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Health-promoting benefits of plant-based by-product extracts obtained by innovative technologies

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Innovative processing technologies have been extensively investigated over the last decade, as a sustainable way to recover high-added-value compounds from food by-products. In this sense, these alternative technologies have been optimized for a variety of plant-based matrices, demonstrating higher yields compared with conventional methods. However, the functionality of the extracts obtained has been mainly assessed based on the characterization of the compounds recovered or in terms of their bioactivity properties, but there is a lack of studies focused on the effect of these green technologies on the bioaccessibility/bioavailability of the compounds recovered. There is a challenge herein, since the health-related properties of a compound cannot be claimed until there is sufficient evidence to support that it reaches its biological targets.

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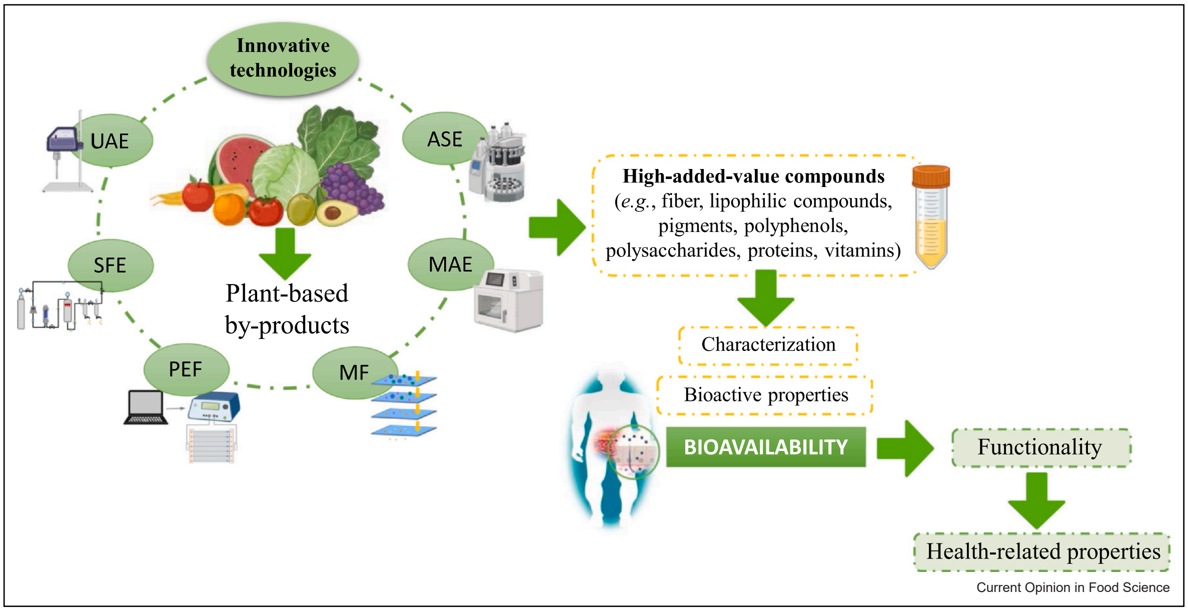
Introduction

The rapid growth of the human population and the resulting increase in industrial food production are behind the significant amounts of sidestreams generated nowadays. Although these biowastes are often discarded or used as low-value ingredients, they represent an outstanding potential good source of bioactive compounds and nutrients, with important functional properties. Therefore, food by-products have been the subject of study in recent years. In this sense, innovative green processing technologies such as ultrasound-assisted extraction (UAE), pulsed electric fields (PEF), accelerated solvent extraction (ASE), supercritical fluid extraction (SFE), or microwave-assisted extraction (MAE) among others, have been extensively investigated during the last decade. These alternative techniques are usually optimized to operate at conditions that maximize the

Figure 1



Overview of the health-related properties' assessment in food by-product extracts. UAE: Ultrasound-Assisted Extraction; PEF: Pulsed Electric Fields; ASE: Accelerated Solvent Extraction; SFE: Supercritical Fluid Extraction; MAE: Microwave-Assisted Extraction; MF: membrane filtration.

preservation of the target compounds [1]. However, optimizing the extraction conditions for the different matrices to obtain the highest yields (bioactive compounds' content) with the best bioactivity, may not indicate that these compounds are potentially bioaccessible and bioavailable to exert their beneficial effects (Figure 1). Therefore, the aim of this review is to provide a critical update of the health-related properties attributed to the extracts obtained from food by-products using innovative technologies, taking into account not only their bioactivity but also their bioaccessibility, which really determines their functionality and potential use as food ingredients.

