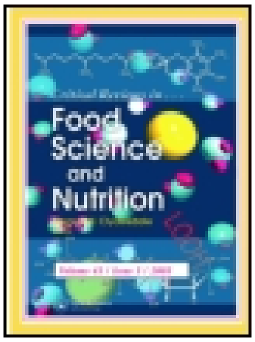

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: http://www.tandfonline.com/loi/bfsn20

Novel technologies applied for recovery and value addition of high value compounds from plant byproducts: A review

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Novel technologies applied for recovery and value addition of high value compounds from plant byproducts: A review

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Abstract

Plant byproducts of food processing industry line are undervalued yet important resource. These byproducts contain large percentage of high value functional substances such as antioxidants, pectin, polyphenols and so on. Recently, many research studies concentrated on innovative technologies that promise to overcome such issues as time consuming, inefficiency, and low yield, among others, which exist in most conventional techniques. Consequently, to achieve the recovery of nutraceuticals from high added-value by-products, it is necessary to have more knowledge of these novel technologies and more importantly explore the possibility of

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application of these latest technologies to the recovery downstream processing. The present work will summarize state-of-the-art technological approaches concerning extraction, superfine and drying applied to plant food processing residues. Simultaneously, the application of the bioactive components originated from byproducts in food industry will also be reviewed.

Keywords

Plant-based byproducts, Innovative technologies, Extraction, Superfine, Drying techniques, Application

INTRODUCTION

The food waste has been an important issue for effective utilization of bioresource, reducing environmental pollution, increasing economic benefits, and conquering hunger. It was estimated that approximately one-third of food produced globally (1.3 billion tons per year) for human consumption is lost or wasted (Gustavsson et al. 2011). This means that a large proportion of human effort and financial resource used in food production are wasted. The residues resulting from food processing of plant foods account for a large proportion of food waste. A growing body of publications suggest that waste from plant foods is a promising source of nutritionally and functionally important compounds such as phenolic compounds including polyphenols (Drosou et al. 2015), pectin (Oliveira et al. 2015), anthocyanins (He et al. 2016; Dranca and Oroian 2016), and pectins (de Oliveira et al. 2016). For example, coconut protein was successfully obtained from the wet waste of coconut processing. It was showed that this product was a good substitute of coconut milk in dessert and had very high potential as a natural dietary food additive or supplement (Naik et al. 2012).

The potential of value addition of these by-products is currently investigated extensively. For instance, red wine production usually generates a large volume of byproducts including solid grape parts (skin, rest of pulp, and seeds) and stalk (Garcia-Lomillo et al. 2014), most of which contain bioactive compounds such as polyphenols, dietary fibers, procyanidins (Yu and Ahmedna 2013). Similarly, milling of wheat into wheat flour generates large quantity of residues including

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wheat bran, parts of wheat germ and endosperm totaling about 23--27% of the milling output. Wheat bran contains large proportion of biologically active compounds and dietary fibers (Prueckler et al. 2014). For this reason, new and innovative technologies are increasingly invented and applied for to add value to the waste streams generated by plant food industries.

In terms of the recovery of high value compounds from plant waste, solvent extraction appears to be the most common method used in the past. Solvent extraction consumes large amount of organic solvents, leaves behind substantial proportion of solvent residue and cannot avoid the possibility of negative impact on the target compounds. Because of this reason, large number of studies focused on seeking alternative extraction technologies that do not use solvent or use in much lower amount. For example, ursolic acid was extracted from apple pomace using ultrasound-assisted extract method (Fan et al. 2016). This novel method delivered higher extraction yield in shorter extraction time compared to the conventional heat reflux extraction. Similarly, (Shi et al. 2014) extracted crude ganoderma lucidum polysaccharide (GLPL) from fermented soybean curd residue with ultrasound-assisted extraction. Higher extraction yield of GLPL was achieved using easily achievable extraction conditions in aqueous medium.

In addition, increasing attention is being paid to develop technologies that reduce the particle size by mechanical or hydrodynamic means (Chen et al. 2016). The bioactive compounds can be easily extracted if finer particles can be produced. In general, the superfine grinding has positive impact on physicochemical and functional properties of byproducts (Sun et al. 2015; Zhang et al. 2014; Zhao et al. 2015).

Dehydration of wet pomace is a necessary step for subsequent extraction of bioactive compounds. The high moisture content of wet pomace hinders extraction and also leads to microbial spoilage. Among the drying methods, infrared drying (IR), microwave assisted freeze drying (MFD), vacuum microwave drying (VMD), microwave-assisted spouted bed drying (MWSBD), and pulse-spouted microwave-assisted vacuum drying (PSMVD) are considered as relatively new technologies. They showed some noted advantages, such as shorter drying time and/or lower dying temperature and better quality of dried products compared to conventional drying methods (Bejar et al. 2011; Duan et al. 2010; Liu et al. 2016b).

