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Review

Influence of the extraction method on the recovery of bioactive phenolic compounds from food industry by-products

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ABSTRACT

Agro-foodindustries generate colossal amounts of non-edible waste and by-products, easily accessible as raw materials for up-cycling active phytochemicals. Phenolic compounds are particularly relevant in this field given their abundance in plant residues and the market interest of their functionalities (e.g. natural antioxidant activity) as part of nutraceutical, cosmetological and biomedical formulations. In "bench-to-bedside" achievements, sample extraction is essential because valorization benefits from matrix desorption and solubilization of targeted phytocompounds. Specifically, the composition and polarity of the extractant, the optimal sample particle size and sample:solvent ratio, as well as pH, pressure and temperature are strategic for the release and stability of mobilized species. On the other hand, current green chemistry environmental rules require extraction approaches that eliminate polluting consumables and reduce energy needs. Thus, the following pages provide an update on advanced technologies for the sustainable and efficient recovery of phenolics from plant matrices.

1. Introduction

Diet is the modifiable morbidogenic component with the greatest impact on health, quality and life expectancy. The last study on Global Burden of Disease (2019) placed diet as the 2nd death risk factor among females (13.5% of global attributable burden) and 3rd among males (14.6%) (GBD 2019 Risk Factors Collaborators, 2020). Aware of this reality, consumers currently demand functional foods that beyond their organoleptic and nutritional properties, provide beneficial health outcomes (Schwingshackl et al., 2018; Santos-Buelga et al., 2019).

Prospective observational studies have reached a consensus on benefits of plant-based foods (fruits, vegetables and legumes), such as in the Mediterranean diet (Dinu et al., 2018; Román et al., 2019). Plants are rich in trace components, secondary metabolites of non-energetic function and active in signaling, that provide protective actions (preventive and/or curative) on disease (Chiocchio et al., 2021). Among these bioactive phytochemicals are antioxidants, to which available evidence attributes some of the prophylactic/therapeutic benefits of the diet (Amarowicz & Pegg, 2019). Initially focused on antioxidant vitamins, more recently (poly)phenolic derivatives widely distributed in fruits, vegetables, cereals and beverages have taken centre stage due to their appreciated antioxidant, allelopathic antimicrobial and UV-protection activities (Fig. 1). Thus, phenolic compounds are defense agents that counteract biotic and abiotic stresses, scavenge reactive oxygen and nitrogen species (RONS), chelate pro-oxidant metals and regenerate antioxidants, thereby becoming pleiotropic barriers against nitrooxidative damage and degenerative pathologies (Pagliarulo et al., 2016; Forni et al., 2019; Tuladhar et al., 2021). Indeed, over the past decades epidemiological surveys have provided robust evidence on the association between regular polyphenol-rich intakes and the decreased incidence of cancer, inflammation, obesity and diabetes, cardiovascular disorders and neurodegenerative diseases (Cory et al., 2018). Hence the

Abbreviations: DM, dry matter; DW, dry weight; GAE, Gallic acid equivalents; TE, Trolox equivalents; RtE, rutin equivalents.

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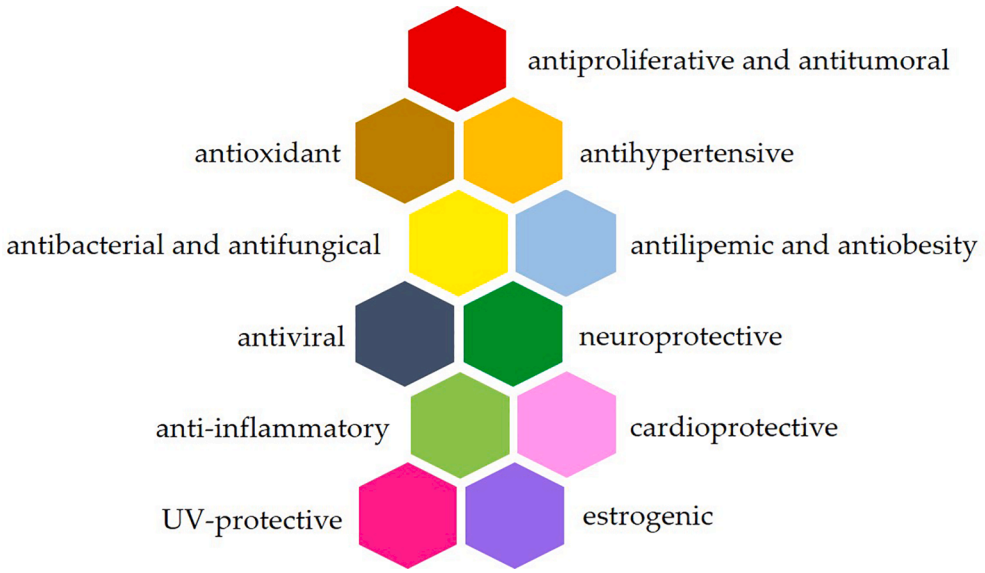


Fig. 1. Main bioactivities reported for phenolic compounds. The wide family of plant phenolic compounds integrates a powerful defense against biotic and abiotic stress. The scavenging of reactive species and the reinforcement of antioxidant mechanisms, protection against UV-irradiation and allelopathic antimicrobial activities make phenolics a barrier to prevent nitrooxidative and inflammatory damage and the onset of degenerative pathologies associated with them.

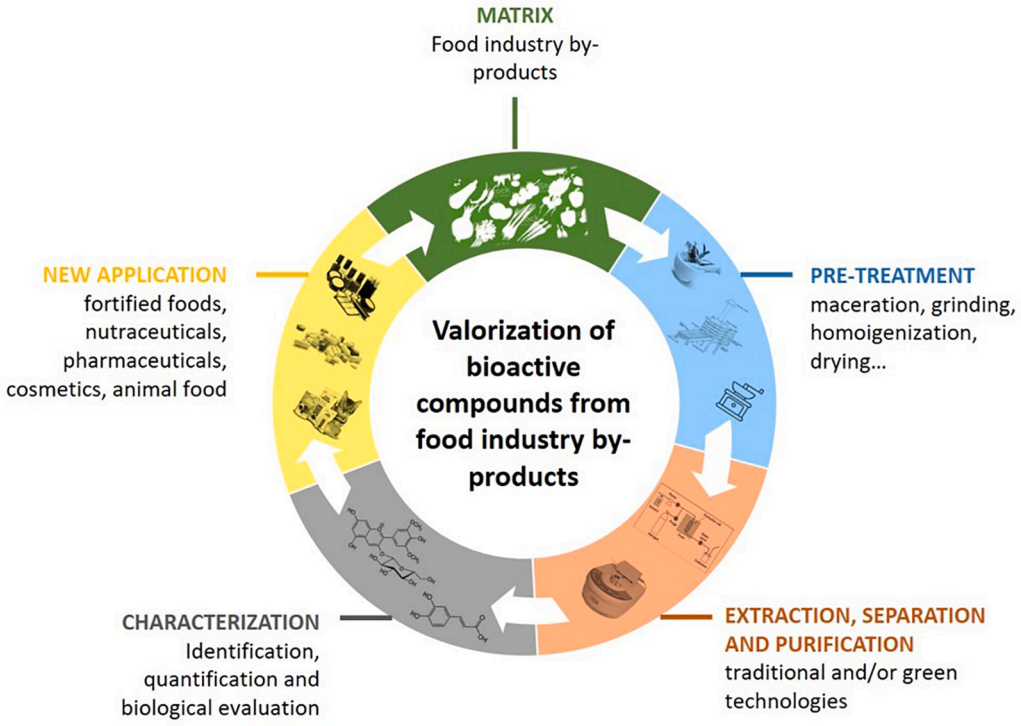


Fig. 2. Schematization of the cycle of valorization of active phytochemicals from by-products of the agro-foodindustry. In the framework of the circular economy, the by-products of the agri-foodindustry are considered high-potential raw materials, from which to obtain derivatives of high-added value and great applicability as nutraceuticals and/or fortification additives in pharmacological, food or cosmetic formulations.

growing interest of phenolics as nutraceuticals and/or fortification additives in the high-value chains of numerous biosectors (pharmacological, food processing and preservation, cosmetic, etc) (Albuquerque et al., 2021; Yan et al., 2021). In this regard, it should be noted that phenolic compounds are devoid of unstability and volatility at high temperatures that synthetic antioxidants may manifest (Lobo et al., 2010). Additionally, preparations manufactured from raw plant matrices retain endogenous phenolics in amounts to ensure their functional properties (Pandey & Rizvi, 2009).

Plant food production and processing generate huge volumes of organic residues that give rise to significant expenses for removal to the agro-foodindustry and, furthermore, environmental stress due to the possible presence of phytotoxic substances. The important olive oil and wine industry in Southern Europe, for example, wastes by-products estimated in 5000 and 3500 kton/year, respectively (Tapia-Quirós et al., 2020). However, the olive/grape underused co-products are important sources of nutritionally valuable compounds including phenolics (e.g. ≈70% of grape polyphenols remain in the pomace), which

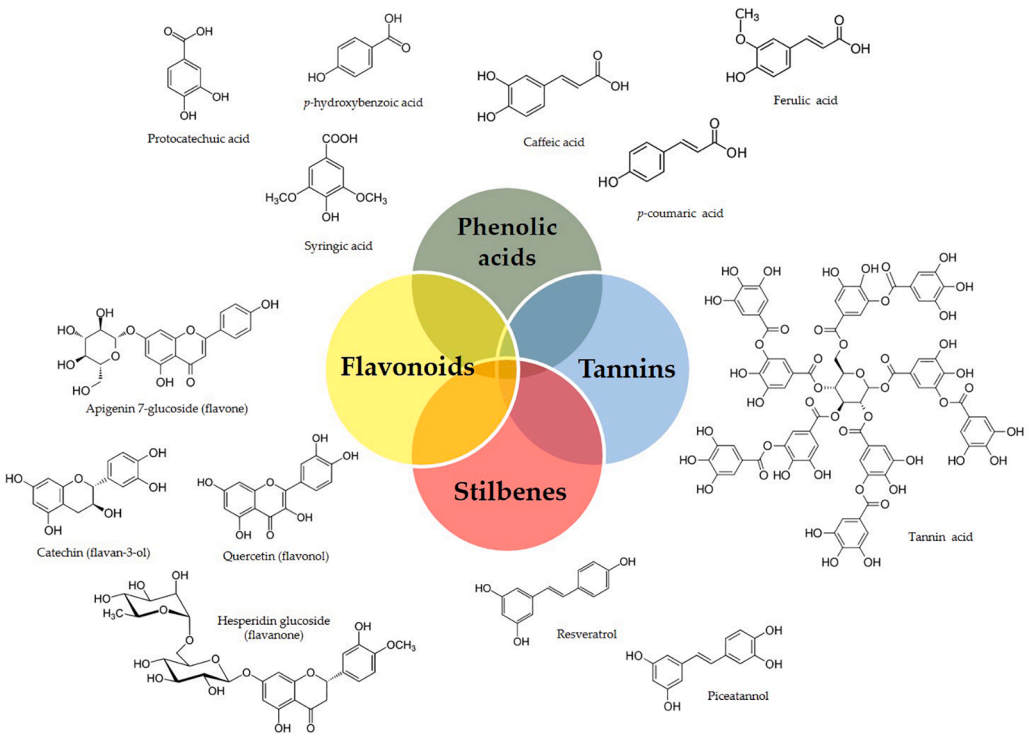


Fig. 3. Main structural classes of phenolic compounds. Phenolic compounds can be divided into four broad clases (phenolic acids, flavonoids, stilbenes and tannins), based on the number of phenol rings and the substituents attached to them. All these variety of chemical species can occur in plants as free or conjugated molecules (with sugars, proteins or other biomolecules), the latter either in a soluble state or attached to the matrix. Phenolic acids are basically integrated by a phenolic ring and a carboxylic group, which can be further be classified in two subtypes, derivatives of hydroxybenzoic acid or hydroxycinnamic acid, according to their carbon skeleton. Throughout the manuscript we have referred to some of them, as *p*-hydroxybenzoic, protocatechuic and syringic acids (hydroxybenzoic acid derivatives) or caffeic, *p*-coumaric and ferulic acids (hydroxycinnamic acid derivatives). Flavonoids are the most abundant phenolics. Their canonical structure consists in a 15-C backbone formed by two aromatic rings linked via the O-heretocycle pyrane. Flavonoids can be subdivided into several types depending on the chemical characteristics of the pyrane ring: the degree of unsaturation or oxidation and the atom that is involved in the link of the two benzene rings. Different flavones, isoflavones, flavonols, flavanols, flavanones and anthocyanins have been mentioned in some instances throughtout the manuscript. Stilbenes are molecules composed of two phenyl moieties attached through a 2-C methylene group, which can isomerize betwwen Z (*cis*) and E (*trans*) configurations. Two of them, piceatannol and the well-known resveratrol are expressly mentioned in the manuscript. Tannins are the main complex phenolic polymers present in plants, both in hydrolyzable or condensed forms. The former are mixtures of simple phenols (e.g. ellagic or gallic acids) linked to carbohydrates, while condensed tannins come from the polymerization of 2->200 monomers of flavan-3-ol units.

have straightforward human/animal feed, cosmetic and pharmaceutical applications (Roselló-Soto et al., 2015; Averilla et al., 2019a). Therefore, the new occurring paradigm of circular bioeconomy conceptualizes food waste as low-cost supplies of phytochemicals that can be transformed into highly-demanded additives and/or derivatives (Fig. 2) (Ben-Othman et al., 2020; Osorio et al., 2021). Consequently, valorization of plant by-products has become strategic to the agro-foodindustry, but also to sustainability policies since it can avoid the eutrophization of ecosystems and thereby help to preserve the ecological standards (Jimenez-Lopez et al., 2020). Moreover, owing to accelerated aging and increased awareness on diet-health relationships, the global polyphenol market is estimated to reach $1.82 billion by 2025 and a growth of 7.44% in the period 2020–2025 (IndustryARC™. Polyphenols Market – Forecast (2021 - 2026)), particularly as functional components deriving from grapes, apples, olives and green tea (Wijngaard et al., 2012; Panzella et al., 2020). In agreement with this *statu quo*, the scope of this review is to provide an overview of the current strategies with which the technical challenge of recovering phenolics from agro-foodindustry by-products can be successfully undertaken.

2. The challenge of dealing with the compositional heterogeneity of phenolic fractions from plant matrices

The denomination of phenolics comes from the one or more mono- or poly-hydroxylated aromatic rings present in their structures, the antioxidant groups capable of detoxifying RONS as well as organic and mineral substrates (Pérez-Jiménez et al., 2010). Depending on the number of phenol rings and their structural peculiarities, the phenolic family can be divided into different classes (Fig. 3) which, categorized according to their relationships with the carrier plant, appear as soluble or matrix-bound species. Generally coming from the shikimic or malonic acids pathways (Martillanes et al., 2018), phenolics globally account for 8,000–10,000 molecules ranging from 200 to 3500 kDa (Lecour & Lamont, 2011; Brglez Mojzer et al., 2016). Among this plethora of types, phenolic acids, flavonoids and tannins predominate in plants (Minatel et al., 2017).

Plant matrices include variable percentages of monomer (phenolic acids or anthocyanins) and high polymeric derivatives (such as tannins), glycosylated or aglycone species, as well as protein/carbohydrate-conjugated insoluble phenolic compounds (Garcia-Salas et al., 2010; Alara et al., 2021). This extraordinary diversity in polarity, polymerization, conjugation and matrix interactions changes with maturation, environmental parameters (climate, soil quality, topography) and cultivar (Perussello et al., 2017; Dossou et al., 2021; Lin et al., 2021). On the other hand, the phenolic composition is determinant of organoleptic idiosyncrasy and nutritional quality of plants and derivatives (Cheynier, 2005). Hence the complexity which arises in approaching structure, bioavailability and biological activity of each species, to the point that little or nothing is known about the short and long-term health impact of a large part of them. However, the resolution of structures with positive contributions to health or interest for the industry must inexcusably be delineated before standardizing the commercial use of whatever extract or clinical preparation in pharmacological doses.

In the challenge of profiling the microheterogeneity of phenolic fractions from solid/liquid plant matrices, extraction is the critical step of downstream processing (Galanakis, 2012; Pimentel-Moral et al., 2020) because it determines the efficiency of recovery. Extraction is a sequential separation in which the targeted phenolics must transition

from the sample to the extractant according to their specific distribution coefficients. For this purpose, the suitability of the solvent and physicochemical conditions (such as time, pH, temperature, sample-to-solvent ratio or the number of extraction cycles, among others) must be carefully addressed to avoid out-of-control changes that alter the native structures and the co-elution of unwanted species. Regarding this, extraction usually begins by mobilization of soluble moieties. The insoluble non-extractable cell-wall conjugates need to be previously released from the matrix by acid/base or enzymatic hydrolysis (Ross et al., 2009).

Unfortunately, there is no guide from which to standardize the extraction setting (the most adequate solvent and operational parameters) to yield unaltered and uncontaminated fractions of targeted biocompound(s). Indeed, to maximize yielding an optimum commitment between solubilization and degradation must be empirically reached. In response to this issue, the present review summarizes the general rules and technical strategies to properly address the complexity of (poly) phenolic extraction, exemplified with some representative laboratory workflows providing active fractions from diverse plant by-products. It should be pointed out that an excellent complement to this review includes some recent descriptions of commercially available instrumentation and technical configurations (Chávez-González et al., 2020; Rodríguez de Luna et al., 2020).

3. Cardinal factors for liquid extraction of phenolic compounds from plant by-products

3.1. Solvent is strategic for the success of plant phenolic extraction

The extraction effectiveness comes from the interplay between the solubilisation ability of the solvent and the relative solubility of sample phenolics, which determines their distribution coefficient and extractability. In this regard, the ability of the solvents to establish hydrogen bonds is decisive, specifically for the achievement of solvation and release of the matrix-bound species (Jessop et al., 2012). Thus, the greater the diffusivity of the solvent within the matrix, the easier the destabilization of the hydrogen bond network within its structure and higher the solvation of the target compounds (Alara et al., 2021). To fulfill all these purposes, the polarity of the solvent(s) is particularly critical since it greatly determines the selectivity of the partition system and therefore the different phenolic species that can be distributed in the extract. Thus, the significant influence that solvents with different polarities have on yield, composition profile and antioxidant activity of phenolic preparations has been clearly shown in the study of the extracts obtained from 8 major classes of food legumes (Xu & Chang, 2007). Unfortunately, precise indications about solvents for specific (poly)phenols or phenolic fractions are lacking, except the principle of classical Chemistry "like dissolves like". As phenolic derivatives are generally polar and hence more hydrophilic than lipophilic, although their specific hydro/lipophilicity depends on the number and conjugation of the phenol groups, polar protic solvents generally provide better extraction results. Hence, aliphatic alcohols (e.g. methanol, ethanol) and polar organic solvents (e.g. acetone, ethyl acetate) are the most popular options to extract phenolics from plant by-products (Garcia-Salas et al., 2010; Tsao, 2010). For example, methanol and ethanol together with acetone and ethyl acetate are frequent in the extraction of phenolics from citrus peels. Orange, mandarin and grapefruit by-products submitted to decoction in acidified methanol:water (50:50, pH 2) and ulterior washing in acetone:water (70:30) provided extracts rich in hesperidin, naringin, and narirutin flavanones (Reynoso-Camacho et al., 2021). Nonetheless, more polar phenolics such as benzoic and cinnamic acids may not be fully solubilized in organic solvents and therefore mixtures with different proportions of water are also frequent in many contexts. Thus, simple decoction in methanol:water (70:30) at room temperature has been shown to be efficient for the extraction of derivatives of caffeic acid, coumaric acid and kaempferol from 7 European varietals and cultivars of *Vicia faba* pods (Valente et al., 2018), displaying high antioxidant capacity (3.1–4.73 μg TE/g DM) correlated with the total phenolic content. Similarly, kiwifruit seeds extracted in 59.45% acetone at 38.35 °C for 79.65 min yielded preparations enriched in five polyphenols (protocatechuic, *p*-hydroxybenzoic, caffeic, *p*-coumaric and ferulic acids) that exhibited high total phenolic content (53.73 mg GAE/g DW) and strong antioxidant and anti-inflammatory activities (Deng et al., 2016). Also, the mixture acetone: water (50:50) provided the highest extraction capacity of phenolic and phytosterol compounds from the walnut septum (67.03 ± 9.76 GAE/g DW of walnut septum; Rusu et al., 2018) and hazelnut (370.42 ± 7.07 GAE/g DW of hazelnut involucre; Rusu et al., 2019). Both preparations displayed potential applicability to treat skin hyperpigmentation and wrinkle formation (Rusu et al., 2018), diabetes, obesity and cancer (Rusu et al., 2019; Rusu et al., 2020). Furthermore, extraction in aqueous methanol (1:10) of golden kiwifruit peel provided a fraction with 10 phenolic compounds (including isoquercetin, epigallacatechin, chlorogenic acid, catechin, ferulic acid, epicatachin, caffiec acid, kaempferol, quercetin and rutin) with positive effects on lipid homeostasis, fatty acid metabolism and gut microbiota of rats (Alim et al., 2020). Another possibility to amplify the collection of extracted polyphenols is the combination of different extractants in successive cycles. From this assumption, interesting developments have been obtained for acidified aqueous methanol (50:50) and acetone:water (70:30) on dried and ground peel from three tonalities of prickly pears (*Opuntia ficus indica*), which have provided total phenolic contents ranging from 9.64 to 12.28 mg GAE/g dry basis, including 68 extractable polyphenols and 15 hydrolysable polyphenols (Amaya-Cruz et al., 2019).

A large part of the extraction protocols includes no-GRAS (Generally Recognized As Safe) solvents, which are contaminant, biologically aggressive and consequently inadequate for food, cosmetic or pharmaceutical industries. Hence, the high toxicity of methanol makes it unfeasible for applications involving contact or ingestion by humans. Instead, ethanol is low-toxic, environmental friendly (Shi et al., 2005; Chaves et al., 2020), provides good polyphenol extractions and has good aptitudes for large-scale processes. Thus, in melon peels (extracted in 95% ethanol at 30 °C for 24 h) 332 and 95.46 mg/100 g extract of polyphenols and flavonoids were obtained, respectively, with hydroxybenzoic acids (3-hydroxybenzoic acid: 33.45 ± 0.37 mg/100 g) and flavones (apigenin-7-glycoside: 29.34 ± 0.17 mg/100 g) as the most abundant species (Mallek-Ayadi et al., 2017). Likewise, the equivolumetric mixture water:ethanol at high temperatures (up to 200 °C) has demonstrated excellent ability to extract phenols from avocado peels (Figueroa et al., 2018a; 2018b; 2018c) and aromatic *Thymus serpyllum* herbal dust (6.6560 ± 0.4595 g GAE/100 g; Mrkonjić et al., 2021). On this occasion, the solubilization efficiency was enhanced by application of high pressure (Hot Pressurized Liquid Extraction or HPLE) to reduce time and solvent volumen, as described in Section 6. Similarly, sustainable liquid extraction and HPLE routes in polar media, such as hydroalcoholic solutions or organic solvent water mixtures have been assayed with grape pomace in a full valorization setting for solid pomace residues (Ferri et al., 2020). In addition to this exemplified casuistry, the water/ethanol GRAS systems have been successfully tested in green extraction of polyphenols from a wide variety of plant by-products, as shown in some recent examples from citrus (Gómez-Mejía et al., 2019), grape seeds (Antoniolli et al., 2015; Kato-Schwartz et al., 2020) or pequi fruit peel (Caldeira et al., 2021) or spent coffee grounds (Ramón-Gonçalves et al., 2019). Pomegranate peels (Pagliarulo et al., 2016), blackberry seed pomace (Wajs-Bonikowska et al., 2017), *Castanea sativa* chesnut (Vella et al., 2018), skin peanut by-products (Franco et al., 2018) or onion papery skin (Saptarini & Wardati, 2020), are other sources in which ethanol has achieved the extraction of phenolic fractions.

Based on this eco-friendly perspective, glycerol has fully entered the green chemistry scene as a new candidate to replace petroleum-derived solvents in extraction processes (Manousaki et al., 2016; Ameer et al., 2017; Makris & Lalas, 2020). Naturally occurring in plants, protic

glycerol shares with hydroethanolic mixtures good capacities for extracting phenolics because of its relatively low dielectric constant ($\varepsilon = 42.5$), which reduces polarity ($\varepsilon_{water} = 80.1$) and facilitates the solubilization of moderately water-soluble molecules. This capacity has been reported for concentrations up to 90% (w/v) in the recovery of total polyphenols from two *Artemisia* species (Shehata et al., 2015), as well as in the valorization of polyphenols from dried olive leaf by-products (heated 9.3% aqueous glycerol at 80 °C; Apostolakis et al., 2014; Mourtzinos et al., 2016). In peppermint (*Mentha* × *piperita* L.) and common nettle (*Urtica dioica* L.) leaves, glycerol-water systems (30.5% aqueous glycerol at 80 °C and 12.5% aqueous glycerol at 20 °C, respectively) were better extractants than classical solvents such as water or ethanol (Kowalska et al., 2021). Likewise, in chlorogenate-rich potato peels, eggplant peels and spent filter coffee, the low-transition temperature glycerol:ammonium acetate mixture (molar ratio 3:1) demonstrated an efficiency greater than or equal to other green solvents (aqueous glycerol, aqueous ethanol or water) in the extraction of flavonoids (Manousaki et al., 2016). This low-transition temperature solvent extracted chlorogenates in amounts of 4.66 ± 0.05, 24.68 ± 0.80 and 12.48 ± 0.05 mg RtE/g DW, respectively, with caffeoylquinic and *p*-coumaroylquinic acid conjugates as the predominant phenolics, having presumed antioxidant effects.