Health-related properties of by-product extracts

Extracts obtained by ultrasound-assisted extraction

UAE has been revealed as one of the most efficient techniques for the extraction of phenolic and antioxidant compounds from agro-industrial by-products. Not only the extraction yield (total phenolic and total flavonoid content), but also the antioxidant capacity of the extracts has been enhanced in comparison with conventional extraction techniques [2]. In addition, some of the other biological activities attributed to these compounds (antimicrobial, antiproliferative, antidiabetic, and anti-obesity, among others) could result affected [3–5]. The optimal conditions for the extraction of these compounds from several fruit and vegetable by-products and their health-promoting benefits are given in Table 1. In general, it could be said that ethanol concentration, sample size, temperature, probe time, and amplitude were the most significant variables for the maximum yield and functionality of polyphenols [3,4,6]. Currently, the association of UAE with the use of natural deep eutectic solvents (NADES) performs better in the extraction yield and radical scavenging activity than ethanol–water solutions [5]. UAE has also been applied to recover hydroxytyrosol and tyrosol from olive pomace, reducing times and solvent consumption and increasing extraction yields but decreasing their biological activity (antioxidant, antibacterial, antidiabetic, anti-inflammatory, and cytotoxic effects) compared with heat-assisted extraction [7]. The extraction of bioactive polysaccharides (BPSs) with antioxidant, antibacterial, antitumor, immunoregulation, and antidiabetic activities from vegetable by-products has also been addressed by UAE (Table 1). UAE affects their extraction rate and molecular weight, monosaccharide composition, molar ratio, and spatial configuration, characteristics highly related to their biological activity. In this case, the solvent used proved to be one of the most important parameters to achieve the desired results. For instance, UAE using water as solvent allowed the extraction of BPSs from fresh bitter gourd pomace with the strongest antioxidant potential and the best α-amylase and α-glycosidase inhibitory activity (antidiabetic potential), mainly attributed to their higher uronic acid content. Meanwhile, the use of NaOH as a solvent allowed the extraction of BPSs with the highest bile acid-binding capacity (that might be attributed to its branched structure) with a potential cholesterol-lowering effect [8].

Decrease in total phenolic content, antioxidant activity, and bioaccessibility of polyphenol extracts after *in vitro*

Table 1

Health-promoting benefits of by-product extracts obtained by innovative technologies.

