. Chlorophyll a alone was found in blue-green and some red algae. The accessory pigments in photosynthesis transfer light energy to Chlorophyll a. One of them is Chlorophyll b, blue-green in solution found in higher plants and green algae along with Chlorophyll a. Chlorophyll c is also an accessory pigment found with Chlorophyll a in brown algae and diatoms. Chlorophyll d along with Chlorophyll a is found in some red algae. All forms of chlorophyll are oil-soluble [42].

Chlorophyllin is a chlorophyll derivative used as a food additive and is alternative medicine. As a food-colouring agent, chlorophyllin is known as natural green 3 with E number of E141 in food labelling. The major food groups contributing to dietary intake of copper complexes of chlorophylls and chlorophyllins are sugar confectionery, desserts, sauces and condiments, cheese and soft drinks. The ADI for copper complexes of chlorophylls and chlorophyllins is 15 mg/Kg body/day [43].

Chlorophyll is a good source of antioxidant nutrients. Antioxidant nutrients like vitamins A, C and E help to neutralize free radicals formed in the body that otherwise can cause damage to healthy cells. The pro-oxidant and antioxidant properties of chlorophylls and its derivatives depend on the presence of light, when in dark medium chlorophylls and its derivatives act as antioxidant and otherwise as pro-oxidant. Calcium oxalate stones are better known as kidney stones may be inhibited by chlorophyllin in its primary phase when present as calcium oxalate dihydrate [10]. Therapeutic properties of chlorophyll can be summarized as following [43].

- Stimulating the immune system
- Benefit against sinusitis, fluid buildup and skin rashes
- Ability to help alleviate anemia and normalize blood pressure
- Eliminating moulds in the body
- Ability to help prevent cancer and was being used in cancer therapy
- Cleaning the intestines
- Ability to help to rejuvenate and energize the body by removing toxins
- Detoxification of liver
- Combating bad odours, bad breath as magnesium salts contained in it help supplement the body.

Microbial food pigments: Microorganisms are used for the production of food pigments and there are several benefits like low cost of production, higher yield, easy extraction, no seasonal variations, strain improvement techniques along with health benefits like anticancer, antimicrobial and antioxidant activity. Microbes produce a variety of pigments that can be used as food colours and the major pigments were canthaxanthin, astaxanthin, prodigiosin, phycocyanin, violacein, riboflavin, β-carotene, melanin and lycopene. They are also used as additives, antioxidants, colour intensifiers and functional food ingredients. They can be either inorganic or organic, although organic pigments tend to be more useful as food colourants [44].

Canthaxanthin: It is an orange to deep pink coloured trans-carotenoid, lipid soluble and a potent antioxidant isolated from *Bradyrhizobium Sepp*, that is approved as a food colourant and used in a range of foods including in salmon and poultry feed [45].

Among 750 known carotenoids, canthaxanthin had a special place with proven antioxidant and other biologically-relevant functions. It was indicated that antioxidant defences of chicken eggs is due to vitamin E and their concentrations in the egg yolk is dependent on its dietary provision. Canthaxanthin is well absorbed from the feed and effectively transferred to egg yolk and further to developing embryo. The increased concentration of this pigment in embryonic tissues is associated with increased resistance to oxidative stress. Oxidative stress is an important element that influences embryonic mortality during the last week of incubation and it is highly likely that dietary canthaxanthin can support chicken hatchability [46].

Astaxanthin: A red-orange lipid soluble pigment naturally found in basidiomycetous yeast, microalgae, salmon, crustaceans, red shrimp, cray fish and feathers of some birds [47]. It is an approved colouring agent used in fish and animal foods [48].

It is a powerful bioactive antioxidant with demonstrated efficacy in animal or human models on macular degeneration which was a cause of blindness in a large population. It is also helpful in treating degenerative diseases like Alzheimer's and Parkinson's diseases and is known to offer protection against cancer. Astaxanthin has 10 times higher antioxidant activity than β-carotene and 500 times more effective was than α-tocopherol. Hence, it is proposed as the super vitamin E. Mammals lack the ability to synthesize astaxanthin or convert it to vitamin A. Unlike β-carotene, astaxanthin has no provitamin activity in animals. It has significant enhancing action on the production of immunoglobulin A, M and G and T-helper cell antibodies even when suboptimal amounts of antigens are present [16].

Prodigiosin: Many strains of *Serratia marcescens* produced a red pigment that showed antibacterial, antimalarial, antibiotic and antineoplastic activity [15]. It is successfully applied used as colouring agents in yogurt, milk and carbonated drinks [49].

Phycocyanin: A blue pigment produced by chlorophyll A containing cyanobacteria. *Aphanizomenon flos-aquae* and *Spirulina* produces phycocyanin being used in the food and beverage industry specially sweets and ice creams as the natural colouring agent, 'Lina Blue' [50].

Phycobiliproteins are the major photosynthetic accessory pigments in cyanobacteria and red algae. It is an efficient scavenger of oxygen free radicals. The therapeutic use of it appears to be promising as many diseases are related to excessive formation of ROS that cause many lifestyle diseases [51].