In the concern for greener and more sustainable extraction methods, the capacity of pure water is an important option that has also been investigated. Indeed, water assisted by ultrasound irradiation has been able to extract polyphenols from lemon pomace (*p*-coumaric acid, caffeic acid, chlorogenic acid and hesperidin) endowed with antioxidant and antimicrobial activities (Papoutsis et al., 2018). Other developments of rich-phenolic fractions exhibiting interesting functional properties, have been achieved in recent years. Polyphenol-rich cocoa bean shells (Okiyama et al., 2017), extracted by infusion with mineral water in different home coffee makers for screening their chemical composition, demonstrated health benefits and marketing possibilities as functional beverages (Rojo-Poveda et al., 2019). Likewise, pecan nut shells extracted for 20 min in boiling distilled water provided important amounts of total polyphenols (192.4 ± 1.9 mg GAE/g), which showed antioxidant activity (2218.8 ± 0.8 μmol of TE/g) surpassing green tea and able to prevent disease-liver and erythrocyte genotoxicity in ethanol-treated rats (Müller et al., 2013). In addition, water-soluble polyphenols extracted in boiling water with 1% acetic acid (pH 2.5) from diverse apple peels yielded 3.3 g of polyphenols per kg of dry apple pomace responsible for antioxidant and anti-inflammatory activities useful in yogurt supplementation (Fernandes et al., 2019). Similarly, chestnut shells extracted in boiling water for 60 min provided polyphenol extracts with a total phenolic content of 312.44 ± 3.32 mg GAE/g of chesnut shells dry extract, displaying natural cytostatic activity, capable of reducing cell-viability and coadjuvate conventional chemotherapy (Cacciola et al., 2019). Moreover, three wastes from the wine industry (red pomace, white pomace and canes), under optimal leaching in hot water at atmospheric pressure, gave rise to a valorized source of natural polyphenol antioxidants with preventive and supportive potential for periodontal diseases (Moldovan et al., 2019). The total phenolic content ranged from 18.45 ± 0.48 mg GAE/g DM in canes to 32.00 ± 0.76 mg GAE/g DM in red pomace and the highest amount of 37.80 ± 0.19 mg GAE/g DM in white pomace. Additionally, water at room temperature has also provided valuable extractions, like that obtained from pistachio green hull (total phenolic content = 33.08 ± 1.68 mg GAE/g DW), which exhibited antioxidant and anti-lipase activity (un-competitive inhibitor of porcine pancreatic lipase), efficient against obesity (Noorolahi et al., 2020).

Another recent option to dispense with toxic solvents and approach phytochemical' extraction for the provision of sustainable chemistry are deep eutectic solvents (DES) and their natural DES counterparts (NADES) (Socas-Rodríguez et al., 2021). DES/NADES are water-soluble binary/ternary mixtures of hydrogen bonding donors and acceptors with organic cations, with the ability to establish hydrogen bonds and solubilize phenolic conjugates (Panzella et al., 2020). The reciprocal interactions inside the mixture provide DES/NADES with significantly reduced melting points compared to separated components, so they are liquid at room temperature. Nonetheless, to achieve their full extraction capacity DES/NADES need certain finely-tuned operational requirements such as compositional stechiometry, relative affinity for specific phenolics or sample:solvent ratio, among others (Ruesgas-Ramón et al., 2017). Moreover, their physicochemical characteristics (e.g. polarity, solubility, pH) are unpredictable and must be empirically adjusted for particular functionalities (Hansen et al., 2021). It is particularly noteworthy that beyond their exceptional capacities for extraction in environmentally friendly conditions, specific DES/NADES components can enhance the biochemical potential of plant extracts. This has been found for the first time in the antioxidant activity of polyphenols from grape skin (mainly anthocyanins, flavonoids and resveratrol), that seemed reinforced by the ROS scavenging capacity of the eutectic mixture itself or by some NADES-forming compound (Radošević et al., 2016).

DES/NADES share low toxicity, easy implementation, wide biodistribution, and biocompatibility, which allow the extracts to have direct utility without prior purification (Dai et al., 2013; Socas-Rodríguez et al., 2021). Therefore, numerous studies have recently emerged reporting eutectic developments for extraction of active phenolic fractions from agri-food waste. Indeed, a choline-chloride-based NADES (35.4% in water content) and malic acid as hydrogen donor, coupled to ultrasound-assisted extraction (Section 8) have shown to be more effective in the extraction of anthocyanins from wine lees (6.55 mg/g DW) than a conventional solvent, an acidified aqueous solution of ethanol/water/formic acid (50:48.5:1.5) at pH 2.7 (Bosiljkov et al., 2017). This has been also the case of oil by-products treated with NADES and different technical-assisted extraction methods to obtain phenolic fractions (Chanioti & Tzia, 2018; Bonacci et al., 2020) or to assess specific phenolic species (Paradiso et al., 2019). Likewise, recoveries of active flavonoids from onion (222.97 mg GAE/g DW; Pal & Jadeja, 2019), grapefruit (5 and 2-fold higher anthocyanin extraction than water and methanol; El Kantar et al., 2019) and orange (3.61 mg GAE/g; Ozturk et al., 2018) peels, as well as other many sources (Redha, 2021) have been addressed. To a similar extent, mixtures of glycerol: choline chloride and glycerol:sodium acetate have provided efficiencies of polyphenol extraction comparable to those obtained with aqueous ethanol in by-products such as lemon peels, olive leaves, onion solid wastes, red grape pomace, spent filter coffee and wheat bran (Mouratoglou et al., 2016). Notwithstanding, there appear to be several limitations in the use of DES for phenolic extraction, such as chemical interferences in polyphenol determination through Folin-Ciocalteu assay (for which recently an alternative assay has been proposed; Percevault et al., 2021). Nevertheless, despite these set-up challenges, the physicochemical versatility, sustainability and inexpensive character place DES/NADES in the future of plant by-product valorization (Ivanović et al., 2020).

3.2. . Pretreatment and physicochemical and biological factors influencing plant polyphenol extraction

Extraction is usually preceded by physical sample pretreatments such as drying, milling, grinding and homogenization, among others, to reduce the particle size. The increase of active surface enhances the extraction kinetics and correspondingly the yield of targeted phenolics (Pinelo et al., 2005; Bucić-Kojić et al., 2007; Makanjuola, 2017; Betoret & Rosell, 2020). With the aim of increasing the extraction surface as much as possible, solvent aerosolization has also shown efficient in polyphenol extraction. Thus, for example, in the determination of the total phenolic content in 42 Spanish extra virgin olive oils, in addition to extractive capacity, the method proved to be respectful of the environment and cost-effective by reducing time and consumables (Mirón et al., 2020).

In general, sample pretreatment and its protocolization have a deep impact on the chemical composition of the extract. It is important to note that water activity should be cancelled by drying, freezing or lyophilisation to prevent microbial and/or enzymatic spoilage (Stalikas, 2007; Alara et al., 2021). In this regard, drying has an effect on the amount of phenolics that can be mobilized and on the preservation of their native structures, as has recently been addressed in the loss of polyphenol extractability due to the chemical unstability of native 5-O-caffeoylquinic acid and flavan-3-ols from apple pomace (Birtic et al., 2019). Therefore, drying can introduce unpredictable distortions in the chemical profile of plant samples, and consequently the functional attributes of preparations should be studied in detail and interpolated with caution. Despite lacking systematic investigation, freeze-drying has been considered more adequate than hot air-drying to preserve polyphenols and retain the functional potential of plant extracts, as found in olive pomace (Difonzo et al., 2021). However, it has also been reported to be detrimental for the biomedical properties of food and spice phenolic extracts (Abascal et al., 2005). There is a lack of conclusive data on the negative effects attributed to freeze-drying, although certain evidence has been described, specifically on the preservation of phenolics, so the utilization of lyophilized material for pharmacological and clinical purposes should be further investigated and carefully considered.

Operating parametres such as pH, temperature and time must also be fine-tuned to avoid the oxidative damage and protect the antioxidant capacity and functional properties of plant-extracted phenolics. In this regard, temperature decreases solvent viscosity and surface tension, enhancing diffusion and thereby the mass transfer rate and extraction efficiency (Dai & Mumper, 2010). However, high temperatures may accelerate degradation of labile species, reduce antioxidant capacity and produce solvent evaporation. Thus, for example, in the phenolic extraction from Brazil nut cake moderate values (<60 °C) are preferred (Gomes & Torres, 2016). Also, the extraction and concentration of anthocyanins should not exceed 60 °C (it is usually carried out in the 20–50 °C range) to avoid chemical degradation (Oancea, 2021).

On the other hand, the extraction of polyphenols is generally performed at low pH because in acidic environments these compounds adopt the neutral form, which is the most suitable to be solubilized. However, excessive acidification could impair extraction since the profile of native polyphenols may be distorted due to the hydrolysis of simple (acyl)glycosides (Tsao, 2010). Moreover, pH is also essential in the release of non-extractable polyphenols, which in their native form remain attached to structural elements of the matrix. On these occasions a hydrolytic pretreatment is required: acidic (e.g. pomegranate peel at 6 M HCl and 40 °C for 2 h; Sun et al., 2021), basic (e.g. red cabbage and Brussels sprouts at 4 M NaOH and 80 °C for 30 and 45 min, respectively; Gonzales et al., 2015) or enzymatic digestion (e.g. espresso coffee digested with Clara-Diastase at 10% (w/v) and 37 °C for 3 h; Angeloni et al., 2018).

The extraction time is also decisive because prolonged oxygen/light exposure can deteriorate phenolics and, therefore, reduce their RONS scavenging ability. Furthermore, other polyphenols are prone to oxidation or volatility, requiring short processes or conditions that protect the solubilized fraction from oxygen/light deterioration and/or prevent the transition of released species to the gas phase (Alara et al., 2021). Taking these considerations into account, the time for targeted phenolics must double that of their partition equilibrium. Nevertheless, to reinforce chemical protection, antioxidants such as ascorbate or butylated hydroxytoluene can be included into the extraction cocktail (Tsao, 2010), in addition to post-extraction protective measures such as encapsulation, previous to final formulations (Paulo & Santos 2021).

In sum, the extractability of plant phenolics depends on a plethora of physicochemical parameters that must accomplish the delicate compromise between partition and protection of native structures to preserve the functional potential of final preparations. Biological factors such as microheterogeneity of target phenolics and their conjugation with matrix components are also relevant to extraction quality goals. In this sense, the anatomical (Vella et al., 2018) or varietal origin (de la Cerda-Carrasco et al., 2015) are particularly determinant of 'matrix effects' (the presence of co-extractives in the final preparation) and, therefore, of the need for specific extraction systems according to the phenolic profiles contained in the different parts or plant varieties. Likewise, in the design of extractants, the dielectric constant/polarity of the solvent(s) and thereby their solvation/solubilisation capacity, are decisive. Additionally, the solvent stoichiometry is also critical to fully achieve the extraction objectives, as seen in the preparation of anthocyanin-rich extracts, in which the acidified methanol- or ethanol-based media are able to solubilize membranes and analytes, while the excess of acid can hydrolyze acyl and sugar labile residues (Dai & Mumper, 2010). In view of the complexity involved in extraction settings, it is of great help the *a priori* modelization of chemothermodynamic properties of different solvents to ascertain their solubilization capacity and suitability, as the Nonrandom Two-Liquid Segment Activity Coefficient (NRTL-SAC) model (Silva et al., 2018) or the theorical approach by Hansen solubility parameters (Ballesteros-Vivas et al., 2019b). In this regard, also encouraging is the approach of dealing with the numerous factors that affect yield and extract quality through simulation tools that help to achieve optimal achievements. Thus, for example, chemometric designs based on the Response Surface Methodology (RSM) multifactorial regression model discriminate response variables among the many influential factors and provide predictive models to drive efficient workflows (Aydar, 2018).

4. Classical extraction methods: Efficiency involves operating and environmental costs generally unaffordable at this time

The traditional approach for more than a century to yield phenolic fractions has been the extraction on solid–liquid (matrix-solvent) systems, in which plant matrices upon maceration, percolation or lixiviation (Soxhlet method) release different phenolics according to their solubility. Typically, dry samples are mechanically pretreated to reduce the particle size to diameters that maximize sample-solvent contacts. Once powdered, samples are contacted with the extractants either in an open atmosphere at basal pressure for minutes, hours or days, usually at room temperature (maceration), or inside closed compartments (extraction chamber) under controlled conditions (percolation, Soxhlet apparatus) (Aires, 2017). The extraction is performed at defined solid–liquid proportions in water, ethanol (compatible with some industrial applications), environmentally hazardous solvents (acetonitrile, methanol, ethyl acetate, petroleum ether, etc) or water:solvent formulations. After extraction, samples are centrifuged and/or filtered to discard solid debris and separate the extract, which is ready to be used. Alternatively, the initial preparation can be subfractionated to isolate more specific species (Kumar et al., 2017).

Soxhlet decoction is the most common modality since, in addition to being easy to develop and cost-effective, it achieves remarkable yields with numerous matrices due to the continuos lixiviation of the target phenolics by refluxing the condensed solvent in successive leaching cycles. Thanks to iterative sample-solvent contacts, the Soxhlet design can reach quality extractions in relatively short times and lower solvent volumes than the other classical options, although large amounts are wasted compared to the advanced alternatives currently in use. Moreover, the high solvent/sample ratios involved can lead to environmental disturbances and the high temperatures, usually close to the boiling point of the solvent, can impair the recovery of heat-sensitive native species (Alara et al., 2021). In addition, the extensive use of hazardous solvents causes the inclusion of post-extraction evaporation/concentration cleaning phases to discard solvent traces, which complicates workflows and makes them more expensive.

4.1. Limitations of classical liquid extraction in the face of the challenges of the 21st century

Conventional liquid extraction combines simplicity (easy manual operating), basal pressure (room conditions) and possibly mild temperature. Its wideranging applicability comes from the numerous solvents available and the ductility to suit fresh solid or semi-solid, frozen or dried materials. In addition, its reasonable efficiency and affordability make this alternative the first option as standard procedure for the extraction and concentration of phenolic compounds (Stalikas, 2007; Garcia-Salas et al., 2010). However, the frequent involvement of large volumes of high purity solvents, which can have harmful impacts on health and the environment, or the evaporation and/or concentration requirements, which increase run times and energy supplies, represent serious drawbacks to the evolution of traditional extraction. Furthermore, the need for human intervention compromises the reproducibility and hence, the applicability of the valorizations achieved. Last but not least, low resolution cannot be ruled out due to the presence of traces of solvent and unwanted co-solutes that co-solubilize in the final extracts (Brglez Mojzer et al., 2016). However, this drawback of incomplete phase separations can be overcome by solid phase extraction (SPE), also denominated resin-based extraction, which does not pose the problem of deficient yields (less-than-quantitative) that characterizes basal liquid extraction. In this regard, extraction of *C. reticulata* peels in liquid phase coupled to subsequent reverse-phase solid extraction, have provided phenolic fractions enriched 4.5-fold, free of non-phenolic compounds (hesperidin, naringin, tangeritin, and rutin accounting for ≈86% of the total phenolics extracted), and without reduction in their quantitative recovery and antioxidative or anti-proliferative potential (Ferreira et al., 2018).

Additionally, SPE is highly versatile due to the wide availability of absorbents and presentation forms that, like solvents, must be specifically screened for the sample and application in progress. Moreover, SPE has the advantage of reducing large volumes of hazardous and expensive organic solvents and is adaptable to samples in different physical states if they have been previously pre-fractionated. Nonetheless, the facilities required for SPE are more sophisticated than in traditional liquid partitioning and, therefore, extraction of plant phenolics is often accomplished sequentially by combining liquid extraction with SPE or another non-conventional technique. So, acidic (pH 2.5) pre-fractionation in boiling water and subsequent sub-fractionation by SPE in reverse-phase C18 has allowed the screening of the native and carbohydrate-conjugated polyphenolic composition of apple pomace (Fernandes et al., 2019). Similarly, solvent extraction followed by SPE on mesostructured C18 octadecylsilane-derived silica has been reported for extraction of two dozen polyphenols from mixed fruit-vegetable juices and smoothies (Casado et al., 2019). Likewise, SPE on reusable molecularly imprinted 4-ethenylphenol polymers has demonstrated to be robust to selectively fractionate (*E*)-resveratrol and other polyphenols from an Australian Pinot red wine (Hashim et al., 2013) and aqueous peanut meal extracts (Schwarz et al., 2016). In the same way, styrene–divinylbenzene copolymer resin has provided absorption of phenolic compounds without appreciable losses from red grape marc, acidic pomace extracts and dried apple seeds (Kammerer et al., 2014).

5. Non-conventional modern extraction strategies for plant by-product phenolics

The wide-ranging microheterogeneity of phenolics, together with their frequent polymerization and conjugation of hydroxyl radicals continue to make their solubilization and extraction challenging. In agreement with this panorama, the valorization of agro-food chain by-products is trying to move from the classical, time-consuming methods (hours at atmospheric pressure and relatively high temperatures), and greatly dependent on large volumes of potentially aggressive solvents, towards cleaner, more efficient and low-impact alternatives, environmentally friendly. Regarding this issue, some brand-new technology-assisted extraction methods have been implemented to reduce waste generation, save time and increase the reproducibility and affordability of large-scale processes (Carciochi et al., 2017). In other words, the new approaches seek to optimize the extraction parameters (yield, purity, selectivity) within the strict standards of green chemistry commitments; as few solvents as necessary, preferably green solvents, easy to recover and/or reuse, and capable of meeting extraction goals in short-time and low-energy workflows (Chemat et al., 2011). To reach these objectives, ultrasound-assisted extraction, microwave-assisted extraction, subcritical or supercritical fluid extraction, hot-pressurized liquid extraction and accelereated solvent extraction, as well as electro-assisted extraction and enzyme-assisted extraction have received great attention in recent decades. These advanced extraction strategies deploy forces that, from direct extracellular action or internal physicochemical destabilization, promote cell lysis. To be successful, however, their application regimen and the prevailing physicochemical conditions are also decisive. At that point, the solvent can comfortably penetrate the matrix and enhance solubilization, achieving significant amounts of intracellular compounds to incorporate into the solvent (the mass transfer increases). Furthermore, both the prevailing physicochemical conditions and the application regime are decisive for the success of the extraction (Arruda et al., 2021). In this scenario it should also be noted that the combination of various methods is being increasingly tested to overcome extraction limitations and to take advantage of synergies that facilitate scaling processes.

Technologically-assisted extraction frequently operates at extreme pressures and temperatures (sometines, moderate/high temperatures as well) that reduce time and consumable requirements (especially strong solvents) and generate negligible waste. Therefore, they provide significant enhancements in the recovery capacity, selectivity and yield. In short, technically-assisted extraction improves quality standards in three strategic axes; reduced solvent volume, short operating times and energy savings. These fundamental achievements provide environmental benefits that shall greatly facilitate the industrial escalation of the processes implemented in the laboratory.

6. Hot-Pressurized liquid extraction (HPLE)

Advanced HPLE streams, also denominated accelerated solvent extraction or pressurized solvent extraction, consist in the solubilization of solid matrices by solvents at temperatures above their boiling points, although remaining in liquid state by pressurization (Mendiola et al., 2007). The sample extraction with GRAS green-solvents (ethanol and/or water) under high pressure (4–20 MPa) and moderate-high temperature (50–250 °C) results in the breaking of secondary bonds and thereby in the enhancement of desorption and solubilization speed of matrix-bound species (Azmir et al., 2013). To this aim solid sample and solvent remain encapsulated in a vessel and are statically extracted for intervals of few minutes (Rodríguez de Luna et al., 2020). Alternatively, HPLE can be performed as dynamical runs, in which the solvent continuously enters the extraction chamber (Chaves et al., 2020). Either way, HPLE is efficient, short-time and low-solvent consuming, devoid of filtration step and compatible with food-grade solvents providing environmentally friendly workflows (Ameer et al., 2017; Chaves et al., 2020). Additionally, the commercial equipment can be programmed and allowed to operate in automatic mode, which improves reproducibility and quality control (Rodríguez de Luna et al., 2020) and makes HPLE ideal for automation, better than alternatives based on ultrasound or microwaves. Compared with traditional extraction designs HPLE reduces the solvent volume (Dai & Mumper, 2010) and provides cleaner extracts that can possibly dispense with subsequent filtration and/or purification of crude preparations. Moreover, the improved purity increases signal-to-noise ratio and the reduced background increases reliability of downstream workflows, especially LC-MS separation and analytical screenings due to ion-suppression effects of the matrix (Sosa-

Table 1
Technical description of some representative Hot-Pressurized Liquid Extraction (HPLE) workflows (optimal conditions) reporting polyphenol recovery from plant by-products.

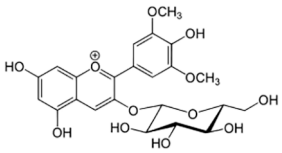
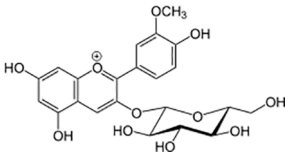
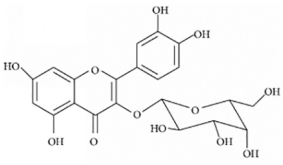
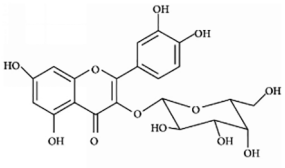
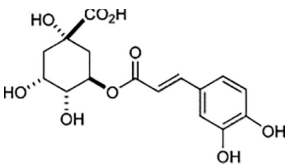
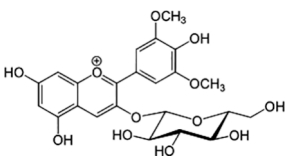
Matrix	Extracting solvent	T (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
Red grape skins	Water	75–100	10.1	20 min; 8 g sample	Anthocyanins	Malvidin 3-glucoside  381.2 mg/L Peonidin 3-glucoside  130 mg/L	~90–100% TAC: 722.6 mg/L	n.d	Liazid et al., 2014
Industrial apple products	Water	120	10.3	3 min	Flavonols	Hyperoside  362 nmol/g DW	~39% TPC: 1.59 μg/L 0.97 mg GAE/g (FC)	0.03 mM TE/g (TEAC)	Plaza et al., 2013
Freeze-dried apple peel and pulp	Methanol	40	6.9	5 min; 2 cycles	Catechins, quercetin glycosides, hydroxycinnamic acids	Peel: Hyperoside  1680 μg/g DW Pulp:  Chlorogenic acid 540 μg/g DW	<9% TPC: 7566 μg GAE/g (Peel) TPC: 1337 μg GAE/g (Pulp)	n.d	Alonso-Salces et al., 2001
Freeze-dried red grape skin	0.1% HCl in 60% methanol	80–100	10.1	3 × 5 min extraction cycles	Anthocyanins	Malvidin 3-glucoside  20.56 mg/g DW	~1.5 higher *vs.* acidified water TPC: 163.4 mg GAE/g	4466 μMTE/g (ORAC)	Ju & Howard, 2003

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Table 1 (*continued*)

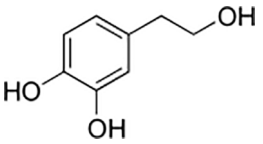
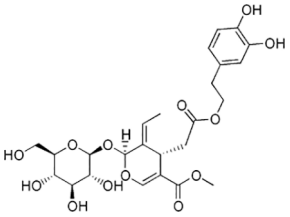
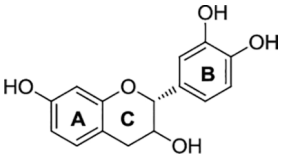
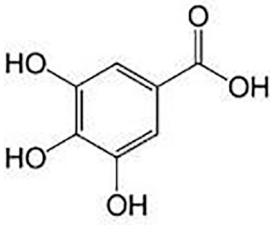
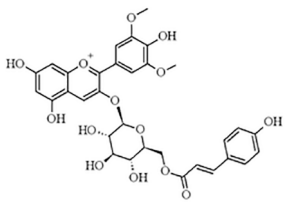
Matrix	Extracting solvent	T (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
Olive leaves	Water	200	10.34	20 min	Phenolic acids, secoiridoids, hydroxycinnamic acid derivatives, flavonols and flavones	Hydroxytyrosol  8.542 mg/g DW	~40% TPC: 58.7 ± 0.9 mg GAE/g	2.661 ± 0.188 mmol TE/g (TEAC)	Herrero et al., 2011
Olive leaves	Ethanol	150	10.34	20 min	Phenolic acids, secoiridoids, hydroxycinnamic acid derivatives, flavonols and flavones	Oleuropein  6.156–2.819 mg/g DW	~30% TPC: 45.8 ± 0.6 mg GAE/g	0.677 ± 0.025 mmol TE/g (TEAC)	
Passiflora mollissima seeds	Ethanol	150	10	–	Flavonoids, flavan-3-ols, proanthocyanidins oligomers, phenolic acids	(*Epi*)fisetinidol  5.3 mg/L Gallic acid  2.6 mg/L	~7% TPC: 29.99 mg GAE/g	6.94 mM TE/g (TEAC)	Ballesteros-Vivas et al., 2019a
Grape skins	Ethanol: acidified water (0.8% HCl) 50:50 (v/v)	120	8	30 min; 1.2 mL/min	Anthocyanins, flavonols, *p*-coumaroyl derivatives, hydroxycinnamic acids, pyranoanthocyans	Malvidin-3-(6-*p*-coumaroyl) glucoside  2519.1 ± 116.1 μg/g DW	~30% TPC: 126 mg GAE/g TAC: 17.15 μg/g	n.d	Luque-Rodríguez et al., 2007