To the best of our knowledge, there is no systematic and critical review of availability, applicability and advantage and disadvantage of innovative technologies applied to plant byproducts. This work reviews currently available breakthrough technologies that are used for extraction, ultrafine and drying of food processing byproducts. The application of the bioactive components from byproducts in food industries are also reviewed and evaluated.

EMERGING EXTRACTION TECHNOLOGIES

In addition to the substantial economic benefits of bioactive compounds extracted from plant byproducts, their recovery from food waste is increasingly being mandated by government laws

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(Civita and Shirl 2015). The limitations of conventional extraction technologies, such as long extraction time and high consumption of harmful chemicals (Tiwari 2015), have been substantiated. Consequently, numerous attempts to find new and green separation technologies have been made. Out of these technologies: Ultrasonic-assisted extraction, supercritical fluid extraction, electric field treatment and microwave-assisted extraction have been acknowledged as the most promising ones. These new and advanced technologies deliver much higher process efficiency and extraction yield. The quality of the extracted compounds, produced using these new technologies, is much better than the quality of products produced using their corresponding conventional methods.

Ultrasound-assisted Extraction

Ultrasonic-assisted extraction (UAE) combines the merits of acoustic energy and solvents to extract target compounds from various plant materials (Wang et al. 2015). The instantaneous formation and collapse of cavitation bubbles, generation of instantaneous high pressure and temperature are achieved due to the application of ultrasound energy. And therefore, the penetration of solvent into the cellular materials, disruption of cell wall and the release of contents are strengthened. To make best use of ultrasound energy, it is essential to understand the mechanism and kinetics of extraction process as well as the effect of sonication on plant extracts. Based on the hypothesized and simplified extraction mechanism, a number of empirical kinetics models have been developed to quantify or predict the extent of extraction of bio-active substances from fruits and vegetables byproducts such as grape pomace (Gonzalez-Centeno et al. 2015; Sant'Anna et al. 2012), olive leaves (Hussam Ahmad-Qasem et al. 2013), grape seed (Bucic-Kojic et al. 2013), and pomegranate seed (Goula 2013). It was concluded that the proposed model was suited to fit experimental data and to simulate the extraction of these compounds. On the other hand, the effect of acoustic frequency and power density on the extraction performance has also been extensively discussed. According to (Awad et al. 2012), low power (high frequency) with frequencies higher than 100 kHz and intensities lower than 1 W/cm^2 can be used to monitor the quality of food materials during processing and storage; while the high power (low frequency) ultrasound can be used to accelerate the extraction, freezing, drying, and emulsification processes.

UAE has been successfully used to recover various functional compounds from the waste of plant food processing: For example, pectin from passion fruit peel (de Oliveira et al. 2016), lycopene from tomatoes (Kumcuoglu et al. 2014), quercetin from onion solid wastes (Jang et al. 2013), antioxidants from pomegranate peel (Pan et al. 2012), and carotenoids from pomegranate wastes (Goula et al. 2017). Similarly, polyphenols and anthocyanins have also been more efficiently extracted from plum and grape peels (Medina-Meza and Barbosa-Canovas 2015), jabuticaba peel (Rodrigues et al. 2015), and grape pomace(Goula et al. 2016), using this extraction method.

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It was highlighted that the application of ultrasound energy could be regarded as an efficient alternative as a means of intensifying the extraction process of bioactive compounds from plant processing byproducts.

Microwave-assisted Extraction

Microwave assisted extraction (MAE) is another innovative technology which greatly shortens the extraction time and rate, and reduces the consumption of solvent. Microwave energy interacts with the polar components by dipole rotation or ionic conduction and thus only permeates through selective and targeted materials based on their dielectric constant. The efficiency of the sample to absorb microwave energy is measured by the dissipation factor of the material (Chan et al. 2011). Accordingly, MAE is tremendous and potential, as a technology, for the extraction of high value constituents from plant materials. For example, optimized MAE has been successfully used to extract polyphenols and condensed tannins from grape residues (Brahim et al. 2014; Ping et al. 2012). Similarly, phenolic compounds from sour cherry pomace and pectin from passion fruit peel were also more effectively extracted compared to traditional extraction methods (Simsek et al. 2012; Seixas et al. 2014).

Pulsed Electric Field Assisted Extraction

Pulsed electric field (PEF) is a promising non-thermal and low energy consuming technology which can be used in organic solvent or aqueous media to extract valuable plant compounds. PEF processing involves placing plant materials or bio-suspensions between two electrodes and pulses of electric potential of the order of 0.1–80 kV/cm (Yu et al. 2015). At certain critical electrical potential (specific to plant sample used) is reached, the structure of cell membranes is destroyed, which leads to the rupture of cytoplasmatic membranes and permeation or leakage of intracellular compounds. Due to these reasons, PEF has been used to improve the value addition of plant food residues. For example, (Yu et al. 2015) showed that PEF assisted extraction of polyphenols and proteins extraction from rapeseed stems and leaves resulted in higher polyphenols purity. And thus it was more effective than the non-assisted one. The recovery of anthocyanins, flavonoids and phenols from plum and grape peels also increased when PEF was used (Medina-Meza and Barbosa-Canovas 2015). Besides, (Yu et al. 2016) found that significantly higher extraction yield of polyphenol and total proteins was obttained when PEF was used.