However, the use of this pigment in food and other applications are limited due to its heat sensitivity that results in precipitation and fading of blue colour. Sodium azide and dithiothreitol are the commonly used preservatives for phycocyanin for analytical purposes, but they are toxic and thus cannot be used for food-grade phycocyanin production. In contrast, sugars and polyhydric alcohols that are safe for consumption and used to stabilize proteins. The modification of protein conformation itself can also improve the stability of phycocyanins [52].

Violacein: *Chromobacterium violaceum* is one of the most prominent producers of this purple pigment with other bacterial species producing the pigment with varying purple hue. It exhibits antifungal, antibiotic, antitumor and antibacterial properties. Violacein had shown potential use in food, cosmetic and textile industries [15].

Violacein appeared as an important pharmaceutical for many infectious diseases, such as leishmaniasis, trypanosomiasis and malaria, besides its major potential as an anticancer agent. In parallel, violacein has showed potential economic importance for industrial purposes, offering the opportunity for unique applications in cosmetics, textiles as well as in the agro-industry [53].

Riboflavin: Water soluble vitamin B_2, is a yellow-coloured pigment and produced by various microorganisms. It is used in diary items, breakfast cereals, baby foods, sauces, fruit and energy drinks. It had a special affinity for cereal-based products, but its use in these applications is somewhat limited due to its slight odour and naturally bitter taste. Riboflavin fermentation is classified into three categories as weak overproducers 100 mg/L or less like *Clostridium acetobutylicum*, moderate overproducers up to 600 mg/L like yeasts which include *Candida guilliermundii* or *Debaryomyces subglobosus* and strong overproducers over 1 g/L like the fungi *Eremothecium ashbyii and A. gossypii* [16].

Melanin: Melanins are natural pigments present in animals, plants and in many micro-organisms. They are widely used in eye glasses, cosmetics, food items, sunscreen protection creams, pharmaceuticals and food items [15].

Lycopene: It is widely present and consumed in tomatoes, a brilliant red pigment with a carotenoid. It has been isolated from microbes like *Fusarium, Sporotrichioides* and *Blakeslea trispora*, with potential to attenuate persistent diseases like some types of cancers and coronary heart diseases [54].

Synthetic food pigments: Synthetic food colours are manufactured by chemical modification of several precursor compounds like diazotization of amino benzenesulfonic acid from hydrochloric acid and sodium nitrite. In contrast, natural food sources are produced by solvent extraction and subsequent purification from their natural sources for instance, anthocyanins from red grapes or blackcurrants. However, some food colours were chemically modified from precursor compounds naturally sourced like indigo carmine [E132] is obtained by sulfonation of indigo obtained from tropical indigo plant or woad or Chinese indigo [55].

Azo-dyes are synthetic food colours and do not occur naturally. These colours are manufactured by chemical synthesis that allows them to be produced in high purity, constant quality and large quantities. They have some advantages over natural food colours in terms of sensitivity to heat, light and chemical interactions. In addition, these colours are tasteless and provide a high colouring intensity. Within the synthetic food colours, azo-dyes are the largest group and are able to provide colouring shades from yellow, red, blue and black [56]. The chemical group classified as azo-dyes possess azo groups in the molecular structure, typically linking two aromatic systems. Depending on the number of azo groups in the molecular structure, azo colours can be classified into mono, di, tri, tetra and poly-azo compounds [57].

The authorisation of colours to be used in foods is subject to the regulations imposed by the European Commission in Regulation [EC] No. 1333/2008. Due to their colouring properties and the need of food manufacturers, the use of yellow/red synthetic azo-dyes are more common than those of blue/brown dyes. According to the European Food Safety Authority [EFSA], approximately 70.0% of all dyes used in food manufacture are azo-dyes. In particular, adverse reactions to synthetic food colour, Tartrazine were published more than 50 years ago, leading to repeated requests for the discontinuation of its use as a food colour. However, most studies published so far have been inadequately conducted and it remains unclear whether the reported adverse reactions to this colour are indeed a consequence of its use in foods [55].

Other synthetic food colours are the triarylmethane dyes, Patent Blue, Brilliant Blue, and Green S and their chemically related compounds Quinoline Yellow and Erythrosine along with Indigo Carmine and apo-beta-8'-carotenal. All these colours are authorised food additives in Europe [55]. Table 1 represents authorised synthetic food colours in the European Union as per European Commission Regulation (EC) No. 1333/2008.

Table 1. **Authorised synthetic food colours in the European Union**

E number	Name of synthetic food colour
E 102	Tartrazine
E 104	Quinoline Yellow
E 110	Sunset Yellow FCF/Orange Yellow S
E 122	Azorubine, Carmoisine
E 123	Amaranth
E 124	Ponceau 4R, Cochineal Red A
E 127	Erythrosine
E 129	Allura Red AC
E 131	Patent Blue V
E 133	Brilliant Blue FCF
E 142	Green S
E 151	Brilliant Black BN, Black PN
E 154	Brown FK
E 155	Brown HT
E 160e	Beta-apo-8'-carotenal [C 30]
E 180	Litholrubine BK

Nanotechnology: Nanotechnology has become one of the most promising technologies to revolutionize conventional food science and the food industry. Nanotechnology-assisted processing and packaging has proved its competence in food systems. Different preparation technologies can produce nanoparticles with different physical properties and thus, used in foods [58].

