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Review

Valorisation of food wastes to produce natural pigments using non-thermal novel extraction methods: a review

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Summary Waste or by-products produced during food processing can be used as a potential source of bioactive compounds including natural pigments. Natural pigments/colourants have numerous health benefits whereas the synthetic colourants have many negative effects on human health. Thus, there is a considerable interest worldwide in pigments extraction from natural sources. Conventional extractions such as soxhlet extraction, water distillation, and solvent extraction have many limitations such as large solvent consumption, long extraction time, and low extraction yields. Therefore, novel techniques such as high pressure, ultrasound, negative pressure and electric field have been employed to assist the pigment extraction process. The novel extraction methods are being developed with the primary aim of higher pigment yield, lower solvent consumption, minimised environmental effects and the convenience of extraction. With this perspective, the present review provides recent insights into the recovery of natural pigments from food wastes/by-products and the application of novel non-thermal technologies for their recovery.

Keywords Applications, food waste, natural pigment, non-thermal extraction.

Introduction

Food waste is very important for the sustainability and economic development of food systems. The nutrition security, quality, safety of foods and environmental protection are highly influenced by food waste. Food waste utilisation and management have fetched attention from research and industries in the last few decades (Otles *et al*., 2015). Food waste may contain several industrially important components such as polyphenols (Paes *et al*., 2014), bioactive compounds (Herrero *et al*., 2015), dietary fibre (Pereira *et al*., 2016a), pigments (Loypimai *et al*., 2015; Pereira *et al*., 2016b) and nutraceuticals (Galanakis, 2013). Several pigments are present in nature, and the chemical structure of some common pigments is shown in Fig. 1a.

Pigments are added to foods as additives to improve their appearance and occasionally quality as well; which goes against what Sant'Anna *et al*. (2013) declared, that colour is one of the major attributes that affect the consumer perception of food quality. In this way, food colourants are one of the prime additives used in food products to enhance the appeal or give a specific colour to them. The colourant used as a food additive may be synthetic, natural or natural identical. The role of natural food colouring agents such as carotenoids and anthocyanins is becoming increasingly important (Chedea *et al*., 2009; Loypimai *et al*., 2015). Besides contributing to the appearance value and quality evaluation, they also tend to yield potential positive health effects in functional foods thus increases consumer acceptance (Duangmal *et al*., 2008). The natural colourant 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 (Simpson *et al*., 2012). Synthetic colourants and their residual toxic chemicals are harmful to plants, animals and even human beings, and lead to cancer and mutation in adults and allergic dermatitis, hyperactivity problems in children (Shahram & Dinani 2019). Therefore, considering the above mentioned negative aspects

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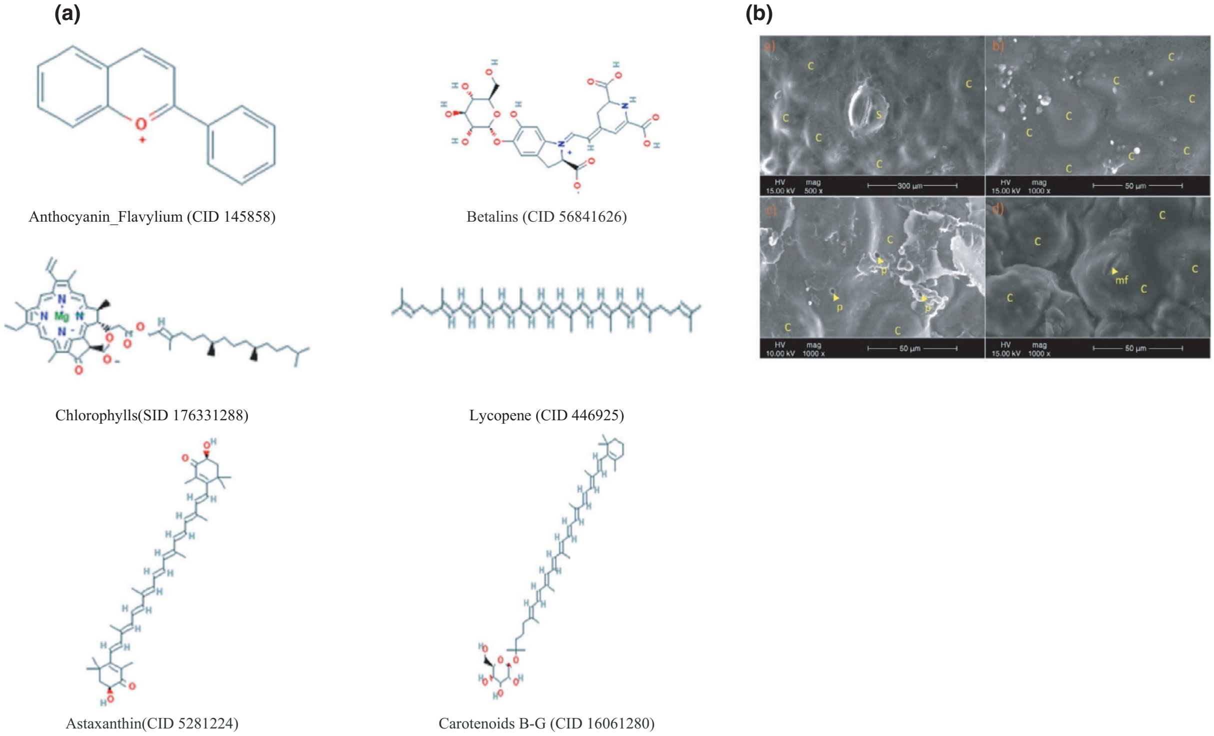