Supercritical Fluid Extraction

Supercritical fluid extraction (SFE) depends on some immanent tunable natures of supercritical fluid like temperature, pressure as well as some exterior features like the characteristics of the sample and interaction with targeted analysts (Pereira and Meireles 2010). SFE can enhance the solvating power of the solvent. Taking the technical and economic aspects into account, SFE has been quite intensely studied for valorization of wastes and side-products of plant food industries. The research on the application of SFE, to recovery the high value compounds from plant materials, has been more or less confined to fruit and vegetable waste (**Table 1**).

CO_2 is the most commonly used supercritical solvent as it is non-toxic, non-carcinogenic, non-flammable, cheap and has modest critical point. CO_2 can be easily converted into supercritical fluid by adjusting temperature. Once the high value compounds are extracted, it can be easily evaporated to recover the extracted compound. Despite these advantages, due to its non-polar nature, it may not be effective, in its own, in extracting polar substances (such as phenolic compounds). Hence, a small quantity of cosolvent (e.g. ethanol and water) may need to added in supercritical CO_2.

Supercritical CO_2 extraction using tomato seed oil as a co-solvent has been used to extract lycopene from tomato seeds (Machmudah et al. 2012). And ethanol was used together with supercritical CO_2 to plant based byproducts for the extraction of phenolic compounds like proanthocyanidins from grape seeds and polyphenols from hazelnut, coffee and grape wastes (Yilmaz et al. 2011; Manna et al. 2015). Besides, it was employed to the extraction of oil and diterpenes from spent coffee grounds (Barbosa et al. 2014). Substitution of CO_2 with other more polar solvents has also attracted much attention. For instance, (Marqués et al. 2013) carried out supercritical antisolvent extraction (SAE) of antioxidants from grape seeds. They reported that the SAE method extracted 150% more antioxidants with regard to the starting extracts. Pomegranate seed oil and lycopene from tomato adopting have also been successfully extracted using superheated hexane and supercritical ethane, respectively (Eikani et al. 2012; Nobre et al. 2012a).

Subcritical water extraction, also known as pressurized polarity water extraction, superheated water extraction or hot liquid water extraction, is another excellent alternative method (Ko et al. 2011). For instance, phenolic compounds from pomegranate seed residues and potato peels and antioxidants from winery wastes are efficiently recovered using subcritical water extraction (He et al. 2011; Singh and Mda 2011; Aliakbarian et al. 2012). It was showed that higher content of phenolic compounds was extracted and shorter time was needed using subcritical water compared to methanol or ethanol.

Moreover, SFE assisted by ultrasound is another promising treatment to decrease extraction time, and to raise the extraction yields compared to those obtained without ultrasound (Santos et al. 2015). For example, the extraction of fatty acids, tocopherol and tocotrienol from passion fruit seed oil was successfully accomplished combining supercritical CO_2 extraction with ultrasound (Barrales et al. 2015). These authors showed that the application of ultrasound made the extraction process more efficient and the yield of these compounds was improved by 29%. Similarly, the ultrasound assisted SFE was also applied to extract antioxidant compounds from blackberry bagasse (Pasquel Reategui et al. 2014). It was concluded that SFE assisted by ultrasound contributed to enhancing the extraction kinetics, increasing its global yield and improving the quality of the extracts.

SUPERFINE TECHNOLOGY

The particle size affects the physicochemical and functional characteristics of food materials. For example, the specific surface area, water-holding capacity, water-retention capacity and oil-binding capacity increase as the particle size decreases. Therefore, the technologies that reduce particle size can be used to improve some physicochemical properties of plant food byproducts.

Superfine grinding technology is an emerging technology applied in functional food processing (Li et al. 2012; Yi et al. 2014). The superfine powders (micron to nano-size range) have shown some districting properties and effects that the conventional particles do not have; such as surface effect, mini-size effect, quantum effect, optical property, magnetic property, and catalytic properties (Zhao et al. 2015). Due to these effects of properties, this technology can be used to produce nutraceuticals and functional foods that can enhance the utilization of bio-resources.

The influence of superfine particle size on the antioxidant capacity of wheat bran was studied by (Rosa et al. 2013). These authors found that antioxidant capacity of the wheat bran increased as a result of ultra-fine grinding. Similar antioxidant enhancing effect was observed in superfine persimmon peel powders (Hwang et al. 2011). Literature also shows that cryogenic grinding lowers the energy consumption of grinding process. This is because sub-zero temperature accelerates the fragmentation process by increasing brittleness and help produce fine particles (Hemery et al. 2011). Indeed, the glass transition of lipidic compounds occurring in the cuticles of the testa and hyaline layers at negative temperatures could lead to the observed increase in brittleness (Hemery et al. 2010).