Coproduct	Technology	Compound extracted	Extraction conditions	Health-promoting benefits	Reference
Defatted raspberry seeds	UAE	Polyphenols	15 min, 58°C, LSR 17.8 mL/g, 80% ethanol	Antiproliferative activity	[4]
Pomegranate rind	UAE	Polyphenols	5.5 min, 42°C, 20 kHz 30% amplitude, LSR 1 mL/g	Antioxidant activity, anticancerous activity	[2]
Bitter melon pomace	UAE	Polyphenols	15 min, 270 W, 60% ethanol, LSR 20 mL/g, 20-kHz constant frequency	Antioxidant activity, antidiabetic activity, and pancreatic lipase inhibitory activity	[3]
Apple pomace	UAE (NADES)	Polyphenols	40 min, 40°C, 83.2 W/cm^2, 75% duty cycle, LSR 30 mL/g,	Antioxidant activity	[5]
Meghalayan cherry pomace	UAE	Polyphenols	28 min, 55°C, 55% ethanol, LSR 23 mL/g, 33% amplitude	Antioxidant activity	[6]
Fresh bitter gourd pomace	UAE	BPSs	30 min, 25°C, 350 W, 20-Hz constant frequency, LSR 10 mL/g, water	Antioxidant activity, α-amylase, and α-glycosidase inhibitory activities	[8]
Fresh bitter gourd pomace	UAE	BPSs	30 min, 25°C, 350 W, 20-kHz constant frequency, LSR 10 mL/g, NaOH	Bile acid-binding capacity	[8]
Mushroom (*Agaricus bisporus*)	PEF	Polyphenols, BPSs, and proteins	2.5 kV/cm, 50 kJ/kg, 6 hours, liquid:solid ratio at 10:1, water	Antioxidant activity	[16]
Tomato peels and seeds	PEF	Polyphenols, lycopene, and proteins	Polyphenols: 2 kV/cm, 700 pulses Lycopene: 1 kV/cm, 500 pulses Proteins: 5 kV/cm, 200 pulses	Antioxidant activity	[15]
Apple pomace	PEF	Polyphenols (phloridzin)	Polyphenols: 3 kV/cm, 17 kJ/kg, ethanol–water (30:70 v/v)Phloridzin: 2 kV/cm, 100 kJ/kg, ethanol–water (70:30 v/v)	Antioxidant activity	[27]
Barberry stem	PEF	Polyphenols	1 kV/cm, 100 pulses	Antioxidant activity	[18]
Jackfruit rind and core	PEF+MAE	BPSs (pectin)	10 kV/cm, 5 min (PEF) 650 W/g, 10 min (MAE)	Hypolipidemic and hypocholesterolemic activity, anticarcinogenic activity	[17]
Apple pomace	ASE	Polyphenols (phloridzin)	Polyphenols: three cycles, 50% flush, 1500 psi, 40°C, ethanol:water (50:50, v/v) Phloridzin: three cycles, 50% flush, 1500 psi, 40°C, ethanol:water (30:70, v/v)	Antioxidant activity	[27]
Pomegranate seed	ASE	Polyphenols, proteins	Five cycles, 1500 psi, 170°C, 12 min, pH 11, ethanol (0%)	Antioxidant activity, hypocholesterolemic capacity	[26]
Cranberry pomace	ASE	Polyphenols (proanthocyanidin, anthocyanins)	Ethanol: three cycles, 1500 psi, 83°C, 15 min	Antioxidant activity	[31]
Cocoa shell	ASE	Alkaloids (caffeine, theobromine)	Five cycles, 90°C, 6 min, ethanol (15%)	Antioxidant activity, anticarcinogenic activity	[30]
Red onion peel	ASE	Polyphenols (anthocyanin, flavonoids)	Three cycles, 1500 psi, 50°C, ethanol:water (50:50, v/v)	Antioxidant activity, antimicrobial, antibiofilm, and quorum-sensing inhibition activities	[25]
Orange peels	ASE	Carotenoids	46 min, 1.53 mm, 80-mL heptane	Antioxidant activity	[28]
Grape skins and seeds	ASE	Polyphenols	Seeds: eight cycles, 10 min, water:acetone + four cycles, 20 min, water:methanol Skins: eight cycles, 1 min, water:acetone + 1 cycle, 20 min, water:methanol	Antioxidant activity	[29]
Black bean (*Phaseolus vulgaris* L.) seeds	SFE	Soyasaponins, flavonoids	10 MPa, 70°C, 100 g/min, cosolvent: ethanol 10%	Antioxidant, anti-inflammatory, and antihyperglycemic activities	[40]
Date (*Phoenix dactylifera*) seed	SFE	Anthocyanins, carotenoids flavonoids, and phenolic acids	27.50 MPa, 52.50°C, 5 mL/min, cosolvent: ethanol 30%	Antioxidant activity	[42]

Table 1 (*continued*)

Coproduct	Technology	Compound extracted	Extraction conditions	Health-promoting benefits	Reference
Mandarin (*Clementina orogrande*) peel	SFE	Phenolic compounds (hesperidin)	300–400 bar, 40–50°C, cosolvent: ethanol 10%	Antioxidant activity	[39]
Pomegranate (*Punica granatum*) peels	SFE	Flavonoids (catechin, epicatechin, hesperidin, and rutin), phenolic acids (caffeic, chlorogenic, ellagic, and gallic)	20 MPa, 40°C, 45 min, cosolvent: ethanol	Antioxidant, antimicrobial activities	[38]
Quinoa (*Chenopodium quinoa* Willd.)	SFE	PUFA (oleic acid, linoleic acid, and linolenic acid), saponins	23 MPa, 55°C, 35 g/min, 8 g of quinoa/100 mL of ethanol, 4 hours	Antioxidant activity	[43]
Broccoli florets, stems, and leaves	MAE	Polyphenols	74.5/80/80% MetOH, 15.9/10/18.9 min, and 74.5/73.3/75°C for stalks, leaves, and florets, respectively; ratio 1:20	Antioxidant activity	[45]
Jojoba seed cake	MAE	Polyphenols	500 W, 15 min, 42–46% ethanol, ratio 41–45 mL/g	Antioxidant activity	[47]
Residues from mate tree	NF	Polyphenols (chlorogenic acid and epigallocatechin gallate)	150–300 Da/thin-film/spiral wound	Antioxidant activity	[48]
Olive mill wastewater	UF	Pectin	100 kDa/polysulfone/spiral wound	Gellining agent	[49]
Pigmented citrus residue	UF	Pectin	10 kDa/fluoropolymer/spiral wound	Gellining agent	[50]

GAE: gallic acid equivalents; RUE: rutin equivalents; TPI: total phenolic index; PUFA: polyunsaturated fatty acids.