With the advent of nanotechnology, a wide range of nano scale colour additives are being studied and manufactured. Certain nanomaterial products have currently been approved for use as food colour additives, which have a vital role in the psychological appeal of consumer products. The U.S. FDA approved TiO_2 as a food colour additive with the stipulation that the additive should not to exceed 1.0% w/w and now are exempted from certification [59]. Colour additive mixtures used in food use made with TiO_2 may also contain SiO_2 and/or Al_2O_3, as dispersing aids not more than 2.0% total. However, the use of carbon black as a food colour additive is no longer authorized [60].

Organic nanomaterials are used or have been developed for use in food/feed products for their increased uptake, absorption and improved bioavailability of vitamins, antioxidants in the body, compared to conventional bulk equivalents. A wide range of materials are available in this category like food additives like benzoic acid, citric acid and ascorbic acid along with supplements like vitamins A and E, isoflavones, β-carotene, lutein, omega-3 fatty acids, and coenzyme-Q_{10}. An example of an organic nanomaterial is the tomato carotenoid lycopene. The synthetic nano sized form of lycopene has been produced and found as equivalent sources of lycopene compared to natural lycopene with better dispersibility [61].

Table 2. Advantages, limitations, regulatory concerns and future concerns of food pigments

Aspects	Synthetic food pigments	Natural food pigments	Organic food pigments
Advantages	• Highly stable to heat, pH, light and processing, providing consistent colour retention [62] • Wide range of vibrant hues, reproducible batch-to-batch [63]. • Cost-effective and available in multiple formulations as powder, gel and liquid [64]	• Perceived as safer by consumers with potential health benefits [antioxidant and anti-inflammatory] as well as biodegradable and eco-friendly alternatives to petrochemical dyes [65] • Some microalgal pigments add functional value beyond colour in terms of nutritional and health aspects [66].	• Combines advantages of natural pigments with additional organic certification benefits such as no synthetic chemicals in cultivation [67] • Aligns with organic market trends and clean-label consumer demand [68].
Limitations	• Health concerns linked with long-term exposure; regulatory scrutiny remains stringent [62]. • Environmentally hazardous production byproducts due to petrochemical raw materials. Consumer perception increasingly negative and pushing reformulation [69].	• Limited palette compared with synthetic colours [69]. • Lower physicochemical stability [sensitive to pH, heat, light, oxygen], leading to fading or change in hue. [70] • Higher cost and seasonal/raw material variability vs synthetics [71]	• Yield and colour intensity may be lower than conventional natural sources [67]. • Even more constrained by production standards [organic certification] which increase cost and limit scalable sourcing [68].
Regulatory concerns	• Subject to premarket safety approval [FDA/EFSA], must meet strict limits and labelling requirements. • Ongoing regulatory shifts [Ex.: Phased removal of certain petroleum-based dyes in the U.S.] Labelling changes risk consumer confusion [e.g., “no artificial colours” can include some natural colour [72]	• Although generally regarded as safe, natural pigments still require safety and toxicology data for new food uses [73]. • Global regulatory frameworks vary; many natural additives lack harmonized approval pathways, slowing commercialization. Stability and interaction issues must be validated for regulatory acceptance [74].	• Organic certification adds another layer of regulation beyond food additive approval [organic farming standards]. • Not all natural pigments automatically qualify for organic labelling if sourced from non-organic agriculture [75].
Future perspectives	• Reformulation driven by regulatory phase-out timelines for problematic dyes; synthetic palettes may narrow.	• Research focused on enhancing stability [Ex.: Encapsulation, advanced extraction] and expanding colour range [70]. Biotechnological	• Organic pigments viewed as premium ingredients in clean-label and sustainability narratives.

The above Table 2 depicts the advantages, limitations, regulatory concerns and future concerns of natural, synthetic and organic food pigments as their use in day to day foods is on the rise.

Conclusion

For some time, interest in synthetic food colours is high because of the perceived disadvantages with natural pigments. These disadvantages include inconsistency in the product quality and yields from batch to batch, susceptibility to factors such as heat, pH, light and air as well as the high cost. However, pressure now seems to be increasing for less use of synthetic pigments as food colourants. Consumers are showing higher preference for natural pigments in foods for health safety reasons and recent studies published in various scientific journals, including the Lancet, linked synthetic colours with hyperactivity in children. In addition to their colouring power, some of these natural pigments have also been shown to have more potent antioxidant and free radical scavenging capabilities than the synthetic ones commonly used in foods. Thus, what needs to be done is more research to address the disadvantages with the commercial production and use of natural food pigments.

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