Dietary fibers are acknowledged to promote beneficial physiological functions including reduction of blood cholesterol and glucose, prevention of diet-dependent diseases as obesity, atherosclerosis and colon cancer, and reduction of the risks of cardiovascular diseases. A large body of literature has shown that the pomace coming from byproducts of plant foods is rich in dietary fibers. Due to this importance, studies were undertaken to assess the effect of ultra-fine grinding on the physicochemical and antioxidant properties of dietary fibers obtained from fruits and their pomace (Niu et al. 2014a; Wu et al. 2007).

It has been shown that the soluble-to-insoluble fiber ration of dietary fibers (e.g. from orange pomace) can be increased due to micronization (Wu et al. 2007). These authors also observed an improvement in water-holding, swelling, oil-holding, cation-exchange, and glucose-a absorption capacities in dietary fibers through micronization. In addition to that, the micronization also decreased the degrading power of α-amylase and pancreatic lipase in insoluble fiber. Similar beneficial properties were observed for superfine insoluble fibers prepared from carambola and orange pomace (Wu et al. 2009). Interestingly, the ability of these micronized insoluble fibers to lower the concentration of serum triglyceride and serum total cholesterol was significantly improved (Zhu et al. 2015). It has also been shown that the functional properties (the total phenolic content, DPPH radical scavenging activity and ferric reducing antioxidant power) of bran dietary

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fibers from hull-less barley were increased effectively after superfine grinding (Zhu et al. 2015). This superfine powder of barley bran dietary fibers can be highly desired ingredient in food and pharmaceutical industries. However, (Zhu et al. 2014) observed, in the case of grape pomace dietary fibers, that the DPPH radical scavenging capacity decreased as a result of micronization. The micronization or superfine grinding also improved the ability of dietary fibers to promote intestinal health. In this regard, (Wu et al. 2007) reported that the incorporation of 5% micronized insoluble fiber into diet decreased the fecal ammonia concentration and the activities of bacterial enzymes in feces.

The application of ultrafine powders as food ingredients has been reported by numerous articles. For instance, (Niu et al. 2014b) reported that compared with coarser whole-wheat flour (WWF), the ultrafine WWF increased the brightness and attractiveness of noodles. The application of ultrafine WWF also decreased the cooking loss in noodles. The textural properties (hardness and cohesiveness) of cooked WWF noodles were greatly increased as the particle size of millfeeds was decreased. In addition, the micronized particle samples obtained from orange byproducts through ball milling were used as fat replacer in yoghurts (Yi et al. 2014). It was shown that micronized dietary fiber (MDF) showed better physicochemical and functional properties (such as water retention capacity, oil holding capacity and antioxidant activity) than common dietary fiber powders. The incorporation of up to 2% MDF as a fat replacer in yogurt retained most of the textural and sensory properties of full-fat yogurt. The dough which contained the micronized bran was shown to increase the concentration of free amino acids, total phenols and dietary fibers (Rizzello et al. 2012).

The body of evidence presented above indicates that the application of superfine technology increases the functionality and applicability of insoluble fibers and fiber-rich plant byproducts.

INNOVATIVE DRYING TECHNIQUES

Drying is an essential step for converting the high value ingredients recovered from plant byproducts into powders and broadening their application in food. Powdered materials are preferably used as industrial ingredients. The very low water activity and much reduced volume (compared to original wet products) of dried products significantly increases their shelf-life and transportability.

However, drying is an energy intensive process and any technology that increases energy efficiency will economize the drying process. Moreover, drying can exert negative influence on unstable compounds such as phenols and pigments. It has been reported that different drying processes affect the phenolics content and their antioxidant activity in mango peel and seed and muscadine pomace (Dorta et al. 2012; Vashisth et al. 2011). Therefore, innovative and hybrid drying has been extensively investigated for the improvement of drying process recently.

Infrared-assisted Convective Drying

Infrared radiation supplies energy within the body of a sample and thus causes its rapid heating. Infrared (IR)-assisted drying is very efficient because infrared energy is directly absorbed by the material without requiring a transfer medium (hot air). Infrared-assisted drying has been studied as a potential method for improving the property of dried products. (Bejar et al. 2011) studied the influence of the IR drying on the quality (color, water and oil holding capacity, total phenolic content) of the orange peel and leaves. These authors reported that the IR-assisted drying could better preserve total phenolic contents in orange peel and leaves. Also, it performed increased water holding capacity and better retention of the color. IR-assisted drying can be easily combined with conventional convection drying technologies in industrial setting. Combined infrared and convective drying has shown great promising industrial drying technology (Lechtanska et al. 2015). It has been shown that the combined IR and convective drying caused less damage to phonolic compounds in wine grape pomace compared to simply infrared drying or convective drying (Sui et al. 2014).