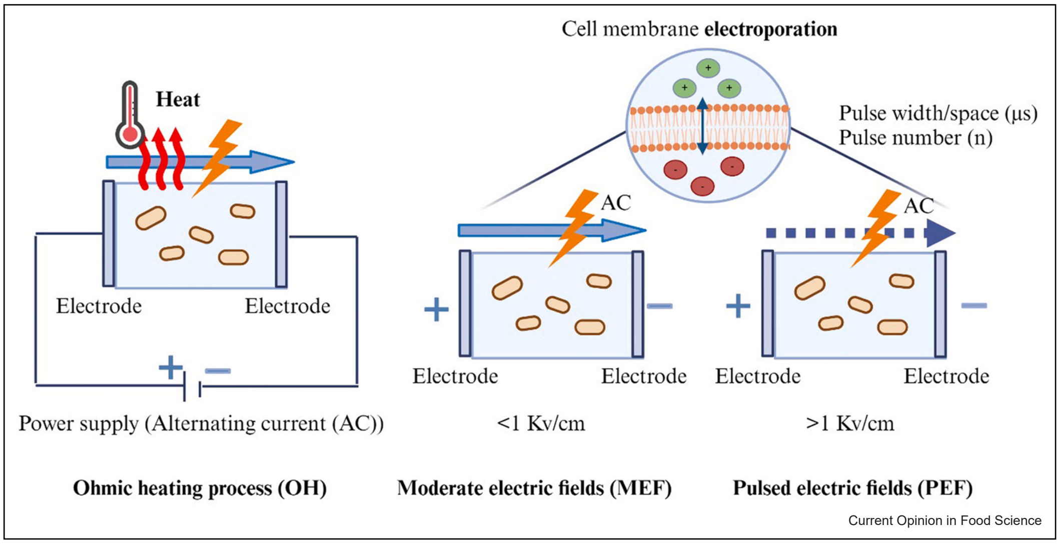
gastrointestinal digestion has been reported greater in extracts obtained from conventional procedures than in UAE [6]. Higher bioaccessibility of UAE (compared with conventional) has been reported for berry pomace [9], cherry pomace [6], and Meghalayan cherry *(Prunus nepalensis)* pomace [6], being attributed to the cavitation effect of ultrasound, which releases polyphenols into the solvent matrix normally bound to cell wall structural components such as lignins, cellulose, and hemicellulose. The low stability of polyphenols to pH changes and enzymatic activity (occurring during digestion), together with their biotransformation into other compounds, has been argued as potential reasons for their variable bioaccessibility. For instance, p-coumaric acid and catechin underwent drastic changes after digestion resulting in lower bioaccessibility; after intestinal digestion, phenolic acids showed higher bioaccessibility than flavonoids [10].

Extracts obtained by electric field processing

Within the electric field processing, different types can be found, such as ohmic heating (OH), moderate electric fields (MEF), and PEF processing, whose principles present certain differences. OH is a thermal process in which a moderate electric current is passed through the food matrix to increase the temperature, resulting in nutritional and structural changes [11]. The MEF and PEF treatments, on the other hand, are nonthermal processes in which an electric current is passed through the sample to produce the electroporation of the cell membrane, which allows the extraction of the compounds of interest with a greater preservation of the structure [12]. MEF processing uses an electric field strength < 1 kV/cm, while PEF processing is based on the emission of electric pulses with an electric field strength > 1 kV/cm [13] (Figure 2). In this overview, the extracts obtained by PEF processing were considered, as they have great advantages over conventional thermal methods.