Figure 1 Chemical structure of some common natural pigments and disruption of tissue showing recovery of pigments. (a) The chemical structure of some common natural pigments (Source: National Center for Biotechnology Information (2021). https://pubchem.ncbi.nlm.nih.gov/compound). (b) SEM images indicating disruption in red prickly pear peels tissue during recovery of colorants (Koubaa *et al*., 2016)

of synthetic colourants, for human health and safety, environment friendliness, the addition of natural colourants in foods, cosmetics and pharmaceutical products is preferred as an alternative to synthetic colours (Maran *et al*., 2013). The major difficulty in using natural colourants lies in their availability as the primary sources of colourants (Velmurugan *et al*., 2010). Therefore, colourants may be recovered from the food waste that is generated during processing to overcome this problem.

Many researchers have studied the extraction, method of extraction, by-product utilisation during the colourant recovery from food waste, such as rice bran (Loypimai *et al*., 2015), grape pomace (Corrales *et al*., 2008), blueberry waste (Lee & Wrolstad, 2004), cranberry waste (Jun, 2006), tomato waste (Strati & Oreopoulou, 2011b; Catalkaya & Kahveci, 2019); orange waste (Chedea *et al*., 2009) and shrimp waste (Babu Madhu *et al*., 2008), crawfish waste for astaxanthin; orange waste (Kantifedaki *et al*., 2018)for β-carotene, etc.

The use of non-thermal processes for the extraction of natural pigments is ecofriendly and economical in long run. Hence, the aim of the present review was to evaluate the recently conducted studies on natural pigments from food waste by the application of emerging, non-thermal and novel extractions methods.

Colour measurement and pigments

Wide range of pigments are present in every plant which are responsible for providing the colour of plant material. Generally, pigments absorb light in the wavelength range of 350 and 770 nm (Sant'Anna *et al*., 2013) and the unabsorbed energy by chromophore is reflected or refracted which can be seen as colour by human eyes. The instrumental colour in food textiles and pharmaceutical items is primarily measured by the Hunter (*L*, *a*, *b*) and International Commission on Illumination (CIE) L^*, a^* and b^* colour measurement systems or colour space system, where L^* value represents the lightness (dark to white), a^* value indicates the colour from green to red and b^* value signifies the colour perception of blue to yellowness (Sant'Anna *et al*., 2013; Cheng *et al*., 2018). Colour is the primary quality characteristic of most food products for consumers. As the colour of any food or its product is generally due to the presence of pigments, therefore, pigments extracted from different food wastes are used in food industries and added to the food products to increase the appeal and acceptability of food products.

Pigments can be classified as natural or synthetic, natural pigments are those that are derived from natural matter of plants and animals while as synthetic colours are chemically synthesised in laboratories.