Microwave Drying and Combined Microwave Drying

Heat is generated within a material due to molecular friction when microwave energy is applied. It has been shown that unwanted oxidation in biomatrials can be greatly decreased and drying time shortened when microwave system is combined to convective drying. However, uneven heating, possible textural damage, and limited penetration are major limitations of the microwave radiation. Therefore, a proper combination with other drying methods has to be done to overcome these limitations.

Microwave-assisted freeze drying (MFD) has shown the ability to produce product with high quality and reduce operating costs compared to the unassisted freeze drying (Duan et al. 2010). It has been observed that MFD technique was also a suitable way for the production of re-structured manufactures of high quality. However, MFD does not appear to be not very effective when applied in food materials with high moisture content due to low dielectric constant and loss factor of frozen water. Vacuum microwave drying (VMD), microwave-assisted spouted bed drying (MWSBD) and pulse-spouted vacuum-microwave drying (PSVMD) were also studied for understanding their potential as an industrial scale technology to produce restructured fish granules (Chen et al. 2014). (Liu et al. 2016a) examined the effect of pulse-spouted microwave-assisted vacuum drying (PSMVD), microwave-assisted vacuum drying (MVD) and vacuum drying (VD) on quality of restructured chips. This is a kind of fiber-enriched chip which composed by mixture of old stalks of asparagus officinalis, pre-gelatinized wheat starch, isolated soybean protein and white sugar. In addition, ultrasound (US), pulsed electric field (PEF), and high hydrostatic pressures(HHP) can be used to decrease the heat damage to heat-sensitive foods (Witrowa-Rajchert et al. 2014). The self-heat recuperation process, in which adiathermic compression and expansion are attained by adding air as the heating medium, can also significantly reduce the energy consumption(Fushimi and Fukui 2014).

The byproducts from plant food processing contain abundant high value food compounds; however, their recovery and drying process has to be highly effective to make the recovery process economically viable. For this reason, it is imperative to develop cost-effective drying technologies for transforming the low cost byproducts into high value food ingredients.

APPLICATION OF BIO-ACTIVE COMPOUNDS FROM RESIDUES IN FOOD INDUSTRY

Compounds derived from food processing residues contain a lot of functional substances like phenols, antioxidant, dietary fiber, and so on. Therefore it is important to take full advantage of them to produce high added-value products and/or food additives. A large portion of functional foods or nutraceuticals are marketed as microcapsule (Kaderides et al. 2015), nutraceutical oil (Verardo et al. 2014), emulsifying agent in beverage (Mohagheghi et al. 2011), among others.

It has been suggested that integrated processes are of great importance while turning industrial food wastes into value-added products. Consequently, much attention has been paid to the integrated processes for utilization of plant food waste. For example, (Goula and Lazarides 2015) suggested an appropriate approach for more effective utilization of olive mill and pomegranate wastes (Fig. 1 and Fig. 2). The olive mill residue was recycled adequately using a specially designed system that combined fermentation and spray drying to produce olive paste or olive powder. It can be also used to produce encapsulated polyphenols. Approximate provisions were made to extract oil and phenolics from pomegranate seeds and peels. (Kalamara et al. 2014) extracted the pomegranate seed oil using ultrasound-assisted extraction and subsequently encapsulated this oil. It was found that the extraction yield was related to wall material, maltodextrin, ratio of core to wall material, inlet air temperature, drying air flow rate, and feed solids concentration.

Since a large number of studies have focused on the application of food by-products in food industry in recent ten years, some representative publications that report the developments in the utilization of functional compounds (extracted from plant food waste) in foods reported from year 2011--2017 are compiled in table 2**.**

OTHER TECHNOLOGIES

Extrusion is a unique technology that uses high temperature, short time and high shear force to produce a product with characteristic physical and sensorial characteristics. It offers a good avenue to incorporate fruits and/or vegetable pomace into ready-to-eat snacks and breakfast cereals. It has been shown that the incorporation of pomace can improve nutrient balance of extruded products (Brennan et al. 2013). Extruded foods possess distinctive texture such as crispiness or crunchiness and are appealing to consumers. Recent studies have shown that plant byproducts can be conveniently incorporated into extruded products. For example, orange pomace (Huang and Ma 2016), apple pomace (Karkle et al. 2012), pineapple pomace (Selani et al. 2014),

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carrot pomace (Alam et al. 2016), rye bran (Moisio et al. 2015) have already been added into extruded products. The sensory and nutritional quality of extruded plant byproducts depends on the parameters used during extrusion, pre or post-extrusion treatments, source of byproducts, etc. For instance, the extrusion temperature was found to affect the texture and nutritional attributes of extruded products. The increase in compactness and hardness yet decrease in crispness was observed in extrudates containing carrot due to increase in extrusion temperature (Dar et al. 2014). Supercritical fluid extrusion that uses supercritical CO_2 has been used instead of steam to extrude heat and shear sensitive materials. The extrusion process using supercritical CO_2 was also used to produce shelf-stable and ready-to-eat puffed products that used apple pomace together with cheese and whey (Paraman et al. 2013; Paraman et al. 2015). These authors reported significant improvement in weight and density as well as retention of dietary fiber, phenolics content and vitamin C when supercritical CO_2 was used in the extrusion process.