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Table 1 (*continued*)

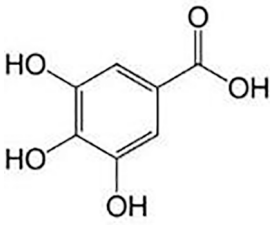
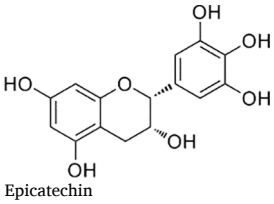
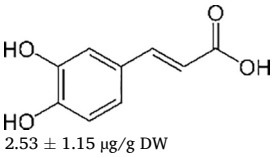
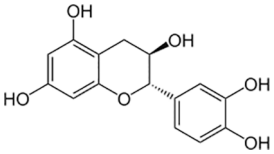
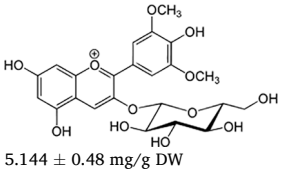
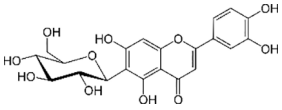
Matrix	Extracting solvent	T (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
Grape pomace	Ethanol: water 32.5:67.5 (v/v)	150	1	–	Flavanols, stilbenes, phenolic acids, flavonols	Gallic acid  59.92 ± 0.11 μg/g DW  Epicatechin 58.99 ± 5.89 μg/g DW	~19 higher *vs.* conventional extraction with water TPC: 229.48 ± 18.36 μg GAE/g	0.34 mM TE/g (TEAC)	Huaman-Castilla et al., 2019
Skin and seeds of *Vitis vinifera* L. cv. Negra Criolla Pomace	Ethanol: water 60:40 (v/v)	160	1	5 min	Flavanols, flavonols, phenolic acids	Skin: Caffeic acid  2.53 ± 1.15 μg/g DW Seeds:  Catechin 85.91 ± 6.87 μg/g DW	~1.5–2.5 higher *vs.* conventional extraction with acetone TPC: 1.98 ± 0.12 mg GAE /g (Skin) TPC: 12.54 ± 0.25 mg GAE/g (Seeds	Skin: 36.33 ± 2.18 μMTE/g (ORAC) Seeds: 137.65 ± 15.14 μMTE/g (ORAC)	Allcca-Alca et al., 2021
Grape marc	Ethanol: acidified water (pH 2) 50:50 (v/v)	40	10	40 min; 5 g/min	Monomeric anthocyanins	Malvidin 3-glucoside  5.144 ± 0.48 mg/g DW	n.d TPC: 28.66 ± 0.29 mg GAE/g	571.76 ± 22.73 μmol TE/g (ORAC) 478.40 ± 9.73 mg TE/g (FRAP)	Pereira et al., 2019
Varieties of red grapes pomace	Ethanol: water 50:50 (v/v)	120	9	90 min; 5 g/min	Anthocyanins	n.d	~87% TAC: 107.0 ± 11.3 to 741.9 ± 41.7 mg/g	7.5 to 9.2 μg/mL EC_{50} (DPPH)	Otero-Pareja et al., 2015
Passion fruit rinds	Ethanol: water 70:30 (v/v)	60	10	2.4 g/min	Flavones	Isoorientin  118 ± 2 μg/g DW	~35% TPC: 3.18 ± 0.02 mg GAE/g	5.75 ± 0.05 mg TE/g (FRAP) 112 ± 10 μmol TE/g (ORAC)	Viganó et al., 2016
Avocado peel		200	11					n.d	

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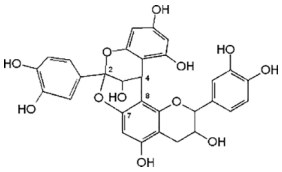
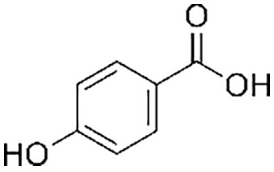
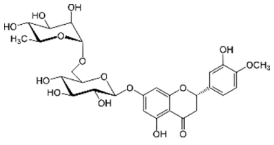
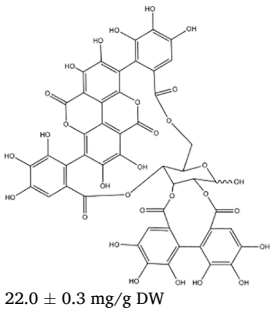
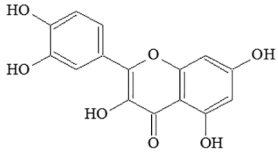
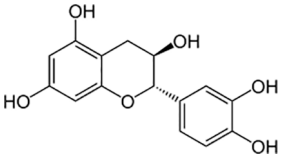
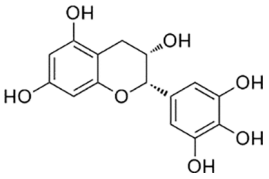
Table 1 (*continued*)

Matrix	Extracting solvent	T (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
	Ethanol: water 50:50 (v/v)			Previous sonication for 15 min; 20 min of static extraction	Procyanidins, flavonoids, phenolic acids, flavanols, glucosylated acid derivates	Type A-procyanidin  n.d	n.d TPC: 34 ± 1 mg GAE/g		Figueroa et al., 2018c
Avocado seed	Ethanol: water 50:50 (v/v)	200	11	Previous sonication for 15 min; 20 min of static extraction	Organic acids, phenolic acids, flavonoids, catechins, condensed tannins	4-hydroxybenzoic acid  n.d	n.d	310 ± 30 μmol TE/g (ORAC) 300 ± 20 μmol TE/g (TEAC)	Figueroa et al., 2018c
Orange peel	Ethanol: water 75:25 (v/v)	65	10	2.37 g/min; 40 min	Glycosylated flavonoids, hydroxybenzoic acids	Hesperidin  58 ± 3 mg/g DW	~35% TPC: 14.9 ± 0.7 mg GAE/g	255 ± 9 mg TE/g (FRAP) 4.6 ± 0.3 mg TE/g (DPPH)	Barrales et al., 2018
Pomegranate peel	Ethanol: water 50:50 (v/v)	200	10.34	20 min	Phenolic acids, flavonoids, hydrolysable tannins	Punicalagin  22.0 ± 0.3 mg/g DW	n.d TPC: 149.0 ± 5.3 mg GAE/g	2265.6 ± 100.5 μmol TE/g (FRAP) 916.4 ± 102.0 μmol TE/g (ORAC)	García et al., 2021
Olive oil mill and winery wastes	Ethanol: water 50:50 (v/v)	100	10.34	5 min, 1 cycle	Polyphenols	n.d	n.d TPC: 9.52 ± 0.20 mg GAE/g (Olive pomace) TPC: 3.58 ± 0.02 mg GAE/g (Winery wastes)	Olive pomace: 2.41 ± 0.11 to 31.63 ± 0.46 mg TE/g (TEAC) Winery wastes: 0.15 ± 0.01 to 7.18 ± 0.10 mg TE/g (TEAC)	Tapia-Quirós et al., 2020
Grape pomace	Glicerol: water 32.5:67.5 (v/v)	150	10	5 min	Flavonols, flavanols, phenolic acids, stilbenes	Quercetin  257.60 ± 0.12 μg/g DW	n.d TPC: 444.52 ± 35.56 μg GAE/g	n.d	Huaman-Castilla et al., 2020
Grape pomace		150	10	5 min		Catechin	~3 higher *vs.* conventional	314.05 ± 15.7 μmol	

(*continued on next page*)

Table 1 (*continued*)

Matrix	Extracting solvent	T (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
	Glicerol: water 15:85 (v/v)				Monomers of flavanols, flavonols, phenolic acids	 203.60 ± 12.22 μg/g DW Epicatechin	extraction with water TPC: 20.21 ± 0.2 mg GAE/g	TE/g (ORAC) 21.59 ± 0.65 mg/mL EC_{50} (DPPH)	Huamán-Castilla et al., 2021
Grape pomace	Ethanol: water 15:85 (v/v)					 189.44 ± 25.52 μg/g DW	~2 higher *vs.* conventional extraction with water TPC: 18.40 ± 0.2 mg GAE/g	293.81 ± 11.75 μmol TE/g (ORAC) 23.78 ± 0.71 mg/mL EC_{50} (DPPH)	

DPPH: 2,2-diphenyl-1-picryl-hydrazyl-hydrate
DW: Dry weight
EC_{50}: Half maximal effective concentration (concentration required to obtain a 50% radical inhibition)
FC: Folin Ciocalteu
FRAP: Ferric reducing antioxidant power
GAE: Gallic acid equivalents
n.d: Not declared
ORAC: Oxygen radical absorbance capacity
TAC: Total anthocyanins content
TE: Trolox equivalents
TEAC: Trolox antioxidant equivalents
TPC: Total polyphenols content

Ferrera et al., 2013). Thus, globally HPLE offers benefits in extraction quality and favourable characteristics for the scaling of plant-waste valorization (Wijngaard et al., 2012). However, along with pros HPLE has some limitations. The most important drawback is the selectivity, lower than desired in many applications, since the co-extraction of inferents from certain complex matrices together with the targeted species is relatively frequent (Ramos et al., 2002; Sosa-Ferrera et al., 2013). Dilution can be another unwanted consequence associated with HPLE, especially if the extraction is carried out in successive cycles (Alara et al., 2021). Additionally, the instrumentation required is expensive, although its excellent capabilities can offset the initial investment in a short period of time.

At the prevailing pressures in HPLE applications sample disruption and pore formation are facilitated. As solvents remain liquid, their viscosity and tension surface decrease while matrix penetration and desorption kinetics are enhanced (Ramos et al., 2002). Consequently, the particle size diminishes and mass transfer rates of solubilized polyphenol species increase (Mustafa & Turner, 2011; Plaza & Turner, 2015). These pressure-mediated effects allow extraction in reduced time and temperature and therefore preserve the integrity and biochemical potential of thermolabile species (Zhang et al., 2018). It should be noted that in optimized HPLE settings it is sufficient to keep the solvent liquid, since overpressing above this threshold does not result in new improvements (Mustafa & Turner, 2011; Alara et al., 2021). Temperature is also pivotal in the performance of HPLE. The breaking of sample-analyte links and the reduction of solvent viscosity cause the temperature to enhance the diffusivity and solubility of polyphenols (Mustafa & Turner, 2011; Machado et al., 2015). However, thermal extractability has a threshold above which the temperature undermines chemical stability and polyphenols begin to degrade into unwanted neoproducts such as Maillard derivatives or 5-(hydroxymethyl)furfurals (Wijngaard et al., 2012). This is the reason why many polyphenol extractions have intermediate optimal temperatures ranging between 40 and 60 °C (Chaves et al., 2020). Thus, in pressurized solvent extraction of anthocyanins from red cabbage (water:ethanol:formic acid, 94:5:1; 50 bar; 7 min), temperature ranged between 80 and 120 °C because < 80 °C rendered a poor yield while > 120 °C caused polyphenol degradation (Arapitsas & Turner, 2008). Likewise, anthocyanins from red grape skins undergo significant 50% degradation in 100 atm (10.1 MPa) HPLE water extracts above 100 °C (Liazid et al., 2014). However, temperatures not exceeding 120 °C at short extraction times (up to 10 min) avoided thermal degradation of phenolic antioxidants (mainly polymer procyanidins and flavan-3-ol monomers and oligomers) extracted in 30% ethanol from grape stems (Nieto et al., 2020). On the other hand, since phenolics become oxidized at high temperatures, the chemical state in which they are recovered must be checked. In this regard, nine phenolic compounds from grape seeds and skins extracted in superheated methanol at 100 °C and 100 atm showed a deterioration of < 10%, including the most oxidizable catechins that only suffered degradation at 150 °C (Palma et al., 2001). The efficiency of HPLE in hydromethanolic mixtures (up to 100%) has also been reported in the extraction of phenolics (catechins, phloretin glycosides, quercetin glycosides and hydroxycinnamic acids) from apple skin and pulp, with significant reductions in time and sample handling (Alonso-Salces et al., 2001). Similarly, 100% ethanol in acethyl acetate mixture operating on banana passion fruit seeds at high pressure and temperature (100 bar, 150 °C) showed an optimal performance in extracting phenolic-rich fractions (29.99 mg GAE/g DW), composed primarily of a wide collection of flavonoids, flavanols and abundant proanthocyanidins, and antioxidant activity (6.94 mM Trolox/g extract) (Ballesteros-Vivas et al., 2019a).

Pressure and temperature greatly affect the dielectric constant/polarity of the solvent. Indeed, the extractability by HPLE of a wide range

of compounds is dependent on *ad hoc* combinations of the temperature–pressure-solvent triad (Table 1). Solvent and solvent flow rate are crucial in HPLE tracks and, on this matter, water and hydroalcoholic mixtures are preeminently based on their solubilization capacity, selectivity and environmental neutrality (Wijngaard et al., 2012). In this regard, at high pressure and temperatures above its boiling point (around 200–275 °C) water remains liquid but considerably less polar due to the breakdown of intermolecular hydrogen bonds. Therefore, the molecule becomes capable of dissolving less polar compounds, in a similar way to classical solvents such as ethanol or methanol under normal atmospheric conditions (Plaza & Turner, 2015; Brglez Mojzer et al., 2016). In addition, pressurized water breaks internal matrix bonds, increasing the diffusivity and extractability of analytes. According to these reinforced aptitudes, extraction designs based on pure water have been shown to be efficient for phenolics of plant by-products (Section 7). In this regard, the coupling of hot water at 70 °C with ultrasound (480 W) was also demonstrated to be an efficient green alternative for the extraction of phenolics from pomegranate peels (with a yield of 61.72 ± 7.7 mg/g of compounds mainly related to ellagic acid) (Sumere and de Souza, 2018). In hydroethanolic mixtures, protic ethanol reduces polarity and improves the solubilization of polyphenolic compounds, while water enhances their desorption from the matrix, which improves the extraction efficiency (Mustafa & Turner, 2011; Mrkonjić et al., 2021). Besides, as a co-solvent ethanol diminishes thermal hydrolysis and polyphenol decomposition in toxic derivatives (Otero-Pareja et al., 2015; Mariotti-Celis et al., 2018). These properties of hydroethanol systems make them highly recommended not only for HPLE but, as will be discussed in later sections, also for ultrasound or microwave assisted extraction (Osorio-Tobón, 2020) or for mixed settings in which HPLE is used combined with some other technology. Thus, an efficient and environmentally friendly hydroethanolic HPLE system coupled with ultrasounds (240–260 W; 65–75 °C) improved by 60% the extraction yield of thermolabile phenolics (including the stilbene piceatannol) from defatted passion fruit bagasse (Viganó et al., 2020). HPLE has also been successfully combined with supercritical CO_2 (SC-CO_2) to consecutively fractionate cranberry pomace and extract the lipophilic and polyphenolic fractions, the latter consisting of anthocyanins and procyanidins (Tamkutė et al., 2020). Noteworthy, the assistance of RSM made it posible to optimize the operating parameters to gradually increase yields and antioxidant activity after each extraction step and configure a by-product platform "zero waste" for biorefining cranberry pomace at the industrial scale. In another recent study comparing the efficiency of HPLE and SC-CO_2 in screening the chemical profile of sweet cherry (*Prunus avium*) stems, HPLE (10.3 MPa in 15% ethanol at 176 °C for 20 min) was found to be more efficient (37.31% *vs.* 4.42%, respectively) than supercritical fluid (SC-CO_2, 30 MPa, 15% ethanol, 40 °C for 1 h) releasing a wide variety of phenolic acids and flavonoids with different polarities (Nastić et al., 2020).

Ultra-high pressure extraction (UHPE) is a HPLE variant developed two decades ago to shorten extraction times of plant biocompounds, improve yield and quality and reduce or eliminate the environmental impact of phytochemical' extraction. UHPE operates with ultra-high pressure in short pulse cycles (100–1000 MPa) and subsequent relaxation, which produce cell shape deformations. Plant cell wall results damaged and solvent penetration, diffusion of active compounds and mass transfer accelerated (Andreou et al., 2020). Moreover, the extreme pressure allows working at moderate temperature (20–50 °C) thereby improving the recovery of thermolabile bioactive species. UHPE is recognized as environmentally friendly by the US FDA (Xi & Wang, 2013) and has been proven in the recovery and up-cycling of several plant by-products (Xi, 2017). So, UHPE assisted by an electric-pulse pretreatment seemed to produce irreversible pores in plant membranes and the inactivation of degrading enzymes. Thus, 70 °C UHPE coupled with 3 kV cm^{-1} pulses increased the extractability up to 17% and quadrupled the antioxidant capacity of anthocyanins from grape by-products in comparison with classical water bath at 70 °C held for 1 h (Corrales et al., 2008). At the same time, high hydrostatic pressure (600 MPa) provided three-fold and ultrasound-assisted extraction two-fold higher total phenolic content than control extraction in heated water. Similarly, compared with conventional and ultrasound-assisted extraction, UHPE (70% ethanol, 295 MPa) showed improved yield of total procyanidins, flavonoids and phenolics from lychee pericarp (Zhang et al., 2017). Other successful UHPE setting (600 MPa, 5 min in water: ethanol 30:70 at 25 °C as initial temperature) performed greater yield and antioxidant activity from Djulis hulls (*Chenopodium formosanum*) than conventional extraction in the same solvent at 25 °C for 12 h (Huang et al., 2019). Specifically, the total phenolic (567–642 mg GAE/g DW) and flavonoid (47.2–57.2 mg quercetin/g extract) content, with gallic acid and rutin as the main phenolic and flavonoid species, as well as the functionalities of the UHPE extracts revealed this plant waste to be a potential source of antioxidants for food and cosmetic industry.

Another green pressurized extraction method is the cyclically Rapid Solid-Liquid Dynamic Extraction (RSLDE), a technically-assisted solid–liquid extraction modality that allows rapid extraction at room temperature pressurizing the extractant on the solid matrix. The improvements in yield and extraction times of high-pressure extraction are preserved in innovative RSLDE, but additionally low temperatures allow the release of structurally inaltered thermolabile polyphenols. Thus, water-based RSLDE (30 programmed cycles at a maximum pressure of 10 bars) has been reported to be efficient for the rapid and reproducible extraction of more than two dozen polyphenols from grape peel (9210.4 ± 45.8 mg/L in 48 h from 200 g dried and chopped peels) at low environmental temperatures (Gallo et al., 2019). Proposed as a viable alternative to maceration, RSLDE allows green extractions with minimal energy requirements and without stressing thermal conditions that can damage targeted species.

7. Subcritical water extraction (SWE)

Despite ethanol being commonly accepted as a GRAS solvent, the adoption of water as the unique extractant is a step forward in affordability, profitability and sustainability of by-products recovery, fully adapted to the strict international regulations for organic solvents (Wijngaard et al., 2012). Pressurized hot water extraction, more commonly known as Subcritical Water Extraction (SWE) takes full advantage of the well-known physicochemical capacities of this essential molecule to effectively replace organic solvents in extraction processes and provide completely green and inexpensive valorization approaches, in line with the aspirational standards of circular bioeconomy. As indicated in the previous section, SWE corresponds to the HPLE using water at temperatures above the boiling point (up to ≈200 °C but below the critical one, > 374 °C) and pressures under the critical point (> 21.8 MPa) suitable for maintaining the liquid state. Indeed, 5 MPa is a high enough pressure to keep liquid water in the 100–250 °C range (Selvamuthukumaran & Shi, 2017). Since approximately three decades, supercritical water has been gradually replaced by SWE because it operates at relatively mild temperatures and pressures, as once the threshold pressure is reached, like in the case of HPLE, overpressure does not significantly improve the water's solvent capabilities. Besides, similarly to HPLE, SWE can be performed in two regimens; static (batch) or dynamic (continuous flow). Therefore, pure water displays outstanding temperature-dependent dynamic abilities to improve mass transfer rate and to selectively extract a variety of polyphenols as function of temperature (Vergara-Salinas et al., 2015). In this subcritical region, the viscosity of water is reduced and therefore the diffusion coefficient and mass transfer ratio increase. Moreover, the hydrogen bonds are broken, the dielectric constant is considerably reduced and water becomes less polar, behaving like classic organic solvents such as methanol or ethanol (Mendiola et al., 2007; Chaves et al., 2020) and exhibiting their same solvation properties (Gil-Chávez et al., 2013). Consequently, at moderate pressures the density, ion product and dielectric constant of water can be modulated over a wide

Table 2
Technical description of some representative Subcritical Water Extraction (SWE) workflows (optimal conditions) reporting polyphenol recovery from plant by-products.

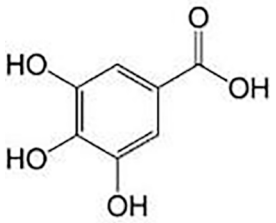
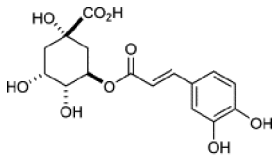
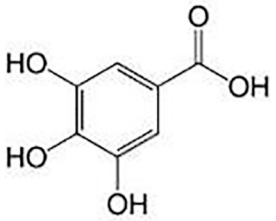
Matrix	Extracting solvent	Tª (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
Potato peels	Water	180	6	30 min; 2 mL/min	Chlorogenic and hydroxybenzoic acids	Gallic acid  29.56 mg/100 g WB Chlorogenic acid  14.59 mg/100 g WB	~1.75 higher *vs.* conventional solid–liquid extraction TPC: 81.83 mg GAE/100 g WB	n.d	Singh & Saldaña, 2011
Grape seeds	Water	150	6–7	30 min, single extraction	Hydroxybenzoic acids, catechins proanthocyanidins	Gallic acid  232.1 ± 22.7 mg/100 g DW	~1.3 higher *vs.* conventional solid–liquid extraction with MeOH:H_2O TPC: 380.6 mg GAE/100 g DW	n.d	García-Marino et al., 2006
Mango peels	Water	180	Atmospheric	90 min; solid/water ratio 1:40; pH 4	Phenolic compounds	n.d	~1.4 higher *vs.* conventional Soxhlet ethanol extraction TPC: 50.25 mg GAE/g DW	n.d	Tunchaiyaphum et al., 2013

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Table 2 (*continued*)

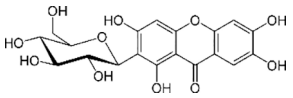
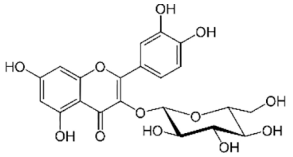
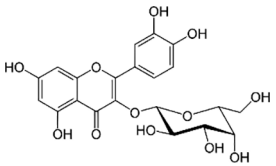
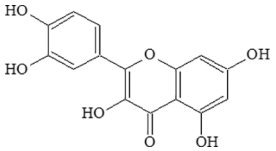
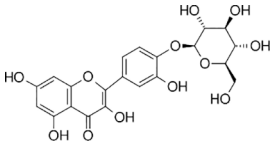
Matrix	Extracting solvent	T[a] (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
Mango leaves	Water	100	4	3 h; flow rate 10 g/min	Flavonoids, xanthonoids	Mangiferin 1365.9 ± 1.2 mg/100 g DW  Quercetin3-β-*d*-glucoside 409.5 ± 6.7 mg/100 g DW 	~35% TPC: 1775.4 mg/100 g DW	4.02 to 7.92 μg/mg EC_{50} (DPPH)	Fernández-Ponce et al., 2012
Pomegranate seed residues	Water	220	6	30 min; solid/water ratio 1:40; pH 4	Phenolic compounds	n.d	n.d TPC: 4854.7 mg/100 g DW	4100 mmol/100 g (DPPH) 2250 mmol TE/100 g (TEAC)	He et al., 2012
Apple by-products	Water	120	10.3	3 min	Flavonols	Hyperoside: quercetin-3-O-galactoside  362 nmol/g dry apple	Total flavonols content: 1.3 μmol/g dry apple by-product	0.01 to 0.47 mmol/g (TEAC) 0.26 to 8.51 1/EC_{50} (DPPH)	Plaza et al., 2013
Onion skin wastes	Water	145	5	30 min; 2.5 mL/min	Flavonoids, hydroxybenzoic acid, flavonols	Quercetin  15.4 ± 0.4 mg/g DW Quercetin-4′-glucoside  8.4 ± 0.1 mg/g DW	~2.1 higher *vs.* conventional extraction with 70% EtOH/H_2O TPC: 97.8 ± 2.1 mg GAE/g DW TFC: 27.4 ± 0.9 mg/g DW	156.7 ± 6.2 mg $FeSO_4$/g (FRAP)	Benito-Román et al., 2020

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Table 2 (*continued*)

Matrix	Extracting solvent	Tª (°C)	Pressure (MPA)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/yield	Antioxidant capacity (method)	References
Potato peel	Water	240	10*, 9**	15 min at 2 mL/min* / 16 min at 3 mL/min**	Phenolic compounds	n.d	~10 higher *vs.* conventional solid–liquid batch extraction TPC: 45.13 mg GAE/g DW	86.39 mg $FeSO_4$/g (FRAP)	Alvarez et al., 2014
Yarrow by-products	Water	198	3	16.5 min	Phenolic compounds	n.d	n.d TPC: 52.42 to 128.2 mg GAE/g DW TFC: 26.32 to 79.19 mg/g DW	890.92 to 1853.57 μg TE/mL (TEAC)	Vladić et al., 2020
Coffee powder and defatted cake	Water	200●, 175●●	22.5	≈9 min	Phenolic compounds	n.d	n.d TPC: 26.6 ± 0.6 mg GAE/g DW (Coffee powder) TPC: 55.7 ± 1.9 mg GAE/g DW (Defatted cake)	n.d	Mayanga-Torres et al., 2017

*According to the One Factor At a Time (OFAT) design; **according to the Taguchi method. ●For powder coffee; ●●for defatted coffee cake.
DPPH: 2,2-diphenyl-1-picryl-hydrazyl-hydrate
DW: Dry weight
EC_{50}: Half maximal effective concentration (concentration required to obtain a 50% radical inhibition)
FC: Folin Ciocalteu
FRAP: Ferric reducing antioxidant power
GAE: Gallic acid equivalents
n.d: Not declared
ORAC: Oxygen radical absorbance capacity
TAC: Total anthocyanins content
TE: Trolox equivalents
TEAC: Trolox antioxidant equivalents
TFC: Total flavonoids content
TPC: Total polyphenols content
WB: Wet basis

range by changing the temperature, thus achieving great versatility in the extraction of less polar compounds (Smith, 2002; Cheng et al., 2021). In apple pomace, for example, SWE (200 °C, 30 min) demonstrated selectivity for the extraction of active antioxidant polyphenolic compounds (Ibrahim et al., 2018).

