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REVIEW

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Food waste: a potential bioresource for extraction of nutraceuticals and bioactive compounds

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Abstract

Food waste, a by-product of various industrial, agricultural, household and other food sector activities, is rising continuously due to increase in such activities. Various studies have indicated that different kind of food wastes obtained from fruits, vegetables, cereal and other food processing industries can be used as potential source of bioactive compounds and nutraceuticals which has significant application in treating various ailments. Different secondary metabolites, minerals and vitamins have been extracted from food waste, using various extraction approaches. In the next few years these approaches could provide an innovative approach to increase the production of specific compounds for use as nutraceuticals or as ingredients in the design of functional foods. In this review a comprehensive study of various techniques for extraction of bioactive components citing successful research work have been discussed. Further, their efficient utilization in development of nutraceutical products, health benefits, bioprocess development and value addition of food waste resources has also been discussed.

Keywords: Bioactive compounds, Food waste, Nutraceuticals, Extraction, Diseases

Background

Food waste is produced in all the phases of food life cycle, i.e. during agricultural production, industrial manufacturing, processing and distribution. Up to 42% of food waste is produced by household activities, 39% losses occurring in the food manufacturing industry and 14% in food service sector (ready to eat food, catering and restaurants), while 5% is lost during distribution. Food waste is expected to rise to about 126 Mt by 2020, if any prevention policy or activities are not undertaken (Mirabella et al. 2014). It can be achieved through the extraction of high-value components such as proteins, polysaccharides, fibres, flavour compounds, and phytochemicals, which can be re-used as nutraceuticals and functional ingredients (Baiano 2014).

Attempts have been made broadly for the past few decades to develop methods and find different ways to utilise fruit and vegetable wastes therapeutically. Generally, agro-industrial wastes have been used extensively as animal feeds or fertilisers. Recent reports shows development of high value products (such as cosmetics, foods and medicines) from agro-industrial by-products (Rudra et al. 2015).

Natural bioactive compounds are being searched for the treatment and prevention of human diseases. These compounds efficiently interact with proteins, DNA, and other biological molecules to produce desired results, which can then be used for designing natural therapeutic agents (Ajikumar et al. 2008). There is growing interest of consumers towards food bioactives that provide beneficial effects to humans in terms of health promotion and disease risk reduction. Detailed information about food bioactives is required in order to obtain appropriate functional food products (Kumar 2015).

Nutraceuticals are medicinal foods that play a role in enhancing health, maintaining well being, improving immunity and thereby preventing as well as treating

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specific diseases. Phytochemicals have specific role and can be used in different forms, e.g. as antioxidants and have a positive effect on human health. Recently, lot of attention has been given to phytochemicals that possess cancer preventive properties (Kumar and Kumar 2015). Nowadays, there is growing trend in the food industry toward the development and manufacture of functional and nutraceutical products. This new class of food products have got huge attention in food market due to the increased consumer interest for "healthy" food. Hence, pharmaceutical and food domains have common interest to obtain new natural bioactive components which can be used as drugs, functional food ingredients, or nutraceuticals (Joana Gil-Chávez et al. 2013). Bioactives from food waste can be extracted and utilized for development of nutraceuticals and functional foods. This review describes the utilization of different extraction techniques for extraction of bioactives and nutraceuticals from food waste and their uses in prevention of chronic and lifestyle diseases.

Food waste as a source of bioactive compounds

Bioactive compounds comprise an excellent pool of molecules for the production of nutraceuticals, functional foods, and food additives (Joana Gil-Chávez et al. 2013). Fruits and vegetables represent the simplest form of functional foods because they are rich in several bioactive components. Fruits containing polyphenols and carotenoids have been shown to have antioxidant activity and diminish the risk of developing certain types of cancer (Day et al. 2009). The vegetable waste includes trimmings, peelings, stems, seeds, shells, bran and residues remaining after extraction of juice, oil, starch and sugar. The animal-derived waste includes waste from dairy processing and seafood industry. The recovered biomolecules and by-products can be used to produce functional foods in food processing or in medicinal and pharmaceutical preparations (Baiano 2014). Bioactive phytochemicals like sterols, tocopherols, carotenes, terpenes and polyphenols extracted from tomato by-products contain significant amounts of antioxidant activities. Therefore, these value adding components isolated from such waste can be used as natural antioxidants for the formulation of functional foods or can serve as additives in food products to extend their shelf-life (Kalogeropoulos et al. 2012).

The bioactive compounds present in mango peel are phenolic compounds, carotenoids, vitamin C and dietary fibre. It has been well recognized that these compounds contribute to lower the risk of cancer, cataracts, Alzheimer's disease and Parkinson's disease (Ayala-Zavala et al. 2010). Wastes from wine making industry include biodegradable solids namely stems, skins, and seeds. Bioactive compounds from winery by-products have been shown to improve health promoting activities both in vitro and in vivo. These compounds act as effective agents for prevention of degenerative processes through their incorporation into functional foods, nutraceuticals, and cosmetics (Teixeira et al. 2014). These are commonly utilized for the production of pharmaceuticals and as food additives to increase the functionality of foods (Ayala-Zavala et al. 2010). Citrus is the most abundant fruit crop in the world. Its one-third of the crop is processed. Oranges, lemons, grapefruits and mandarins represent approximately 98% of the entire industrialized crop. Citrus fruits are processed, not only to obtain juice, but also, in the canning industry to produce jam and segments of mandarin.

Lemes et al. (2016) reported bioactive peptides as the new generation of biologically active regulators that can prevent oxidation and microbial degradation in foods, and might be helpful in treatment of various diseases. These can be extracted from residual waste and incorporated into value added products. Their encapsulated form may be utilized in a controlled manner for efficient use in human body. Development of suitable techniques for large-scale recovery and purification of peptides will increase their applications in pharmaceutical and food industries.

Pujol et al. (2013) investigated the chemical composition of exhausted coffee waste generated in a soluble coffee industry and found that total polyphenols and tannins represent <6 and <4% of the exhausted coffee wastes, respectively. Zuorro and Lavecchia (2012) extracted total phenolic content of 17.75 mg gallic acid equivalent GAE (gallic acid equivalents)/g from spent coffee grounds (SCG) collected from coffee bars and 21.56 mg GAE/g from coffee capsules unloaded from an automatic espresso machine. Mussatto et al. (2011) optimised the extraction of antioxidant phenolic compounds from SCG and found that extraction using 60% methanol in a solvent/solid ratio of 40 ml/g SCG, for 90 min, was the most appropriate condition to produce an extract with 16 mg GAE/g SCG of phenolic compounds having high antioxidant activity, i.e. Ferric reducing antioxidant power (FRAP) of 0.10 mM Fe(II)/g). Rebecca et al. (2014) extracted the amount of caffeine from used tea leaves of black, white, green and red tea using dichloromethane as solvent and found that caffeine content was maximum (60 mg/100 g) in green tea and minimum in red tea (3 mg/100 g). Some of the bioactive components found in different food waste residues are summarized in Table 1.

Extraction technologies for bioactive compounds from food waste

Bioactive components present in agro-industrial waste can be recovered using various techniques. Availability of these techniques provides an opportunity for optimal use

Table 1 Bioactive components in different industrial food waste residues

S. no.	Source	Residue	Bioactive components	References
Fruits				
1.	Apple	Peel and pomace	Epicatechin, catechins, anthocyanins, quercitin glycosides, chlorogenic acid, hydroxycinnamates, phloretin glycosides, procyanidins	Wolfe and Liu (2003), Foo and Lu (1999), Lu and Foo (1997)
2.	Avocado	Peel and seeds	Epicatechin, catechin, gallic acid, chlorogenic acid, cyanidin 3-glucoside, homogentisic acid	Deng et al. (2012)
3.	Banana	Peel	Gallocatechin, anthocyanins, delphindin, cyaniding, catecholamine	Someya et al. (2002), Kanazawa and Sakakibara (2000), González-Montelongo et al. (2010)
4.	Citrus fruits	Peel	Hesperidin, naringin, eriocitrin, narirutin	Coll et al. (1998)
5.	Grapes	Seed and skin	Coumaric acid, caffeic acid, ferulic acid, chlorogenic acid, cinnamic acid, neochlorogenic acid, *p*-hydroxybenzoic acid, protocatechuic acid, vanillic acid, gallic acid, proanthocyanidins, quercetin 3-*o*-gluuronide, quercetin, resvaratrol	Shrikhande (2000), Negro et al. (2003), Maier et al. (2009)
6.	Guava	Skin and seeds	Catechin, cyanidin 3-glucoside, galangin, gallic acid, homogentisic acid, kaempferol	Deng et al. (2012)
7.	Litchi	Pericarp, seeds	Cyanidin-3-glucoside, cyanidin-3-rutonoside, malvidin-3-glucoside, gallic acid, epicatechin-3-gallate	Lee and Wicker (1991), Duan et al. (2007)
8.	Mango	Kernel	Gallic acid, ellagic acid, gallates, gallotannins, condensed tannins	Arogba (2000), Puravankara et al. (2000)
9.	Palm	By-products of palm oil milling	Tocopherols, tocotrienols, sterols, and squalene, phenolic antioxidants	Tan et al. (2007), Choo et al. (1996)
10.	Pomegranate	Peel and pericarp	Gallic acid, cyanidin-3,5-diglucoside, cyanidin-3-diglucoside, delphinidin-3,5-diglucoside	Noda et al. (2002), Gil et al. (2000)
Vegetables				
11.	Carrot	Peel	Phenols, beta-carotene	Chantaro et al. (2008)
12.	Cucumber	Peel	Chlorophyll, pheophytin, phellandrene, caryophyllene	Zeyada et al. (2008)
13.	Potato	Peel	Gallicacid, caffeic acid vanillic acid	Zeyada et al. (2008)
14.	Tomato	Skin and pomace	Carotenoids	Strati and Oreopoulou (2011)
Cereal crops				
15.	Barley	Bran	β-Glucan	Sainvitu et al. (2012)
16.	Rice	bran	γ-Oryzanol, bran oil	Perretti et al. (2003), Oliveira et al. (2012)
17.	Wheat	Bran and germs	Phenolic acids, antioxidants	Wang et al. (2008)