CONCLUDING REMARKS

The best possible recovery and utilization of plant byproducts is important from resource utilization and environmental protection perspectives. Innovative technologies, such as emerging extraction techniques, superfine treatment and innovative drying methods, play an important role in effectiveness of the recovery of bioactive compounds and converting them into valuable industrial ingredients. However, many of these useful technologies are yet to be applied in food industry. The recovery of bioactive compounds from plant food byproducts, using the innovative technologies, requires high capital cost and has some inherent safety concerns which can restrict their broader application in food industry. Nevertheless, these technologies will be increasingly used by food industry to achieve the recovery of bioactive and functional compounds from plant food waste when more research is undertaken and technologies become more mature.

ACKNOWLEDGMENTS

This work was financially supported by China Key Research Program (Contract No. 2017YFD0400901), Jiangsu Province (China) Key Project in Agriculture (Contract No. BE2016362), Jiangsu Province (China) "Collaborative Innovation Center for Food Safety and Quality Control "Industry Development Program, Jiangsu Province (China) Infrastructure Project (Contract No. BM2014051).

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Table 1 Some representative studies which used supercritical technologies to value add fruit and vegetable waste in previous 5 years (2011-2015).

Applied technology	**Source**	**Target compounds**	**Process condition**	**Reference**
Supercritical CO_2 extraction	Grape seeds	Proanthocyanidin	Pressure	(Yilmaz et al. 2011)
			25MPa,27.5MPa,30MPa	
			Temperature	
			30℃,50℃	
Supercritical CO_2 extraction	Tomato peel	Lycopene	Pressure	(Machmudah et al. 2012)
			20--40 MPa	
			Temperature	
			70--90℃	
Supercritical CO_2 extraction	Grape Seeds	Phenolic compounds and antioxidants	Pressure	(Ghafoor et al. 2012)
			15.3-16.1 MPa	
			Temperature	
			44--46℃	
Supercritical CO_2 extraction	Grape bagasse	Polyphenol	Pressure	(Farías-Campomanes et al. 2013)
			20--35 MPa	
			Temperature	
			40℃	
Supercritical	Jabutic-	Anthocyanin	Pressure	(Santos et

CO_2 extraction	aba skins		10--35 MPa	al. 2013)
			Temperature	
			40--50℃	
Supercritical CO_2 extraction	Blackb-erry bagasse	Antioxidant compounds	Pressure	(Reátegui et al. 2014)
			15 MPa	
			Ultrasonic power	
			800W	
Supercritical CO_2 extraction	Coffee grounds	Oil and diterpenes	Pressure	(Barbosa et al. 2014)
			14--19 MPa	
			Temperature	
			40--70℃	
Supercritical CO_2 extraction	Coffee grounds	Triacylglycerides	Pressure	(Melo et al. 2014)
			19 MPa	
			Temperature	
			40--55℃	
Supercritical CO_2 extraction	Passion fruit seeds	Seed oil	Pressure	(Barrales et al. 2015)
			16 MPa,26 MPa	
			Ultrasonic power	
			0W,160W,640W	
Supercritical	Hazelut	Triglycerides and	Pressure	(Manna et

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CO_2 extraction	, coffee and grape wastes	polyphenols	35--50 MPa Temperature 40--60℃	al. 2015)
Supercritical CO_2 hydrolysis	Sugarca -ne bagasse	Fermentable sugars	Pressure 10--25 MPa Temperature 40--80℃	(Benazzi et al. 2013)
Supercritical CO_2 hydrolysis	peach seeds	Oil and β-sitosterol	Pressure 16--24 MPa Temperature 35--55℃	(Ekinci and Gürü 2014)
Subcritical water extraction	Onion skin	Flavonol quercetin	Pressure 9-13.1MPa Temperature 100--190℃	(Ko et al. 2011)
Subcritical water extraction	Potato peel	Phenolic compounds	Pressure 6MPa Temperature 100--240℃	(Singh and Mda 2011)
Subcritical water	Pomegr -anate	Phenolic compounds	Pressure 6MPa	(He et al. 2012)

extraction	seeds		Temperature 80--280℃	
Subcritical water extraction	Winery wastes	Antioxidants	Pressure 8MPa,11.5MPa,15MPa Temperature 100℃,120℃,140℃	(Aliakbarian et al. 2012)
Supercritical water hydrolysis(continuous system)	Corn residue	Hexoses	Pressure 23--24MPa Temperature 380℃	(Zhao et al. 2012)
Subcritical water hydrolysis (batch)	Sugarca-ne bagasse	Reducing sugars	Temperature 200--240℃ Reaction time 120 s	(Zhu et al. 2013)
Subcritical water hydrolysis	Cocont husk, defatted grape seed, and pressed palm fiber	Fermentable sugars.	Pressure 20MPa Temperature 208--257℃	(Juliana M. Prado et al. 2014)

