International Journal of Botany Studies
www.botanyjournals.com
ISSN: 2455-541X
Received: 29-11-2021, Accepted: 15-12-2021, Published: 30-12-2021
Volume 6, Issue 6, 2021, Page No. 1464-1470

Plant-based colorants in the food Industry: Trends and challenges

Susai Arul Selvam[1], Khalid Imran[1*], Sarita Iyer[2], Rajendra SV[3]
[1] Department of Microbiology, Krupanidhi Degree College, Bengaluru, Karnataka, India
[2] Department of Management, Krupanidhi Group of Institutions, Bengaluru, Karnataka, India
[3] Department of Pharmacology, Krupanidhi Pharmacy College, Bengaluru, Karnataka, India

Abstract
Colours derived from plants are in high demand, with several multinational corporations announcing plans to phase out all certified artificial colours from their products. As colours can influence emotions, which are a deciding element in food purchases, the visual perception of colour can override the perception of taste and smell. Customer demand for plant-based versus artificial food colours has a significant impact on the food industry, with the belief that former foods are of higher quality, healthier, and safer. This belief stems from several reported cases of the adverse effects of artificial food colourants on human health. The common plant-derived food colourants that have attracted food industry are anthocyanins, betacyanins, carotenoids, and chlorophylls as these colourants have been documented in the prevention and management of chronic diseases. Establishing standards for food colours derived from plants can help the food industry sector grow its market and broaden its economic potential. The objective of this review is to highlight consumer interest in plant-based food colourants as a result of their health benefits, as well as the challenges that the food industry faces in this field.

Keywords: plants, colourants, anthocyanin, betacyanin, carotenoids, chlorophyll, food industry

Introduction
"We eat with your eyes first before we eat with our mouth," says a well-known culinary proverb. This adage refers to the food that appears appealing is more likely to be consumed. The appearance of a food has a great influence on its acceptance and ability to entice people to try it. Discolored, irregularly shaped, or otherwise unusual foods, on the other hand, are regarded with distrust [1]. Colour is added to food to make it more appealing, appetizing and an essential factor in the choice of food. The first moment of truth is the first few seconds when the consumer is actually attracted to the food based on its appearance and its odour. Those few seconds are crucial in determining whether or not to consume the food item. Colour accounts for between 62 to 90 percent of a consumer's evaluation [2]. In this context, learning about food colourants can be a lucrative endeavor. According to a new study, the global food colour business would be worth USD 2.97 billion by 2025 [3]. As a result of consumer complaints, the food industry has become more cautious over time, taking into account the negative effects of synthetic colourants and preservatives, and is shifting to natural plant-based colourants in foods. With "fun foods" as the current trend, the food industry is making food products to be more savory, nutritious, appealing, and healthy [4].

Food colourants are an inevitable response to this international trend. Natural colour additives such as plant pigments, dyes, and other components can be passed on to important goods of food, pharmaceuticals and cosmetic products. Colour additives on foods become a remarkable way to promote products in the market. Food manufacturers add indicators such as colour additives to a variety of food products to enhance their flavour, safety, and nutritional value. In the year 1856, first organic synthetic colourant "mauveine" was developed [5]. It became a massive success as an essential food colourant because of its lower cost in productivity, high tinctorial strength, and chemical stability. Now there is a great demand from the consumer's side to replace artificial colourants with nature's colour [6]. Colour is a persuasive aspect that influences customer acceptance of food. This acceptance is because consumers compare the colour of foods with other qualities like ripening, freshness, and safety of foods. As a result, many of the food products are coloured to increase their acceptability [7]. When artificial colourants are utilized, it causes adulteration, ecological imbalance, and adverse health impacts in humans. Plantae, Animalia, Insecta, and minerals are the sources of nature's hues [8]. Natural food colours are being used to replace artificial food dyes due to the health benefits and customer concerns about safety.

Origin of food colorant
As far back as 1500 BCE, food colouring is thought to have been used [5]. Writings from the ancient Roman and Egyptian eras reveal actions such as the colouring of medications and wine. Paprika, berries, turmeric, indigo, saffron, and other flowers were once the primary sources of culinary colouring agents [9]. In the Middle Ages colouring of food was carried out with mala fide intentions which lead to the adulteration of the food products. In Europe, "pure food laws" were originally enacted during the medieval period. France passed a law in 1292, prohibiting the adulteration of beer [10]. Another food that was frequently adulterated was butter. The use of flowers, plants, or medications to alter the hue was outlawed by a Parisian Edict in 1396. According to historical records, bread seems to be the most tampered food in England during the medieval period. Laws governing its composition, price, and formation were in place as early as 1155. The penalties for selling tainted bread were harsh [11].