of any of these for recovery of specific compounds. Based on literature survey, the extraction techniques for bioactive compounds are mainly based on solvent extraction (SE), supercritical fluid extraction (SFE), subcritical water extraction (SCW), use of enzymes, ultrasounds and microwaves. In the following sections, these techniques have been discussed independently in reference to recent studies.

Solvent extraction technique

In this extraction approach, the suitably sized raw material is exposed to different organic solvents, which takes up soluble components of interest and also other flavouring and colouring agents such as anthocyanins which are anti-cancerous and anti-inflammatory (Vyas et al. 2009, 2014) (Fig. 1). Samples are usually centrifuged and filtered to remove solid residue, and the extract could be used as additive, food supplement or for the preparation of functional foods (Zulkifli et al. 2012). Solvent Extraction is beneficial compared to other methods due to low processing cost and ease of operation. However, this method uses toxic solvents, requires an evaporation/concentration step for recovery, and usually calls for large amounts of solvent and extended time to be carried out. Moreover, the possibility of thermal degradation of natural bioactive components cannot be ignored due to the high temperatures of the solvents during the long times of extraction. Solvent extraction has been improved by other methods such as Soxhlet's, ultrasound, or microwave extraction and SFE in order to obtain better yields (Szentmihályi et al. 2002).

Baysal et al. (2000) utilized ethanol for extraction of Lycopene and β-carotene from tomato pomace containing dried and crushed skins (rich in lycopene and carotenes) and seeds of the fruit along with supercritical CO_2 for resulting in recoveries of up to 50%. Gan and Latiff (2011) studied the extraction of polyphenolic compounds from *Parkia speciosa* pod powders using 50% acetone solution. They concluded that that 50% acetone yielded the highest content of polyphenols compared to methanol, ethanol, ethyl-acetate and hexane. Safdar et al. (2016) extracted and quantified polyphenols from kinnow (*Citrus reticulate* L.) peel. Maximum polyphenols were extracted with 80% methanol (32.48 mg GAE/g extract) using ultrasound assisted extraction, whereas, minimum phenolics (8.64 mg GAE/g extract) were obtained with 80% ethyl acetate through the maceration technique.

Bandar et al. (2013) found that out of the various organic solvents used in their study, ethanol was the most efficient one, producing the highest extraction yield and hexane gave the lowest yield in extracting bioactive compounds by these methods. Further they found that there was an increase in the yield of extracted compounds with increasing extraction time.

Supercritical fluid extraction

Supercritical fluid extraction is an environment friendly technology and is commonly used for extraction of bioactive compounds from natural sources such as plants, food by-products, algae and microalgae. Supercritical carbon dioxide (SC-CO_2) is an attractive alternative to organic solvents as it is non explosive, non-toxic and inexpensive. It possesses the ability to solubilise lipophilic substances, and can be removed easily from the final products (Wang and Weller 2006).

During the process of extraction, raw material is placed in an extraction container equipped with temperature and pressure controllers to maintain the required conditions. Following this, the extraction container is pressurized with the fluid by a pump. Once the fluid and dissolved compounds are transported to separators, the products are collected through a tap located in the lower part of the separators. Finally, the fluid is regenerated and cycled or released to the environment. Selection of supercritical fluids is very important for proper functioning of this process and a wide range of compounds can be used as solvents in this technique (Sihvonen et al. 1999).

Giannuzzo et al. (2003) found that SC-CO_2 modified with ethanol gave higher extraction yields of naringin (flavonoid) from citrus waste than pure SC-CO_2 at 9.5 MPa and 58.6 °C. Ashraf-Khorassani and Taylor (2004) extracted polyphenols and procyanidins from grape seeds using SFE, where, methanol was used as modifier and methanol modified CO_2 (40%) released more than 79% of catechin and epicatechin from grape

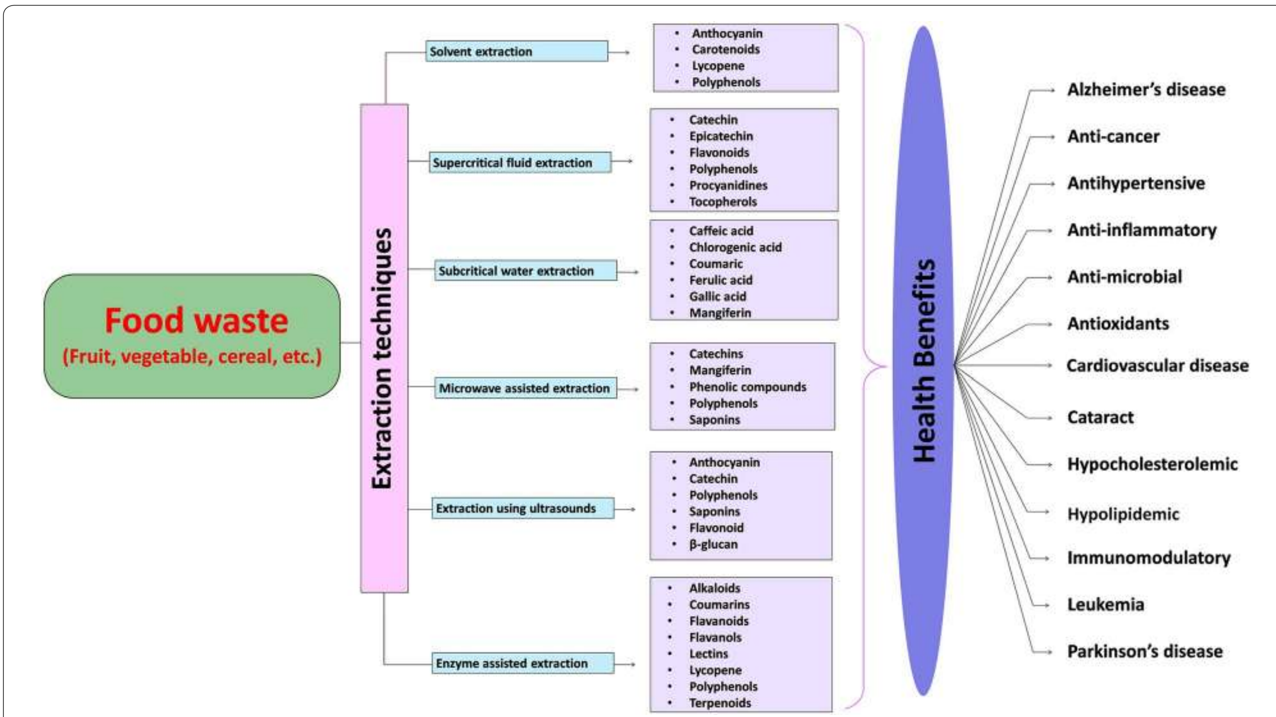

Fig. 1 A schematic representation of different techniques for extraction of bioactive compounds from food wastes and their health benefits

seed. Liza et al. (2010) studied the feasibility of the SFE method to extract lipophilic compounds such as tocopherols, phytosterols, policosanols and free fatty acids from sorghum and the preventive role of these compounds in many diseases (skin, cardiovascular, coronary heart diseases, and cancer).

Farías-Campomanes et al. (2015) extracted polyphenols (gallic, protocatechuic, vanillic, syringic, ferulic derivatives and p-coumaric derivatives) and flavonoids (quercetin and its derivatives) from Lees generated from pisco-making process with SFE at 20 MPa and 313 K. Jung et al. (2012) carried out extraction of oil from wheat bran which is a rich source of antioxidants using SC-CO_2 and Soxhlet extraction. Pressure and temperature ranged from 10 to 30 MPa and 313.15–333.15 K, respectively during SC-CO_2 extraction. It was observed that oil obtained by SC-CO_2 extraction had higher resistance against oxidation and higher radical scavenging activity compared to hexane extracted oil. Wenzel et al. (2016) extracted phenolic compounds from black walnut (*Juglans nigra*) husks using SC-CO_2 with an ethanol modifier. The optimal extraction conditions were 68 °C and 20% ethanol in SC-CO_2.