Natural pigments of animal source include the haeme pigments (Mb and Hb) which are the main colouring agents present in meats. Haeme compounds are responsible for oxygen transport and energy generations functions in animal tissues. They are soluble in water and provide red, purplish or brownish colour to the animal tissue (muscles) (Simpson *et al*., 2012). Carotenoids are abundant and widely available in nature, and they can be found in plants, animals or microbes such as orange, shrimps and carrot. Carotenoids are soluble in fat, and they provide colour range of bright red, orange and yellow (Sachindra *et al*., 2007). The photosynthetic organisms plants, algae and some bacteria contain chlorophyll pigments in their plastids, and these pigments tend to occur with the carotenoids (Macıas-Sánchez *et al*., 2005). Anthocyanins are present in various plant materials such as fruits and vegetables (such as grapes and cranberry), grains (rice bran) etc and some microbes. They provide red, blue and violet colour and can dissolve in water (Paes *et al*., 2014). A water-soluble colourless to yellow pigment compounds known as Anthoxanthins or commonly called as flavonoids are derived from plants or microorganisms. Betalains are red to yellow pigments soluble in water widely present in plants (Jayan *et al*., 2016; Utpott *et al*., 2020). The oxidation of polyphenolic compounds leads to the formations of brown or dark-coloured pigments in plants microbes and animals, and such pigments are known as Melanins. The bark of various plants/trees (sumac, oak etc.) contains yellow to brown or sometimes colourless pigment known as Tannins. Some microbes and plants contain quinones, which are pale yellow to dark brown or even black pigments. Some peculiar plant species such as *Clusiaceae*, *Podostemaceae* and *Bonnetiaceae* contain a yellow coloured pigment called as Xanthones (Simpson *et al*., 2012).

Both natural and synthetic pigments have wide industrial applications such as in food industries clothing, medicine, furniture as well as in cosmetics (Farooq *et al*., 2020). In plants, the natural pigment present in chlorophyll helps in photosynthesis whereas for human beings, natural pigments are important because they prevent various risky diseases like cancer and cardiovascular diseases (Duangmal *et al*., 2008; Chedea *et al*., 2009; Loypimai *et al*., 2015). The source of pigments used in food colouring (natural or synthetic) was not a concern for the consumers at the beginning of the food industry, but now people prefer natural pigments because of their various pharmacological benefits (Lee & Wrolstad, 2004; Loypimai *et al*., 2015).

Natural pigments are usually safe, non-carcinogenic, non-toxic, different types of natural plant pigments include anthocyanins, carotenoids, betalains and chlorophylls (Duangmal *et al*., 2008; Simpson *et al*., 2012; Loypimai *et al*., 2015). Researchers have reported the recovery of natural pigments from the food by-products and or waste (Table 1). Natural pigments are further subdivided into fat-soluble (carotenoids and chlorophylls) and water-soluble pigments (anthocyanins and anthoxanthins (flavonoids)). The most abundant pigments found in nature are chlorophylls and carotenoids, and the carotenoids act as antioxidants, membrane stabilisers and precursors to essential metabolites, such as vitamin A. Other than fruits, vegetables and some sea foods, carotenoids are also produced by various microbes like algae and fungi.

Industrial food waste and natural colourants

Food industries generate a lot of waste in the form of peels, seeds, whey and liquid waste such as apple pomace and grape pomace. The waste generated from different food industries usually has high water content as well as high biological oxygen demand and chemical oxygen demand which can lead to contamination (Lin *et al*., 2013). Also, this food waste may be rich in nutrients, antioxidants, colourants etc. and can be recovered from the waste, and Table 1 listed various wastes utilised for the recovery of naturally occurring pigments from them. Food waste is processed to recover many important components such as biofuels, organic acids, enzymes, nutraceuticals, dietary fibres and colourants (Galanakis, 2012). Biofuels such as bioethanol have been recovered from instant noodle waste (Yang *et al*., 2014). Biodiesel has been recovered from cooking oil waste using lipolytic enzymes (Seong *et al*., 2011), and many enzymes such as cellulase, amylase, phytase and lipase are also recovered from food waste (Narra *et al*., 2012; Kiran *et al*., 2014; Zhou *et al*., 2014; Ho, 2015). Bio actives and nutraceuticals such as fibre, vitamins and phytochemicals like tocopherols, polyphenols and nanoparticles can be recovered from rice bran which is a waste product of the rice milling industry (Irakli *et al*., 2015). Carotenoids can be derived from the peels of citrus fruits (Abad-García *et al*., 2012; He *et al*., 2013). Food and or agricultural wastes can be used to produce polyhydroxyalkanoates, such as Obruca *et al*. (2014) produced poly (3-hydroxybutyrate) (PHB) from the spent coffee waste. Shrimp shells, a by-product of the fish industry, is used for chitosan production, chitosan has antimicrobial activity, biocompatibility and biodegradability effect (Benhabiles *et al*., 2012), and fish waste has also been used to recover collagen which is a