The history of tea dyeing in 18th century England is especially fascinating. Mineral salts were used to colour tea brought from China to England. Between 1780 and 1820, there was a noticeable increase in the occurrences of food adulteration using doubtful hues. This growth can be attributed to at least two factors. First, during this period, there was extensive distribution of business brochures and guidebooks with secret formulas explaining how colourants were added to foodstuffs. Second, this time period saw the birth of modern chemistry. As a result, the newly developed knowledge of chemistry was applied for food adulteration to increase profits by the food manufacturers and traders [12].

William Henry Perkin, an English scientist, discovered in 1856 that the pigment aniline derived from coal tar produced a purple tint (mauve). Soon, several of these synthetic colours were being used instead of minerals as food colouring. While, toxic mineral salts, were still utilized as food colours until the turn of the century [13]. The "Pure Food and Drug Act" was signed by the US President in 1906 [14]. The Secretary of Agriculture was authorized by this law to certify food colours, although this certification was entirely voluntary. This law, on the other hand, established the framework for the "Federal Food, Drug, and Cosmetic Act" in 1938, which mandated that food additives be certified.

Natural food colours of plant origin based on pigment

The four plant origin food colorants are mostly attributed to: anthocyanins (red-blue-purple), betacyanin (red), carotenoids (yellow-orange-red) and chlorophylls (green) [15]. The following section outlines some of the most important sources, properties, and challenges associated with using anthocyanins, betacyanins, carotenoids, and chlorophylls as colourants.

Anthocyanin

Several blue and red vegetables and fruits contain anthocyanins. The amount of anthocyanins in plants varies significantly depending on the variety, environment, agricultural methods, harvest time, light exposure, seasonal variations, ripening, temperature, and processing and storage [16].

Anthocyanins are an appealing alternative to synthetic chemicals because they are both safe and potentially beneficial to one's health. In many countries including Japan, Europe, and the United States, anthocyanins use as food pigment in food and beverages is extensively approved [17]. Anthocyanins have a dual benefit in addition to supplying colour to food. They have antioxidant properties, protecting the food to which they've been added and provide health benefits via enhancing the nutritional value of the food.

The stability of anthocyanins is not optimal, as they degrade quickly in the presence of metals, oxygen, light, enzymes, and other oxidants, and also with variation in temperature and pH [18, 19, 20, 21]. Additionally, in comparison to synthetic compounds, they are relatively costly. Anthocyanins obtained from red radish may cause off-flavors in food products, similar effects can also be expected from other sources of anthocyanins [22]. Food colourants that are from acylated anthocyanins are preferred over nonacylated anthocyanins because they are more stable [17].

Betacyanins

The red-violet betacyanin is one of the two types of betalains, the other type being yellow-orange betaxanthins. Betanin is the most common betacyanin found in plants. Betanin is a natural red food colourant (E162), permitted quantum satis, according to food additive regulations and is also used as a colourant in cosmetics and pharmaceuticals [23]. Beetroot was once thought to be the only source of betacyanin for culinary colouring. Other sources, such as *Ullucus tuberosus Basella rubra*, *Cactus pear*, red-purple pitaya *Hylocereus polyrhizus*, and *Amaranthus* species, have become more popular in recent years [15]. High glucosylation and acylation, high concentration of pigment, low pH, and low a_w, chelating agents, antioxidants, darkness, low temperature, and nitrogen environment all promote betalain stability [24]. Betalains are stable in the pH range of 3 to 7, with an optimum pH range of 4 to 6. This optimum was moved towards pH 6 as the temperature increased [25]. When contrasted to anthocyanins, betalains have the benefit of having a colour that is mostly unaffected by pH. Betalain pigments are water soluble and stable in the pH range of 3 to 7 and hence can be used to colour foods ranging from sour to neutral, but anthocyanins cannot be used because of their instability at pH values higher than 3 [26]. Colours in foods should remain stable during production and storage. Exogenous variables such as pH value, temperature, light, and oxygen affect the stability of betalains during food processing or storage, where chelating compounds and antioxidants might act as stabilizers [27].