Ahmadian-Kouchaksaraie and Niazmand (2017) used the SC-CO_2 for the extraction of antioxiant compounds from *Crocus sativus* petals at 62 °C for 47 min and 164 bar pressure. Extraction using these optimized conditions resulted in recovery of 1423 mg/100 g total phenolics, 180 mg/100 g total flavonoid and 103.4 mg/100 g total anthocyanin content. Wang and Weller (2006) described supercritical method as a significant substitute to conventional extraction methods using organic solvents for extracting biologically active compounds.

Some of the conditions used for the extraction, recovery and characterization of bioactive compounds from food and plants using SC-CO_2 are summarized in Table 2.

Subcritical water extraction

Subcritical water extraction is a growing alternative technology for extraction of phenolic compounds from different foods. Subcritical water refers to water at temperature between 100 and 374 °C and a pressure which is high enough to maintain the liquid state (below the critical pressure of 22 MPa). Main advantages of SCW over conventional extraction techniques are shorter extraction time, lower solvent cost, higher quality of the extraction and environment-friendly (Herrero et al. 2006). SCW is the most promising engineering approach that offers an environmentally friendly technique for extracting various compounds from plants and algae (Zakaria and Kamal 2016).

Tunchaiyaphum et al. (2013) extracted phenolic compounds from mango peels using SCW. The amount of phenolic compounds from mango peels using SCW extraction was higher than that using Soxhlet extraction technique. Therefore, SCW extraction is an alternative green technology for phenolic compounds extraction from agricultural wastes, which substitute conventional method using organic solvents.

Rangsriwong et al. (2009) studied the use of SCW for extraction of polyphenolic compounds from *Terminalia chebula Retz.* fruits and it was found that the amounts of extracted gallic acid and ellagic acid increased with an increasing in subcritical water temperature up to 180 °C, while the highest amount of corilagin was recovered at 120 °C. Kim et al. (2010) extracted mangiferin, a pharmacological active component from *Mahkota Dewa* using subcritical water extractiont at temperatures range of 323–423 K and pressures 0.7–4.0 MPa with extraction times ranging from 1 to 7 h.

Singh and Saldaña (2011) extracted eight phenolic compounds (gallic acid, chlorogenic acid, caffeic acid, protocatechuic acid, syringic acid, *p*-hydroxyl benzoic acid, ferulic acid, and coumaric acid) from potato peel using subcritical water. Phenolic compounds were recovered highest (81.83 mg/100 g fresh wt.) at 180 °C and extraction time of 30 min. Chlorogenic acid (14.59 mg/100 g) and gallic acid (29.56 mg/100 g) were the main phenolic compounds obtained from potato peel at 180 °C. It was concluded that subcritical water at 160–180 °C, 6 MPa and 60 min might be a good substitute to organic solvents (such as methanol and ethanol) to obtain phenolic compounds from potato peel.

Ahmadian-Kouchaksaraie et al. (2016) investigated subcritical water extraction as a green technology for the extraction of phenolic compounds from *Crocus sativus* petals. The optimum conditions of extraction were of 36 ml/g (water to solid ratio) 159 °C temperature and an extraction time of 54 min. Subcritical water extraction using these optimized conditions leads to extraction of 1616 mg/100 g total phenolics, 239 mg/100 g total flavonol content and 86.05% 2,2-diphenyl-1-picrylhydrazyl (DPPH).

Ko et al. (2016) enhanced production of individual phenolic compounds by subcritical water hydrolysis in pumpkin leaves by varying temperatures from 100 to 220 °C at 20 min and also by varying reaction times from 10 to 50 min at 160 °C. Caffeic acid, *p*-coumaric acid, ferulic acid, and gentisic acid were the major phenolic compounds in the hydrolysate of pumpkin leaves. Mayanga-Torres et al. (2017) utilized two abundant coffee waste residues (powder and defatted cake) for extraction of total phenolic compounds using subcritical water under semi-continuous flow conditions. The highest total phenolic compounds (26.64 mg GAE/g coffee powder) was recovered at 200 °C and 22.5 MPa.

Table 2 Extraction, recovery and characterization of bioactive compounds using supercritical fluid extraction

S. no.	Sources	Temperature (°C)	Pressure (Bar)	Co-solvent	Bioactive compounds	References
Fruits						
1.	Blueberry residue	40	150–300		Anthocyanins	Paes et al. (2013)
2.	Apricot pomace	39.85–59.85	304–507	Dimethoxy propane	Carotenoids	Sanal et al. (2004)
3.	Red grape residue	45	100–250	Methanol	Pro-anthocyanidins	Louli et al. (2004)
4.	Citrus peel	58.6	95	Ethanol	Naraingin	Giannuzzo et al. (2003)
5.	Grape by products	35	400	Ethanol	Resveratrol (19.2 mg/100 g)	Casas et al. (2010)
6.	Banana peel	40–50	100–300		Essential oils	Comim et al. (2010)
7.	Grape peel	37–46	137–167	Ethanol	Phenolic, anti-oxidants, anthocyanins	Ghafoor et al. (2010)
8.	Orange peel	19.85–49.85	80–280		Limonene and linalool	Mira et al. (1999)
9.	Guava seeds	40–60	100–300	Ethyl acetate,	Phenolic compounds	Castro-Vargas et al. (2010)
10.	Apricot by products	59	310	Ethanol	β-Carotene	Sanal et al. (2005)
11.	Pistachio hull	45	355	Methanol	Polyphenols (7810 mg GAE/100 g	Goli et al. (2005)
Vegetable						
12.	Tomato waste	40–80	200–300		Trans-lycopene	Nobre et al. (2009)
13.	Tomato skin	75	350	Ethanol	Carotenoids	Shi et al. (2009)
14.	Sweet potato waste	40–80	350		Beta-carotene and alpha tocopherol	Okuno et al. (2002)
15.	Carrot press cake	55	345	Ethanol	β-Carotene	Vega et al. (1996)
Others						
16.	Green tea leaves	60	310	Ethanol	Catechins	Chang et al. (2000)
17.	Tea seed cake	80	200	Ethanol	Kaempferol glycosides (11.4 mg/g)	Li et al. (2010)
18.	Spearmint leaves	40–60	100–300	Ethanol	Flavonoids	Bimakr et al. (2009)

There are number of advantages of SCW extraction over traditional extraction techniques used, such as higher quality of the extracts, lower extraction times, lower costs of the extracting agent, and an environment friendly technique (Joana Gil-Chávez et al. 2013).

Enzyme assisted extraction

There is wide use of enzymes for extraction of bioactive components from food wastes. The main sources for extraction of antioxidants are plant tissues. Plant cell walls contain polysaccharides such as cellulose, hemicellulose, and pectins which act as barriers to the release of intracellular substances. Enzymes such as cellulase, β-glucosidase, xylanase, β-gluconase, and pectinase help to degrade cell wall structure and depolymerize plant cell wall polysaccharides, facilitating the release of linked compounds (Moore et al. 2006; Singh et al. 2016). Because of using water as a solvent instead of organic chemicals, the enzyme assisted extraction is recognized as more eco-friendly technology for extraction of bioactive compounds and oil (Puri et al. 2012).

Zuorro et al. (2011) studied the enzyme-assisted extraction of lycopene from the peel fraction of tomato processing waste and found that the recovery of lycopene could be greatly improved by the use of mixed enzyme preparations with cellulolytic and pectinolytic activities, and the comparatively low cost of commercial food-grade enzyme preparations, having possible implementation on industrial scale. Puri et al. (2012) studied the enzyme-assisted extraction of bioactive compounds stevioside from *Stevia rebaudiana* from plant sources particularly for food and nutraceutical purposes. Reshmitha et al. (2017) prepared lycopene rich extracts by enzyme assisted extraction of tomato peel using cellulase (20 units/g) and pectinase (30 units/g) at 50 °C for 60 min.

These studies suggested that the release of bioactive compounds from plant cells by cell disruption and extraction can be optimized using enzyme preparations either alone or in mixtures. Enzyme-assisted extraction is a promising alternative to conventional solvent-based extraction methods. It is based on the ability of enzymes to catalyze reactions, under mild processing conditions, in aqueous solutions (Gardossi et al. 2010).

Extraction using ultrasounds

Ultrasound-assisted extraction is considered as a simpler and more effective technique compared to traditional extraction methods for the extraction of bioactive compounds from natural products. Ultrasound induces a greater diffusion of solvent into cellular materials, thus improving mass transfer and also disrupts cell walls, thus facilitating the release of bioactive components. Extraction yield is greatly influenced by ultrasound frequency, depending on the nature of the plant material to be extracted (Wang et al. 2008).