Notwithstanding, the prevailing temperatures entail a real risk for particularly heat-sensitive phenolics, such as anthocyanins of red grape skin above 100 °C (Ju & Howard, 2003). Similarly, phenolic compounds from potato peels have displayed significant degradation above 180 °C, concluding that SWE at 160–180 °C and 6 MPa for 1 h can efficiently replace organic solvents to successfully extract species such as, predominantly, caffeic, chlorogenic, gallic and syringic acids (Singh & Saldaña, 2011). Purple sweet potato peels are rich in anthocyanins and SWE in 80% aqueous ethanol at 90 °C, for 2 consecutive cycles of 15 min, yielded greater extraction efficiency (244.07 ± 11.84 mg cyanidin-3-glucoside equivalents/100 g DW) than ultrasound-assisted extraction (Section 8) and conventional extraction: 229.41 ± 4.59 and 217.58 ± 2.90 mg cyanidin-3-glucoside equivalents/100 g DW, respectively (Cai et al., 2016). Unlike anthocyanins, tannins from red and white grape pomace at extraction temperatures ≈200 °C and 2.5 MPa yielded higher concentrations of tannins, achieving a total content of 68 mg/g DM (Yammine et al., 2020), which was above that obtained by conventional extraction in ethanol:water (50:50) at room temperature.

In this field, the combination of the solubilization capacity of NADES together with the extractive power of SWE has produced a remarkable synergy in the results achievable with SWE alone. Specifically, the extraction of catechin and epicatechin from winery by-products has shown enhancements of 45.05% and 47.98%, respectively, operating in choline-chloride containing urea at 30%, 100 °C and 10.34 MPa in two 10-min cycles (Loarce et al., 2020). This first SWE-NADES implementation initiates a new approach to achieve highly efficient and fully environmentally friendly extractions.

Low-polarity SWE is inexpensive, non-contaminant, selective according to temperature and capable of high recoveries, which is why it has gained great attention in recent years for the extraction of natural phenolic compounds (Table 2). Indeed, there is at least one patent on the suitability of SWE to extract polyphenols from fruit and vegetable by-products, specifically anthocyanins, and other flavonoids and related polyphenolic compounds from fruits or highly pigmented garden vegetables and their by-products (King & Grabiel, 2007). In light of this background, the main strengths of SWE are the environmentally friendly conditions, atoxicity and the high extraction quality provided. For these reasons, the suitability of SWE for human uses is maximum and therefore, it is considered the closest option to sustainable and cost-effective valorization of the by-products of herbs, vegetables and fruits (Zakaria & Kamal, 2016; Cheng et al., 2021).

8. Ultrasound-assisted extraction (UAE)

Ultrasounds correspond to sonic waves of > 20 kHz (20–2000 kHz) and wavelengths in the millimetre range. The wavelengths of ultrasound are much greater than biomolecules and macromolecules, so their energy cannot be directly absorbed by matrix particles. On the contrary, chemical effectiveness of ultrasounds lies on the strong shocking forces of microjets and shock waves produced by liquid ultrasonication. In such a context, the isotropic transmittance of mechanical energy occurs by rapidly alternating cycles of compression/rarefaction. The rapid high/low pressure oscillations produce vacuum nanobubbles at innumerable nucleation points in the propagation directions. Over successive compression-rarefaction fluctuations, the bubbles accumulate energy until their resistance threshold is exceeded and they violently collapse. Thus, the simultaneous implosion of huge amounts of vaccum bubles produces powerful shearing forces that propagate in the form of microjets (speeds ≈280 m/s) and shock waves (5000 °C, 200 MPa) (Suslick & Flannigan, 2008), a phenomenom of fluid mechanics that sonochemistry denominates cavitation. The mechanical energy deployed by sonication has extreme physical and chemical repercussions on the sample matrix. Collisions break cell microstructure (cell wall, membrane) and diminish the sample particle size (Suslick & Flannigan, 2008). Correspondingly, as mechanical impacts increase the surface area, the penetration of the extractant and the diffusion and mass transfer of the active compounds are facilitated (Dai & Mumper, 2010).

UAE is considered an easy-to-use and relatively affordable low-cost extraction, since to perform ultrasonic-assisted leaching it is sufficient to deposit the crushed sample in contact with the solvent in an ultrasonic bath, generally operating at 40 kHz or, alternatively, a more energy concentrating probe at 20 kHz (Rodríguez de Luna et al., 2020). However, UAE can be carried out in a closed container or dynamically, in which the solvent is refreshed permanently (Talmaciu et al., 2015). Either way, UAE protects the environment by using small volumes of sustainable solvents (Chemat et al., 2017; Rodríguez de Luna et al., 2020) in accordance with international food regulations (FDA, EFSA). Regarding this, UAE modalities facilitate the efficient diffusion of phenolics in the presence of GRAS solvents such as ethanol, water or hydroethanolic mixtures, which are the most efficient in their extraction. Hence, equivolumetric ethnol:water UAE at 35 kHz for 30 min has shown the ability of mobilizing polyphenols from defatted cocoa beans avoiding degreasing and apolar non-GRAS phases, thereby allowing to increase by 59.7% and 12.8% the total amount extracted and recovery, respectively (Toro-Uribe et al., 2020). Similarly, the cavitation energy deployed by UAE (150 W, 19.9 kHz) for 15 min at 40 °C in a ternary hexane:ethanol:water (30:49:21) mixture has demonstrated that main roasting by-product of coca shells is a valuable source of phenolics (51.1 mg GAE/g extract) such as flavonols (Grillo et al., 2019). Likewise, in valorization of apple pomace from cider industry, an aqueous ethanol UAE-setting based on RSM (50:50 ethanol:water; 25 kHz, 150 W; 40.1 °C; 45 min) yielded 20% greater polyphenol recovery (mainly flavanols) than conventional maceration performed in identical conditions without ultrasounds, 964 *vs*. 769 mg catechin equivalent/100 g of apple pomace, respectively (Virot et al., 2010).

Some other solvents are also efficient in plant phenolic extraction by UAE. In this regard, 90% aqueous glycerol has yielded polyphenols and pigments from red grape pomace (66.70 mg GAE/g DW; Trasanidou et al., 2016) and onion solid wastes (90.07 mg GAE/g DW; Katsampa et al., 2015), probably due to the positive effect of glycerol on solubilization of relatively low polar molecules, such as phenolics. Similarly, the presence of ethylene glycol in the ethanol:polyethylene glycol:water mixture (48:32:20, v/v) increased the yield of *trans*-resveratrol from red grape skin and pulp by nearly 40% (Babazadeh et al., 2017). For habanero chili (*Capsicum chinense*) by-products (leaves, peduncles and stems), UAE (42 kHz for 30 min at 28 °C) in methanol:water (80:20) allowed the characterization of polyphenols in the different parts of the plant and soil types (Chel-Guerrero et al., 2021). Noteworthy, statistically significant differences in concentrations were found, with the highest total polyphenols in leaves and peduncles, opening the way to the full profitability of the plant. Likewise, a NADES extraction medium based on choline-chloride with malic acid and the assistance of ultrasounds (35.4% water content in NADES, 341.5 W, 30.6 min) has proven effective in extracting anthocyanins from wine lees (Bosiljkov et al., 2017). Additionally, aqueous extracts of citrus pomace (Papoutsis et al., 2018), grape skin pomace (Gerardi et al., 2020) and black carrot pomace (Agcam et al., 2017), as well as jussara pulp (Vieira et al., 2013) obtained through UAE, have been also reported.

Compared to traditional methods UAE is cost-effective because it minimizes time, solvent, energy and temperature, so it has good starting conditions to be scalable (Soria & Villamiel, 2010). Although temperature causes the viscosity and surface tension of the solvents to decline, it simultaneously increases their vapor pressure, which tends to reduce acoustic cavitation and thereby the efficiency of the extraction (Chaves et al., 2020). Consequently, UAE, as well as HPLE applications, are usually carried out at moderate temperatures ranging between 20 and

Table 3
Technical description of some representative Ultrasound-Assisted Extraction (UAE) workflows (optimal conditions) reporting polyphenol recovery from plant by-products.

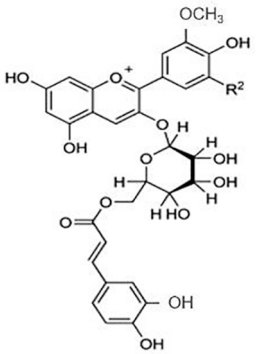
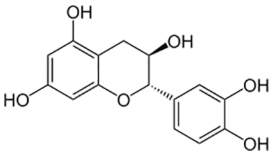
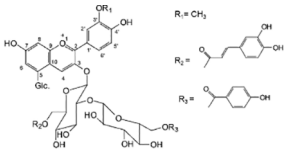
Matrix	Extracting solvent	T[a] (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
Red grape skins	Water	25	400 W	1.5 g/9 mL; 20 min	Anthocyanins	Malvidin 3-caffeoylglucoside  7.9 mg/L	~107.5% TAC: 722.6 mg/L	n.d	Liazid et al., 2014
Cocoa shells	Hexane/ethanol/ water30:49:21 (v/v)	40	150 W	1:10 (sample/ solvent ratio, w/v); 15 min	Flavanols: catechins, epicatechins and proanthocyanidins	Catechin  n.d	n.d TPC: 51.1 mg GAE/g	76.9 ± 3 μg/mL EC_{50} (DPPH) 204.7 ± 9.6 μmolTE/g (DPPH)	Grillo et al., 2019
Purple sweet potato peels	Acidified 90% ethanol	50	200 W	2 cycles, 15-min c/ u	Anthocyanins	*Pn*-3-caffeoyl-*p*-hydroxybenzoyl soph-5-glc  n.d	~80.58% TPC: 769.65 ± 1.5 mg GAE/100 g	1036.94 ± 110.80 mg TE/ 100 g (ORAC) 1303.14 ± 1.2 mg TE/ 100 g (FRAP)	Cai et al., 2016
Apple pomace	Ethanol:water 50:50 (v/v)	40.1	150 W	sample/solvent ratio < 15% (w/v); 45 min	Flavan-3-ols; flavonols; phenolic acids	n.d	~1.25 higher *vs.* conventional extraction TPC: 964 mg CE/100 g	n.d	Virot et al., 2010
Red beet roots	Water		90 W	1:20 sample: solvent ratio; 16 min	Betaxanthins and betacyanins	n.d	~4 higher *vs.* conventional extraction TPC: 10.1 ± 0.9 mg	n.d	Nutter et al., 2021

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Table 3 (*continued*)

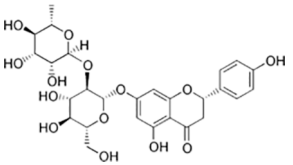
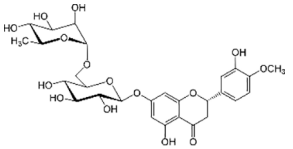
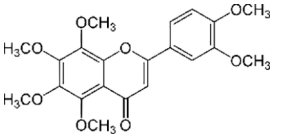
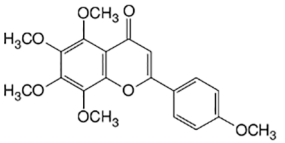
Matrix	Extracting solvent	T[a] (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
							GAE/ g		
Olive leaves	Acidified water	59.87	40 kHz ultrasound bath	500 mg/19.78 mL; pH 3.52; 59.57 min	Phenolic compounds	n.d	n.d TPC: 46.21 ± 0.15 mg GAE/g	n.d	Ilbay et al., 2014
Grapefruit wastes	Ethanol/ water50.50 (v/v)	25	100 W	1:8 (g/g) sample/ solvent ratio; 3 or 55 min	Flavonoids	Naringin  36 mg/g DW	n.d TPC: 71.1 mg GAE/g	26.6 mmol TE/g (DPPH)	Garcia-Castello et al., 2015
Grape canes	Acetone/water 50:50 (v/v)	60	50 Hz	1:50 (g/mL) sample/solvent ratio 60 min	Stilbenes Flavanols	ε-Viniferin (+)-Catechin(-)-Epicatechin ()	10552 μg/g DW 3718 μg/g DW 2486 μg g-1 DW	88 to 188 μmol TE/g DW (DPPH)	Ferreyra et al., 2020
Mandarin peel	80% Acetone	48	56.71 W	40 min	Flavonoids	Hesperidin  6.43 g/100 g DW	26.52%: ~1.7 higher *vs.* conventional extraction TPC: 15.26 g GAE/ 100 g	n.d	Nipornram et al., 2018;
Orange peel	85% Ethanol	50	150 W	40 min	Flavonoids	Nobiletin  6.4 ± 0.04 mg/g Tangeretin  2.6 ± 0.1 mg/g	~1.5 higher *vs.* conventional extraction n.d	n.d	Wang et al., 2018
	70% Ethanol	<25	40 W	10 g simple/100 mL; 14.4 min	Flavonols	Quercetin-3-rhamnoside	n.d	6.06 to 11.42 mg GAE/g (DPPH)	Ben-Othman et al., 2021

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Table 3 (*continued*)

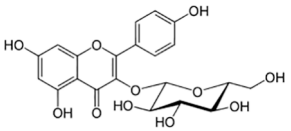
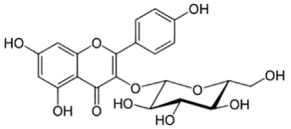
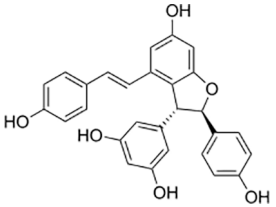
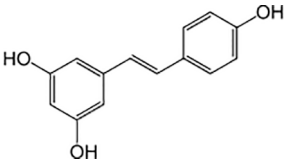
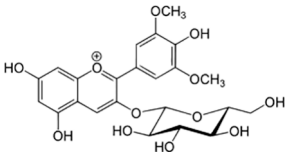
Matrix	Extracting solvent	T[a] (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
Apple tree leaves (different cultivars)						 1988 to 4290 μg/g DW Kaempferol-3-  glucoside 809 to 1680 μg/g DW	TPC: 35.67 to 57.74 mg GAE/g		
Grape canes (different cultivars)	60% Ethanol	75	140 W	1:40 (sample/ solvent ratio, w/v); 10 min	Stilbenes	*trans*-ε-Viniferin  620.1 to 2996.1 mg/kg DW *trans*-Resveratrol  37.5 to 1529.4 mg/kg DW	n.d Total stilbenes content: 1362.9 ± 19.8 mg/kg	n.d	Piñeiro et al., 2016
Grape pomace	Ethanol/water 1:1 (v/v)	20	300 W	60 min	Anthocyanins, flavonols	Malvidin-3-glucoside  17052 ± 297 ppm	~10% TPC: 167661 ± 7277 ppm	0.91 ± 0.02 mg/mL EC_{50} (DPPH)	Drosou et al., 2015
Vine cans			20 kHz						Dorosh et al., 2020

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Table 3 (*continued*)

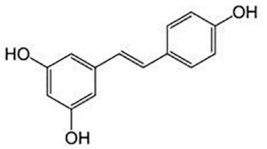
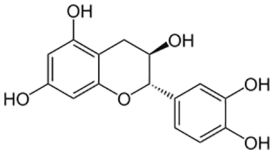
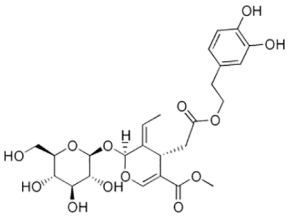
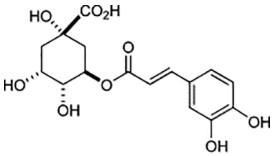
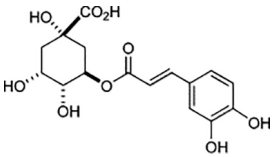
Matrix	Extracting solvent	Tª (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
	Ethanol/water 50:50 (v/v)			1:50 (sample/ solvent ratio, w/v); 60 min Without ice bath	Phenolic acids, flavanols, flavanones, flavonols, stilbenes	Resveratrol 153.4 ± 7.7 mg/100 g DW  Catechin  131.4 ± 6.6 mg/100 g DW	n.d Lab scale: TPC: 32.6 ± 2.1 mg GAE/g TFC: 9.5 ± 0.6 mg EC/ g Pilot scale: TPC: 26.0 ± 1.5 mg GAE/g TFC: 8.3 ± 0.8 mg EC/ g	Lab scale: 26.3 ± 1.5 mg TE/g (DPPH) 20.1 ± 1.5 mg AAE/g (FRAP) Pilot scale: 33.4 ± 2.1 mg TE/g (DPPH) 15.1 ± 1.5 mg AAE/g (FRAP)	
Olive leaves	Ethanol/water 50:50 (v/v)	25	200 W	1:20 (sample/ solvent ratio, w/v); 60 min	Phenolic compounds	Oleuropein n.d 	n.d TPC: 0.72 ± 0.03 mg GAE/g TFC: 0.39 ± 0.03 mg QE/g	3.10 ± 0.17 μmol $FeSO_4{\cdot}7H_2O$/g (FRAP)	Cedola et al., 2020
Potato peels and the outer layers of flesh	Ethanol/water 55:45 (v/v)	35	34 kHz	1:10 (sample/ solvent ratio, w/v); 35 min	Phenolic compounds	Chlorogenic acid  1.27 ± 0.01 to 4.10 ± 0.03 mg/g DW	n.d TPC: 2.48 ± 0.02 to 7.23 ± 0.06 mg /g	2104.18 ± 14.38 to 4639.59 ± 60.71 μmoles TE/100 g (DPPH) 3179.92 ± 30.25 to 6037.12 ± 98.10 TE/100 g (TEAC)	Riciputi et al., 2018
Potato peels	Ethanol/water 59:41 (v/v)	77	140 W	84 mL/g; 90 min	Phenolic compounds	Chlorogenic acid  n.d	n.d TPC: 9.11 mg CA/g	56.4 ± 1.30 μmol TE/ g (DPPH) 43.07 ± 1.61 μmol AAE/g (FRAP)	Paleologou et al., 2016
	Glycerol /water 83:17 (v/v)	80					n.d TPC: 8.71 mg CA/g	43.89 ± 0.00 μmol TE/g (DPPH) 35.92 ± 0.05 μmol AAE/g (FRAP)	

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Table 3 (*continued*)

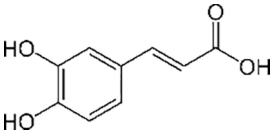
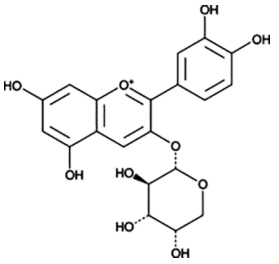
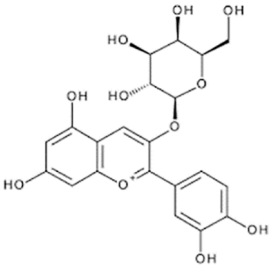
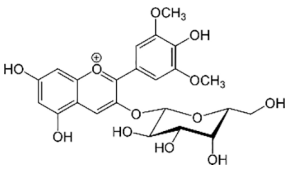
Matrix	Extracting solvent	Tª (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
Potato peels	80% Methanol	30–45	33 kHz	1:10 (sample/ solvent ratio, w/v)	Chlorogenic acid and caffeic acid	Caffeic acid  118.28 ± 0.97 μg/g DW	n.d TPC: 4.24 ± 0.01 mg GAE/g	3.66 ± 0.00 mg TE/g (DPPH) 5.64 ± 0.05 mg TE/g (FRAP)	Kumari et al., 2017
Berry press residues	96% ethanol and 0.5% TFA, v/v	<30	100 W	1:100 (sample/ solvent ratio, w/v); 20 min	Anthocyanins	Cyanidin-3-O-arabinoside  3.07 ± 0.31 mg/g DW	~1.2 higher *vs.* microwave or Soxhlet extractions TPC: 1.59 ± 0.07 g/ 100 g TAC: 0.14 ± 0.00 g/ 100 g	n.d	Klavins et al., 2017;Klavins et al., 2018
						Peonidin-3-O-galactoside  3.04 ± 0.21 mg/g DW			
Blueberries peels	70% methanol	30	185 W	1:10 (sample/ solvent ratio, w/v); 20 min	Anthocyanins	Malvidin-3-galactoside  161.44 μg/g FW	n.d TPC: 2.04 mg GAE/g FW	4.85 mg AAE/g WB (DPPH)	Wang et al., 2016

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Table 3 (*continued*)

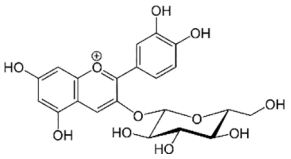
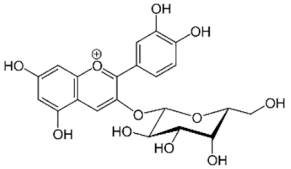
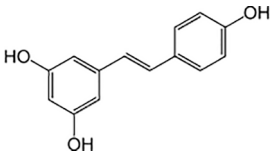
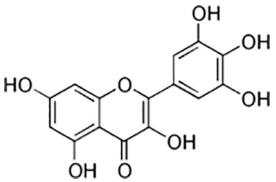
Matrix	Extracting solvent	T[a] (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
Cherry peels	80% ethanol			1:10 (sample/ solvent ratio, w/v); 20 min		Cyanidin 3-O-glucoside  11.39 μg/g FW	n.d TPC: 1.44 mg GAE/g FW	0.88 mg AAE/g WB (DPPH)	
Red pear peels	60% ethanol			1:10 (sample/ solvent ratio, w/v); 60 min		Cyanidin 3-O- galactoside  6.39 μg/g FW	n.d TPC: 1.48 mg GAE/g FW	5.71 mg AAE/g WB (DPPH)	
Red grape wastes (different varieties)	Ethanol:PEG: water48:32:20 (v/v)	53.6	1800 W	19.4 min	*trans*-Resveratrol	*trans*-Resveratrol  Skin: 98.7 ± 9.83 to 862 ± 4.67 μg/g DW Pulp: 78 ± 8.04 to 384.3 ± 6.02 μg/g DW	~1.38 higher *vs.* conventional extraction	2735.88 ± 36 to 4726.8 ± 78 μM TE/g (TEAC)	Babazadeh et al., 2017
Dried habanero pepper by-products	Methanol:water 80:20 (v/v)	28	42 kHz	30 min	Phenolic compounds	Leaves: Myricetin  29.76 ± 0.68 mg/100 g DW Peduncles: Catechin	n.d Leaves: TPC: 154.04 ± 0.23 mg/100 g DW Peduncles: TPC: 140.26 ± 0.46 mg/100 g DW Stems: TPC: 56.94 ± 0.16 mg/100 g DW	n.d	Chel-Guerrero et al., 2021

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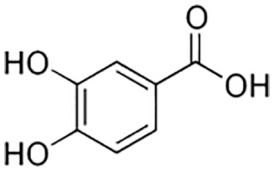
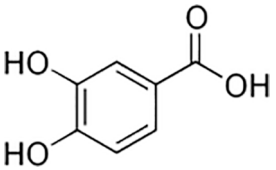
Table 3 (*continued*)

Matrix	Extracting solvent	T[a] (°C)	Energy (W, kHz)	Other operation parameters	Target compounds	Chemical structure of main compounds	Extraction recovery/ yield	Antioxidant capacity (method)	Reference
						 47.11 ± 0.33 mg/100 g DW Stems: Protocatechuic acid			
						 19.20 ± 0.18 mg/100 g DW			
Wine lees	35.4% aqueous NADES (w/w)	35	341.5 W	0.1 g/mL; 30.6 min	Anthocyanins	n.d	n.d	n.d	Bosiljkov et al., 2017
Wine grape pomace	Acidified water	Room temperature	88 W	1:20 (sample/ solvent ratio, w/v); 15 min	Phenolic compounds	Phenolic acids n.d	n.d TPC: 183.5 ± 11.9 mg GAE/L	2.00 ± 0.01 mmol TE/L (TEAC)	Gerardi et al., 2020