Carotenoids

Orange, red and yellow colours in plant tissues are mainly due to presence of carotenoids pigment. The primary carotenoids present in food are β-carotene, α-carotene, β-cryptoxanthin, lycopene, lutein, and zeaxanthin [28, 29]. Orange-fleshed sweet potato, carrot, apricot, mango, cantaloupe, non-leafy and green leafy vegetables, few palm fruits, and squash cultivars, all have high levels of β-carotene. In carrots, palm fruits, pumpkins, and certain squashes, β-carotene is sometimes found alongside α-carotene. Many foods are high in lycopene, namely, tomatoes, watermelon, red-fleshed papaya, pink-fleshed guava, and pitanga fruit [30, 31]. Extensive research has been carried out to find out the factors that affect the carotenoid composition. The factors include the maturity level, the variety, the season, the location of the farm, and how the plant is harvested [15]. Carotenoids, β-carotene, annatto, paprika extract, lycopene and mixed carotenes are allowed to be used as colourant additives by the European Food Safety Authority (EFSA) and Food and Drug Administration (FDA). The carotenoids, namely, mixed carotenes, β-carotene, annatto, paprika extract, and lycopene are designated the E-numbers E160a (i), E160a (ii), E160b, E160c and (E160d (i) and (ii)) respectively by the EFSA [32]. Although the EFSA and FDA have approved carotenoids for use in food products, their stability may provide a challenge. Due to the abundance of unsaturated bonds in their structure, these compounds may oxidize in the presence of light, oxygen, and ambient temperature, resulting in colour shift [33]. The nature of the carotenoid and the food (root, fruit, puree, juice, leaf), disruption of the food matrix (sliced, peeled, shredded), light, oxygen, processing method and condition (specifically duration and temperature), and storage condition and duration, atmosphere, water content/activity, antioxidants, oxidizing enzymes, free radical initiators and pro-oxidants, and metal catalysts and inhibitors all affect carotenoid stability [34, 35, 36]. In comparison to other pigments like anthocyanins, carotenoids are more resistant to pH fluctuations [33].

Chlorophylls

Chlorophylls are the most prevalent pigments in nature, and they are the only ones accountable for the green colour observed in vegetal tissues; nonetheless, they have remained the least investigated natural colourants [37]. Chlorophyll *a*, *b*, *c*, *d*, and *e* are the five classes of chlorophylls present in plants; chlorophyll *a* and *b* are the most abundant in various plant tissues and fruits [33]. Thermally, chlorophyll *b* was shown to be more stable than chlorophyll *a* [38, 39]. Chlorophyll is primarily found in leaves, although it can also be found in fruits before the maturity process and the creation of other colours [40]. Green fruits also have a lot of chlorophyll throughout their existence [41]. Cucumber fruit (*Cucumis sativus* L.) and olive fruit (*Olea europaea* L.) have the highest chlorophyll content [42, 43]. Cultivation circumstances, temperature, and soil elements can all influence the proportion of chlorophylls (and other pigments), hence controlling the cultivation conditions is critical for standardizing the yield of natural colourants from fruits [42, 41]. Chlorophylls [E140 (i)] and chlorophyllins [E140 (ii)] derived from edible or non-edible plant material [e.g. grass, lucerne (*Medicago sativa* L.), or nettle (*Urtica dioica* L.)] can be utilized as natural colourants [44]. The stability of chlorophylls is influenced by acidic pH and high temperatures, which can result in the creation of various different derivatives, changing the colour from green to brown.

The representative images of the plant-based colourant sources of anthocyanins, betacyanins, carotenoids, and chlorophylls that are employed in food industry is presented in Table 1

Table 1: Sources of Plant-based Colorants in the Food Industry

Anthocynins	*Raphanus raphanistrum* (Red Radish)	
Betacyanins	*Beta vulgaris* (Beetroot)	
Carotenoids,	*Daucus carota* (Carrot)	

Chlorophylls	*Cucumis sativus* L. (Cucumber)	

Health Benefits

The health benefits of primary food colourants of plant origin are listed in Table 2.