Wang et al. (2011) used ultrasound-assisted extraction to extract three dibenzylbutyrolactone lignans (including tracheloside, hemislienoside, and arctiin) from *Hemistepta lyrata*. High-performance liquid chromatography was used for simultaneous determination of the target compounds in the corresponding extracts.

Rostagno et al. (2003) studied extraction efficiency of four isoflavone derivatives, i.e. glycitin, daidzin, genistin, and malonyl genistin from soybean with mix-stirring method using different extraction times and solvents. Use of ultrasound was found to improve the extraction yield depending on solvent use. Ghafoor et al. (2011) extracted anthocyanins and phenolic compounds from grape peel using ultrasound-assisted extraction technique. Bimakr et al. (2013) also applied the ultrasound-assisted extraction technique for the extraction of bioactive valuable compounds from winter melon (*Benincasa hispida*) seeds.

Piñeiro et al. (2016) optimised and validated ultrasound-assisted extraction for rapid extraction of stilbenes from grape canes. By this method, stilbenes in grape canes was extracted 10 min only using extraction temperature of 75 °C and ethanol (60%) as the extraction solvent. It was concluded that grape cane by-products were potential sources of bioactive compounds of interest for pharmaceutical and food industries.

Aguiló-Aguayo et al. (2017) studied the effect of ultrasound technology in extract of water soluble polysaccharides from dried and milled by-products generated from *Agaricus bisporus*. β-Glucan were obtained in amounts of 1.01 and 0.98 g/100 g dry mass in particle sizes of 355–250 and 150–125 µm, respectively, from the mushroom by-products. The highest extraction yield of 4.7% was achieved with an extraction time of 15 min, amplitude of 100 µm with 1 h of precipitation in 80% ethanol.

Microwave assisted extraction

Microwave-assisted extraction (MAE) is a new extraction technique that combines microwave and traditional solvent extraction. It is an advantageous technique due to shorter extraction time, higher extraction rate, less requirement of solvent and lower cost over traditional method of extraction of compounds (Delazar et al. 2012). The main advantage of MAE over ultrasonic assisted extraction and Soxhlet extraction is that, it can be used to extract plant metabolites at a shorter time interval (Afoakwah et al. 2012). Padmapriya et al. (2012) extracted mangiferin present in *Curcuma amada* with the help of MAE using ethanol as a solvent. The mangiferin content was reportedly increased until 500 W, but decreased as the microwave power was increased further. An optimal mangiferin yield of 41 µg/ml was obtained from an extraction time of 15.32 s for a microwave power of 500 W. Kerem et al. (2005) extracted saponins from chickpea (*Cicer arietinum*) using MAE and found this method superior over Soxhlet extraction with regard to amounts of solvents required, time and energy expended. The pure chickpea saponin exhibited significant inhibitory activity against *Penicillium digitatum* and additional filamentous fungi (Fig. 1).

Kulkarni and Rathod (2016) extracted mangiferin from the *Mangifera indica* leaves by microwave assisted extraction conditions using water as a solvent. The maximum extraction yield of 55 mg/g was obtained at extraction time 5 min, solid to solvent ratio 1:20 and microwave power of 272 W. In comparison to the sequential batch extraction and Soxhlet extraction, MAE increased the yield of extraction in a short span of time and also reduced the solvent requirement as compared to the conventional methods.

Smiderle et al. (2017) studied MAE and pressurized liquid extraction (PLE) as advanced techniques to obtain polysaccharides (particularly biologically active β-glucans) from *Pleurotus ostreatus* and *Ganoderma lucidum* fruiting bodies and detected β- and α-glucans and heteropolysaccharides in all extracts. In an interesting study, Filip et al. (2017) optimized MAE by response surface methodology in order to enhance the extraction of polyphenols from basil (*Ocimum basilicum* L). Optimal conditions for extraction were 50% ethanol, microwave power of 442 W, and an extraction time of 15 min. Under these conditions, obtained basil liquid extract contained 4.299 g GAE/100 g of total polyphenols and 0.849 g catechin equivalents/100 g DW of total flavonoids.

Therefore, it can be concluded that microwave assisted method has many advantages compared with other methods due to its higher extraction efficiency, reduced extraction time, less labor and high extraction selectivity which makes it a favourable method in extraction of bioactive compounds (Bandar et al. 2013).

Comparative evaluation of different extraction technologies for recovery of bioactive compounds

Zhang et al. (2005), compared a number of extraction methods for the recovery of alkaloids from fruit of *Macleaya cordata* (Willd) R. Br. The techniques used include maceration, ultrasound-assisted extraction (UAE), MAE and percolation. The method of MAE was found to be the most effective method capable of yielding 17.10 ± 0.4 mg/g sanguinarine and 7.04 ± 0.14 mg/g chelerythrine with 5 min of extraction time. They further concluded that the alkaloid content of the fruit shell was much greater than that of seed.

Corrales et al. (2008) extracted bioactive substances from grape by-products such as anthocyanins which can be used as natural antioxidants or colouring agents. They studied the effect of heat treatment at 70 °C combined with the effect of different novel technologies such as high hydrostatic pressure (600 MPa) (HHP), ultrasonics (35 kHz) and pulsed electric fields (3 kV cm^{-1}) (PEF). After 1 h extraction, the total phenolic content of samples subjected to novel technologies was 50% higher than in the control samples. They further concluded that the application of novel technologies increased the antioxidant activity of the extracts with PEF fourfold, with HHP three-fold and with ultrasonics two-fold higher than the control extraction carried out in a water bath incubated at a temperature of 70 °C for 1 h.

Plaza et al. (2011) studied the effect of different extraction technologies on extraction of bioactive compounds of orange juice. Juice was treated by high pressure (HP) (400 MPa/40 °C/1 min), pulsed electric fields (PEF) (35 kV cm^1/750 ms) and low pasteurization (LPT) (70 °C/30 s). They extracted various bioactive compounds such as lutein, zeaxantin, α and β-cryptoxanthin, α and β-carotene, naringenin and hesperetin from grape juice. It was concluded that HPT was the most effective treatment for extraction of bioactive components from orange juice with highest recovery of bioactive components from orange juice followed by PEF and LPT.

Drosou et al. (2015) compared the extraction yield of air dried Agiorgitico red grape pomace by-products by three different extraction methods using water, water: ethanol (1:1) and ethanol as solvents. The methods included the conventional Soxhlet extraction, MAE and ultrasound assisted extraction (UAE). They concluded that UAE water: ethanol extracts were found to be rich in phenolic compounds (up to 438,984 ppm GAE in dry extract).

Jayathunge et al. (2017), investigated the influence of moderate intensity pulsed electric field pre-processing on increasing the lycopene bioaccessibility of tomato fruit, and the combined effect of blanching, ultrasonic and high intensity pulsed electric field processing on further enhancement of the lycopene bioaccessibility after juicing. They concluded that only the treatment of blanching followed by high intensity pulsed electric field showed a significant release of *trans*-(4.01 ± 0.48) and *cis*-(5.04 ± 0.26 lg/g) Lycopene. They further concluded that processing of pre-blanched juice using high intensity pulsed electric field, derived from pre-processed tomato was the most excellent approach to achieve the highest nutritive value.

Kehili et al. (2017) extracted lycopene and carotene as oleoresin from a Tunisian industrial tomato peels by-product using supercritical CO_2 and solvent extraction using hexane, ethyl acetate and ethanol. Supercritical CO_2 extraction resulted in a lycopene extraction of 728.98 mg/kg of dry tomato peels under processing conditions of 400 bar, 80 °C and 4 g CO_2/min for 105 min. Solvent extraction of lycopene using overnight maceration with hexane, ethyl acetate and ethanol yielded 608.94 ± 10.05 mg/kg, 320.35 and 284.53 mg/kg of dry tomato peels, respectively. They further concluded that SC-CO_2 extraction method resulted in a higher lycopene production as compared to solvent extraction under the above mentioned processing conditions.

Espinosa-Pardo et al. (2017) extracted total phenolic contents (TPC) from the pomace generated in the industrial processing of orange (*Citrus sinensis*) juice in Brazil by SFE method. Process was carried out at pressures of 15, 25 and 35 MPa and temperatures of 40, 50 and 60°C, using pure ethanol and ethanol: water (9:1 v/v) as co-solvents. They observed that high pressures improved the recovery of TPC (18–21.8 mg GAE/g dry extract) from pomace. They further observed that the use of ethanol 90% as co-solvent enhanced the extraction of antioxidant compounds. Finally, it was concluded that biotransformation process improved the TPC and provided extracts with higher antioxidant activities.

Some of the methods, optimum conditions and yield of some bioactive compounds from different food wastes are summarized in Table 3.