Table 1 Food waste and by-products as a source of colourants

Source by-product/Waste	Pigment	References
Tomato waste; Orange and citrus peel; Carrot waste; Banana peel; Pineapple peel; Mango waste	Carotenoids	Baysal *et al.* (2000), Chedea *et al.* (2009), Strati and Oreopoulou (2011a, 2011b), Kumcuoglu *et al.* (2013), Strati *et al.* (2015), Kantifedaki *et al.* (2018), Catalkaya and Kahveci (2019), Shahram & Dinani (2019a)
Blueberry; Fig; Plum; Rice bran; Grape waste; Cranberry; Shrimp and crawl fish waste; Eggplant peel; Coffee exocarp	Anthocyanins	Parra-Campos & Ordóñez-Santos (2019), Todaro et al. (2009), Lee *et al.* (1999), Lee and Wrolstad (2004), Kammerer and Gajdos (2005), Corrales *et al.* (2008), Silveira *et al.* (2008), Mazza and Francis (2009), Paes *et al.* (2014), Loypimai *et al.* (2015), Parra-Campos and Ordóñez-Santos (2019)
Red pitaya; Beetroot peel and pomace	Betalains	Jayan *et al.* (2016), Utpott *et al.* (2020), Zin *et al.* (2020)
Nannochloropsisgaditana Botryococcusbraunii (microalga)	Chlorophylls	Macıas-Sánchez *et al.* (2005), Uquiche *et al.* (2016)

Pigment recovered	Waste/By-product	Interested findings	Reference
Anthocyanin	Blueberry	Results showed that there was not much effect on anthocyanin recovery due to enzyme treatment. Higher concentration of anthocyanins was extracted when heat, SO_2 and citric acid treatment were given in combination	Lee and Wrolstad (2004), Paes *et al.* (2014)
Anthocyanin	Coffee exocarp	The study concluded that coffee exocarp-extracted pigment has a great potential to replace the use of synthetic dyes in the manufacture of French meringue	Parra-Campos and Ordóñez-Santos (2019)
Astaxanthin	Crawfish	Results showed that when antioxidants BHA and santoquine were used, pigment concentration decreased 45% over 3 weeks. Levels of santoquine at 0.5% minimised pigment loss during storage	Parra-Campos & Ordóñez-Santos (2019), Todaro et al. (2009)
Anthocyanin	Cranberry	Results showed that 0.11% of anthocyanins were extracted on a dry weight basis	Woo and Amundson (1980)
Anthocyanin	Grape waste	Results showed that when normal technologies were applied, the antioxidant capacity of sample increased up to fourfolds and anthocyanins were selectively extracted	Lee and Wrolstad (2004), Paes *et al.* (2014)
Carotenoids	Orange waste	Findings showed that the yield and quality of the pectin did not affect by the removal of carotenoid from the orange peel	Aravantinos-Zafiris *et al.* (1992), Chedea *et al.* (2009), Kantifedaki *et al.* (2018)
Beta Carotene	Orange peel waste	The higher yield of beta carotene was extracted when ultrasound and the enzymatic process were used in combination	Shahram & Dinani (2019a)
Violet pigment	Pineapple waste	Results showed that a higher amount of violet pigment was obtained under static condition compared with shaking condition	Aruldass and Ahmad (2015)
Red colourant	Red prickly Pear (*Opuntia*) peel	Results showed that the higher yield of red pigment present in red prickly pear was obtained by using a pulsed electric field (PEF) and ultrasound-assisted extraction (UAE) followed by supplementary aqueous extraction	Koubaa *et al.* (2016)
Anthocyanin	Rice bran	Results showed that when the ohmic heating method was used for extraction of anthocyanin from rice bran, high yield of colourant was obtained. Compared with conventional methods, the colourant obtained by ohmic heating had the highest level of bioactive compounds present in it	Loypimai *et al.* (2015)
Anthocyanin	Red onion peels	Candy with 0.3% natural anthocyanins extracted from red onion peels was as much accepted as the once added with Allure (synthetic colour). The similar colour was observed in glazing jelly containing synthetic colour and 0.25% of the extracted natural anthocyanins	Ali *et al.* (2016)
Carotenoids	Shrimp waste	When 60% hexane was used in the solvent mixture, maximum yield of carotenoid was obtained	Sachindra *et al.* (2007)
Astaxanthin		91.9% pigments were recovered in the top layer; therefore, top layer was concentrated and then purified to get the maximum yield...	Lee *et al.* (1999)