Table 2: Health benefits of food colourants of plant origin based on pigment

Primary Food Colorant of Plant Origin	Colour	Health Benefits
Anthocyanins	Red, purple, and blue	Prevention of chronic diseases: cardiovascular disease (CVD) [45], anticancer effect [46], diabetes - improved dyslipidemia, prevented insulin resistance and enhanced antioxidant capacity in human subjects with type 2 diabetes [47], visual health [48], anti-obesity [49], antimicrobial activity [50]
Betacyanins	Red to red-violet betacyanins and yellow-orange betaxanthins	Prevents cancers like, lung cancer, skin cancer, *etc*., [51, 52], prevention of oxidative-stress related disorders: CVD, aging, neurodegenerative disorders [53, 54]
Carotenoids	From yellow, red to orange	Prevent and reduce the symptoms of many diseases like cancer, neurodegenerative diseases such as Alzheimer, cerebral ischemia, diabetes associated with obesity and hypertension, ophthalmic diseases and many more [55]
Chlorophylls	Green	Blood vessel support, antioxidant activity, role in healthy circulation and methylation [56], detoxification of the liver, combating bad odours, bad breath as well as body odour; due to the magnesium salts that it contains, purifying the blood and the organism, cleaning it of toxins [57].

Challenges of food colourants derived from plants

To assure quality and safety throughout the supply chain, industry-wide safety standards are required for the manufacturing, processing, application, and international trading of colours derived from natural sources [58]. Plant colourants are frequently made from crop-based foods or food by-products, and thus carry a microbial contamination risk. Figure 1 illustrates the safety and quality concerns associated with colours derived from plants namely, microbial contamination, heavy metals, pesticide residues and solvent residues.

Plant colourants are generally very concentrated and may contain natural or added microbial inhibitors or even solvent residues that interfere with assessments, making standard microbial testing procedures challenging [59].

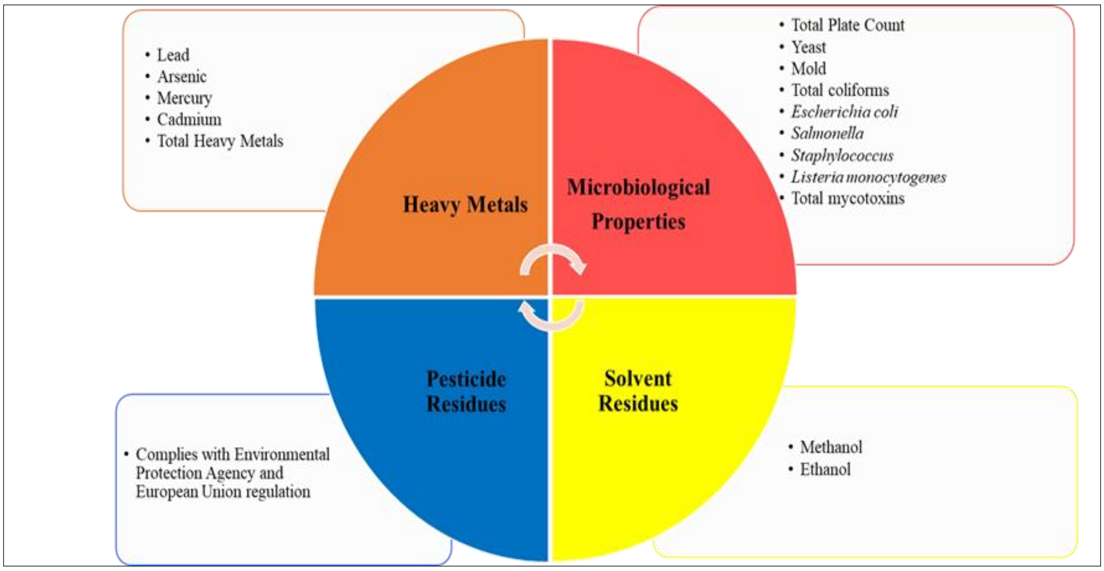

Fig 1: Safety and quality concerns associated with food colours derived from plants [59]

The potential of intentional adulteration is the most worrisome among the many risks linked with the colour industry. Although private laboratories may have established testing protocols for colour adulterants in certified colours, regulatory agencies would need to review, compare, validate, and publish these methods before adopting them as standard methods to ensure that no intentional adulteration occurs in the food industry. Natural compounds analytical chemistry is more complex and diversified than those of approved colours and moreover, the food industry may lack the skills or equipment needed to conduct extensive chemical characterizations on their own. Basic and advanced evaluations are performed using thin layer chromatography (TLC) and high performance liquid chromatography (HPLC), respectively. Both are frequently utilized in the creation of international standards as well as the identification and quality assessment of natural colour additives [59, 60]. The development of universal standards by an industry is a critical step in assuring the public's safety and quality of its ingredients. Natural colours are made from agricultural raw materials, and their complicated chemical makeup makes it difficult to agree on techniques of identification, analysis, or reference standards. Natural colours can vary significantly due to cultivar variances, ambient influences, handling conditions, and processing procedure, similar to difficulties with fruit juice authentication [59].