PEG: polyethylene glicol; NADES: choline–chloride-based NADES with malic acid
AAE: Ascorbic acid equivalents
CA: Caffeic acid equivalents
DPPH: 2,2-diphenyl-1-picryl-hydrazyl-hydrate
DW: Dry weight
EC: Epichatechin equivalents
EC_{50}: Half maximal effective concentration (concentration required to obtain a 50% radical inhibition)
FC: Folin Ciocalteu
FRAP: Ferric reducing antioxidant power
FW: Fresh weight
GAE: Gallic acid equivalents
n.d: Not declared
ORAC: Oxygen radical absorbance capacity
QE: Quercetin equivalents
TAC: Total anthocyanins content
TE: Trolox equivalents
TEAC: Trolox antioxidant equivalent
TFA: Trifluroacetic acid
TPC: Total polyphenols content.
WB: Wet basis

70 °C (Pasrija & Anandharamakrishnan, 2015). Reduction of temperature and run times are ideal for the preservation of thermolabile and/or unstable polyphenols (Vilkhu et al., 2008; Alara et al., 2021), as well as for savings in the cost per unit volume of the extract. It should be noted that yield improvements achieved (ranging from 6 to 35%, for example, in red grape marc and apple; Vilkhu et al., 2008) are crucial for the operational costs of industrial polyphenol extraction. Predictability is another noticeable feature that makes ultrasonication attractive since, up to a certain limit, at sufficiently low solid/liquid ratios UAE achieves a positive correlation between yield and acoustic wave energy (Salarbashi et al., 2014). Indeed, as power increases, cavitation enhances, which is generally accompanied by improvements in polyphenol recovery; e.g. 14.9 mg/g of red beet roots at 90 W for 16 min (Nutter et al., 2021) or 4,324.32 mg GAE/100 g of tangerine peel at 51 W/cm^2 in slightly acidic electrolyzed water (Soquetta et al., 2019). However, there is a threshold limit beyond which recovery begins to decrease due to the induction of free hydroxyl radicals that degrade target species (Dzah et al., 2020). In this regard, protons released from acidified solvents stabilize free radicals and protect sensitive polyphenols (e.g. flavonoids) from chemical oxidation (Dzah et al., 2020). Thus, in olive tree leaves, acid conditions in UAE (40 kHz, pH 3.52, 59.87 °C, 59.57 min) were found to be efficient in maximizing total phenolic extraction (56.17 mg GAE/g DM) (Ilbay et al., 2014). Likewise, in pome-granate peel, ultrasounds (40 kHz at pH 4.5 and 60 °C for 30 min) maximized total phenolic (96.28 mg GAE/g) and flavonoids (12.27 mg quercetin equivalents/g) extracted (Motikar et al., 2021). Apart from power, temperature and ultrasound regimen (frequency and intensity) also affect the removal and recovery of polyphenols from plant matrices. Thus, acoustic frequency (40 KHz), ultrasound power density (150 W/L) and time (25 min) were decisive for the content of phenolics (32.31 mg GAE/100 g) and flavonoids (2.04 mg quercetin equivalents/100 g), as well as the antioxidant capacity (53.47 mg Trolox/100 g) of aqueous preparations obtained by UAE from grape pomace (González-Centeno et al., 2014). Similarly, 70% ethanol, temperature (50–60 °C), frequency (37 kHz) and ultrasonic operation mode (both normal or pulsed) were shown to be determinant on the extraction of polyphenols α-punicalagin, β-punicalagin and ellagic acid from pomegranate peel (Machado et al., 2019). Not least, the reduction of human intervention enhances reproducibility and reliability in UAE settings. In this regrad, ultrasound-bath applications are less reproducible than probe operations because water absorbs part of the energy, which does not finally reach the sample. However, probe systems are limited to working with small sample amounts.

Short workflows and low degradation of the target species is a strength of the UAE to obtain extracts of high quality and biochemical potential, that allows to foresee a future of technical and economic viability to the recovery of plant residues (Vilkhu et al., 2008; Aires, 2017; Chemat et al., 2017; Medina-Torres et al., 2017; Kumar et al., 2021). Extraction in bath sonication for 10 min of an ethanol:water (80:20) mixture coupled to downstream screening by LC-LTQ-Orbitrap achieved the comprehensive identification of 75 different phenolic compounds from grape canes, including phenolic acids, flavanols, flavonols, flavanonols, flavanones and stilbenoids (Escobar-Avello et al., 2019). Interestingly, this same extraction approach carried out in a pilot-plant scale reactor (750 L) allowed the identification of 44 compounds configuring a compositional profile significantly different from that obtained at laboratory scale (Escobar-Avello et al., 2021). Similarly, spent coffee ground residues extracted by UAE (40 KHz for 120 min at 20 °C) in hydroethanol (water:ethanol, 30:70) and downstream analytical separation by a resolutive HPLC-MS/MS setting, allowed the quantification of 30 molecules including phenolic compounds such as phenolic acids, flavonoids and secoiridoids (Angeloni et al., 2020). The same extraction medium assisted by ultrasounds and HPLC-MS/MS and applied to coffee silverskin detected 18 phenolic compounds, with caffeoylquinic acids as the most abundant (Nzekoue et al., 2020). Noticeably, these extracts showed neuroprotective activity against H_2O_2-induced damage by counteracting oxidative stress and the maintainance of cell viability. In a similar way, UAE in a water:ethanol system with 80% ethanol produced flavonoid-rich extracts of potato peel with interesting antibacterial properties, especially against certain Gram-positive species (Wang et al., 2017a).

Efficiency and versatility are thus rapidly positioning UAE as an affordable option for the valorization of plant by-products (Table 3) and competitive in many scenarios among the available methodologies. This has been demonstrated in the extraction of flavonoid compounds from grapefruit solid wastes, in which compared to other alternatives the assistance by ultrasounds yielded higher recovery on average, both of total phenolics (50%) and antioxidant activity (66%), together with time savings and milder temperatures (Garcia-Castello et al., 2015). In the same way, low-power UAE on mandarin peels provided 1.77 times greater yield than maceration and a flavonoid esperidin content of 6435.53 mg/100 g DW (Nipornram et al., 2018). Likewise, on orange peels UAE produced 1.5 times more flavonoids (tangeretin and nobiletin) than conventional solvent extraction (Wang et al., 2018). In the case of American cranberry press residues, UAE in 96% ethanol displayed higher phenolic extraction capacity than MAE or Soxhlet extraction (Klavins et al., 2017; Klavins et al., 2018). In lime peel UAE prevailed over MAE as the most effective technique in the extraction of total phenolics with a 33% saving in time (Rodsamran & Sothornvit, 2019). UAE in 60% ethanol for 60 min was found optimal in specifically enhancing the extraction of total monomeric anthocyanins from red pear peels (and other fruits) by dissociating the native polymeric counterparts (Wang et al., 2016). Likewise, UAE in ethanol:water mixtures has also proven to be advantageous as a green alternative for the recovery of antioxidant polyphenols from chicory by-products (Pradal et al., 2016).

9. Microwave-assisted extraction (MAE)

Non-ionizing microwave radiation (100–900 W) is absorbed and transduced into thermal energy to varying degrees by molecules. Microwaves directly target dipolar molecules by ion conduction or dipole rotation allowing extraction system (sample and solvent) to agitation, rapid dielectric heating without thermal gradients and disruption of hydrogen bonds (Cassol et al., 2019). Dielectric heating depends on microwave frequency and power, so MAE can become relatively selective for certain compounds or groups of compounds. However, power and potency/sample mass ratio (power density) cannot exceed a certain limit, specific to matrix and extraction conditions, so as not to cause heat damage of solubilized compounds (Chaves et al., 2020). On the other hand, high temperatures cause water evaporation, dehydration of cellulose and overpressure inside the plant cells until swelling and wall/cell rupture. Therefore, microwaves destroy the structure of plant materials and increase their capillary-porous characteristics and solvent absorption capacity (Kratchanova et al., 2004). Correspondingly, the enhanced accessibility of cell components to the solvent increases matrix desorption and mass transfer of extractable species to the solvent, reducing extraction times and solvent volumes (Biesaga, 2011).

To maximize extractability and selectivity, the selection of the solvent should be done with extreme caution since the extractant is expected to combine solvation capacity of the targeted species and heat absorption (determined by its dissipation factor; Zhang et al., 2011). Microwave radiation is absorbed by polar species and hence MAE mostly uses polar solvents such as methanol, ethanol or water (Dudley et al., 2015). The dielectric constant allows these solvents to absorb microwave radiation and heat up rapidly, thus reducing operation times and deleterious effects on thermally unstable compounds (Alara et al., 2021). However, it is common to modulate the properties of the extraction system by combining solvents with low/high dielectric constant to avoid excessive heating (Routray & Orsat, 2012). Meanwhile, there are no *a priori* indications on suitability of particular solvents, except for the aforementioned rule that polar solvents are more suitable

for polar phenolics and vice versa. In this regard, recent efficient MAE-based workflows have been carried out in equivolumetric ethanol:water, such as the extraction of polyphenols (flavonoids, anthocyanins, phenolic acids, etc) from olive pomace residues (Tapia-Quirós et al., 2020), red grape pomace from winemaking (Drosou et al., 2015), grape juice by-products (Al Bittar et al., 2013) or kiwiberry leaves (Silva et al., 2021a). Likewise, an integrated setting of MAE in 75% ethanol:water (350 W, pH ≈2) coupled to membrane filtration has been reported for the production of concentrated fractions of phenolic compounds from red grape lees in which 5 polyphenols were identified: flavanol catechin derivative, gallic acid, (+)-catechin, syringic acid and gallocatechin derivate (Arboleda Meija et al., 2019). Moreover, MAE in 100% ethanol at 180 °C and 200 W also allowed high extraction yield (75.5%) and total phenolic content (66.8 mg GAE/g of extract) in concentrated extracts from tomato pericarps without seeds, the most common tomato wastes (Pinela et al., 2017). These preparations were rich in the major phenolic acids (benzyl alcohol dihexose and a cis *p*-coumaric acid derivative) and flavonoids (quercetin pentosylrutinoside and quercetin-3-orutinoside), among other important phytochemicals. It is noteworthy that MAE in water have led to acceptable results for monomeric anthocyanins present in grape juice waste, 1.3 mg/g of grape juice waste under optimum conditions (Varadharajan et al., 2017).

Plant material is generally dried and powdered before MAE since milling improves the extraction of phenolics. The reduction in diameter of sample particles maximizes the surface area in contact with solvent(s) and decreases diffusion distances, which results in greater mass transfer and yield (Mustafa & Turner, 2011). However, excessively small particles (< 250 μm) can make it difficult to separate the extract from the residue, necessitating a cleaning step (Talmaciu et al., 2015). On the other hand, the high water content makes biological samples explicit targets for microwave absorption. As in HPLE and UAE, the high temperatures reached by microwave radiation generally reduce the viscosity and surface tension of the solvent, improving the diffusivity of targeted phenolics (Zhao et al., 2017). Nevertheless, excessive temperatures can decrease extraction yields due to thermal degradation (Chaves et al., 2020) and the promotion of spurious derivatives such as 5-(hydroxymethyl)furfurals (Tsubaki et al., 2010). This has been described for the matrix-bound phenolic fraction of citrus mandarin pomace (phenolic acids, flavanol, flavanone and flavonol compounds), in which high power (> 250 W) and prolonged times (> 10 min) resulted in flavonoid degradation (Hayat et al., 2010). The chemical stability is different for each molecule and, consequently, the optimal compromise between temperature (energy) and time must be scrutinized to avoid overheating and physical damage to the target species. In this regard, a new green industrial application based on the administration of microwave radiation under vacuum (Vaccum Microwave Aqueous Assisted Extraction or VMAAE) has been developed to preclude the damage of (thermo)sensitive species. Microwaves increase the rotation and ionic mobility of water molecules and speed the mobilization of water-soluble compounds from the sample to the aqueous extractant. This MAE variant works without harmful organic solvents and at low pressure and temperature values, making it an alternative to protect labile compounds from degradation and oxidation. Different VMAAE setups have been recently reported for extracting phenolics from diverse plant by-products. Thus, pomegranate peels extracted in water at 60 °C and 2000 W for 10 min, led to a total phenolic content of 137.97 ± 0.99 mg GAE/g fresh sample (Skenderidis et al., 2020). Likewise, in orange pomace VMAAE at ≈6000 W and 120 min produced a maximum of 37667 mg GAE/Kg DM (Petrotos et al., 2021).

The occasional superiority of MAE over UAE and Soxhlet leaching for extracting plant biocompounds is the significant reduction of time and solvent volume (Chávez-González et al., 2020). Hence, characteristically extraction cycles involve short intervals (15–30 min) and small solvent volumes ranging 10–30 mL (Eskilsson & Björklund, 2000) or even non-solvent extractions (Rodríguez de Luna et al., 2020). Reduction of extraction times (usually < 1 h) protects matrices from the enzymatic degradation (Garcia-Salas et al., 2010). Likewise, solvent reduction is important because larger volumes need higher microwave energies, which could greatly increase heating of the solvent and/or sample and thus the risk of thermal degradation. This has been reported in the extraction of phenolic compounds from *Vernonia amygdalina* (maximum yield = 22.34% w/w and total phenolic content = 102 ± 24 mg GAE/g DW) in boiling water in a sample-to-solvent ratio of 1:8 g/mL, and 8 min of irradiation at a microwave power of 416 W (Alara et al., 2018). Indeed, under predetermined conditions of time, temperature and energy, the lowest sample:solvent proportions provided the highest extraction yields. Moreover, certain MAE applications can be carried out in modified kitchen microwave ovens, in open mode compatible with milder conditions of pressure and temperature that preserve the stability of thermosensitive phenolics (Panzella et al., 2020). Alternatively, as in other high-pressure modalities, professional instrumentation equipped with closed sample vessels where extraction works in the absence of light, is commercially available. Darkness is especially important in polyphenol extraction because some species are light-sensitive and may undergo chemical transformations. For example, isomeric resveratrol appears in natural sources as a diastereomer mixture of differentially active *cis*-resveratrol and the most stable *trans*-resveratrol (Gambini et al., 2015). Photochemical and thermal diastereomerization accelerates *cis*-to-*trans* isomerization and, therefore, MAE in the absence of light can prevent this reaction (Garcia-Salas et al., 2010).

The greatest applicability of MAE occurs for short chain polyphenols (e.g. phenolic acids, flavonoids), which are stable to microwave heating up to 100 °C (Liazid et al., 2007), while those that are polymeric with numerous hydroxyl conjugates (e.g. tannins) or thermolabile (e.g. anthocyanins) can be structurally damaged by microwave energy and are unsuitable as MAE targets (Alara et al., 2021). Additionally, hydroxylates are more susceptible to chemical alteration during MAE than methoxylates (Routray & Orsat, 2012). On the other hand, microwave radiation can be also administered as part of the matrix pretreatment, prior to extraction. For example, the valorization of tea leaves from agricultural pruning remains has been reported following a multiple sequential protocol integrated by pretreatment through microwave hydrodifusion and gravity (MHG). This design seeks to dehydrate the raw material and thereby enhance the release through the cell membrane of phenolics (reaching ≈130 mg GAE/g extract) and antioxidants (capacity ranging 0.3–0.9 g TE/g extract), giving rise to a green modality of extraction assisted by ultrasounds and pressurized hot water that produces high added-value phytocompounds (Sanz et al., 2020).

Theoretical considerations have led to thinking about the production of synergies in maximizing yields and reducing costs by optimal UAE/MAE combinations designed with the help of statistical and modeling resources such as RSM (Wu et al., 2015). Thus, working with avocado peels, Trujillo-Mayol et al. (2019) fitted an experimental setting composed of 15 min of sonication at 60 °C and 95.1 s of microwaving irradiation (500 W). Under this combined strategy, the maximum phenolic content (total phenolic content of 281.4 ± 0.2 mg GAE/g dry extract) and a higher efficiency (270.4 ± 3.6 and 274.9 ± 2.2 mg GAE/g dry extract for sonication and microwaving, respectively) were achieved. These comparative studies (some of which already indicated in previous Sections) are of fundamental importance in R&D&I of valorization, since they allow the comparison of the relative efficiency and suitability of different technical options. In this regard, the study of Trujillo-Mayol and collaborators showed that the economic viability of MAE is greater when the price of energy is high while the UAE-MAE synergy is more competitive for expensive raw materials. Similarly, RSM succeeded in optimizing the hydroethanolic extraction of phenolics (1.72 mg GAE/g), flavonoids (3.01 mg/100 g) and anthocyanins (3.36 mg/100 g), as well as the antioxidant activity from husk of milled black rice co-applicating 10 min of sonication and 31 s of microwaving (Jha et al., 2017). By contrast, Casazza et al. reported greater antiradical recovery from grape seeds using MAE for 30 min (78.6 ± 0.7 $\mu L_{extract}/\mu g_{DPPH}$) than employing UAE for 60 min (53.5 ± 0.4 $\mu L_{extract}/\mu g_{DPPH}$) or

other classical and advanced techniques (Casazza et al., 2010). However, the highest content of total polyphenols, *o*-diphenols and flavonoids in seeds (108.3, 47.0 mg GAE/g DW and 47.2 mg catechin equivalents/g DW, respectively) and skins (34.2, 10.1 mg GAE/g DW and 21.6 mg catechin equivalents/g DW, respectively) was obtained with HPLE for 15 min. Indeed, MAE and HPLE share similarities in the conditions achieved inside the closed sample chamber when solvents are highly pressurized and heated to optimize extraction. MAE at optimized conditions (19.8% ethanol at 348.07 W for 9.8 min) was also superior to UAE and conventional solvent extraction in the recovery in a short interval of polyphenolic content (264.9 ± 10.025 mg GAE/100 mL) and antioxidant capacity (13.14 ± 1.05 μmol TE/mL) from black carrot pomace (Kumar et al., 2019).

10. Supercritical fluid extraction (SFE)

Supercritical fluids (SCFs) are hybrid media that in a single phase combine properties of liquids and gases. In the supercritical region (at pressures and temperatures above their thermodynamic critical values), SCFs exhibit low surface tensions, which protect the more labile compounds, the reduced viscosities of organic liquids, which enhance penetration into the solid matrices, and diffusion coeficients close to those of gases, which facilitate the partition of soluble biocompounds (Dassoff & Li, 2019). Therefore, the improved solubility and solvating capacity at high pressure and temperature increases extractability and efficient recovery of solutes, making dual gas–liquid SCFs extraordinarily versatile extractants for innumerable end-products on laboratory and industrial scales (Herrero et al., 2015; Justyna et al., 2017).

Extraction by compressed SCFs has the great advantage to be innocuous to food components and harmless to human consumption. Moreover, SFE has no environmental impact because toxic solvents can be completely avoided and the high energy required by other extraction options is reduced (Brunner, 2005). Health safety comes mainly from SC-CO_2, the most common extractant for natural matrices (Silva et al., 2016), which is atoxic and non-flammable, non-corrosive, thermodynamically stable, chemically inert and non-mutagenic (Wrona et al., 2017; Zhou et al., 2021). Readily available at high purity and non-polluting, dense SC-CO_2 has low critical properties (critical point at 31.6 °C and 73.8 MPa), which guarantees efficiency avoiding organic solvents and deterioration of thermolabile species (Lack et al., 2000). Consequently, EFSA and FDA recognize that SC-CO_2 is safe (Uwineza & Waśkiewicz, 2020).

SC-CO_2 dissolves numerous bio- and macromolecules and is cost-effective (Morgan, 2013; Herrero et al., 2015). Depending on pressure and density, SC-CO_2 can fractionate complex plant matrices to provide phytochemical fractions according to the polarity and *M*r of specific phytochemicals. From this premise, SC-CO_2 in continuos mode (flow = 2 mL/min) and isothermal extraction at 40 °C has recently provided gradient workflows (pressure and co-solvent) capable of fractionating extracts rich in lipids or phenolic compounds from pomegranate (*Punica granatum*) peels (Silva et al., 2021b). Moreover, under atmospheric pressure/temperature CO_2 is volatile and can be removed directly by decompression, resulting in cleaner phenolic preparations. Alternatively, CO_2 can be captured and reused in future extraction cycles, helping to reduce costs and improve scalability. Therefore, SFE with SC-CO_2 avoids cumbersome of subsequent concentration and purification by providing fully active, solvent-free extracts ready for food, pharmacological and cosmetic utilities.

The dielectric constant and thus, polarity and solvating capacity of SC-CO_2 are pressure/temperature-dependent (Shams et al., 2015). In this regard, it is essential that SC-CO_2 can maintain supercritical diffusivity and extractability at moderate temperatures to ensure the recovery of heat-sensitive species (Fabrowska et al., 2016). In isobaric processes, as the temperature rises (usually in the range 40–60 °C for plant by-products), the solvent becomes less viscous and the vapor pressure of analytes diminishes, increasing their extraction rate (Bubalo et al., 2018). Under isothermal conditions, as pressure increases (20–30 MPa is usual for polyphenols), the solvation capacity of CO_2 increases as a consequence of high (liquid-like) density, thus enhancing the mass transfer and diffusion coefficients of solubilized species (Molino et al., 2020).

The low polarity makes SC-CO_2 ideal for the extraction of low/medium polarity or non-polar species, losing efficiency with natural compounds bearing hydroxyl and carboxyl groups, such as polar polyphenols (Fiori et al., 2009). Although in some instances the solubility in CO_2 of certain polyphenols (e.g. flavonoids) is enhanced by increased solvent density at high pressure, as in the enhanced yield from spearmint leaves with increasing pressure from 100 to 200 bar (Bimakr et al., 2012), in others it is not. However, introducing relatively small percentages (1–10%) of polar organic cosolvents denominated modifiers or entrainers, such as water and ethanol, occasionally ethyl lactate or methanol (Khaw et al., 2017; Rodríguez de Luna et al., 2020), the extraction mixture becomes more polar. Modifiers undergo dipole–dipole and hydrogen-bonding interactions that ameliorate the solubility of polar compounds at temperatures suitable for thermolabile species (Sosa-Ferrera et al., 2013; Bubalo et al., 2018). For this reason, modifiers are the *conditio sine qua non* for improving the yield of phenolics and must therefore be selected with the same care as solvents. Low toxicity makes ethanol the preferred option for nutraceutical and food functionalization, since pure water is highly corrosive in the supercritical state (critical point: 374 °C, 22 MPa) and hence unsuitable as cosolvent for polyphenol extraction (Dai & Mumper, 2010). In this regard, ethanol:water mixtures are common in SFE applications because they overcome limitations of SC-CO_2 solubility, they are non-toxic and fully tolerable in developments for human consumption. Notwithstanding, the abundance of polar phenolics in some matrices may explain why the most polar extractants, even under non-critical conditions, achieve higher extraction yields (Goli et al., 2005), such as subcritical H_2O, which is increasingly reported as an alternative (Brglez Mojzer et al., 2016).

The high pressures prevailing in SFE disrupt cells and diminish the particle size. So, by combining optimal values of pressure and temperature, the most adequate particle diameter and run time, SFE achieves suitability for a broad variety of targets (Pimentel-Moral et al., 2019). Nevertheless, high pressures involved in SFE require expertise and specific instrumentation (pressurization unit, gas storage and pressure sample vessel, among others), which compromises accessibility and makes scalability expensive (Panja, 2018). Like HPLE and SWE, to help the solubilization of analytes SFE can be run in a static or continuous mode (Chaves et al., 2020), or as a static phase followed by a dynamic step. Moreover, since SFE is carried out in a dark container within an oxygen-deprived atmosphere, the species susceptible to oxidation are much more protected than in other extraction alternatives (Dai & Mumper, 2010). Therefore, the capacity of SFE to drive optimal developments that preserve the integrity and functionality of labile polyphenols, has encouraged the supercritical extraction of different matrices from the first well-established applications of SC-CO_2 in decaffeination of tea and coffee (Brunner, 2005). This is the case of α-mangostin from mangosteen pericarp (Pimentel-Moral et al., 2019), resveratrol from vineyard leaves (Becze et al., 2020) or different phenolics from grape *Palomino fino* by-products (Casas et al., 2010) and *Vitis vinifera* varieties (Farías-Campomanes et al., 2013; Marqués et al., 2013; Da Porto & Natolino, 2017), among others (Tyśkiewicz et al., 2018).