Table 1 (*Continued*)

Pigment recovered	Waste/By-product	Interested findings	Reference
Carotenoids	Tomato waste	Results showed that by the application of ultrasound, carotenoid extraction yield increased and was higher when static pressure was increased	Baysal *et al.* (2000), Strati and Oreopoulou (2011a, 2011b), Strati *et al.* (2015)
Lycopene		Findings showed that lycopene was extracted in less time using ultrasound-assisted extraction(UAE) at lower temperature and less amount of solvent was used	Baysal *et al.* (2000), Kumcuoglu *et al.* (2013), Catalkaya and Kahveci (2019)

type of protein used in pharmaceutical, leather and cosmetic industries and has medical applications as well (Nagai & Suzuki, 2000).

Natural colourants have been recovered from tomato pomace, grape pomace, beetroots, shrimp waste and eggplant peel, which are the by-products of different industries such as fruit industries, fish industry and others. Carotenoids can be recovered from fruits and vegetable wastes such as carrot waste, orange peel waste and tomato waste by the process of extraction using organic solvents (Galanakis, 2012). Betalains can be extracted from beetroot waste. These colourants have different applications and many uses in different foods. Many important antioxidants, flavonoids and antioxidants have been recovered from various fruits and vegetable wastes such as citrus fruit wastes, potato peels and olive oil wastes. (Moure *et al*., 2001; Kantifedaki *et al*., 2018).

Extraction of pigments

Extraction is a process of transfer of one or more components of a feed from its source to a fluid phase. The process of extracting components from their source by using a solvent is called extraction. The source can be solid or even liquid. The component after extraction is then recovered from the solvent by the process of separation. For recovery of colourants from food waste, there are different methods of extraction which can be categorised into conventional and emerging methods.

Conventional methods

Conventional methods include the methods that have been used for a long time. Some conventional methods of extraction of colourants from food wastes include steam distillation, solvent extraction, water distillation, CO_2 extraction and soxhlet extraction. But these conventional methods are time-consuming and energy-consuming, consume a large amount of solvent required for extraction, represent in loss of nutrients and have many more disadvantages. Therefore, emerging methods of extraction have been developed to overcome the disadvantages of conventional methods.

Emerging natural pigment extraction methods

Several extraction methods are called emergent because they have not yet been used or are still little used at the commercial level. The advantages of the novel non-thermal and emerging approaches in pigments extraction when compared to that of conventional processes include the higher yield, less time and energy consumption, least qualitative damage to the pigments, minimal thermal degradation, green extraction approach with respect to use of hazardous solvents, environmentally friendly and or convenience. Table 2 presents studies conducted on the extraction of pigments by the application of various emerging and novel extraction methods. The main novel methods developed for the extraction of pigments are discussed below.

High-pressure extraction

Changes in the diffusivity coefficient caused by denaturation of colourant binding protein due to high pressure increases the permeability of cell membranes (Huixing, 2002) and has been reported to be responsible for the higher yield and lesser extraction times during high-pressure extraction of colourants from food waste. Also, when the pressure increases, solubility increases (Sadus, 2012); therefore, the level of positive pressure, duration, solid–liquid ratio and or temperature plays a critical role in the extraction process. The use of high pressure increases the transfer of compounds from food waste because of changes in the diffusivity coefficient thus reducing the processing times and enhancing the extraction. High pressure increases the diffusivity coefficient of the plant cell membrane which increases the permeability of the cell membrane and thus the extraction solvent can easily enter the cells of food waste (Tangwongchai *et al*., 2000). Pereira *et al*. (2020) optimized the extraction time (5–30 min), solvent solid ratio and pressure (0.1–600 MPa) during the high-pressure extraction of