Compared with conventional methods, PEF processing has shown an increase in the recovery of heat-sensitive antioxidant compounds and macronutrients due to the electroporation of cell membranes, which allows selective recovery of compounds considering the main parameters of this technology: electric field strength, specific energy, and total time. Although both processing (OH and PEF) increased the recovery of bioactive compounds, a stronger electropermeabilization was observed for PEF compared with OH [14]. The studies of the different conditions and the result of the optimization of the extraction processes from different plant by-products are presented in Table 1. As can be seen, PEF processing was mainly used for the recovery of compounds with high antioxidant capacity: polyphenols (flavonoids, anthocyanins, and tannins), pigments (lycopene), and vitamin C, for which the specific energy showed a great

Figure 2



Principles and differences between the types of electric field processing: OH, MEF, and PEF. Created with BioRender.com.

influence on the extracted concentration [15]. At higher specific energy, a decrease in the extracted antioxidant compounds was observed, mainly due to thermal degradation [16]. In addition, the solvent used in the extraction also showed differences in the yield of polyphenols, being higher when aqueous and alcoholic solvents were used, while the use of organic solvents was avoided. This fact is due to the polarity of the compounds of interest, since polyphenols and BPSs are the most-studied compounds from plant peels and pomace due to their therapeutical properties [17,18]. Regarding the use of technology, when PEF was combined with MAE, favorable results were observed in the recovery of polysaccharides. This is due to the synergy between the electroporation produced and the increased solubility of the compounds, as well as the penetration of the solvent into the matrix due to the increase in temperature [17]. This synergy with MAE is observed for both PEF and MEF. The application of MAE has been used in several plant matrices due to the selective heating of matrix components, which increases the yield by coupling heat and mass transfer in a fast and efficient process. Subsequently, process control is increased by reducing thermal gradients compared with conventional heating strategies. These advantages are further enhanced by combining this method with MAE/PEF processing, which improves mass transfer [14,19]. However, despite the remarkable benefits of this combination, the time and economic investments at the industrial level must be considered when two technologies are used in succession for the recovery of a specific compound. Therefore, further studies are needed on the combination of methods at the technical and industrial production levels.

Regarding bioaccesibility and bioavailability, in the study published by Lopez-Gámez et al. [20], it was shown that the bioaccessibility of phenolic compounds and carotenoids in carrots increased by 20.8% and 11.9%, respectively, after PEF treatment followed by *in vitro* digestion. This was attributed to increased cell permeability due to electroporation, which resulted in degradation of cell membranes responsible for solute transport through the plant parenchyma and facilitated incorporation of carotenoids into micelles during digestion. Increased bioaccessibility of phenolic compounds was also observed in apples (27%) [21] and orange peels (82% carotenoids, 40.7% phenolic compounds) [22], although in the latter matrix, it was found that an increase in applied specific energy increased the bioaccessibility of carotenoids, while that of polyphenols decreased. The study on apple peels (17–39% flavonols, 2–9% anthocyanins) [23] showed that bioaccessibility was lower than in apple flesh with a 14% decrease in flavanols, demonstrating the influence not only of the technology used but also of the composition of the different parts of the same food on the interaction of the components. In general, phenolic compounds have low bioavailability due to limiting factors such as the complexity of their structure, solubility, molecular interaction, and polymerization, which makes the search for technologies to increase their bioavailability particularly interesting [24]. Therefore, further studies are needed to optimize PEF processing in terms of bioaccessibility and bioavailability of specific phenolic compounds present in agri-food by-products, since they behave differently under the same conditions.

Extracts obtained by accelerated solvent extraction

ASE-assisted extraction has been used in different matrices to recover proteins, achieving high extraction efficiency through the application of pressure and temperature. However, the growing demand for the revalorization of plant by-products from agriculture has led to the investigation of this technology for the recovery of phenolic compounds and pigments. Table 1 shows the optimal extraction conditions of ASE after different optimization processes varying different parameters: number of cycles, temperature, and time. In general, a pressure of 1500 psi and a flush rate of 60% were used in most studies. Moreover, aqueous solvent showed the highest recovery rates, followed by ethanol:water at ethanol ratios up to 50% [25–27]. However, for nonpolar β-carotenes, heptane was the solvent with the best results compared with chloroform and hexane [28]. In addition, compound recovery increases as the number of cycles increases, with a general application of three cycles. However, the application of 5–8 cycles showed greater results in the recovery of polyphenols in grape seeds and skins [29], pomegranate seeds [26], and cocoa shells [30]. On the other hand, the optimal temperature was one of the factors with the most variable results. In matrices such as apple pomace [27], cranberry pomace [31], and pomegranate seeds [26], the application of the highest temperature of the selected range from 40 to 170°C, resulted in the highest extraction yields for polyphenols such as phloridzin, proanthocyanidins, and anthocyanins. Nevertheless, in most studies, the highest concentration of these compounds was obtained at a low temperature. In addition to the above factors, in the study published by Toprakçı et al. [28], the particle size of the matrix compared with the extraction time and solvent was the most influential factor for the recovery of carotenoids. A particle size of 1.53 mm was the optimal size because it increased the interaction with the solvent due to a larger number of particles per larger area.