Conclusion

Plant-based food colourants are becoming more popular among consumers, however, they also face obstacles from the food sector when it comes to incorporating them into food products. Although plant-based colourants have the potential to replace synthetic colourants, they would require the optimization of processing conditions, research on alternative sources, and novel formulations to ensure stability in order to match their qualities. Despite the fact that natural food colourants have a significant advantage over synthetic pigments, their safety and overall impacts must be evaluated in order to definitively establish health benefits.

Acknowledgement

The authors would like to thank The Management, Krupanidhi Degree College, and Krupanidhi Research Incubation Centre (K-RIC), Krupanidhi Degree College for providing the resources and support in completing this work.

References

1. Delwiche JF. The impact of perceptual interactions on perceived flavor. Food Qual Prefer,2004:15:137-46.
2. Singh S. Impact of color on marketing. Manag. Decis,2006:44:783–789.
3. Food Colors Market Size, Share & Trend Analysis Report by Product (Synthetic, Natural), by Application (Non-Dairy Food, CSD & Non-Alcoholic Beverages), and Segment Forecasts, 2018–2025. Available online: https://www.grandviewresearch.com/press-release/global-food-colorants-market (accessed on 14 December 2021).
4. Martins N, Roriz CL, Morales P, Barros L. Ferreira, I.C.F.R. Food colorants: Challenges, opportunities and current desires of agro-industries to ensure consumer expectations and regulatory practices. Trends Food Sci,2016:52:1–15.
5. Burrows A. Palette of our palates: A brief history of food coloring and its regulation. Compr. Rev. Food Sci. Food Saf,2009:8(4):394–408.
6. McCann D, Barrett A, Cooper A, Crumpler D, Dalen L, *et al*. Food additives and hyperactive behaviour in 3-year-old and 8/9-year-old children in the community: a randomised, double-blinded, placebo-controlled trial. Lancet,2007:370(9598):1560–67.
7. Duangmal K, Saicheua B, Sueeprasan S. Roselle anthocyanins as a natural food colorant and improvement of its color stability. AIC Color and Paints, Interim Meeting of the International Color Association, 2004, 155-158.
8. Meena Devi, VN. Ariharan VN., Nagendra PP. Annato: Ecofriendly and potential source for natural dye. International Research Journal of Pharmacy,2013:4(6):106-108.
9. Aberoumand A. A review article on edible pigments properties and sources as natural biocolorants in foodstuff and food industry. World J Dairy Food Sci,2011:6:71–8.
10. AW. Blyth, Foods: Their Composition and Analysis, C. Griffin & Co. Ltd., London, 1909, 30.
11. FA Filby, A History of Food Adulteration and Analysis, Allen & Unwin Ltd., London, 1934, 73.
12. McKone HT. The history of food colorants before aniline dyes. Bull Hist Chem, 1991, 10:25–31.
13. National Academy of Sciences, Food Colors, Washington, DC, 1971, 2.
14. Barkan ID. "Industry invites regulation: the passage of the Pure Food and Drug Act of 1906". American Journal of Public Health,1985,75(1):18–26.
15. Rodriguez-Amaya DB. Natural Food Pigments and Colorants. In: Mérillon JM., Ramawat K. (eds.) Bioactive Molecules in Food. Reference Series in Phytochemistry. Springer, 2019, Cham.
16. Mattioli R, Francioso A, Mosca L, Silva P. Anthocyanins: A comprehensive review of their chemical properties and health effects on cardiovascular and neurodegenerative diseases. Molecules,2020:25(17):3809.
17. He J, Giusti MM. Anthocyanins: Natural colorants with health-promoting properties. Annu. Rev. Food Sci. Technol,2010:1:163–187.
18. Patras A, Brunton NP, O'Donnell C, Tiwari BK. Effect of thermal processing on anthocyanin stability in foods; mechanisms and kinetics of degradation. Trends Food Sci. Technol,2010:21:3–11.
19. Tiwari BK, O'Donnell CP, Cullen PJ. Effect of non-thermal processing technologies on the anthocyanin content of fruit juices. Trends Food Sci. Technol,2009:20:137–145.
20. Kırca A, Özkan M, Cemeroglu B. Effects of temperature, solid content and pH on the stability of black carrot anthocyanins. Food Chem,2007:101:212–218.
21. Jackman RL, Yada RY, Tung MA, Speers RA. Anthocyanins as food colorants? A review. J. Food Biochem,1987:11:201–247.
22. Sigurdson GT, Tang P, Giusti MM. Natural colorants: Food colorants from natural sources. Annu. Rev. Food Sci. Technol,2017:8:261–280.