Subcritical ethane extracti-on	Tomato wastes	Lycopene	Pressure 30MPa Temperature 60℃	(Nobre et al. 2012b)
Supercritical antisolvent extraction	Grape seeds	Antioxidants	Pressure 8-15 MPa Temperature 35--60℃	(Marqués et al. 2013)
Pressurized liquid extraction (PLE)	Potato peels	Anthocyanins	Pressure 10MPa Temperature 80℃	(Casas Cardoso et al. 2013)
Pressurized liquid extraction (PLE)	Jabutic-aba skins	Anthocyanins	Pressure 5-10MPa Temperature 40--120℃	(Santos et al. 2012)

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Table 2 **Developments in the application of plant-based byproducts as additives in food products reported in recent years (2011-2017).**

Source material	**Extracted compounds**	**Food**	**Function**	**Reference**
Grape seed	Antioxidants	Corn chips	Preventing lipid oxidation	(Rababah et al. 2011)
Grape seed	Polyphenols	Yogurts	Producing functional yogurts	(Chouchouli et al. 2013)
Grape seed	Antioxidants	Frozen precooked chicken nuggets	Inhibiting lipid oxidation	(Cagdas and Kumcuoglu 2015)
Wine grape pomace	Antioxidant dietary fibre	Yogurt and salad dressing	Enhancing nutritional value and improving storability	(Tseng and Zhao 2013)
Wine grape pomace	Bioactive compound	Fortified baked goods	Improving physicochemical, nutritional, and sensory qualities	(Walker et al. 2014)
Wine grape pomace	Antioxidants	Beef Patties	Reducing protein oxidation	(Garcia-Lomillo et al. 2016a)
Wine grape pomace	Antioxidants	Barbecued beef patties	Reducing polycyclic aromatic hydrocarbons	(Garcia-Lomillo et al. 2016b)

			(PAHs) and heterocyclic aromatic amines (HAs)	
Wine grape pomace	Antioxidants	Refrigerated and frozen beef patties	Inhibiting lipid Oxidation	(García-Lomillo et al. 2017)
Grape marc	Polyphenols	Fettuccini pasta	Increasing antioxidant activity	(Sant'Anna et al. 2014)
Orange byproducts	Dietary fiber	Ice cream.	A fat replacer	(Crizel et al. 2013)
Orange byproducts	Dietary fiber	Yogurts	A fat replacer	(Yi et al. 2014)
Brans	Dietary fibers	Pasta	Producing functional pasta	(Kaur et al. 2012)
Brans	Dietary fibers	Bread	Improving bread-baking qualities	(Cai et al. 2014)
Apple, banana or passion fruit wastes	Dietary fiber	Yogurts	Enhancing probiotic viability and fatty acid profile and increasing CLA content	(do Espirito Santo et al. 2012a)
Passion fruit peel	Dietary fiber	Yogurts	Producing skim yoghurts	(do Espirito Santo et al.

				2012b)
White cauliflower by-products	Antioxidant compounds	Beef sausage	Improving the nutritional, physicochemical and sensory quality	(Abul-Fadl 2012)
Old stalks of Asparagus officinalis	Total flavonoids and total phenolic	Restructured chips	Producing restructured asparagus officinalis chip	(Liu et al. 2016a)

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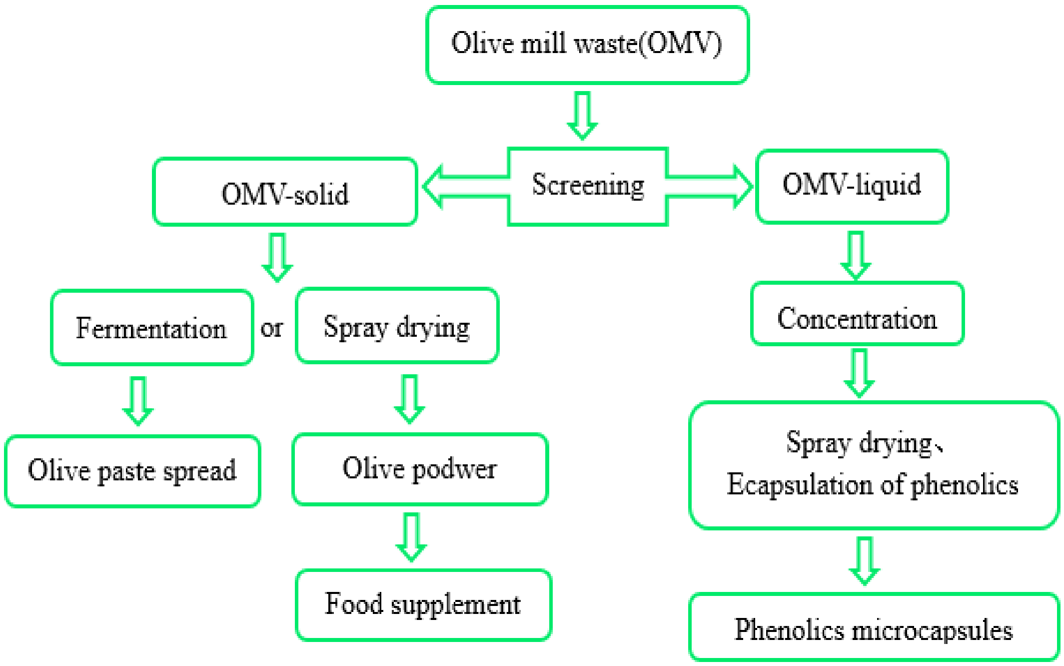