The influence of the chemical profile of by-products in the operational setting and extraction results is noticeable. This has been evidenced in the phenolic extraction of peach and apple pomaces by SC-CO_2 in 20% ethanol and 40 min (Adil et al., 2007), which differed in the optimum of pressure and temperature (54.6–57 MPa and 55.7–58.4 °C for apple pomace; 50.6–51 MPa and 50.9–52.3 °C for peach pomace). The characteristics of both extracts also differed: total phenolic content (0.47 and 0.26 mg GAE/g sample for apple and peach pomace, respectively), and antioxidant capacity (3.30 and 1.5 mg DPPH/mg sample,

respectively). On the other hand, in an attempt to obtain anthocyanin preparations with potential commercial use, pretreatment of grape marc with SC-CO_2 (with or without ethanol as cosolvent) removed the non-polar components and increased the extractability of polar polyphenols compared to single-step batch extraction (Vatai et al., 2009). Although pretreatment with SC-CO_2 did not improve the recovery of anthocyanins, SFE with CO_2 made it possible to dispense hazardous organic solvents such as hexane. Interestingly, biotransformation of orange pomace by fungal fermentation and SC-CO_2 at 25 MPa and 60 °C was enhanced more than twice (2.62 ± 0.06%) and provided a total phenolic content of 21.2 ± 0.8 mg GAE/g dry extract (Espinosa-Pardo et al., 2017). In a similar way, a combined UAE-SFE (SC-CO_2) developed on defatted grape marc at pilot-plant scale yielded the best total polyphenol content (3493 mg GAE/100 g DM) and antioxidant activity (7503 mg α-tocopherol/100 g DM) than each one separately (Da Porto et al., 2015). From the point of view of clinical interest, SC-CO_2 (24.9 MPa, 68 °C) with 10% ethanol as modifier has achieved phenolic-rich extracts from black chokeberryk pulp endowed with antiproliferative effects on breast cancer cells (Wenzel et al., 2020). Soybean oil produced by screw press generates a residue called soybean expeller, usually exploited as animal food. Noticeably, expeller has been recently valorized with SC-CO_2 and impregnation with ethanol (25% w/w expeller), achieving at 40 MPa and 35 °C high contents of total phenolics (10.6–16.0 mg GAE/100 g DM) and antioxidant capacity (9.7–12.0 μmol TE/100 g DM) (Alvarez et al., 2019). In this same regard, the commonly discarded black walnut husks have been found to have a high content of total phenolics (4.06 ± 0.16 and 9.17 ± 0.20 mg GAE/g for dried and wet walnut husk, respectively) thanks to extraction in SC-CO_2 with 20% ethanol at 68 °C (Wenzel et al., 2016). Moreover, SC-CO_2:ethanol achieved better yield than hydroalcoholic UAE. Similarly, 40 °C/20 MPa SC-CO_2 allowed more efficient, rapid and highly concentrated polyphenol extracts (global yield: 10.5 ± 0.2 g/100 g of lees in dry basis) from lees of pisco-making than conventional Soxhlet extraction (Farías-Campomanes et al., 2015). By contrast, 55 °C/30 MPa SC-CO_2 in 5% ethanol yielded less polyphenol from apple pomace than Soxhlet leaching in ethanol or maceration in boiling water, although more active extracts (higher antioxidant activity: 5.99 ± 0.11 mg TE/g of extract) (Ferrentino et al., 2018).

The main advantages of SFE are simplicity, sustainability, the provision in a short time of high-quality extracts (solvent-free and without co-extracted analytes), as well as the possibility of automation by coupling SFE to high throughput analytical technology. However, SFE also entails some limitations to extract whole phenolic fractions, such as the loss of high-*Mr* polymeric species reported in grape pomace (Murga et al., 2000; Pinelo et al., 2007), or the difficult solute–solvent equilibrium. Despite this, the qualities of SC-CO_2 augur SFE a privileged place in the recovery and valorization of agroforestry waste from sustainable coordinates (Zhou et al., 2021), including the industrial scale (Rodríguez de Luna et al., 2020).

11. Electrotechnologies: Pulsed electric field (PEF) and high voltage Electrical discharges (HVED)

Nonthermal electrochemistry applies electric fields in different regimens to cause physical stress in plant walls and cell membranes until their solvent permeability increases significantly and intracellular phytochemicals become available to extractant. The goal of nonthermal sample electrostimulation is to improve mass transfer and thereby save in energy, time and solvent requirements. Recently, several electrotechnical modalities entirely compatible with the green chemistry statements, have been developed for valorization of plant wastes and by-products (Vorobiev & Lebovka, 2010).

In Pulsed Electrical Field (PEF) electrotechnology, pulses from 140 to 220 V to 1000 or even > 25000 V are descharged from a few microseconds to several hundreds of seconds into a sealed chamber with the sample inside. Electric potentials stress cell envelope and induce reversible or irreversible pores depending on energy, time and number of pulses. Once the cell envelope has been weakened, PEF accelerates the extraction of plant biocompounds thanks to the increase of electrical conductivity, permeability and solute diffusivity (Vorobiev & Lebovka, 2006; Soliva-Fortuny et al., 2009; Boussetta et al., 2013; Rodríguez de Luna et al., 2020). In general, electric field/mass ratio is the main factor governing the optimization of PEF extractions, since pore size and wall/membrane disintegration increase with the intensity of electric pulses (Peiró et al., 2019; Rodríguez de Luna et al., 2020). It should be noted that electric fields stimulate the secondary metabolism as a self-protective response, so PEF has been related to the augmentation of phenolics and other secondary metabolites observed in certain matrices (Soliva-Fortuny et al., 2009). At the same time, electric discharges produce hydroxyl radicals during photodissociation of water, atomic hydrogen and ozone that can degrade polyphenolic compounds (Chen et al., 2004). Therefore, the intensity of PEF protocols must be carefully modulated to achieve an optimal compromise between energy and extractability of native species. On the other hand, the combination of PEF with solvent extraction has shown good achievements in the recovery of phenolics by modulating temperature and pH conditions. So, improvements in solvent consumption, extraction time and yield compared to traditional liquid partitioning, have been reported in valorization of plant by-products such as potato peels (Frontuto et al., 2019), grape by-products (Corrales et al., 2008; Boussetta et al., 2013) and vine shoots (Rajha et al., 2014). Plum and grape peels (Medina-Meza & Barbosa-Cánovas, 2015), flaxseed hulls (Boussetta et al., 2014), orange (Luengo et al., 2013) and lemon (Peiró et al., 2019) peel residues, or olive pomace (Andreou et al., 2020) are other examples of by-product valorization by PEF-assisted polyphenol extraction. Moreover, used as a prefermentative strategy to electropermeabilize cell wall, PEF enhanced the phenolic concentration during vinification (El Darra et al., 2013b). Nevertheless, despite the continuous publication of new studies with PEF as extraction reference, more research is still needed on the effects of pulsed electric fields on plant matrices.

Another nonthermal pretreatment electrotechnology to enhance the extraction kinetics of matrix components is the High Voltage Electrical Discharges (HVED) technique. Considered a plausible alternative to conventional extraction methods (Li et al., 2019), HVED's rationale, procedure, and equipment are very similar to PEF's, except that electric discharges occur at a small point. The intense electric fields (20–40 kV) applied from the two electrodes propagate through the solvent to the sample into the discharge chamber and, above certain potential threshold, produce the electroporation of cell wall and membrane (Mahnič-Kalamiza et al., 2014). The origin of this physical effect is the breakdown of water molecules upon the anode-to-cathode electric streamer created by intense electric fields, which is subsequently accompanied by high-amplitude turbulence/cavitation shock waves, ultraviolet radiation and Joule heating (Locke et al., 2006; El Darra et al., 2013a). Electroporation boots diffusivity of intracellular components and reduces extraction times. However, high-energy streamer and arc formation lead to electrochemical and chemical reactions (e.g. reactive radicals and hydrogen peroxide or ozone formation), which have not yet been fully characterized and must be addressed in order to understand their importance in the chemical integrity of target species and viability of biotransformation (Saulis et al., 2015). A recent study on papaya peels addressed the risk of reactive chemicals and electrolysis products appearing after HVED, which can damage the chemical integrity of the extracts (Parniakov et al., 2014). Regarding this issue, the screening of pH can help prevent oxidative damage of extracted phenolics since acidic pH stabilizes ozone and precludes its water-mediated breakdown into hydroxyl radicals (Boussetta et al., 2011; Parniakov et al., 2014). Consequently, the highest voltage that increases solubilization of the targeted phenolics should be set (Boussetta et al., 2009a; Nutrizio et al., 2020), and should not be exceeded to avoid their electro-induced adulteration (Rodríguez de Luna et al., 2020). Accordingly, polyphenol extraction and antioxidant activity from grape

pomace are enhanced as energy increases up to 80 kJ/kg coupled to diffusion in 30% aqueous ethanol at 60 °C for 30 min, whilst when this optimal input is exceeded a decrease begins of the maximum amount of polyphenols extracted (2.8 g GAE/100 g DM) and higher antioxidant activity (70 g TE/kg DM) (Boussetta et al., 2011).

The distance between electrodes is another parameter of paramount importance because it determines the energy deployed on the extraction medium. The distance from the electrode to the discharge plate must be carefully defined, as when it is too short (excessively strong field) or too large (insufficiently powerful field) it reduces the energy transmitted to the sample and yield drops (Rodríguez de Luna et al., 2020). Another influential factor is the solvent volume (liquid–solid ratio), which partly governs the diffusion rate of soluble matrix components. *Ab initio*, as solvent availability increases, the extraction rate rises, but after reaching the optimum the improvement stagnates in a dynamic plateau equilibrium (Rodríguez de Luna et al., 2020). The efficiency of HVED is influenced by other operational factors, such as the HVED treatment time or the extraction solvent, which must be also addressed for the achievement of quality extracts, as reported for the extraction of flavan-3-ols, flavonols and stilbenes from grape stems (Brianceau et al., 2016), in which treatment time, pH and ethanol concentration affeced their extractability, especially regarding the first two types of compounds.

HVED regimes have gained increasing popularity by their feasibility in obtaining phytochemicals from natural sources. In this regard, different electrochemical approaches in pure water, ethanol or hydroethanolic mixtures have been reported in laboratory and pilot scale for polyphenol extraction from agro-food waste; i.e., grape by-products (Boussetta & Vorobiev, 2014; Rajha et al., 2014; El Kantar et al., 2019) or orange peels (El Kantar et al., 2018). It is noteworthy that 80 sucessive HVED pulses of 40 kV (total treatment time: 160 s) more than doubled (70 ± 4% *vs.* 27 ± 2%) the polyphenol recovery in water from fresh grape pomace compared to the non-HVED conventional counterpart after 240 min of extraction under similar conditions (Boussetta et al., 2009a). HVED has also been reported to accelerate the aqueous extraction of polyphenols (especially of catechin) from grape skin layers, pointing out the facilitation that strong shock waves have in the physical disintegration of wall and membrane structures (Boussetta et al., 2009b). On this ground, other solvents such as DESS-6 (lactic acid: glucose) have shown to be effective in the extraction of the most abundant flavonoid naringin in grapefruit peels (El Kantar et al., 2019). It is important to note that PEF and HVED have indistinctly displayed significant yield improvements, as well as reductions in time and temperature. This has been the case of polyphenol extraction from grade seeds (9 g GAE/100 g DM; Boussetta et al., 2012), sesame cake (up to 440.3 mg GAE/100 g; Ribeiro Sarkis et al., 2015) and pomelo peels (2169 mg/kg DM; Parniakov et al., 2016).

12. Enzyme-assited extraction (EAE)

Plant phenolic compounds can be retained by hydrogen and hydrophobic bonds in the polysaccharide-lignin network of wall structure. On other occasions they establish ether-type bonds with lignin through their phenol rings, or remain esterified to carbohydrates and proteins of the wall (Rodríguez de Luna et al., 2020). Pretreatment with a degrading enzyme or different combinations of pectinolytic and polysaccharide degrading enzymes (pectinases, cellulases, hemicellulases) disrupts the cell envelope and releases the network of wall-bound compounds, ameloriating the permeability and extractability (solvation and mass transfer) of the phenolics that are non-extractable with conventional solvents (Papillo et al., 2014; Nadar et al., 2018). Thus, guava (*Psidium guajava*) leaves treated with cellulase or *β*-glucosidase-assisted extraction improved the extraction of soluble phenolics by 103.2% and the antioxidant activity by 126.5% (Wang et al., 2017b).

EAE is recognized as environmentally friendly, which has promoted its application in the valorization of polyphenol-rich matrices from food-agroindustry (Gligor et al., 2019). Correspondingly, enzymes perform extraction in water, under mild conditions, in short intervals and with substrate specificity (Gligor et al., 2019). However, the efficiency of EAE is highly dependent on small physicochemical oscillations that determine the catalytic potential, such as the composition of enzyme mixtures, pH, temperature, and particle size. Specifically, pH and temperature are critical to activate the catalytic potential. In this regard, most of the EAE settings are performed at low pH since acid contexts favor the breakdown of the secondary bonds that link phenolics to wall components. Furthermore, as particle diameter decreases the accessibility of the enzymes to the susceptible bonds increases and the diffusion paths to the solvent of the released species are reduced (Reverchon & De Marco, 2006). The negative interference of improper enzyme activities originating either from plant matrix or from contaminants in commercial preparations is of particular concern in EAE (Chávez-González et al., 2020). There are some precedents in this regard, such as the negative effects of commercial multicomponent preparations on the recovery of anthocyanins from black currant juice pomace (Landbo & Meyer, 2001), which has been attributed to the presence in commercial cocktails of polyphenol oxidase and/or glycosidase activities. In a similar way, the low yield of anthocyanins from grape pomace has been related to polyphenoloxidases and peroxidases (Maier et al., 2008), which had to be inactivated by pasteurization to preclude polyphenol deterioration. Moreover, it is noted that different enzymes can produce specific alterations in the phenolic profile. Thus, the combination of cellulase, pectinase, and tannase under optimal conditions (pH 4.0 at 37 °C) enhanced the extraction of phenolic compounds (mainly gallic acid) from pistachio green hull; the yield increased by up to 112% compared to the untreated extract, as well as the antioxidant capacity which was 71% higher than in the non-enzymatic control extract (Ghandahari Yazdi et al., 2019). At the same time, cellulose and pectinase improved phloroglucinol to the detriment of gallic acid, while tannase alone or in combination increased the yield of gallic acid. Despite these eventualities and the high cost of enzymes, which can hinder development and scaling, EAE has been reported to be useful in the up-grading of numerous plant matrices that retain high amounts of appreciated phenolic compounds, such as red and white grape pomace, skins, seeds and stems (Kammerer et al., 2005; Pinelo et al., 2006; Maier et al., 2008; Gómez-García et al., 2012; Ferri et al., 2016; Rodríguez-Morgado et al., 2015; Ferri et al., 2017; Averilla et al., 2019b). In Syrah grape pomace, one of the most abundant and polyphenol-rich varietals worldwide, the treatment with cellulase and tannase increased the recovery of phenolics (up to 66% of gallic, *p*-coumaric and syringic acids) as well as the antioxidant activity (up to 80%), compared to classic hydroalcoholic (50:50) extraction at 50 °C for 6 h (Meini et al., 2019). Likewise, in Cabernet variety grapes the hydrolysis of wine lees with endoprotease and exopeptidase activities produced a phenolic-concentrated preparation (160.06 ± 0.32 mg GAE/g), especially enriched in anthocyanins and flavanols with blood pressure-lowering effect in spontaneously hypertensive rats (López-Fernández-Sobrino et al., 2021).

The importance of releasing the matrix-bound phenolics to optimize extraction has been shown in the comparison of the basic and enzymatic hydrolysis of the soybean husk (Cabezudo et al., 2021). In this regard, 2 M NaOH for 156 min at 70 °C yielded 0.72 ± 0.05 g GAE/100 g of soybean hull, rich in phenolic acids, anthocyanins and isoflavones and with an antioxidant activity of 2.2 ± 0.3 mmol TE/100 g of soybean hull. Alternatively, fermentation for 120 h with *A. oryzae* or incubation with commercial α-amylase (90 U/mL) also facilitated the release of matrix-conjugated polyphenols, improving the extraction yield up to 160% and 152%, respectively, and the antioxidant activity up to 270% and 144%, respectively, compared to performance without pretreatment. Similar improvements have been reported from aqueous EAE with thermostable alkaline protease (pH 9, 60 °C, 2 hr) of raspberry pomace press-cake, which provided preparations enriched in polyphenols and antioxidant activity, by respectively 48% and 25% greater than those obtained by extraction with a methanol/acetone/water (7:7:6) mixture (Saad et al., 2019). The same happened with the sweet corn cob, an agricultural by-

product of the corn processing industry from which the enzymatic hydrolysis of insoluble ferulic acid has been achieved by treatment with ferulic acid esterase and xylanase, giving rise to a yield (1.69 ± 0.02 g/kg) in close agreement with RSM predictions (Lau et al., 2020). In the same way, the release of phenolics from apple (Pinelo et al., 2008) and citrus (Li et al., 2006) peels, currant juice press waste (Landbo & Meyer, 2001), citrus juice by-products (Roggia Ruviaro et al., 2018) or crude and waste seeds of guarana (Santana & Macedo, 2019), among others, have shown that enzymes provide noticeable achievements in total phenolic yield and extraction quality. The post-extraction utility of enzyme treatment has also been explored. Water extraction at 80 °C of olive leaves coupled to subsequent treatment at 30 °C for 6 h with yeast β-glucosidase and esterase increased the recovery of the total polyphenol (from 38.50 ± 0.791 to 43.08 ± 0.814 and 43.04 ± 0.671, respectively) and DPPH radical scavenging activity, which increased ≈28 times (Palmeri et al., 2017). Sixteen polyphenols were detected and quantified, highlighting oleuropein and hydroxytyrosol glucoside for their concentration. However, post-extraction addition of pectinases and cellulases (pH 3, at 50 °C in darkness for 24 h) did not consistently increase either phenolic acids or anthocyanins from the aqueous extracts of sour cherry wine (Roda-Serrat et al., 2019).

The application of high hydrostatic pressure (HHP) in combination with EAE or the pretreatment by HHP of the enzymatic cocktail, has proven to be advantageous in the recovery of phenolic compounds from grape pomace (Cascaes Teles et al., 2021) because HHP increased by up to 16 times the catalytic potential of enzymes. Specifically, HHP-AEA at 200 MPa for 10 min produced the highest phenolic extraction of 906.34 ± 12.33 mg GAE/100 g. Similarly, a sequential hydrothermal and enzymatic hydrolysis (pH 4.4 at 47 °C for 20.8 h) with a multi-active preparation of β-glucanase and xylanase of wheat bran produced hydrolysates with ferulic acid content, antioxidant and anti-inflammatory activities 4.2, 1.5, 2, and 3 times higher than suspensions without the enzyme (Bautista-Expósito et al., 2020), providing an excellent strategy for wheat bran valorization. Likewise, under optimized conditions, EAE (pH 4.8, 60 °C for 4.8 h) was more efficient than UAE in extracting bioactive compounds from *Citrus paradise* peel powder, achieving a total phenolic content of 3170.35 ± 8.72 mg GAE/100 *vs.* 2116.71 ± 1.73 mg GAE/100 g obtained through UAE (Nishad et al., 2019).

It is also noteworthy that high-voltage electrostimulation (222 kJ/kg) of orange peels before their acid EAE with a cellulolytic mixture, facilitated the accessibility of the cellulosic biomass to the hydrolytic enzymes and, consequently, maximized the extraction of polyphenols (0.7 g/100 g DM) and reduced sugars (El Kantar et al., 2018). Likewise, standard alkaline, EAE, UAE and ultrasound-assisted enzymatic extraction (EAE-UAE) were optimized by RSM and subsequently compared for effectiveness in sesame bran (Görgüç et al., 2019). The experimental results showed that EAE-UAE, at 836 W, 43 °C, 98 min, pH 9.8 and 1.248 alcalase Units/100 g enzyme, provided the highest phenolic (3.82 to 6.03 mg GAE/g) and protein (52.9 to 88.4%) yields, as well as maximal antioxidant capacity (1.24–3.55 μmol TE/g). In this regard, the combination of EAE-UAE or EAE-UAE-MAE produced synergies in the recovery of total flavonoids and antioxidant activity from pomelo (van Hung et al., 2020) peels and flavonoids from chesnut peels (Xu et al., 2018). In the study of van Hung et al., combined EAE-UAE (2% pectinolytic polygalacturonase and 40 KHz at a water–solid ratio of 40 mL/g and 50 °C for 60 min) provided the highest content (in total phenolic, total flavonoid, naringin and hesperidin recovery) and antiradical scavenging activity (24–43.3% DPPH scavenging) from thre three cultivars of *Citrus grandis limonia*. Similarly, a simultaneous MAE-UAE-EAE has been addressed for the extraction of antioxidants of berry (*Nitraria tangutorum*) juice by-products (Wu et al., 2015). In this case, 70% ethanol as extraction solvent, solvent:sample ratio of 20:1, 0.6% of cellulase at pH 4.5 and 66 °C for 43 min, associated to ultrasounds (800 W) and microwaves (420 W), provided flavonoid and anthocyanin contents and antioxidant capacity higher than those obtained by traditional technologies.

13. Concluding remarks

Recent literature concerning the extraction of polyphenols from agri-food by-products highlights a set of technically-assisted strategies that have made great progress in the most recent period. Compared to traditional methods and with respect to the commercial success of waste valorization, many of the developments facilitated by new advanced

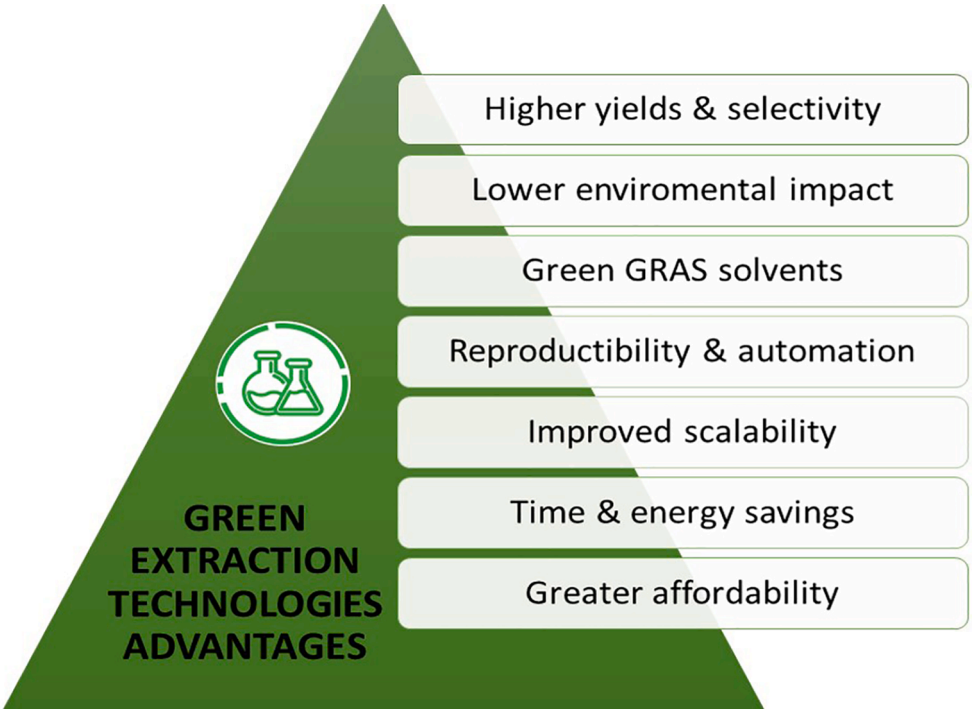


Fig. 4. Some of the most important implementations achieved by advanced extraction techniques.

technologies have shown significant achievements in three fundamental directions (Fig. 4). First, time and energy savings providing cost-effective settings. Second, small solvent requirements and high compatibility with green and more efficient GRAS extractants. Third, yield, selectivity and extraction capacity enhancements based on the physicochemical conditions of matrix-solvent environment in which desorption from the matrix and solubilisation take place. Moreover, technical assistance greatly reduces sample handling and human intervention, thereby increasing reproducibility and automation. As a result, current extraction settings tend to be efficient, sustainable, potentially cost-effective and more easily scalable. Despite this, the aspirational horizon of endowing plant by-product extraction with optimal feasibility, specificity and efficiency is still far from being available. In this order, the rule is to accept as optimum a compromise between maximum recovery and minimal disturbance of the native structure of the extracted species. Notwithstandig technical progress, the most suitable option for extracting targeted phenolic compounds continues depending on the source, targeted species and their structural relationships, so a long trajectory of research will be necessary before the valorization of a great part of plant by-products becomes widely achievable. In order to take advantage of plant waste, an additional difficulty is that phytochemicals (including polyphenols) are usually minoritary. Carbohydrates are predominant in plant matrices and have commercial interest as well. Consequently, future innovative extraction developments will need to be based on sequential workflows that releasing separate bioactive fractions make plausible the ideal of recovering high-added value phenolic preparations.

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References

Abascal, K., Ganora, L., & Yarnell, E. (2005). The effect of freeze-drying and its implications for botanical medicine: A review. *Phytother Res, 19*(8), 655–660. https://doi.org/10.1002/ptr.1651

Adil, I. H., Çetin, H. I., Yener, M. E., & Bayindirli, A. (2007). Subcritical (carbon dioxide +ethanol) extraction of polyphenols from apple and peach pomaces, and determinationof the antioxidant activities of the extracts. *J Supercrit Fluids, 43*, 55–63. https://doi.org/10.1016/j.supflu.2007.04.012

Agcam, E., Akyıldız, A., & Balasubramaniam, V. M. (2017). Optimization of anthocyanins extraction from black carrot pomace with thermosonication. *Food Chem, 237*, 461–470. https://doi.org/10.1016/j.foodchem.2017.05.098

Aires, A. (2017). Phenolics in foods: Extraction, analysis and measurements, In: Phenolic Compounds - Natural Sources, Importance and Applications, Soto-Hernandez, M., Palma-Tenango, M. Garcia-Mateos, M. R. IntechOpen, DOI: 10.5772/66889. Available from: https://www.intechopen.com/books/phenolic-compounds-natural-sources-importance-and-applications/phenolics-in-foods-extraction-analysis-and-measurements.