Use of bioactive compounds as nutraceuticals and functional foods for human health

Being health related compounds, bioactive compounds are known to lower the risk of developing various diseases like cancer, alzheimer, cataracts and parkinson, among others. These beneficial effects have been attributed mainly to their antioxidant and radical scavenging activities which can delay or inhibit the oxidation of DNA, proteins and lipids. Indeed, these compounds have also shown antimicrobial effects, playing an important role in fruits' protection against pathogenic agents, penetrating the cell membrane of microorganisms, causing lysis (Ayala-Zavala and González-Aguilar 2011).

An imbalance between the production of reactive oxygen species (ROS), and their eradication by defensive mechanisms in our body creates oxidative stress. Antioxidant systems of our body detoxify the reactive intermediates and results in reduction of oxidative stress

(Al-Dalaen and Al-Qtaitat 2014). ROS can be divided into free radicals and non-radicals. Molecules containing one or more unpaired electrons are called free radicals whereas non-radical forms are created when two free radicals share their unpaired electrons. The three major ROS of physiological importance are superoxide anion (O_2^-.), hydroxyl radical (.OH), and hydrogen peroxide (H_2O_2) (Birben et al. 2012). There should be interaction between free radicals, antioxidants and co-factors for maintaining health and prevention from aging and age-related diseases. Oxidative stress caused by free radicals is balanced by the endogenous antioxidant systems of our body which get strengthened by the intake of exogenous antioxidants with an input from co-factors. Production of free radicals in excess of the defensive effects of antioxidants and some co-factors causes oxidative damage which gets accumulated during life cycle resulting in aging, and chronic diseases such as cancer, cardiovascular diseases, neurodegenerative disorders, and other life style diseases (Rahman 2007).

Free radicals generated in the body during normal metabolic functions affect the vital cellular structures and functions resulting in various degenerative diseases. These free radicals are deactivated by antioxidant enzymes that catalyze oxidation/reduction reactions and serve as redox biomarkers in various human diseases along with controlling the redox state of functional proteins. Redox regulators with antioxidant properties related to active intermediates, cell organelles, and the neighbouring environments are involved in diseases related to redox imbalance including neurodegenerative diseases, aging cancer, ischemia/reperfusion injury and other lifestyle diseases (Yang and Lee 2015).

Nutraceuticals are usually consumed in pharmaceutical preparations such as pills, capsules, tablets, powder, and vials (Espín et al. 2007). Núñez Selles et al. (2016) reportred that Mangiferin (1,3,6,7-tetrahydroxyxanthone-C2-β-D-glucoside), a natural bioactive xanthonoid found in many plant species such as mango tree (*Mangifera indica* L) has attracted the attention of research groups around the World for cancer treatment. Single administration of mangiferin or in combination with known anticancer chemicals has shown the potential benefits of this molecule in brain, lung, cervix, breast and prostate cancers, and leukemia besides its antioxidant and anti-inflammatory properties.

Meat industry by-products such as brains, nervous systems and spinal cords are a source of cholesterol, which after extraction are used for the synthesis of vitamin D3 (Ejike and Emmanuel 2009). Chávez-Santoscoy et al. (2016) studied the the health promoting benefits of flavonoids and saponins from black bean seed coats. The effect of adding flavonoids and saponins from black bean seed coat to whole wheat bread formulation was resulted in retention of more than 90% of added flavonoids and saponins, and 80% of anthocyanins in bread after baking. Use of such breads rich in these health promoting compounds might have significant health consequences.

In the production of rolled oats, phenolic compounds derived from natural sources such as benzoin, catechin, chlorogenic acid, and ferulic acid, mixed with the other ingredients prior to extrusion might obtain products more resistant to oxidation (retardation of hexanal formation). Although processing resulted in a 24–26% reduction of the amount of the phenolic compounds added (Viscidi et al. 2004). Lozano-Sánchez et al. (2017) reported that olive by-product, so called "pâté," generated during a modern two-phase centrifugal processing technique can be used as a natural source of bioactive compounds. It was characterized by the presence of hydroxytyrosol, β-hydroxyverbascoside, oleoside derivative, luteolin etc., as potential ingredients for nutraceuticals preparations or feed industry.

Conclusion and future prospects

As an indication, various reports of diverse array of bioactive compounds from specific food residues and availability of highly sensitive measurement tools provide a great opportunity to quantify metabolites in different range of food waste materials. Based on higher quantity of specific bioactive components, a food waste by-product could be utilized for its extraction using any of approaches discussed above. Utility of extraction methods is evident based on various reports and supercritical fluid extraction technology was proved to be very useful. A suitable extraction method could be adopted based on outcome of optimization process. Development of a bioprocess with better efficiency of bioactive component recovery will not only add value to the food waste but also be useful in reducing cost of formulated products and decreasing the use of synthetic chemicals in such formulations. With increasing setup of food processing industries and post harvest losses of fruits and vegetables, the increasing amount of food and agriculture waste is available and its utilization as a source of bioactive compounds will increase the financial status of farmers and decrease the burden of waste management. Improvement in extraction technology with lesser or no use of solvent will be of great significance towards a sustainable bioprocess.

Moreover, in India, the discarded portion of industrial waste is very high and it creates a serious waste disposal problem. Organic wastes generated from industries are hazardous to the environment and can be used as a potential bioresource for extraction of bioactive

Table 3 Comparative evaluation of different extraction techniques for extraction of bioactive compounds

S. no.	Bioactive component	Sources	Method	Extraction solvent used	Optimum conditions	Yield	References
1.	Alkaloid (sanguinarine)	*Macleaya cordata*	Maceration	Hydrochloric acid	100 °C/30 min	16.87[a]	Zhang et al. (2005)
			MAE	Hydrochloric acid	280 W/5 min	17.10	
			UAE	Hydrochloric acid	250 W/30 min	10.74	
			Percolation	Hydrochloric acid and sodium hydroxide	–	6.14	
2.	Anthocyanin	Grape	WE	Water	70 °C	7.93[b]	Corrales et al. (2008)
			Ultrasonics	Water and ethanol	600 MPa	7.76	
			HHP	Water and glycol	35 kHz	11.21	
			PEF	Water and ethanol	3 kV cm^{-1}	14.05	
3.	Hesperetin	Orange	LPT	–	70 °C/30 s	11.56[f]	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	13.34	
			PEF	–	35 kV cm^1/750 ms	11.09	
4.	Lutein	Orange	LPT	–	70 °C/30 s	226.42[e]	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	361.17	
			PEF	–	35 kV cm^1/750 ms	260.86	
5.	Lycopene	Tomato waste	SFE	Liquid CO_2	400 bar/80 °C/4 g CO_2/min/105 min	728.98[c]	Kehili et al. (2017)
			SE	Hexane	–	608.94	
				Ethyl acetate	–	320.35	
				Ethanol	–	284.53	
6.	Naringenin	Orange	LPT	–	70 °C/30 s	3.87[e]	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	4.43	
			PEF	–	35 kV cm^1/750 ms	3.42	
7.	Total phenolic	Red grape pomace	SE	Water	Refluxing for 2–3 h	96,386[d]	Drosou et al. (2015)
				Ethanol	Refluxing for 5–6 h	102,995	
			UAE	Water	25 kHz/300 W/20 °C/60 min	50,959	
				Water and ethanol	25 kHz/300 W/20 °C/60 min	438,984	
			MAE	Water	50 °C/200 W/60 min	52,645	
				Water and ethanol	50 °C/200 W/60 min	200,025	
8.	Total phenolic content	Orange pomace (dry)	SFE	Pure ethanol	25 MPa and 60 °C	21.2[g]	Espinosa-Pardo et al. (2017)
				Ethanol:water-9:1	25 MPa and 60 °C	20.7	
		Orange pomace (fermented)	SFE	Pure ethanol	25 MPa and 60 °C	19.0	
				Ethanol:water-9:1	25 MPa and 60 °C	47.0	
9.	Zeaxantin	Orange	LPT	–	70 °C/30 s	259.95[g]	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	408.56	
			PEF	–	35 kV cm^1/750 ms	278.70	
10.	α-Carotene	Orange	LPT	–	70 °C/30 s)	25.04[g]	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	38.06	
			PEF	–	35 kV cm^1/750 ms	26.64	
11.	α-Cryptoxanthin	Orange	LPT	–	70 °C/30 s	93.99	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	167.26	
			PEF	–	35 kV cm^1/750 ms	101.52	

components. The present review ascertains how the use of different technologies can result into the extraction of bioactive compounds which can be used as nutraceuticals and dietary supplements. The replacement of environmentally troublesome organic solvents in such extraction techniques, with green and safe solvents such as CO_2, ethanol, and water is the main objective of this review. Steps should be taken to help build a more rational use of our natural resources. A detailed economic analysis of these extraction techniques will help setting up

Table 3 continued

S. no.	Bioactive component	Sources	Method	Extraction solvent used	Optimum conditions	Yield	References
12.	β-Carotene	Orange	LPT	–	70 °C/30 s	32.72[g]	Plaza et al. (2011)
			HPT	–	400 MPa/40°C/1 min	53.78	
			PEF	–	35 kV cm[1]/750 ms	33.74	
13.	β-Cryptoxanthin	Orange	LPT	–	70 °C/30 s	235.21[g]	Plaza et al. (2011)
			HPT	–	400 MPa/40 °C/1 min	330.07	
			PEF	–	35 kV cm[1]/750 ms	230.53	

HHP high hydrostatic pressure, *HPT* high-pressure treatment, *LPT* low pasteurization treatment, *MAE* microwave assisted extraction, *PEF* pulsed electric field, *SE* solvent extraction, *WE* water extraction

[a] mg/g sample; [b]mg Cy-3-glu eq. g^{-1} dry matter; [c]mg/kg'; [d]ppm GAE in dry extract of air dried grape pomace; [e]µg/100ml; [f]mg/100ml; [g]GAE/g of extract

commercial units, thereby establishing a commercial use for such residues. This will help in complete utilization of the industrial waste thereby providing extra compensation to the industries by sale of residues and will also help in eradicating environmental pollution caused by the poor dumping of industrial food waste.