Table 2 Application of different methods of extraction for the recovery of natural pigments

Extraction method	Material studied	Aim of the study	Outcomes	Reference
Ultrasonication	Orange processing waste	Optimisation of β-carotene	To observe the amount, antioxidant activity and colour parameters of carotenoids extracted	Shahram & Dinani (2019a)
MEF	Rice bran	Anthocyanins extraction	Increased yield recovery of colourant (anthocyanin)	Loypimai *et al*. (2015)
Pulsed electric field	Purple-fleshed potato	Anthocyanins extraction	Pulsed electric field was possible with water, a more environmental-friendly solvent than ethanol, without decreasing the anthocyanin yield	Puértolas *et al*. (2013)
High pressure	Elderberry (*Sambucus nigra L.*) *pomace*	Extraction of anthocyanins	By the application of high pressure, it is possible to obtain anthocyanin-rich extracts from elderberry pomace possessing high antioxidant activity	Seabra *et al*. (2010)
CO_2 depressurisation	*Botryococcusbraunii* (microalga)	Extraction of carotenoid and chlorophyll	Microscopic images showed partial cell disruption by rapid depressurisation improved the extraction of microalga compounds	Uquiche *et al*. (2016)
Microwave	Marine microalgae	Microalgal pigments extraction	Microwave-assisted extraction was identified well than conventional extraction as it combined rapidity, reproducibility, homogeneous heating and high extraction yields	Pasquet *et al*. (2011)
Supercritical fluid extraction	Fruit and vegetable waste	Carotenoids extraction	SFE is a viable method for the recovery of carotenoids from the fruit and vegetable waste, carotenoid-rich extracts obtained by SFE adds value to fruit and vegetable waste	de Andrade Lima *et al*. (2019)
Enzyme and high pressure	Tomato waste	Carotenoids extraction	To obtain increased yield recovery of carotenoids (lycopene)	Jun (2006), Strati *et al*. (2015)
Fermentation	Shrimp waste	Carotenoids	Fermentation was found to be superior to acid ensilaging with respect to stability and extractability of carotenoids from the shrimp waste	Sachindra *et al*. (2007)

phycobiliprotein pigment from red algae (Gracilaria gracilis) biomass. They recovered maximum of 1.27 mg/g biomass of red algae (*G. gracilis*) was obtained at 122 MPa in 10 min using solvent solid ratio of 4.09. High pressure resulte in denaturation of carotenoid binding protein resulting in damage of cell wall of food and therefore facilitates the extraction (Sánchez-Moreno *et al*., 2009).

Negative pressure extraction

A combined mechanism of cavitation, turbulence and collision has been reported to be responsible for higher yield in negative pressure extraction, shorter extraction time and low energy consumption during the negative pressure extraction of natural components (Khan *et al*., 2019). Negative pressure extraction can be used to extract colourants, polyphenols, polysaccharides, flavonoids and alkaloids from plants, fruits and vegetables (Liu *et al*., 2009). In negative pressure extraction, cavitation is formed by negative pressure resulting in the formation of bubbles which enhances the turbulence, collision and mass transfer between solid matrix and solvent resulting in the release of intracellular components into the extraction solvent (Li *et al*., 2009). Higher extraction efficiency can be achieved by negative pressure extraction in a shorter time with low energy consumption (Roohinejad *et al*., 2016).

Supercritical fluid extraction

Supercritical fluid extraction (SFE) is reported to be a selective extraction technique particularly for recovery of plant-based compounds. An increase in the diffusivity of the fluid due to supercritical conditions has been reported to be responsible for the higher yield during the SFE of colourants. The pressure and temperature play a significant role in the overall extraction process. Extraction of different fractions of rich and highly pure bioactive compounds such as pigments can be sequentially extracted with successive conditions, with respect to the physico-chemical characteristics of supercritical fluids, associated to temperature, pressure and addition of modifier/s (Lefebvre *et al.*, 2021). SFE technique was applied for carotenoid recovery from various carotenoid-rich fruit and vegetable wastes (including flesh and peels of sweet potato, tomato, apricot, pumpkin and peach, and the flesh and wastes of green, yellow and red peppers) by De Andrade Lima *et al.* (2019). The SFE conditions used (59 °C, 350 bar, 15 g min^{-1} CO_2, with 15.5% (v/v) ethanol as co-solvent and a total extraction time of 30 min) for the study were previously optimised for carotene extraction from carrot peel. The SFE process was able to extract 74–99% w/w carotenoids from a mixed sample of fruit and vegetable matrices. SFE has been reported to be a viable alternative to conventional solvent-based extraction techniques which adds value to zero or negative cost fruit and vegetable waste by recovering high-quality compounds (Viganó *et al.*, 2015).