The study of optimal extraction conditions by ASE should be accompanied by bioaccessibility/bioavailability studies. In the study published by Picos-Salas et al. [32], ASE-assisted extraction on *Lamiaceae* plants was used to obtain high yields of apigenins and luteolin, whose bioavailability is highly related to the chemical structure of the molecule and the chemical changes due to the solvent influence and the pressure. In addition, polyphenols such as anthocyanins are very sensitive to changes in pH, which is one of the factors involved in the optimization processes for ASE [26]. Anthocyanins are more stable at acidic pH (< 2.8–3) and at low temperatures [33]. According to Domínguez-Rodríguez et al. [34] on sweet cherry pomace, ASE can be used to obtain nonextractable polyphenols in combination with enzyme-assisted extraction (ASE–EAE) with better results than using ASE technology exclusively with a dominance of phenolic acids. These results suggest that combining ASE with other extraction methods would be beneficial to increase bioavailability, although the association of polyphenols and structural changes during the digestion process should be considered. However, it should be emphasized that there is a lack of published studies on the effects of ASE technology on the bioaccessibility and bioavailability of phytochemicals from agri-food by-products. Further studies are needed on the effects of key parameters (pressure, temperature, and time) on these variables, considering that high-pressure processing increases the bioaccessibility of carotenoids by reducing molecular weight and promoting the degree of esterification [35].

Extracts obtained by supercritical fluid extraction

Another technology that is booming today is SFE. Its operational conditions (nontoxic organic solvents, low temperatures and extraction times, higher diffusion, and reduced energy consumption) make it an alternative to the conventional extraction methods [36]. Pressure, temperature, time, and CO_2 flow rate are the main parameters that are necessary to optimize. However, it is also necessary to take into account the characteristics of the matrix (e.g. moisture content, particle size, porosity, and shape), and the compounds to be extracted, since they will condition the selectivity of the technique and therefore, the extraction yield. In this regard, SFE can be effectively used for the extraction of nonpolar fractions [36], especially lipophilic compounds (e.g. carotenoids, essential oils, fatty acids, and fat-soluble vitamins), but also, polar fractions, mainly associated with phenolic compounds, can be obtained. In this case, sometimes it is necessary to use a cosolvent (e.g. ethanol) to facilitate the extraction by increasing the polarity of the CO_2 [37]. The obtained extracts contain high-added-value compounds that in most cases have the health biological activities, which together with their purity and stability makes them potential ingredients for the development of functional foods.

Some examples of the optimal extraction conditions and the health-promoting benefits of extracts obtained by SFE are shown in Table 1**.** SFE has been applied to recover polyphenols from peels of fruits [38]. In the case of mandarin (*Clementina orogrande*), 10% ethanol was used as a cosolvent to favor the extraction [39]. The obtained extracts were rich in flavonoids, which displayed antioxidant and antimicrobial properties. These phenolic compounds were also obtained in the seeds of black beans [40]. Moreover, soyasaponins are the main compounds identified in the extract, also associated with anti-inflammatory and antihyperglycemic activities [40]. Compared with other conventional extraction methods, SFE allowed to obtain higher extraction yields and higher contents of polyphenols, especially phenolic acids [38]. In addition to polyphenols (e.g. naringenin, caffeic acid), tomato skin is also an important source of carotenoids (e.g. lycopene and β-carotene). Pressure was the parameter that has the most influence on the extraction of these compounds. In this regard, Pellicanò et al. [41] observed that although increasing the pressure favored the extraction of bioactive compounds, this was inversely proportional to their antioxidant activity. Pressure also significantly affected the oil extraction from date seeds, since an increase in pressure conditions resulted in an increase in CO_2 density, which favored the extraction yields [42]. In addition to observing higher yields, higher contents of anthocyanins, carotenoids, phenolics, and flavonoids than those obtained by conventional techniques were found, resulting in increased antioxidant activity.