Authors' contributions

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Competing interests

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References

Afoakwah A, Owusu J, Adomako C, Teye E (2012) Microwave assisted extraction (MAE) of antioxidant constituents in plant materials. Glob J Biosci Biotechnol 1:132–140

Aguiló-Aguayo I, Walton J, Viñas I, Tiwari BK (2017) Ultrasound assisted extraction of polysaccharides from mushroom by-products. LWT Food Sci Technol 77:92–99

Ahmadian-Kouchaksaraie Z, Niazmand R (2017) Supercritical carbon dioxide extraction of antioxidants from *Crocus sativus* petals of saffron industry residues: optimization using response surface methodology. J Supercrit Fluids 121:19–31

Ahmadian-Kouchaksaraie Z, Niazmand R, Najafi MN (2016) Optimization of the subcritical water extraction of phenolic antioxidants from *Crocus sativus* petals of saffron industry residues: Box-Behnken design and principal component analysis. Innov Food Sci Emerg Technol 36:234–244

Ajikumar PK, Tyo K, Carlsen S, Mucha O, Phon TH, Stephanopoulos G (2008) Terpenoids: opportunities for biosynthesis of natural product drugs using engineered microorganisms. Mol Pharm 5:167–190

Al-Dalaen S, Al-Qtaitat A (2014) Review article: oxidative stress versus antioxidants. Am J Biosci Bioeng 2:60–71

Arogba SS (2000) Mango (*Mangifera indica*) kernel: chromatographic analysis of the tannin, and stability study of the associated polyphenol oxidase activity. J Food Compos Anal 13:149–156

Ashraf-Khorassani M, Taylor LT (2004) Sequential fractionation of grape seeds into oils, polyphenols, and procyanidins via a single system employing CO_2-based fluids. J Agric Food Chem 52:2440–2444

Ayala-Zavala JF, González-Aguilar GA (2011) Use of additives to preserve the quality of fresh-cut fruits and vegetables. CRC Press, Boca Raton, pp 231–254

Ayala-Zavala J, Rosas-Domínguez C, Vega-Vega V, González-Aguilar G (2010) Antioxidant enrichment and antimicrobial protection of fresh-cut fruits using their own by products: looking for integral exploitation. J Food Sci 75:R175–R181

Baiano A (2014) Recovery of biomolecules from food wastes-a review. Molecules 19:14821–14842

Bandar H, Hijazi A, Rammal H, Hachem A, Saad Z, Badran B (2013) Techniques for the extraction of bioactive compounds from Lebanese Urtica Dioica. Am J Phytomed Clin Ther 6:507–513

Baysal T, Ersus S, Starmans D (2000) Supercritical CO_2 extraction of β-carotene and lycopene from tomato paste waste. J Agric Food Chem 48:5507–5511

Bimakr M, Rahman RA, Taip FS, Chuan L, Ganjloo A, Selamat J, Hamid A (2009) Supercritical carbon dioxide (SC-CO_2) extraction of bioactive flavonoid compounds from spearmint (*Mentha spicata* L.) leaves. Eur J Sci Res 33:679–690

Bimakr M, Abdul Rahman R, Taip FS, Mohd Adzahan N, Sarker ZI, Ganjloo A (2013) Ultrasound-assisted extraction of valuable compounds from winter melon (*Benincasa hispida*) seeds. Int Food Res J 20:331–338

Birben E, Sahiner UM, Sackesen C, Erzurum S, Kalayci O (2012) Oxidative stress and antioxidant defense. World Allergy Org J 5:9–19

Casas L, Mantell C, Rodríguez M, de la Ossa EM, Roldán A, De Ory I, Caro I, Blandino A (2010) Extraction of resveratrol from the pomace of *Palomino* fino grapes by supercritical carbon dioxide. J Food Eng 96:304–308

Castro-Vargas HI, Rodríguez-Varela LI, Ferreira SR, Parada-Alfonso F (2010) Extraction of phenolic fraction from guava seeds (*Psidium guajava* L.) using supercritical carbon dioxide and co-solvents. J Supercrit Fluids 51:319–324

Chang CJ, Chiu K-L, Chen Y-L, Chang C-Y (2000) Separation of catechins from green tea using carbon dioxide extraction. Food Chem 68:109–113

Chantaro P, Devahastin S, Chiewchan N (2008) Production of antioxidant high dietary fiber powder from carrot peels. LWT Food Sci Technol 41:1987–1994