Al Bittar, S., Périno-Issartier, S., Dangles, O., & Chemat, F. (2013). An innovative grape juice enriched in polyphenols by microwave-assisted extraction. *Food Chem, 141*(3), 3268–3272. https://doi.org/10.1016/j.foodchem.2013.05.134

Alara, O. R., Abdurahman, N. H., Abdul Mudalip, S. K., & Olalere, O. A. (2018). Microwave-assisted extraction of Vernonia amygdalina leaf for optimal recovery of total phenolic content. *J Appl Res Med Aromat Plant, 10*, 16–24. https://doi.org/10.1016/j.jarmap.2018.04.004

Alara, O. R., Abdurahman, N. H., & Ukaegbu, C. I. (2021). Extraction of phenolic compounds: A review. *Curr Res Food Sci, 4*, 200–214. https://doi.org/10.1016/j.crfs.2021.03.011

Albuquerque, B. R., Heleno, S. A., Oliveira, M. B. P. P., Barros, L., & Ferreira, I. C. F. R. (2021). Phenolic compounds: Current industrial applications, limitations and future challenges. *Food Funct, 12*, 14–29. https://doi.org/10.1039/d0fo02324h

Alim, A., Li, T., Nisar, T., Ren, D., Liu, Y., & Yang, X. (2020). Consumption of two whole kiwifruit (Actinide chinensis) per day improves lipid homeostasis, fatty acid metabolism and gut microbiota in healthy rats. *Int J Biol Macromol, 156*, 186–195. https://doi.org/10.1016/j.ijbiomac.2020.04.028

Allcca-Alca, E. E., León-Calvo, N. C., Luque-Vilca, O. M., Martínez-Cifuentes, M., Pérez-Correa, J. R., Mariotti-Celis, M. S., & Huamán-Castilla, N. L. (2021). Hot Pressurized Liquid Extraction of Polyphenols from the Skin and Seeds of *Vitis vinifera* L. cv. Negra Criolla Pomace a Peruvian Native Pisco Industry Waste. *Agronomy, 11, 5*, 866. https://doi.org/10.3390/agronomy11050866

Alonso-Salces, R. M., Korta, E., Barranco, A., Berrueta, L. A., Gallo, B., & Vicente, F. (2001). Pressurized liquid extraction for the determination of polyphenols in apple. *J Chromatogr A, 933*(1–2), 37–43. https://doi.org/10.1016/s0021-9673(01)01212-2

Alvarez, M. V., Cabred, S., Ramirez, C. L., & Fanovich, M. A. (2019). Valorization of an agroindustrial soybean residue by supercritical fluid extraction of phytochemical compounds. *J Supercrit Fluids, 143*, 90–96. https://doi.org/10.1016/j.supflu.2018.07.012

Alvarez, V. H., Cahyadi, J., Xu, D., & Saldaña, M. D. A. (2014). Optimization of phytochemicals production from potato peel using subcritical water: Experimental and dynamic modeling. *J Supercrit Fluids, 90*, 8–17. https://doi.org/10.1016/j.supflu.2014.02.013

Amarowicz, R., & Pegg, R. B. (2019). Natural antioxidants of plant origin. *Adv Food Nutr Res, 90*, 1–81. https://doi.org/10.1016/bs.afnr.2019.02.011

Amaya-Cruz, D. M., Pérez-Ramírez, I. F., Delgado-García, J., Mondragón-Jacobo, C., Dector-Espinoza, A., & Reynoso-Camacho, R. (2019). An integral profile of bioactive compounds and functional properties of prickly pear (Opuntia ficus indica L.) peel with different tonalities. *Food Chem, 278*, 568–578. https://doi.org/10.1016/j.foodchem.2018.11.031

Ameer, K., Shahbaz, H. M., & Kwon, J. H. (2017). Green Extraction Methods for Polyphenols from Plant Matrices and Their Byproducts: A Review. *Compr Rev Food Sci Food Saf, 16*, 295–315. https://doi.org/10.1111/1541-4337.12253

Andreou, V., Psarianos, M., Dimopoulos, G., Tsimogiannis, D., & Taoukis, P. (2020). Effect of pulsed electric fields and high pressure on improved recovery of high-added-value compounds from olive pomace. *J Food Sci, 85*(5), 1500–1512. https://doi.org/10.1111/1750-3841.15122

Angeloni, S., Navarini, L., Sagratini, G., Torregiani, E., Vittori, S., & Caprioli, G. (2018). Development of an extraction method for the quantification of lignans in espresso coffee by using HPLC-MS/MS triple quadrupole. *J Mass Spectrom, 53*(9), 842–848. https://doi.org/10.1002/jms.4251

Angeloni, S., Nzekoue, F. K., Navarini, L., Sagratini, G., Torregiani, E., Vittori, S., & Caprioli, G. (2020). An analytical method for the simultaneous quantification of 30 bioactive compounds in spent coffee ground by HPLC-MS/MS. *J Mass Spectrom, 55*(11), Article e4519. https://doi.org/10.1002/jms.4519

Antoniolli, A., Fontana, A. R., Piccoli, P., & Bottini, R. (2015). Characterization of polyphenols and evaluation of antioxidant capacity in grape pomace of the cv. *Malbec. Food Chem, 178*, 172–178. https://doi.org/10.1016/j.foodchem.2015.01.082

Apostolakis, A., Grigorakis, S., & Makris, D. P. (2014). Optimisation and comparative kinetics study of polyphenol extraction from olive leaves (Olea europaea) using heated water/glycerol mixtures. *Separ Purif Technol, 128*, 89–95. https://doi.org/10.1016/j.seppur.2014.03.010

Arapitsas, P., & Turner, C. (2008). Pressurized solvent extraction and monolithic column-HPLC/DAD analysis of anthocyanins in red cabbage. *Talanta, 74*, 1218–1223. https://doi.org/10.1016/j.talanta.2007.08.029

Arboleda Meija, J. A., Parpinello, G. P., Versari, A., Conidi, C., & Cassano, A. (2019). Microwave-assisted extraction and membrane-based separation of biophenols from red wine lees. *Food Bioprod Process, 117*, 74–83. https://doi.org/10.1016/j.fbp.2019.06.020

Arruda, H. S., Silva, E. K., Peixoto Araujo, N. M., Pereira, G. A., Pastore, G. M., & Marostica Junior, M. R. (2021). Anthocyanins recovered from agri-food by-products using innovative processes: Trends, challenges, and perspectives for their application in food systems. *Molecules, 26*, 2632. https://doi.org/10.3390/molecules26092632

Averilla, J. N., Oh, J., Kim, H. J., Kim, J. S., & Kim, J. S. (2019a). Potential health benefits of phenolic compounds in grape processing by-products. *Food Sci Biotechnol, 28*(6), 1607–1615. https://doi.org/10.1007/s10068-019-00628-2

Averilla, J. N., Oh, J., Wu, Z., Liu, K. H., Jang, C. H., Kim, H. J., … Kim, J. S. (2019b). Improved extraction of resveratrol and antioxidants from grape peel using heat and enzymatic treatments. *J Sci Food Agric, 99*(8), 4043–4053. https://doi.org/10.1002/jsfa.9632

Aydar, A. Y. (2018). Utilization of Response Surface Methodology in Optimization of Extraction of Plant Materials. In: Valter Silva (Ed.), Statistical Approaches With Emphasis on Design of Experiments Applied to Chemical Processes, IntechOpen, 2018. https://doi.org/10.5772/intechopen.73690.

Azmir, J., Zaidul, I. S. M., Rahman, M. M., Sharif, K. M., Mohamed, A., Sahena, F., … Omar, A. K. M. (2013). Techniques for extraction of bioactive compounds from plant materials: A review. *J Food Eng, 117*, 426–436. https://doi.org/10.1016/j.jfoodeng.2013.01.014

Babazadeh, A., Taghvimi, A., Hamishehkar, H., & Tabibiazar, M. (2017). Development of new ultrasonic–solvent assisted method for determination of trans-resveratrol from red grapes: Optimization, characterization, and antioxidant activity (ORAC assay). *Food Biosci, 20*, 36–42. https://doi.org/10.1016/j.fbio.2017.08.003

Ballesteros-Vivas, D., Alvarez-Rivera, G., Ibánez, E., Parada-Alfonso, F., & Cifuentes, A. (2019a). Integrated strategy for the extraction and profiling of bioactive metabolites from Passiflora mollissima seeds combining pressurized-liquid extraction and gas/liquid chromatography–high resolution mass spectrometry. *J Chromatogr A, 1595*, 144–157. https://doi.org/10.1016/j.chroma.2019.02.031

Ballesteros-Vivas, D., Álvarez-Rivera, G., Morantes, S. J., Sánchez-Camargo, A. P., Ibáñez, E., Parada-Alfonso, F., & Cifuentes, A. (2019b). An integrated approach for the valorization of mango seed kernel: Efficient extraction solvent selection,

phytochemical profiling and antiproliferative activity assessment. *Food Res Int, 126*, Article 108616. https://doi.org/10.1016/j.foodres.2019.108616
Barrales, F. M., Silveira, P., Barbosa, P. P. M., Ruviaro, A. R., Paulino, B. N., Pastore, G. M., Alves Macedo, G., & Martínez, J. (2018). Recovery of phenolic compounds from citrus by-products using pressurized liquids — an application to orange peel. *Food Bioprod Process, 112*, 9–21. https://doi.org/10.1016/j.fbp.2018.08.006
Bautista-Expósito, S., Tomé-Sánchez, I., Martín-Diana, A. B., Frias, J., Peñas, E., Rico, D., … Martínez-Villaluenga, C. (2020). Enzyme selection and hydrolysis under optimal conditions improved phenolic acid solubility, and antioxidant and anti-inflammatory activities of wheat bran. *Antioxidants (Basel), 9*, 984. https://doi.org/10.3390/antiox9100984
Becze, A., Babalau-Fuss, V. L., Varaticeanu, C., & Roman, C. (2020). Optimization of high-pressure extraction process of antioxidant compounds from *Feteasca regala* leaves using response surface methodology. *Molecules, 25*(18), 4209. https://doi.org/10.3390/molecules25184209
Benito-Román, Ó., Blanco, B., Sanz, M. T., & Beltrán, S. (2020). Subcritical water extraction of phenolic compounds from onion skin wastes (*Alliumcepa* cv. Horcal): Effect of temperature and solvent properties. *Antioxidants (Basel), 9, 12*, 1233. https://doi.org/10.3390/antiox9121233
Ben-Othman, S., Jõudu, I., & Bhat, R. (2020). Bioactives from agri-food wastes: Present insights and future challenges. *Molecules, 25*, 510. https://doi.org/10.3390/molecules25030510
Ben-Othman, S., Kaldmäe, H., Rätsep, R., Bleive, U., Aluvee, A., & Rinken, T. (2021). Optimization of ultrasound-assisted extraction of phloretin and other phenolic compounds from apple tree leaves (*Malus domestica* Borkh.) and comparison of different cultivars from Estonia. *Antioxidants (Basel), 10, 2*, 189. https://doi.org/10.3390/antiox10020189
Betoret, E., & Rosell, C. M. (2020). Effect of particle size on functional properties of *Brassica napobrassica* leaves powder. Starch interactions and processing impact. *Food Chem X, 8*, Article 100106. https://doi.org/10.1016/j.fochx.2020.100106
Biesaga, M. (2011). Influence of extraction methods on stability of flavonoids. *J Chromatogr A, 1218*(18), 2505–2512. https://doi.org/10.1016/j.chroma.2011.02.059
Bimakr, M., Rahman, R. A., Ganjloo, A., Taip, F. S., Salleh, L. M., & Sarker, M. Z. I. (2012). Optimization of supercritical carbon dioxide extraction of bioactive flavonoid compounds from spearmint (Mentha spicata L.) leaves by using response surface methodology. *Food Bioprocess Technol, 5*, 912–920. https://doi.org/10.1007/s11947-010-0504-4
Birtic, S., Régis, S., Le Bourvellec, C., & Renard, C. M. G. C. (2019). Impact of air-drying on polyphenol extractability from apple pomace. *Food Chem, 296*, 142–149. https://doi.org/10.1016/j.foodchem.2019.05.131
Bonacci, S., Di Gioia, M. L., Costanzo, P., Maiuolo, L., Tallarico, S., & Nardi, M. (2020). Natural deep eutectic solvent as extraction media for the main phenolic compounds from olive oil processing wastes. *Antioxidants (Basel), 9*(6), 513. https://doi.org/10.3390/antiox9060513
Bosiljkov, T., Dujmić, F., Bubalo, M. C., Hribar, J., Vidrih, R., Brnčić, M., … Jokić, S. (2017). Natural deep eutectic solvents and ultrasound-assisted extraction: Green approaches for extraction of wine lees anthocyanins. *Food Bioprod Process, 102*, 195–203. https://doi.org/10.1016/j.fbp.2016.12.005
Boussetta, N., Lanoisellé, J. L., Bedel-Cloutour, C., & Vorobiev, E. (2009a). Extraction of soluble matter from grape pomace by high voltage electrical discharges for polyphenol recovery: Effect of sulphur dioxide and thermal treatments. *J Food Eng, 95*, 192–198. https://doi.org/10.1016/j.jfoodeng.2009.04.030
Boussetta, N., Lebovka, N., Vorobiev, E., Adenier, H., Bedel-Cloutour, C., & Lanoisellé, J. L. (2009b). Electrically assisted extraction of soluble matter from chardonnay grape skins for polyphenol recovery. *J Agric Food Chem, 57*(4), 1491–1497. https://doi.org/10.1021/jf802579x
Boussetta, N., Lesaint, O., & Vorobiev, E. (2013). A study of mechanisms involved during the extraction of polyphenols from grape seeds by pulsed electrical discharges. *Innov Food Sci Emerg Technol, 19*, 124–132. https://doi.org/10.1016/j.ifset.2013.03.007
Boussetta, N., Soichi, E., Lanoisellé, J. L., & Vorobiev, E. (2014). Valorization of oilseed residues: Extraction of polyphenols from flaxseed hulls by pulsed electric fields. *Ind Crop Prod, 52*, 347–353. https://doi.org/10.1016/j.indcrop.2013.10.048
Boussetta, N., Vorobiev, E., Deloison, V., Pochez, F., Falcimaigne-Cordin, A., & Lanoisellé, J. L. (2011). Valorisation of grape pomace by the extraction of phenolic antioxidants: Application of high voltage electrical discharges. *Food Chem, 128*(2), 364–370. https://doi.org/10.1016/j.foodchem.2011.03.035
Boussetta, N., Vorobiev, E., Le, L. H., Cordin-Falcimaigne, A., & Lanoisellé, J. L. (2012). Application of electrical treatments in alcoholic solvent for polyphenols extraction from grape seeds. *LWT - Food Sci Technol, 46*, 127–134. https://doi.org/10.1016/j.lwt.2011.10.016
Boussetta, N., & Vorobiev, E. (2014). Extraction of valuable biocompounds assisted by high voltage electrical discharges: A review. *C R Chim, 17*, 197–203. https://doi.org/10.1016/j.crci.2013.11.011
Brglez Mojzer, E., Knez Hrnčič, M., Škerget, M., Knez, Ž., & Bren, U. (2016). Polyphenols: Extraction methods, antioxidative action, bioavailability and anticarcinogenic effects. *Molecules, 21*(7), 901. https://doi.org/10.3390/molecules21070901
Brianceau, S., Turk, M., Vitrac, X., & Vorobiev, E. (2016). High voltage electric discharges assisted extraction of phenolic compounds from grape stems: Effect of processing parameters on flavan-3-ols, flavonols and stilbenes recovery. *Innov Food Sci Emerg Technol, 35*, 67–74. https://doi.org/10.1016/j.ifset.2016.04.006
Brunner, G. (2005). Supercritical fluids: Technology and application to food processing. *J Food Eng, 67*(1–2), 21–33. https://doi.org/10.1016/j.jfoodeng.2004.05.060
Bubalo, M. C., Vidović, S., Redovniković, I. R., & Jokić, S. (2018). New perspective in extraction of plant biologically active compounds by green solvents. *Food Bioprod Process, 109*, 52–73. https://doi.org/10.1016/j.fbp.2018.03.001
Bucić-Kojić, A., Planinić, M., Tomas, S., Bilić, M., & Velić, D. (2007). Study of solid–liquid extraction kinetics of total polyphenols from grape seeds. *J Food Eng, 81*(1), 236–242. https://doi.org/10.1016/j.jfoodeng.2006.10.027
Cabezudo, I., Meini, M. R., Di Ponte, C. C., Melnichuk, N., Boschetti, C. E., & Romanini, D. (2021). Soybean (Glycine max) hull valorization through the extraction of polyphenols by green alternative methods. *Food Chem, 338*, Article 128131. https://doi.org/10.1016/j.foodchem.2020.128131
Cacciola, N. A., Squillaci, G., D'Apolito, M., Petillo, O., Veraldi, F., La Cara, F., Peluso, G., Margarucci, S., Morana, A. (2019). *Castanea sativa* mill. Shells aqueous extract exhibits anticancer properties inducing cytotoxic and pro-apoptotic effects. *Molecules, 24*, 18, 3401. https://doi.org/10.3390/molecules24183401.
Cai, Z., Qu, Z., Lan, Y., Zhao, S., Ma, X., Wan, Q., … Li, P. (2016). Conventional, ultrasound-assisted, and accelerated-solvent extractions of anthocyanins from purple sweet potatoes. *Food Chem, 197*, 266–272. https://doi.org/10.1016/j.foodchem.2015.10.110
Caldeira, A. S. P., Mbiakop, U. C., Pádua, R. M., van de Venter, M., Matsabisa, M. G., Campana, P. R. V., … Braga, F. C. (2021). Bioguided chemical characterization of pequi (Caryocar brasiliense) fruit peels towards an anti-diabetic activity. *Food Chem, 345*, Article 128734. https://doi.org/10.1016/j.foodchem.2020.128734
Carciochi, R. A., D'Alessandro, L. G., Vauchel, P., Rodriguez, M. M., Nolasco, S. M., Dimitrov, K. (2017). Chapter 4 - Valorization of agrifood by-products by extracting valuable bioactive compounds using green processes. In Handbook of Food Bioengineering, Ingredients Extraction by Physicochemical Methods in Food. Grumezescu, A. M., Holban, A, M, (Ed.). Elsevier Academic Press Inc, 4, 191–228. https://doi.org/10.1016/B978-0-12-811521-3.00004-1.
Casado, N., Morant-Zarcero, S., Pérez-Quintanilla, D., Cámara, J. S., & Sierra, I. (2019). Dispersive solid-phase extraction of polyphenols from juice and smoothie samples using hybrid mesostructured silica followed by ultra-high-performance liquid chromatography-ion-trap tandem mass spectrometry. *J Agric Food Chem, 67*(3), 955–967. https://doi.org/10.1021/acs.jafc.8b05578
Casas, L., Mantell, C., Rodríguez, M., De Ossa, E. J. M., Roldán, A., De Ory, I., … Blandino, A. (2010). Extraction of resveratrol from the pomace of Palomino fino grapes by supercritical carbon dioxide. *J Food Eng, 96*, 304–308. https://doi.org/10.1016/j.jfoodeng.2009.08.002
Casazza, A. A., Aliakbarian, B., Mantegna, S., Cravotto, G., & Perego, P. (2010). Extraction of phenolics from Vitis vinifera wastes using non-conventional techniques. *J Food Eng, 100*, 50–55. https://doi.org/10.1016/j.jfoodeng.2010.03.026
Cascaes Teles, A. S., Hidalgo Chávez, D. W., Zarur Coelho, M. A., Rosenthal, A., Fortes Gottschalk, L. M., & Valeriano Tonon, R. (2021). Combination of enzyme-assisted extraction and high hydrostatic pressure for phenolic compounds recovery from grape pomace. *J Food Eng, 288*, Article 110128. https://doi.org/10.1016/j.jfoodeng.2020.110128
Cassol, L., Rodrigues, E., & Noreña, C. P. Z. (2019). Extracting phenolic compounds from Hibiscus sabdariffa L. calyx using microwave assisted extraction. *Ind Crop Prod, 133*, 168–177. https://doi.org/10.1016/j.indcrop.2019.03.023
Cedola, A., Palermo, C., Centonze, D., Del Nobile, M. A., & Conte, A. (2020). Characterization and bio-accessibility evaluation of olive leaf extract-enriched "Taralli". *Foods, 9*(9), 1268. https://doi.org/10.3390/foods9091268
Chanioti, S., & Tzia, C. (2018). Extraction of phenolic compounds from olive pomace by using natural deep eutectic solvents and innovative extraction techniques. *Innov Food Sci Emerg Technol, 48*, 228–239. https://doi.org/10.1016/j.ifset.2018.07.001
Chaves, J. O., de Souza, M. C., da Silva, L. C., Lachos-Perez, D., Torres-Mayanga, P. C., Machado, A. P. D. F., … Rostagno, M. A. (2020). Extraction of flavonoids from natural sources using modern techniques. *Front Chem, 8*, Article 507887. https://doi.org/10.3389/fchem.2020.507887
Chávez-González, M. L., Sepúlveda, L., Verma, D. K., Luna-García, H. A., Rodríguez-Durán, L. V., Ilina, A., & Aguilar, C. N. (2020). Conventional and emerging extraction processes of flavonoids. *Processes, 8*(4), 434. https://doi.org/10.3390/pr8040434
Chel-Guerrero, L. D., Oney-Montalvo, J. E., & Rodríguez-Buenfil, I. M. (2021). Phytochemical characterization of by-products of habanero pepper grown in two different types of soils from Yucatán. *Mexico. Plants (Basel), 10*(4), 779. https://doi.org/10.3390/plants10040779
Chemat, F., Huma, Z., & Khan, M. K. (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. *Ultrason Sonochem, 18*, 813–835. https://doi.org/10.1016/j.ultsonch.2010.11.023
Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. *A review. Ultrason Sonochem, 34*, 540–560. https://doi.org/10.1016/j.ultsonch.2016.06.035
Chen, Y., Zhang, X., Dai, Y., & Yuan, W. (2004). Pulsed high-voltage discharge plasma for degradation of phenol in aqueous solution. *Sep Purif Technol, 34*, 5–12. https://doi.org/10.1016/S1383-5866(03)00169-2
Cheng, Y., Xue, F., Yu, S., Du, S., & Yang, Y. (2021). Subcritical water extraction of natural products. *Molecules, 26*, 4004. https://doi.org/10.3390/molecules26134004
Cheynier, V. (2005). Polyphenols in foods are more complex than often thought. *Am J Clin Nutr, 81*, 223S–229S. https://doi.org/10.1093/ajcn/81.1.223S
Chiocchio, I., Mandrone, M., Tomasi, P., Marincich, L., & Poli, F. (2021). Plant secondary metabolites: An opportunity for circular economy. *Molecules, 26*, 495. https://doi.org/10.3390/molecules26020495
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. *Innov Food Sci Emerg Technol, 9*(1), 85–91. https://doi.org/10.1016/j.ifset.2007.06.002
Cory, H., Passarelli, S., Szeto, J., Tamez, M., & Mattei, J. (2018). The role of polyphenols in human health and food systems: A mini-review. *Front Nutr, 5*, 87. https://doi.org/10.3389/fnut.2018.00087
Da Porto, C., & Natolino, A. (2017). Supercritical fluid extraction of polyphenols from grape seed (Vitis vinifera): Study on process variables and kinetics. *J Supercrit Fluids, 130*, 239–245. https://doi.org/10.1016/j.supflu.2017.02.013
Da Porto, C., Natolino, A., & Decorti, D. (2015). The combined extraction of polyphenols from grape marc: Ultrasound assisted extraction followed by supercritical CO2 extraction of ultrasound-raffinate. *LWT-Food Sci Technol, 61*, 98–104. https://doi.org/10.1016/j.lwt.2014.11.027
Dai, J., & Mumper, R. J. (2010). Plant phenolics: Extraction, analysis and their antioxidant and anticancer properties. *Molecules, 15*(10), 7313–7352. https://doi.org/10.3390/molecules15107313
Dai, Y., van Spronsen, J., Witkamp, G. J., Verpoorte, R., & Choi, Y. H. (2013). Natural deep eutectic solvents as new potential media for green technology. *Anal Chimica Acta, 766*, 61–68. https://doi.org/10.1016/j.aca.2012.12.019
Dassoff, E. S., & Li, Y. O. (2019). Mechanisms and effects of ultrasound-assisted supercritical CO2 extraction. *Trends Food Sci Tech, 86*, 492–501. https://doi.org/10.1016/j.tifs.2019.03.001
de la Cerda-Carrasco, A., López-Solís, R., Nuñez-Kalasic, H., Peña-Neira, Á., & Obreque-Slier, E. (2015). Phenolic composition and antioxidant capacity of pomaces from four grape varieties (Vitis vinifera L.). *J Sci Food Agric, 95, 7*, 1521–1527. https://doi.org/10.1002/jsfa.6856
Deng, J., Liu, Q., Zhang, C., Cao, W., Fan, D., & Yang, H. (2016). Extraction optimization of polyphenols from waste kiwi fruit seeds (Actinidia chinensis Planch.) and evaluation of its antioxidant and anti-iInflammatory properties. *Molecules, 21, 7*, 832. https://doi.org/10.3390/molecules21070832
Difonzo, G., Aresta, A., Cotugno, P., Ragni, R., Squeo, G., Summo, C., … Caponio, F. (2021). Supercritical CO_2 extraction of phytocompounds from olive pomace subjected to different drying methods. *Molecules, 26*(3), 598. https://doi.org/10.3390/molecules26030598
Dinu, M., Pagliai, G., Casini, A., & Sofi, F. (2018). Mediterranean diet and multiple health outcomes: An umbrella review of metaanalyses of observational studies and randomised trials. *Eur J Clin Nutri, 72*(1), 30–43. https://doi.org/10.1038/ejcn.2017.58
Dorosh, O., Moreira, M. M., Rodrigues, F., Peixoto, A. F., Freire, C., Morais, S., & Delerue-Matos, C. (2020). Vine-canes valorisation: Ultrasound-assisted extraction from lab to pilot scale. *Molecules, 25*(7), 1739. https://doi.org/10.3390/molecules25071739
Dossou, S. S. K., Xu, F., Cui, X., Sheng, C., Zhou, R., You, J., … Wang, L. (2021). Comparative metabolomics analysis of different sesame (Sesamum indicum L.) tissues reveals a tissue-specific accumulation of metabolites. *BMC Plant Biol, 21*, 352. https://doi.org/10.1186/s12870-021-03132-0
Drosou, C., Kyriakopoulou, K., Bimpilas, A., Tsimogiannis, D., & Krokida, M. (2015). A comparative study on diferent extraction techniques to recover red grape pomace polyphenols from vinifcation byproducts. *Ind Crops Prod, 75*, 141–149. https://doi.org/10.1016/j.indcrop.2015.05.063
Dudley, G. B., Richert, R., & Stiegman, A. E. (2015). On the existence of and mechanism for microwavespecific reaction rate enhancement. *Chem Sci, 6*, 2144–2152. https://doi.org/10.1039/c4sc03372h
Dzah, C. S., Duan, Y., Zhang, H., Wen, C., Zhang, J., Chen, G., & Ma, H. (2020). The effects of ultrasound assisted extraction on yield, antioxidant, anticancer and antimicrobial activity of polyphenol extracts: A review. *Food Biosci, 35*, Article 100547. https://doi.org/10.1016/j.fbio.2020.100547
El Darra, N., Grimi, N., Vorobiev, E., Louka, N., & Maroun, R. (2013a). Extraction of polyphenols from red grape pomace assisted by pulsed ohmic heating. *Food Bioprocess Technol, 6*, 1281–1289. https://doi.org/10.1007/s11947-012-0869-7
El Darra, N., Grimi, N., Vorobiev, E., Maroun, R. G., & Louka, N. (2013b). Pulsed electric field-assisted cold maceration of Cabernet Franc and Cabernet Sauvignon grapes. *Am J Enol Vitic, 64*, 476–484. https://doi.org/10.5344/ajev.2013.12098
El Kantar, S., Boussetta, N., Rajha, H. N., Maroun, R. G., Louka, N., & Vorobiev, E. (2018). High voltage electrical discharges combined with enzymatic hydrolysis for extraction of polyphenols and fermentable sugars from orange peels. *Food Res Int, 107*, 755–762. https://doi.org/10.1016/j.foodres.2018.01.070
El Kantar, S., Rajha, H. N., Boussetta, N., Vorobiev, E., Maroun, R. G., & Louka, N. (2019). Green extraction of polyphenols from grapefruit peels using high voltage electrical discharges, deep eutectic solvents and aqueous glycerol. *Food Chem, 295*, 165–171. https://doi.org/10.1016/j.foodchem.2019.05.111
Escobar-Avello, D., Mardones, C., Pérez, A. J., Saéz, V., Riquelme, S., von Baer, D., & Vallverdú-Queralt, A. (2019). Phenolic profile of grape canes: Novel compounds identified by LC-ESI-LTQ-Orbitrap-MS. *Molecules, 24*, 3763. https://doi.org/10.3390/molecules24203763
Escobar-Avello, D., Mardones, C., Saéz, V., Riquelme, S., von Baer, D., Lamuela-Raventós, R. M., & Vallverdú-Queralt, A. (2021). Pilot-plant scale extraction of phenolic compounds from grape canes: Comprehensive characterization by LC-ESI-LTQ-Orbitrap-MS. *Food Res Int, 143*, Article 110265. https://doi.org/10.1016/j.foodres.2021.110265
Eskilsson, C. S., & Björklund, E. (2000). Analytical-scale microwave-assisted extraction. *J Chromatogr A, 902*(1), 227–250. https://doi.org/10.1016/s0021-9673(00)00921-3
Espinosa-Pardo, F. A., Nakajima, V. M., Macedo, G. A., Macedo, J. A., & Martínez, J. (2017). Extraction of phenolic compounds from dry and fermented orange pomace using supercritical CO2 and cosolvents. *Food Bioprod Process, 101*, 1–10. https://doi.org/10.1016/j.fbp.2016.10.002
Fabrowska, J., Ibañez, E., & Herrero, M. (2016). Supercritical fluid extraction as a tool to valorize underexploited freshwater green algae. *Algal Res, 19*, 237–245. https://doi.org/10.1016/j.algal.2016.09.008
Farías-Campomanes, A. M., Rostagno, M. A., & Meireles, M. A. A. (2013). Production of polyphenol extracts from grape bagasse using supercritical fluids: Yield, extract composition and economic evaluation. *J Supercrit Fluids, 77*, 70–78. https://doi.org/10.1016/j.supflu.2013.02.006
Farías-Campomanes, A. M., Rostagno, M. A., Coaquira-Quispe, J. J., & Meireles, M. A. A. (2015). Supercritical fluid extraction of polyphenols from lees: Overall extraction curve, kinetic data and composition of the extracts. *Bioresour Bioprocess, 2*, 45. https://doi.org/10.1186/s40643-015-0073-5
Fernandes, P. A. R., Ferreira, S. S., Bastos, R., Ferreira, I., Cruz, M. T., Pinto, A., … Wessel, D. F. (2019). Apple pomace extract as a sustainable food ingredient. *Antioxidants (Basel), 8*(6), 189. https://doi.org/10.3390/antiox8060189
Fernández-Ponce, M. T., Casas, L., Mantell, C., Rodríguez, M., & Martínez de la Ossa, E. (2012). Extraction of antioxidant compounds from different varieties of Mangifera indica leaves using green technologies. *J Supercrit Fluids, 72*, 168–175. https://doi.org/10.1016/j.supflu.2012.07.016
Ferreira, S. S., Silva, A. M., & Nunes, F. M. (2018). Citrus reticulata Blanco peels as a source of antioxidant and anti-proliferative phenolic compounds. *Ind Crops Prod, 111*, 141–148. https://doi.org/10.1016/j.indcrop.2017.10.009
Ferrentino, G., Morozova, K., Mosibo, O. K., Ramezani, M., & Scampicchio, M. (2018). Biorecovery of antioxidants from apple pomace by supercritical fluid extraction. *J Clean Prod, 186*, 253–261. https://doi.org/10.1016/j.jclepro.2018.03.165
Ferreyra, S. G., Antoniolli, A., Bottini, R., & Fontana, A. (2020). Bioactive compounds and total antioxidant capacity of cane residues from different grape varieties. *J Sci Food Agric, 100*, 376–383. https://doi.org/10.1002/jsfa.10065
Ferri, M., Bin, S., Vallini, V., Fava, F., Michelini, E., Roda, A., … Tassoni, A. (2016). Recovery of polyphenols from red grape pomace and assessment of their antioxidant and anti-cholesterol activities. *N Biotechnol, 33*(3), 338–344. https://doi.org/10.1016/j.nbt.2015.12.004
Ferri, M., Rondini, G., Calabretta, M. M., Michelini, E., Vallini, V., Fava, F., Roda, A., Minnucci, G., Tassoni, A. (2017). White grape pomace extracts, obtained by a sequential enzymatic plus ethanol-based extraction, exert antioxidant, anti-tyrosinase and anti-inflammatory activities. *N Biotechnol, 39*, Pt A, 51–58. https://doi.org/10.1016/j.nbt.2017.07.002.
Ferri, M., Vannini, M., Ehrnell, M., Eliasson, L., Xanthakis, E., Monari, S., … Tassoni, A. (2020). From winery waste to bioactive compounds and new polymeric biocomposites: A contribution to the circular economy concept. *J Adv Res, 24*, 1–11. https://doi.org/10.1016/j.jare.2020.02.015
Figueroa, J. G., Borrás-Linares, I., Lozano-Sánchez, J., Quirantes-Piné, R., & Segura-Carretero, A. (2018a). Optimization of drying process and pressurized liquid extraction for recovery of bioactive compounds from avocado peel by-product. *Electrophoresis, 39*(15), 1908–1916. https://doi.org/10.1002/elps.201700379
Figueroa, J. G., Borrás-Linares, I., Lozano-Sánchez, J., & Segura-Carretero, A. (2018b). Comprehensive characterization of phenolic and other polar compounds in the seed and seed coat of avocado by HPLC-DAD-ESI-QTOF-MS. *Food Res Int, 105*, 752–763. https://doi.org/10.1016/j.foodres.2017.11.082
Figueroa, J. G., Borrás-Linares, I., Lozano-Sánchez, J., & Segura-Carretero, A. (2018c). Comprehensive identification of bioactive compounds of avocado peel by liquid chromatography coupled to ultra-high-definition accurate-mass Q-TOF. *Food Chem, 245*, 707–716. https://doi.org/10.1016/j.foodchem.2017.12.011
Fiori, L., de Faveri, D., Casazza, A. A., & Perego, P. (2009). Grape by-products: Extraction of polyphenolic compounds using supercritical CO_2 and liquid organic solvent – a preliminary investigation. *CyTA - J Food, 7*, 163–171. https://doi.org/10.1080/11358120902989715
Forni, C., Facchiano, F., Bartoli, M., Pieretti, S., Facchiano, A., D'Arcangelo, D., … Jadeja, R. N. (2019). Beneficial role of phytochemicals on oxidative stress and age-related diseases. *BioMed Res Int, 2019*, 1–16. https://doi.org/10.1155/2019/8748253
Franco, D., Rodríguez-Amado, I., Agregán, R., Munekata, P. E. S., Vázquez, J. A., Barba, F. J., & Lorenzo, J. M. (2018). Optimization of antioxidants extraction from peanut skin to prevent oxidative processes during soybean oil storage. *LWT, 88*, 1–8. https://doi.org/10.1016/j.lwt.2017.09.027
Frontuto, D., Carullo, D., Harrison, S. M., Brunton, N. P., Ferrari, G., Lyng, J. G., & Pataro, G. (2019). Optimization of pulsed electric fields-assisted extraction of polyphenols from potato peels using response surface methodology. *Food Bioprocess Technol, 12*, 1708–1720. https://doi.org/10.1007/s11947-019-02320-z
Galanakis, C. M. (2012). Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications. *Trends Food Sci Technol, 26*, 68–87. https://doi.org/10.1016/j.tifs.2012.03.003
Gallo, M., Formato, A., Giacco, R., Riccardi, G., Lungo, D., Formato, G., … Naviglio, D. (2019). Mathematical optimization of the green extraction of polyphenols from grape peels through a cyclic pressurization process. *Heliyon, 5*(4), Article e01526. https://doi.org/10.1016/j.heliyon.2019.e01526
Gambini, J., Inglés, M., Olaso, G., Lopez-Grueso, R., Bonet-Costa, V., Gimeno-Mallench, L., … Borras, C. (2015). Properties of resveratrol: In vitro and in vivo studies about metabolism, bioavailability, and biological effects in animal models and humans. *Oxid Med Cell Longev, 2015*, Article 837042. https://doi.org/10.1155/2015/837042
García, P., Fredes, C., Cea, I., Lozano-Sánchez, J., Leyva-Jiménez, F. J., Robert, P., … Jimenez, P. (2021). Recovery of bioactive compounds from pomegranate (*Punica granatum* L.) peel using pressurized liquid extraction. *Foods, 10, 2*, 203. https://doi.org/10.3390/foods10020203
Garcia-Castello EM, Rodriguez-Lopez AD, Mayor L, Ballesteros R, Conidi C, Cassano A. (2015). Optimization of conventional and ultrasound assisted extraction