23. Esatbeyoglu T, Wagner AE, Schini-Kerth VB, Rimbach G. Betanin—A food colorant with biological activity. Molecular nutrition & food research,2015:59(1):36-47.
24. Herbach KM, Rohe M, Stintzing FC, Carle R. Structural and chromatic stability of purple pitaya (*Hylocereus polyrhisus* [Weber] Britton & Rose) betacyanins as affected by the juice matrix and selected additives. Food Res Int,2006:39:667–677.
25. Havliková I, Miková K, Kyzlink V. Heat stability of betacyanins. Z Lebensm-Unters–Forsch,1983:177:247–250.
26. Strack D, Vogt T, Schliemann, W., Recent advances in betalain research. Phytochem,2003:62:247-269.
27. Herbach KM, Stintzing FC, Carle R. Betalain stability and degradation—Structural and chromatic aspects. J. Food Sci,2006:71:R41-R50.
28. Rodriguez-Amaya DB. Update on natural food pigments – a mini-review on carotenoids, anthocyanins, and betalains. Food Research International,2018:124:200–5.
29. Saini RK, Keum Y. Carotenoid extraction methods: A review of recent developments. Food Chemistry,2018:240:90–103.
30. Ishida BK, Turner C, Chapman MH, McKeon TA. Fatty acid and carotenoid composition of Gac (*Momordica cochinchinensis* Spreng) fruit. J Agric Food Chem,2004:52:274–279.
31. Vuong LT, Franke AA, Custer LJ, Murphy SP. *Momordica chochinchinensis* Spreng. (gac) fruit carotenoids reevaluated. J Food Compos Anal,2006:19:664–668.
32. EFSA. Scientific opinion on the re-evaluation of mixed carotenes (E 160a (I)) and Beta-Carotene (E 160a (II)) as a food additive. EFSA Journal,2012:10(3):2593.
33. Ngamwonglumlert L, Devahastin S, Chiewchan N. Natural colorants: Pigment stability and extraction yield enhancement via utilization of appropriate pretreatment and extraction methods. Critical Reviews in Food Science and Nutrition,2017:57(15):3243–59.
34. Hager TJ, Howard LR. Processing effects on carrot phytonutrients. Hort Sci,2006:41:74-79.
35. Shi I, le Maguer M. Lycopene in tomatoes: chemical and physical properties affected by food processing. Crit Rev Food Sci Nutr,2000:40:1–42.
36. Pénicaud C, Archir N, Dhuique-Mayer C, Dornier M, Bohuon P. Degradation of β-carotene during fruit and vegetable processing or storage: reaction mechanisms and kinetic aspects: a review. Fruits,2011:66:417–440.
37. Rodriguez-Amaya, D. B. Natural food pigments and colorants. Current Opinion in Food Science,2016:7:20–30.
38. Canjura FL, Schwartz SJ, Nunes RV. Degradation kinetics of chlorophylls and chlorophyllides. J Food Sci,1991:56:1639–1643.
39. Koca N, Karadeniz F, Burdurlu HS. Effect of pH on chlorophyll degradation and colour loss in blanched green peas. Food Chem,2006:100:609–615.
40. Viera I, Perez-Galvez A, Roca M. Green natural colorants. Molecules,2019:24(1):154.
41. Albuquerque BR, Oliveira MB, Barros L, Ferreira IC. Could fruits be a reliable source of food colorants? Pros and cons of these natural additives. Critical reviews in food science and nutrition,2021:61(5):805-35.
42. Shao S, SL Tan, Li H. Interactive effects of inoculated cucumber (*Cucumis sativus* L.) seedlings and saline soil. Communications in Soil Science and Plant Analysis,2016:47(4):1–13.
43. Gandul-Rojas B, MRL Cepero, MI. Mınguez-Mosquera. Chlorophyll and carotenoid patterns in olive fruits, *Olea europaea* cv. Arbequina. Journal of Agricultural and Food Chemistry,1999:47(6):2207–12.
44. EFSA. Scientific opinion on the re-evaluation of chlorophylls (E 140 (I)) as food additive. EFSA Journal,2015:15(5):60.