Chávez-Santoscoy RA, Lazo-Vélez MA, Serna-Sáldivar SO, Gutiérrez-Uribe JA (2016) Delivery of flavonoids and saponins from black bean (*Phaseolus vulgaris*) seed coats incorporated into whole wheat bread. Int J Mol Sci 17:222
Choo Y-M, Yap S-C, Ooi C-K, Ma A-N, Goh S-H, Ong AS-H (1996) Recovered oil from palm-pressed fiber: a good source of natural carotenoids, vitamin E, and sterols. J Am Oil Chem Soc 73:599–602
Coll M, Coll L, Laencina J, Tomas-Barberan F (1998) Recovery of flavanones from wastes of industrially processed lemons. Eur Food Res Technol 206:404–407
Comim SR, Madella K, Oliveira J, Ferreira S (2010) Supercritical fluid extraction from dried banana peel (*Musa* spp., genomic group AAB): extraction yield, mathematical modeling, economical analysis and phase equilibria. J Supercrit Fluids 54:30–37
Corrales M, Toepfl S, Butz P, Knorr D, Tauscher B (2008) Extraction of anthocyanins from grape by-products assisted by ultrasonics, high hydrostatic pressure or pulsed electric fields: a comparison. Inn Food Sci Emerg Technol 9:85–91
Day L, Seymour RB, Pitts KF, Konczak I, Lundin L (2009) Incorporation of functional ingredients into foods. Trends Food Sci Technol 20:388–395
Delazar A, Nahar L, Hamedeyazdan S, Sarker SD (2012) Microwave-assisted extraction in natural products isolation. Methods Mol Biol 864:89–115
Deng G-F, Shen C, Xu X-R, Kuang R-D, Guo Y-J, Zeng L-S, Gao L-L, Lin X, Xie J-F, Xia E-Q (2012) Potential of fruit wastes as natural resources of bioactive compounds. Int J Mol Sci 13:8308–8323
Drosou C, Kyriakopoulou K, Bimpilas A, Tsimogiannis D, Krokida M (2015) A comparative study on different extraction techniques to recover red grape pomace polyphenols from vinification byproducts. Ind Crops Prod 75:141–149
Duan X, Jiang Y, Su X, Zhang Z, Shi J (2007) Antioxidant properties of anthocyanins extracted from litchi (*Litchi chinenesis* Sonn.) fruit pericarp tissues in relation to their role in the pericarp browning. Food Chem 101:1365–1371
Ejike CE, Emmanuel TN (2009) Cholesterol concentration in different parts of bovine meat sold in Nsukka, Nigeria: implications for cardiovascular disease risk. Afr J Biochem Res 3:095–097
Espín JC, García-Conesa MT, Tomás-Barberán FA (2007) Nutraceuticals: facts and fiction. Phytochemistry 68:2986–3008
Espinosa-Pardo FA, Nakajima VM, Macedo GA, Macedo JA, Martínez J (2017) Extraction of phenolic compounds from dry and fermented orange pomace using supercritical CO_2 and cosolvents. Food Bioprod Process 101:1–10
Farías-Campomanes AM, Rostagno MA, Coaquira-Quispe JJ, Meireles MAA (2015) Supercritical fluid extraction of polyphenols from lees: overall extraction curve, kinetic data and composition of the extracts. Bioresour Bioprocess 2:45
Filip S, Pavlić B, Vidović S, Vladić J, Zeković Z (2017) Optimization of microwave-assisted extraction of polyphenolic compounds from *Ocimum basilicum* by response surface methodology. Food Anal Method. doi:10.1007/s12161-017-0792-7
Foo LY, Lu Y (1999) Isolation and identification of procyanidins in apple pomace. Food Chem 64:511–518
Gan C-Y, Latiff AA (2011) Optimisation of the solvent extraction of bioactive compounds from *Parkia speciosa* pod using response surface methodology. Food Chem 124:1277–1283
Gardossi L, Poulsen PB, Ballesteros A, Hult K, Švedas VK, Vasić-Rački Đ, Carrea G, Magnusson A, Schmid A, Wohlgemuth R (2010) Guidelines for reporting of biocatalytic reactions. Trends Biotechnol 28:171–180
Ghafoor K, Park J, Choi Y-H (2010) Optimization of supercritical fluid extraction of bioactive compounds from grape (*Vitis labrusca* B.) peel by using response surface methodology. Innov Food Sci Emerg Technol 11:485–490
Ghafoor K, Hui T, Choi YH (2011) Optimization of ultrasonic-assisted extraction of total anthocyanins from grape peel using response surface methodolog. J Food Biochem 35:735–746
Giannuzzo AN, Boggetti HJ, Nazareno MA, Mishima HT (2003) Supercritical fluid extraction of naringin from the peel of *Citrus paradisi*. Phytochem Anal 14:221–223
Gil MI, Tomás-Barberán FA, Hess-Pierce B, Holcroft DM, Kader AA (2000) Antioxidant activity of pomegranate juice and its relationship with phenolic composition and processing. J Agric Food Chem 48:4581–4589
Goli AH, Barzegar M, Sahari MA (2005) Antioxidant activity and total phenolic compounds of pistachio (*Pistachia vera*) hull extracts. Food Chem 92:521–525
González-Montelongo R, Lobo MG, González M (2010) Antioxidant activity in banana peel extracts: testing extraction conditions and related bioactive compounds. Food Chem 119:1030–1039
Herrero M, Cifuentes A, Ibañez E (2006) Sub-and supercritical fluid extraction of functional ingredients from different natural sources: plants, food-by-products, algae and microalgae: a review. Food Chem 98:136–148
Jayathunge K, Stratakos AC, Cregenzán-Albertia O, Grant IR, Lyng J, Koidis A (2017) Enhancing the lycopene in vitro bioaccessibility of tomato juice synergistically applying thermal and non-thermal processing technologies. Food Chem 221:698–705
Joana Gil-Chávez G, Villa JA, Fernando Ayala-Zavala J, Basilio Heredia J, Sepulveda D, Yahia EM, González-Aguilar GA (2013) Technologies for extraction and production of bioactive compounds to be used as nutraceuticals and food ingredients: an overview. Compr Rev Food Sci Food Saf 12:5–23
Jung G-W, Kang H-M, Chun B-S (2012) Characterization of wheat bran oil obtained by supercritical carbon dioxide and hexane extraction. J Ind Eng Chem 18:360–363
Kalogeropoulos N, Chiou A, Pyriochou V, Peristeraki A, Karathanos VT (2012) Bioactive phytochemicals in industrial tomatoes and their processing byproducts. LWT Food Sci Technol 49:213–216
Kanazawa K, Sakakibara H (2000) High content of dopamine, a strong antioxidant, in cavendish banana. J Agric Food Chem 48:844–848
Kehili M, Kammlott M, Choura S, Zammel A, Zetzl C, Smirnova I, Allouche N, Sayadi S (2017) Supercritical CO_2 extraction and antioxidant activity of lycopene and β-carotene-enriched oleoresin from tomato (*Lycopersicum esculentum* L.) peels by-product of a Tunisian industry. Food Bioprod Process 102:340–349
Kerem Z, German-Shashoua H, Yarden O (2005) Microwave-assisted extraction of bioactive saponins from chickpea (*Cicer arietinum* L). J Sci Food Agric 85:406–412
Kim W-J, Veriansyah B, Lee Y-W, Kim J, Kim J-D (2010) Extraction of mangiferin from Mahkota Dewa (*Phaleria macrocarpa*) using subcritical water. J Ind Eng Chem 16:425–430
Ko J, Ko M, Kim D, Lim S (2016) Enhanced production of phenolic compounds from pumpkin leaves by subcritical water hydrolysis. Prev Nutr Food Sci 21:132
Kulkarni V, Rathod V (2016) Green process for extraction of mangiferin from *Mangifera indica* leaves. J Biol Act Prod Nat 6:406–411
Kumar K (2015) Role of edible mushrooms as functional foods—a review. South Asian J Food Technol Environ 1:211–218
Kumar K, Kumar S (2015) Role of nutraceuticals in health and disease prevention: a review. South Asian J Food Technol Environ 1:116–121
Lee H, Wicker L (1991) Anthocyanin pigments in the skin of lychee fruit. J Food Sci 56:466–468
Lemes AC, Sala L, Ores JDC, Braga ARC, Egea MB, Fernandes KF (2016) A review of the latest advances in encrypted bioactive peptides from protein-rich waste. Int J Mol Sci 17:950
Li B, Xu Y, Jin Y-X, Wu Y-Y, Tu Y-Y (2010) Response surface optimization of supercritical fluid extraction of kaempferol glycosides from tea seed cake. Ind Crops Prod 32:123–128
Liza M, Rahman RA, Mandana B, Jinap S, Rahmat A, Zaidul I, Hamid A (2010) Supercritical carbon dioxide extraction of bioactive flavonoid from *Strobilanthes crispus* (Pecah Kaca). Food Bioprod Process 88:319–326
Louli V, Ragoussis N, Magoulas K (2004) Recovery of phenolic antioxidants from wine industry by-products. Bioresour Technol 92:201–208
Lozano-Sánchez J, Bendini A, Di Lecce G, Valli E, Gallina Toschi T, Segura-Carretero A (2017) Macro and micro functional components of a spreadable olive by-product (pâté) generated by new concept of two-phase decanter. Eur J Lipid Sci. doi:10.1002/ejlt.201600096
Lu Y, Foo LY (1997) Identification and quantification of major polyphenols in apple pomace. Food Chem 59:187–194
Maier T, Schieber A, Kammerer DR, Carle R (2009) Residues of grape (*Vitis vinifera* L.) seed oil production as a valuable source of phenolic antioxidants. Food Chem 112:551–559
Mayanga-Torres P, Lachos-Perez D, Rezende C, Prado J, Ma Z, Tompsett G, Timko M, Forster-Carneiro T (2017) Valorization of coffee industry

residues by subcritical water hydrolysis: recovery of sugars and phenolic compounds. J Supercrit Fluids 120:75–85

Mira B, Blasco M, Berna A, Subirats S (1999) Supercritical CO_2 extraction of essential oil from orange peel. Effect of operation conditions on the extract composition. J Supercrit Fluids 14:95–104

Mirabella N, Castellani V, Sala S (2014) Current options for the valorization of food manufacturing waste: a review. J Clean Prod 65:28–41

Moore J, Cheng Z, Su L, Yu L (2006) Effects of solid-state enzymatic treatments on the antioxidant properties of wheat bran. J Agric Food Chem 54:9032–9045

Mussatto SI, Ballesteros LF, Martins S, Teixeira JA (2011) Extraction of antioxidant phenolic compounds from spent coffee grounds. Sep Purif Technol 83:173–179

Negro C, Tommasi L, Miceli A (2003) Phenolic compounds and antioxidant activity from red grape marc extracts. Bioresour Technol 87:41–44

Nobre BP, Palavra AF, Pessoa FL, Mendes RL (2009) Supercritical CO_2 extraction of trans-lycopene from Portuguese tomato industrial waste. Food Chem 116:680–685

Noda Y, Kaneyuki T, Mori A, Packer L (2002) Antioxidant activities of pomegranate fruit extract and its anthocyanidins: delphinidin, cyanidin, and pelargonidin. J Agric Food Chem 50:166–171

Núñez Selles AJ, Daglia M, Rastrelli L (2016) The potential role of mangiferin in cancer treatment through its immunomodulatory, anti-angiogenic, apoptopic, and gene regulatory effects. BioFactors 42:475–491

Okuno S, Yoshinaga M, Nakatani M, Ishiguro K, Yoshimoto M, Morishita T, Uehara T, Kawano M (2002) Extraction of antioxidants in sweetpotato waste powder with supercritical carbon dioxide. Food Sci Technol Res 8:154–157

Oliveira R, Oliveira V, Aracava KK, da Costa Rodrigues CE (2012) Effects of the extraction conditions on the yield and composition of rice bran oil extracted with ethanol—a response surface approach. Food Bioprod Process 90:22–31

Padmapriya K, Dutta A, Chaudhuri S, Dutta D (2012) Microwave assisted extraction of mangiferin from *Curcuma amada*. 3 Biotech 2:27–30

Paes J, Dotta R, Martínez J (2013) Extraction of phenolic compounds from blueberry (*Vaccinium myrtillus* L.) residues using supercritical CO_2 and pressurized water. J Supercritic Fluids. doi:10.1016/j.supflu.2014.07.025