Electric field-assisted extraction

Moderate electric field extraction. The moderate electric field (MEF) process has proven to be useful for improving the extraction of colourants from plants (Angersbach *et al.*, 2000; Vorobiev *et al.*, 2005; Vorobiev & Lebovka, 2006). In MEF extraction, the voltage applied across food material destroys the cell membrane and affects the permeability of the cell membrane causing rupture of the cell. MEF results in the electroporation of tissues, making cells permeable to exogenous molecules thereby increasing the extraction yield. Hence, the level of voltage gradient or electric field strength, frequency, shape of current wave (sine, triangular and square), temperature, electrical conductivity of solid and solvent plays a significant role during the MEF extraction process (Lebovka *et al.*, 2007; Makroo *et al.*, 2020). Moderate electric field-assisted extraction of anthocyanin from rice bran was evaluated by Loypimai *et al.* (2015). Promising results were observed in MEF extraction when compared with conventional (steam distillation) method with respect to colour, yield and concentration. The highest level of anthocyanin content was obtained in bran at 30% and 40% moisture content by applying electric field of 100–200 V cm^{-1} and 50–150 V cm^{-1}, respectively.

Pulsed electric field extraction. Pulsed electric field (PEF) is an emerging non-thermal technology used for the processing of food for shelf-life enhancement. However, it has been used for assisting in the extraction process also, during PEF, very high voltage is being passed through the medium in pulses for few microseconds. In PEF, electroporation of cytoplasmic membranes is caused by the application of external electric fields; thus, it promotes the modification of membrane permeability as a result, and the solutes present inside the cells are diffused easily (Nowacka *et al.*, 2019). The level of voltage in (kilo volts), pulse duration and frequency and total extraction time usually plays a significant role in process effectiveness of PEF-assisted extraction. The mechanism of electroporation of cytoplasmic membranes enhancing the diffusion of solutes located inside the cells is reported to be responsible for higher extraction yields, reduced solvent percentage and lesser extraction time during PEF extraction of colourants from food waste. The PEF technology has been observed to be successfully efficient during the recovery of betanin from red beetroots (Kannan, 2011). A pulse between 50 and 200 at 20 kV cm^{-1} was found to be insignificant with respect to betanin recovery; however, the plant tissue begins to fragment at 300 pulses at 20 kV cm^{-1}, and the plant tissue starts to be fragmenting; therefore, 50 pulses at 20 kV cm^{-1} were adequate for an effective colourant extraction without the tissue damage. Pulsed electric field-assisted extraction has proven to improve the extraction of valuable compounds from plant materials (Donsì *et al.*, 2010). As indicated in Fig. 1b, the PEF treatment disrupted plant tissue which leads to the higher recovery of pigment during PEF assisted extraction. Therefore, many authors have studied PEFs, as an alternative method and effective method for the recovery of biomolecules from plant matrices (Koubaa *et al.*, 2016). Hydrophilic compounds such as sugar from the sugar beet, betalain from the red beet, and anthocyanins from grapes, red cabbage, or purple fleshed potatoes can be extracted using PEF treatment (Corrales *et al.*, 2008; Gachovska *et al.*, 2010). The quality of the products does not change as there is no involvement of temperature in PEF treatment (Dobreva *et al.*, 2010).