On the other hand, this technique can be used as pretreatment for the extraction of fat, considered as a by-product in some vegetable matrices. This is the case of quinoa (*Chenopodium quinoa* Willd.), where oil and saponins are considered by-products of the production of quinoa protein hydrolysates [43]. The oil obtained by SFE was characterized by higher extraction yields, phenolic content, and antioxidant activity than the oil obtained using conventional solvent extraction. Moreover, it had significant amounts of unsaturated fatty acids, associated with health-promoting properties and antioxidant activity.

It is important to highlight that there are hardly any studies in which the bioaccessibility of the target compounds found in the extracts obtained by SFE has been evaluated, which would really determine their functionality.

Extracts obtained by microwave-assisted extraction

The main variables that can affect the extraction process in MAE are power and frequency, solvent properties and dielectric constant, temperature, pressure, time, sample size, the reactor design, the irradiation mode, and the use of coupling agents. In this sense, the power and frequency of microwave (MW) energy per unit of weight or volume can affect the efficiency of the process, which is directly proportional to the recovery of health-promoting compounds. The properties of the solvent (its viscosity, polarity, or its boiling point) and the dielectric constant of the sample can influence the absorption and distribution of MW energy, affecting the heating and extraction process. An increase in temperature during extraction promotes the diffusivity of the solid into the solvent, and then a desorption of the health- promoting compounds occurs. Also, in some MW extractors, the pressure can be modulated, which can optimize the mass transfer of phytochemicals from the sample into the solvent, avoiding their degradation. The extraction time is directly proportional to the extraction yield, although high power during extended times is associated with phytochemical degradation. The size and geometry of the sample can affect the distribution of MW energy, the heating rate, and hence the degree of extraction. The design of the MW reactor as well as the type of MW irradiation (continuous or pulsed) can influence the distribution and penetration of MW energy, thus affecting the heating and hence the efficiency of the process. Finally, the use of coupling agents (such as ceramics or susceptors) can enhance the absorption and distribution of MW energy, thereby improving the performance of the process [44].

As the optimal conditions change depending on the sample and target compounds, these characteristics and parameters should be considered when designing and optimizing MAE processes. According to the Web of Science, more than 75 scientific studies on the extraction of food by-products using MAE have been published from 2021, of which 38 used fruit losses as a source of bioactive compounds. In this sense, in the present review, some of the most-cited works [45–47] have been selected and summarized in Table 1. However, as far as the authors are concerned, to date, there are hardly any studies that have evaluated the bioaccessibility of the compounds recovered by MAE.

Extracts obtained by other innovative technologies

In recent years, other innovative technologies, such as membrane filtration (MF) processes, have been used for the recovery of agri-food by-products and plant-based products. MF (e.g. ultrafiltration (UF), nanofiltration (NF), pervaporation, and membrane distillation) allows the separation and concentration of bioactive compounds without requiring chemical solvents or temperature gradients, preventing the degradation of labile compounds and preserving their properties. In this regard, Prudencio et al. [48] used NF to recover polyphenols (chlorogenic acid and epigallocatechin gallate) from mate waste. On the other hand, Galanakis et al. [49] employed UF to obtain pectin from olive mill wastewater. Moreover, UF was also used to recover pigmented citrus residue [50].

Conclusions

The application of emerging technologies (UAE, PEF, ASE, SFE, MAE, etc.) in the valorization of agro-industrial by-products presenting multiple advantages (reduced process time, improved extraction yields, and protection to the bioactive properties of the compounds). Moreover, these technologies confirmed their ability to obtain high-value bioactive compounds such as phenolic compounds, pigments, pectin, organic acids, fiber, and other metabolites with bioactivity properties (e.g. antioxidant, anti-inflammatory, antihyperglycemic, and antimicrobial). However, the effect of these green technologies on the bioaccessibility/bioavailability of the recovered compounds has been slightly investigated, especially in the case of SFE and MAE, although evidence from UAE, PEF, and ASE suggests their potential in this regard as well. Therefore, there is a challenge in this respect, as the health-related properties of a compound can only be claimed if there is sufficient evidence that it reaches its biological targets. Finally, there is no optimal technique and the combination of two or more innovative technologies could enhance the optimization process improving the quantity and quality of the high-value bioactive compounds. However, these green technologies must be adapted to the specific uses and targets of the industry.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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