Perretti G, Miniati E, Montanari L, Fantozzi P (2003) Improving the value of rice by-products by SFE. J Supercrit Fluids 26:63–71

Piñeiro Z, Marrufo-Curtido A, Serrano MJ, Palma M (2016) Ultrasound-assisted extraction of stilbenes from grape canes. Molecules 21:784

Plaza L, Sánchez-Moreno C, De Ancos B, Elez-Martínez P, Martín-Belloso O, Cano MP (2011) Carotenoid and flavanone content during refrigerated storage of orange juice processed by high-pressure, pulsed electric fields and low pasteurization. LWT - Food Sci Technol 44(4):834–839

Pujol D, Liu C, Gominho J, Olivella M, Fiol N, Villaescusa I, Pereira H (2013) The chemical composition of exhausted coffee waste. Ind Crops Prod 50:423–429

Puravankara D, Boghra V, Sharma RS (2000) Effect of antioxidant principles isolated from mango (*Mangifera indica* L) seed kernels on oxidative stability of buffalo ghee (butter-fat). J Sci Food Agric 80:522–526

Puri M, Sharma D, Barrow CJ (2012) Enzyme-assisted extraction of bioactives from plants. Trends Biotechnol 30:37–44

Rahman K (2007) Studies on free radicals, antioxidants, and co-factors. Clin Interv Aging 2:219–236

Rangsriwong P, Rangkadilok N, Satayavivad J, Goto M, Shotipruk A (2009) Subcritical water extraction of polyphenolic compounds from *Terminalia chebula* Retz. fruits. Sep Purif Technol 66:51–56

Rebecca LJ, Seshiah C, Tissopi T (2014) Extraction of caffeine from used tea leaves. Ann Valahia Univ Targ pp 19–22

Reshmitha T, Thomas S, Geethanjali S, Arun K, Nisha P (2017) DNA and mitochondrial protective effect of lycopene rich tomato (*Solanum lycopersicum* L.) peel extract prepared by enzyme assisted extraction against H_2O_2 induced oxidative damage in L6 myoblasts. J Funct Foods 28:147–156

Rostagno MA, Palma M, Barroso CG (2003) Ultrasound-assisted extraction of soy isoflavones. J Chromatogr 1012:119–128

Rudra SG, Nishad J, Jakhar N, Kaur C (2015) Food industry waste: mine of nutraceuticals. Int J Sci Environ Technol 4:205–229

Safdar MN, Kausar T, Jabbar S, Mumtaz A, Ahad K, Saddozai AA (2016) Extraction and quantification of polyphenols from kinnow (*Citrus reticulate* L.) peel using ultrasound and maceration techniques. J Food Drug Anal. doi:10.1016/j.jfda.2016.07.010

Sainvitu P, Nott K, Richard G, Blecker C, Jérôme C, Wathelet J-P, Paquot M, Deleu M (2012) Structure, properties and obtention routes of flaxseed lignan secoisolariciresinol: a review. Biotechnol Agron Soc Environ 16:115

Şanal İ, Güvenç A, Salgın U, Mehmetoğlu Ü, Çalımlı A (2004) Recycling of apricot pomace by supercritical CO_2 extraction. J Supercrit Fluids 32:221–230

Şanal İ, Bayraktar E, Mehmetoğlu Ü, Çalımlı A (2005) Determination of optimum conditions for SC-(CO2 + ethanol) extraction of β-carotene from apricot pomace using response surface methodology. J Supercrit Fluids 34:331–338

Shi J, Khatri M, Xue SJ, Mittal GS, Ma Y, Li D (2009) Solubility of lycopene in supercritical CO_2 fluid as affected by temperature and pressure. Sep Purif Technol 66:322–328

Shrikhande AJ (2000) Wine by-products with health benefits. Food Res Int 33:469–474

Sihvonen M, Järvenpää E, Hietaniemi V, Huopalahti R (1999) Advances in supercritical carbon dioxide technologies. Trends Food Sci Tech 10:217–222

Singh PP, Saldaña MD (2011) Subcritical water extraction of phenolic compounds from potato peel. Food Res Int 44:2452–2458

Singh G, Verma A, Kumar V (2016) Catalytic properties, functional attributes and industrial applications of β-glucosidases. 3 Biotech 6:3

Smiderle FR, Morales D, Gil-Ramírez A, de Jesus LI, Gilbert-López B, Iacomini M, Soler-Rivas C (2017) Evaluation of microwave-assisted and pressurized liquid extractions to obtain β-D-glucans from mushrooms. Carbohydr Polym 156:165–174

Someya S, Yoshiki Y, Okubo K (2002) Antioxidant compounds from bananas (*Musa cavendish*). Food Chem 79:351–354

Strati IF, Oreopoulou V (2011) Effect of extraction parameters on the carotenoid recovery from tomato waste. Int J Food Sci Technol 46:23–29

Szentmihályi K, Vinkler P, Lakatos B, Illés V, Then M (2002) Rose hip (*Rosa canina* L.) oil obtained from waste hip seeds by different extraction methods. Bioresour Technol 82:195–201

Tan YA, Sambanthamurthi R, Sundram K, Wahid MB (2007) Valorisation of palm by-products as functional components. Eur J Lipid Sci Technol 109:380–393

Teixeira A, Baenas N, Dominguez-Perles R, Barros A, Rosa E, Moreno DA, Garcia-Viguera C (2014) Natural bioactive compounds from winery by-products as health promoters: a review. Int J Mol Sci 15:15638–15678

Tunchaiyaphum S, Eshtiaghi M, Yoswathana N (2013) Extraction of bioactive compounds from mango peels using green technology. Int J Chem Eng Appl 4:194

Vega PJ, Balaban M, Sims C, O'keefe S, Cornell J (1996) Supercritical carbon dioxide extraction efficiency for carotenes from carrots by RSM. J Food Sci 61:757–759

Viscidi KA, Dougherty MP, Briggs J, Camire ME (2004) Complex phenolic compounds reduce lipid oxidation in extruded oat cereals. LWT Food Sci Technol 37:789–796

Vyas P, Chaudhary B, Mukhopadhyay K, Bandopadhyay R (2009) Anthocyanins: looking beyond colors. In: Bhowmik PK, Basu SK, Goyal A (eds) Advances in biotechnology. Bentham Science Publishers Ltd., Oak Park, pp 152–184

Vyas P, Haque I, Kumar M, Mukhopadhyay K (2014) Photocontrol of differential gene expression and alterations in foliar anthocyanin accumulation: a comparative study using red and green forma *Ocimum tenuiflorum*. Acta Physiol Plant 36:2091–2102

Wang L, Weller CL (2006) Recent advances in extraction of nutraceuticals from plants. Trends Food Sci Technol 17:300–312

Wang J, Sun B, Cao Y, Tian Y, Li X (2008) Optimisation of ultrasound-assisted extraction of phenolic compounds from wheat bran. Food Chem 106:804–810

Wang W, Wu X, Han Y, Zhang Y, Sun Dong F (2011) Investigation on ultrasound-assisted extraction of three dibenzylbutyrolactone lignans from *Hemistepta lyrata*. J Appl Pharm Sci 1:24

Wenzel J, Storer Samaniego C, Wang L, Burrows L, Tucker E, Dwarshuis N, Ammerman M, Zand A (2016) Antioxidant potential of Juglans nigra, black walnut, husks extracted using supercritical carbon dioxide with an ethanol modifier. Food Sci Nutr. doi:10.1002/fsn3.385

Wolfe KL, Liu RH (2003) Apple peels as a value-added food ingredient. J Agric Food Chem 51:1676–1683
Yang H-Y, Lee T-H (2015) Antioxidant enzymes as redox-based biomarkers: a brief review. BMB Rep 48:200
Zakaria SM, Kamal SMM (2016) Subcritical water extraction of bioactive compounds from plants and algae: applications in pharmaceutical and food ingredients. Food Eng Rev 1:23–34
Zeyada NN, Zeitoum M, Barbary O (2008) Utilization of some vegetables and fruit waste as natural antioxidants. Alex J Food Sci Technol 5:1–11
Zhang F, Chen B, Xiao S, S-z Yao (2005) Optimization and comparison of different extraction techniques for sanguinarine and chelerythrine in fruits of *Macleaya cordata* (Willd) R. Br. Sep Purif Technol 42:283–290
Zulkifli KS, Abdullah N, Abdullah A, Aziman N, Kamarudin W (2012) Bioactive phenolic compounds and antioxidant activity of selected fruit peels. In: 2012 international conference on environment, chemistry and biology, vol 49. IACSIT Press, Singapore, pp 66–70
Zuorro A, Lavecchia R (2012) Spent coffee grounds as a valuable source of phenolic compounds and bioenergy. J Clean Prod 34:49–56
Zuorro A, Fidaleo M, Lavecchia R (2011) Enzyme-assisted extraction of lycopene from tomato processing waste. Enzyme Microb Technol 49:567–573