Ultrasonication assisted extraction

Ultrasonication-assisted extraction (UAE) involves transferring a substance from any matrix to a liquid phase assisted by sound waves. In food industries, ultrasonication extraction is highly used for extraction of components from waste (Barba *et al.*, 2015). The use of ultrasound on food can increase the emulsifying capacity of foods and can break the particles apart and enhance foaming (ŠicŽlabur *et al.*, 2015). This powerful technique is used for the extraction of colourants from food waste, as the pigments are efficiently separated by using UAE. Goula *et al.* (2017) extracted carotenoids from pomegranate peels using US in presence of different oils. The carotenoid yield was evaluated with respect to extraction time, temperature, amplitude level and solid oil ratio. The extraction process was best explained by second order model. The highest yield of 0.6715 mg per 100 g dry peels was obtained using sunflower oil as extraction medium in 30 min time at 51.5 °C, using 1:10 peel oil ratio and amplitude level of 58.8%. Similarly, Shahram and Dinani (2019) studied US-assisted enzyme extraction of β carotene from orange waste. The best yield, colour and antioxidant activity of the extract were obtained in 115.5 min at 5.11 pH using US of 20 kHz at power of 500 W. It was also observed that combination of US and enzyme treatment had a combined effect on the quality and quantity of the β carotene recovery. Ultrasound-assisted extraction provides economical extraction (Maran, & Priya, 2014, 2015; Ganesh Moorthy *et al.*, 2015). Because of higher tissue damage, UAE enhances extraction efficiency and reduces the time of extraction and processing temperature (Fig. 1b). The process parameters that play important role in US-assisted extraction includes frequency, power intensity, amplitude, time and temperature; however, the type of sonication setup viz probe and bath also may have effect on the extraction process in terms of extraction yield, convenience, time etc. A combined mechanism of cavitation, high shear stress and physical destruction of cell components have been reported to be responsible for the higher yield during the US-assisted extraction of natural components (Chemat *et al.*, 2017).

Application and uses

There are many applications and uses of natural colourants recovered from food waste. Natural food colourants not only provide identity to foods and make food appealing to the consumers but also improve its nutritive quality and taste. Additionally, the colourants protect the flavours and vitamins present in food from the damage caused by light. Natural colourants extracted from food waste have been used in many food applications. Such as anthocyanins are used in drinks, jams and sugar confectionery; chlorophyll and betalain can be used in confectionery and dairy products; and carotenoids can be used in soft drinks, margarine and dairy products etc. An example of increasing application in the global carotenoid market that is projected to register an annual growth rate of 4% from 2018 to 2023 as the demand for carotenoids has been consistently increasing. With nearly 42% of the world market, Europe has the leading market followed by 25% and 20% by North America and Asia, respectively (Intelligence, 2018). In addition to food application, natural pigments have many non-food applications too. Such as the pomegranate juice containing cyanin (flavylium) was utilised as the light-harvesting analogue in a dye-sensitised solid-state photovoltaic cell by Sirimanne *et al.* (2006).

Conclusion and future directions

Pigments are present in plants, fruits and vegetables, and their incorporation in food products is increasing to enhance the appeal and health benefits. Pigments can be extracted from different food wastes by the process of extraction. Conventionally used techniques such as soxhlet extraction, steam distillation, water distillation and solvent extraction are time-consuming methods, and the pigments can be sensitive to these conventional treatments due to the high temperature, the long processing time, high amounts of solvent used and low yield. Therefore, novel extraction methods such as supercritical fluid, enzyme assisted, PEF, MEF and negative pressure have been developed to overcome the limitations of conventional methods. Novel methods of extraction are less time-consuming; less solvent is used, ecofriendly and sustainable, the low-temperature range is used, and extraction yield is high, but these methods also have some disadvantages such as equipment cost is too high, low possibility of scale-up and industrial application. However, the emerging process may have some lacunas in one way or the other; thus, suitability of specific method to extract a particular pigment depends on various parameters. Such as pigment with polar structure (water soluble) may get damaged during electric field-based extraction methods such as PEF and MEF. Similarly, thermal damage needs to be taken into consideration during US and MEF-based methods where temperature rise may occur if the process is not controlled appropriately. Hence, pressure-based technologies are suitable for heat-sensitive pigments whereas electric field-based methods are suitable for non-polar pigments. Further investigation should target the development of inexpensive equipment, safer and tailor-made processes. Integral studies should be conducted which not only includes recovery procedures but also specific applications to secure the sustainability of final products. The goal of applying emerging technologies should be to optimise overall efficiency.

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There is no conflict of interest to disclose.

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The author elects to not share data as this is a review paper.

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