45. Alvarez-Suarez JM, Giampieri F, Tulipani S, *et al*. One month strawberry-rich anthocyanin supplementation ameliorates cardiovascular risk, oxidative stress markers and platelet activation in humans. J Nutr Biochem,2014:25(3):289–294.
46. Bontempo P, de Masi L, Carafa V, *et al*. Anticancer activities of anthocyanin extract from genotyped *Solanum tuberosum* L. "Vitelotte". J Funct Foods,2015:19:584–593.
47. Li D, Zhang Y, Liu Y, *et al*. Purified anthocyanin supplementation reduces dyslipidemia, enhances antioxidant capacity, and prevents insulin resistance in diabetic patients. J Nutr,2015:145(4):742–748.
48. Mok JW, Chang DJ, Joo CK. Antiapoptotic effects of anthocyanin from the seed coat of black soybean against oxidative damage of human lens epithelial cell induced by H_2O_2. Curr Eye Res,2014:39(11):1090–1098.
49. Wu T, Yu Z, Tang Q, *et al*. Honeysuckle anthocyanin supplementation prevents diet-induced obesity in C57BL/6 mice. Food Funct,2013:4:1654–1661.
50. Genskowsky E, Puente LA, Perez-Alvarez JA, *et al*. Determination of polyphenolic profile, antioxidant activity and antibacterial properties of maqui [*Aristotelia chilensis* (Molina) Stuntz] a Chilean blackberry. J Sci Food Agr,2016:96(12):4235–4242.
51. Dembitsky VM, Poovarodom S, Leontowicz H, Leontowicz M, Vearasilp S, Trakhtenberg S, Gorinstein S. The multiple nutrition properties of some exotic fruits: Biological activity and active metabolites. Food Research International,2011:44(7):1671-1701.
52. Stintzing FC, Carle R. Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. Trends in Food Science & Technology,2004:15(1):19-38.
53. Wu, L.-c., Hsu, H.-W., Chen, Y.-C., Chiu, C.-C., Lin, Y.-I and Ho, J.-a. A. Antioxidant and antiproliferative activities of red pitaya. Food Chemistry,2006:95(2):319-327.
54. Maigoda TC, Sulaeman A, Setiawan B, T Wibawan IW. Effects of red dragon fruits (*Hylocereus polyrhizus*) powder and swimming exercise on inflammation, oxidative stress markers, and physical fitness in male obesity rats (*Sprague dawley*). International Journal of Sciences: Basic and Applied Research,2016:25(1):123-141.
55. Bhatt T, Patel K. Carotenoids: potent to prevent diseases review. Natural products and bioprospecting,2020:10(3):109-17.
56. Minich DM. A review of the science of colorful, plant-based food and practical strategies for "eating the rainbow". Journal of Nutrition and Metabolism, 2019; Article ID 2125070.

57. Ferruzzi, M.G., Blakeslee, J. Digestion, absorption, and cancer preventative activity of dietary chlorophyll derivatives. Nutrition Research 2007, 27:1-12.
58. Lipp M, Chase CG. Chemical contaminants in foods: Health risks and public perception. Food Tech,2015:69:43–48.
59. Simon JE, Decker EA, Ferruzzi MG, Giusti MM, Mejia CD, Goldschmidt M, Talcott ST. Establishing standards on colors from natural sources. Journal of food science,2017:82(11):2539-53.
60. Cassinese C, de Combarieu E, Falzoni M, Fuzzati N, Pace R, Sardone N. New liquid chromatography method with ultraviolet detection for analysis of anthocyanins and anthocyanidins in *Vaccinium myrtillus* fruit dry extracts and commercial preparations. J AOAC Int,2007:90:911–9.
61. Sabuz AA, Khan MH, Rahman MT, Rana R, Brahma S. Stability of organic food colorant extracted from annatto seeds on food matrix. Int. J. Food Sci. Nutr. 2020;5:10-6.