Fig.1. Proposed integrated process for olive mill waste (OMW) utilization

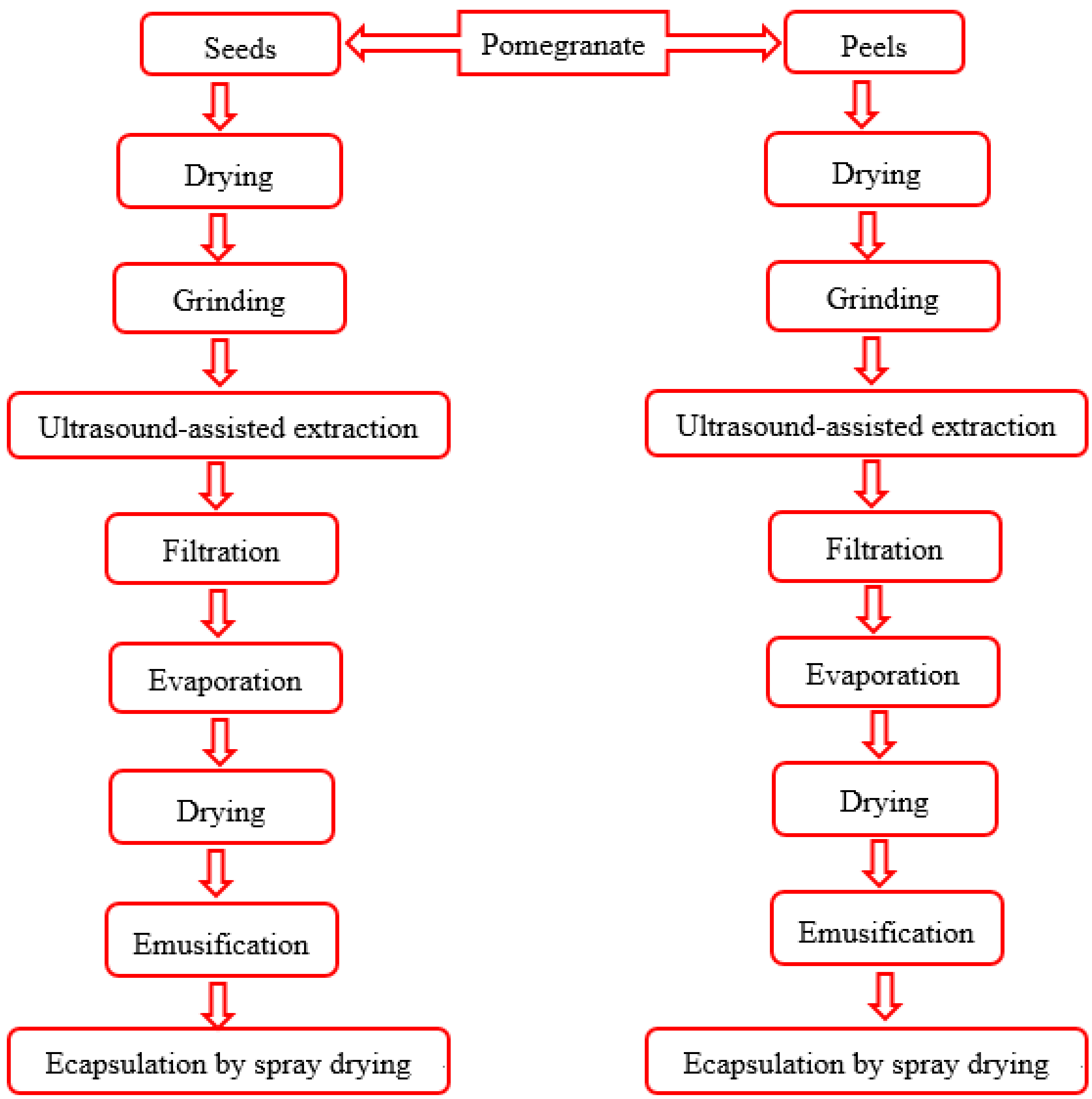

Fig.2. Proposed integrated process for pomegranate wastes utilization.