of flavonoids from grapefruit (Citrus paradisi L.) solid wastes. *LWT - Food Sci Technol, 64*, 2, 1114–1122. https://doi.org/10.1016/j.lwt.2015.07.024.
García-Marino, M., Rivas-Gonzalo, J. C., Ibáñez, E., & García-Moreno, C. (2006). Recovery of catechins and proanthocyanidins from winery by-products using subcritical water extraction. *Anal Chim Acta, 563*(1–2), 44–50. https://doi.org/10.1016/j.aca.2005.10.054
Garcia-Salas, P., Morales-Soto, A., Segura-Carretero, A., & Fernández-Gutiérrez, A. (2010). Phenolic-compound-extraction systems for fruit and vegetable samples. *Molecules, 15*(12), 8813–8826. https://doi.org/10.3390/molecules15128813
GBD 2019 Risk Factors Collaborators. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *Lancet, 396*(10258), 1223–1249. https://doi.org/10.1016/s0140-6736(20)30752-2
Gerardi, C., D'amico, L., Migoni, D., Santino, A., Salomone, A., Carluccio, M. A., & Giovinazzo, G. (2020). Strategies for reuse of skins separated from grape pomace as ingredient of functional beverages. *Front Bioeng Biotechnol, 8*, 645. https://doi.org/10.3389/fbioe.2020.00645
Ghandahari Yazdi, A. P., Barzegar, M., Sahari, M. A., & Ahmadi Gavlighi, H. (2019). Optimization of the enzyme-assisted aqueous extraction of phenolic compounds from pistachio green hull. *Food Sci Nutr, 7*, 356–366. https://doi.org/10.1002/fsn3.900
Gil-Chávez, J. G., Vila, J. A., Ayala-Zavala, J. F., Heredia, J. B., Sepulveda, D., Yahia, E. M., & González-Aguilar, G. A. (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. https://doi.org/10.1111/1541-4337.12005
Gligor, O., Mocan, A., Moldovan, C., Locatelli, M., Crișan, G., & Ferreira, I. C. F. R. (2019). Enzyme-assisted extractions of polyphenols—a comprehensive review. *Trends Food Sci Tech, 88*, 302–315. https://doi.org/10.1016/j.tifs.2019.03.029
Goli, A. H., Barzegar, M., & Sahari, M. A. (2005). Antioxidant activity and total phenolic compounds of pistachio (Pistachia vera) hull extracts. *Food Chem, 92*, 521–525. https://doi.org/10.1016/j.foodchem.2004.08.020
Gomes, S., & Torres, A. G. (2016). Optimized extraction of polyphenolic antioxidant compounds from Brazil nut (Bertholletia excelsa) cake and evaluation of the polyphenol profile by HPLC. *J Sci Food Agric, 96*(8), 2805–2814. https://doi.org/10.1002/jsfa.7448
Gómez-García, R., Martínez-Ávila, G. C. G., & Aguilar, C. N. (2012). Enzyme-assisted extraction of antioxidative phenolics from grape (*Vitis vinifera* L.) residues. *3. Biotech, 2*, 297–300. https://doi.org/10.1007/s13205-012-0055-7
Gómez-Mejía, E., Rosales-Conrado, N., León-González, M. E., & Madrid, Y. (2019). Citrus peels waste as a source of value-added compounds: Extraction and quantification of bioactive polyphenols. *Food Chem, 295*, 289–299. https://doi.org/10.1016/j.foodchem.2019.05.136
Gonzales, G. B., Raes, K., Vanhoutte, H., Coelus, S., Smagghe, G., & Van Camp, J. (2015). Liquid chromatography-mass spectrometry coupled with multivariate analysis for the characterization and discrimination of extractable and nonextractable polyphenols and glucosinolates from red cabbage and Brussels sprout waste streams. *J Chromatogr A, 1402*, 60–70. https://doi.org/10.1016/j.chroma.2015.05.009
González-Centeno, M. R., Knoerzer, K., Sabarez, H., Simal, S., Rosselló, C., & Femenia, A. (2014). Effect of acoustic frequency and power density on the aqueous ultrasonic-assisted extraction of grape pomace (Vitis vinifera L.) - a response surface approach. *Ultrason Sonochem, 21, 6*, 2176–2184. https://doi.org/10.1016/j.ultsonch.2014.01.021
Görgüç, A., Bircan, C., & Yılmaz, F. M. (2019). Sesame bran as an unexploited by-product: Effect of enzyme and ultrasound-assisted extraction on the recovery of protein and antioxidant compounds. *Food Chem, 283*, 637–645. https://doi.org/10.1016/j.foodchem.2019.01.077
Grillo, G., Boffa, L., Binello, A., Mantegna, S., Cravotto, G., Chemat, F., … Telysheva, G. (2019). Cocoa bean shell waste valorisation; extraction from lab to pilot-scale cavitational reactors. *Food Res Int, 115*, 200–208. https://doi.org/10.1016/j.foodres.2018.08.057
Hansen, B. B., Spittle, S., Chen, B., Poe, D., Zhang, Y., Klein, J. M., … Sangoro, J. R. (2021). Deep eutectic solvents: A review of fundamentals and applications. *Chem Rev, 121*(3), 1232–1285. https://doi.org/10.1021/acs.chemrev.0c00385
Hashim, S. N., Schwarz, L. J., Boysen, R. I., Yang, Y., Danylec, B., & Hearn, M. T. (2013). Rapid solid-phase extraction and analysis of resveratrol and other polyphenols in red wine. *J Chromatogr A, 1313*, 284–290. https://doi.org/10.1016/j.chroma.2013.06.052
Hayat, K., Zhang, X., Farooq, U., Abbas, S., Xia, S., Jia, C., … Zhang, J. (2010). Effect of microwave treatment on phenolic content and antioxidant activity of citrus mandarin pomace. *Food Chem, 123*, 423–429. https://doi.org/10.1016/j.foodchem.2010.04.060
He, L., Zhang, X., Xu, H., Xu, C., Yuan, F., Knez, Z., … Gao, Y. (2012). Subcritical water extraction of phenolic compounds from pomegranate (Punica granatum L.) seed residues and investigation into their antioxidant activities with HPLC–ABTS+ assay. *Food Bioprod Process, 90*, 215–223. https://doi.org/10.1016/j.fbp.2011.03.003
Herrero, M., Sánchez-Camargo, A. P., Cifuentes, A., & Ibáñez, E. (2015). Plants, seaweeds, microalgae and food by-products as natural sources of functional ingredients obtained using pressurized liquid extraction and supercritical fluid extraction. *TrAC Trends Analyt Chem, 71*, 26–38. https://doi.org/10.1016/j.trac.2015.01.018
Herrero, M., Temirzoda, T. N., Segura-Carretero, A., Quirantes, R., Plaza, M., & Ibañez, E. (2011). New possibilities for the valorization of olive oil by-products. *J Chromatogr A, 1218*(42), 7511–7520. https://doi.org/10.1016/j.chroma.2011.04.053
Huamán-Castilla, N. L., Campos, D., García-Ríos, D., Parada, J., Martínez-Cifuentes, M., Mariotti-Celis, M. S., & Pérez-Correa, J. R. (2021). Chemical properties of Vitis vinifera *Carménère* pomace extracts obtained by hot pressurized liquid extraction, and their inhibitory effect on type 2 diabetes mellitus related e. *Antioxidants (Basel), 10*(3), 472. https://doi.org/10.3390/antiox10030472
Huaman-Castilla, N. L., Mariotti-Celis, M. S., Martínez-Cifuentes, M., & Pérez-Correa, J. R. (2020). Glycerol as alternative co-solvent for water extraction of polyphenols from *Carménère* pomace: Hot pressurized liquid extraction and computational chemistry calculations. *Biomolecules, 10*(3), 474. https://doi.org/10.3390/biom10030474
Huaman-Castilla, N. L., Martínez-Cifuentes, M., Camilo, C., Pedreschi, F., Mariotti-Celis, M., & Pérez-Correa, J. R. (2019). The impact of temperature and ethanol concentration on the global recovery of specific polyphenols in an integrated HPLE/RP process on Carménère pomace extracts. *Molecules, 24*(17), 3145. https://doi.org/10.3390/molecules24173145
Huang, H. W., Cheng, M. C., Chen, B. Y., & Wang, C. Y. (2019). Effects of high pressure extraction on the extraction yield, phenolic compounds, antioxidant and anti-tyrosinase activity of Djulis hull. *J Food Sci Technol, 56*, 4016–4024. https://doi.org/10.1007/s13197-019-03870-y
Ibrahim, S., Santos, R., & Bowra, S. (2018). Optimization of subcritical water mediated extraction of apple pomace polyphenolics and their antioxidant activity. *J Chromatogr, 9*, 5. https://doi.org/10.4172/2157-7064.1000410
Ilbay, Z., Sahin, S., & Büyükkabasakal, K. (2014). A novel approach for olive leaf extraction through ultrasound technology: Response surface methodology versus artificial neural networks. *Korean J Chem Eng, 31*, 1661–1667. https://doi.org/10.1007/s11814-014-0106-3
IndustryARC™. Polyphenols Market – Forecast (2021 - 2026). [(accessed on 24 June 2021)]. Available online at: https://www.industryarc.com/Report/17797/polyphenols-market.html.
Ivanović, M., Islamčević Razboršek, M., & Kolar, M. (2020). Innovative extraction techniques using deep eutectic solvents and analytical methods for the isolation and characterization of natural bioactive compounds from plant material. *Plants, 9*(11), 1428. https://doi.org/10.3390/plants9111428
Jessop, P. G., Jessop, D. A., Fu, D., & Phan, L. (2012). Solvatochromic parameters for solvents of interest in green chemistry. *Green Chem, 14*, 1245–1259. https://doi.org/10.1002/CHIN.201235265
Jha, P., Das, A. J., & Deka, S. C. (2017). Optimization of ultrasound and microwave assisted extractions of polyphenols from black rice (*Oryza sativa* cv. Poireton) husk. *J Food Sci Technol, 54, 12*, 3847–3858. https://doi.org/10.1007/s13197-017-2832-0
Jimenez-Lopez, C., Fraga-Corral, M., Carpena, M., García-Oliveira, P., Echave, J., Pereira, A. G., … Simal-Gandara, J. (2020). Agriculture waste valorisation as a source of antioxidant phenolic compounds within a circular and sustainable bioeconomy. *Food Funct, 11*, 4853–4877. https://doi.org/10.1039/d0fo00937g. PMID: 32463400.
Ju, Z. Y., & Howard, L. R. (2003). Effects of solvent and temperature on pressurized liquid extraction of anthocyanins and total phenolics from dried red grape skin. *J Agric Food Chem, 51*(18), 5207–5213. https://doi.org/10.1021/jf0302106. PMID: 12926860.
Justyna, P., Owczarek, K., Tobiszewski, M., & Namie, J. (2017). Trends in analytical chemistry extraction with environmentally friendly solvents. *Anal Chem, 91*, 12–25. https://doi.org/10.1016/j.trac.2017.03.006
Kammerer, D., Claus, A., Schieber, A., & Carle, R. (2005). A novel process for the recovery of polyphenols from grape (Vitis vinifera L.) pomace. *J Food Sci, 70*, C157–163. https://doi.org/10.1111/j.1365-2621.2005.tb07077.x
Kammerer, D. R., Kammerer, J., Valet, R., Carle, R. (2014). Recovery of polyphenols from the by-products of plant food processing and application as valuable food ingredients. *Food Res Int, 65*, Part A, 2–12. https://doi.org/10.1016/j.foodres.2014.06.012.
Kato-Schwartz, C. G., Gomes Corrêa, R. C., de Souza Lima, D., Babeto de Sá-Nakanishi, A., de Almeida Gonçalves, G., Seixas, F. A. V., … Peralta, R. M. (2020). Potential anti-diabetic properties of Merlot grape pomace extract: An in vitro, in silico and in vivo study of α-amylase and α-glucosidase inhibition. *Food Res Int, 137*, Article 109462. https://doi.org/10.1016/j.foodres.2020.109462
Katsampa, P., Valsamedou, E., Grigorakis, S., & Makris, D. P. (2015). A green ultrasound-assisted extraction process for the recovery of antioxidant polyphenols and pigments from onion solid wastes using Box-Behnken experimental design and kinetics. *Ind Crops Prod, 77*, 535–543. https://doi.org/10.1016/j.indcrop.2015.09.039
Khaw, K. Y., Parat, M. O., Shaw, P. N., & Falconer, J. R. (2017). Solvent supercritical fluid technologies to extract bioactive compounds from natural sources: A review. *Molecules, 22*(7), 1186. https://doi.org/10.3390/molecules22071186
King, J. W., Grabiel, R. D. (2007). Isolation of polyphenolic compounds from fruits or vegetables utilizing subcritical water. Espacenet, US7208181. United States.
Klavins, L., Kviesis, J., & Klavins, M. (2017). Comparison of methods of extraction of phenolic compounds from american cranberry (Vaccinium macrocarpon L.) press residues. *Agron Res, 15, 2*, 1316–1329.
Klavins, L., Kviesis, J., Nakurte, I., & Klavins, M. (2018). Berry press residues as a valuable source of polyphenolics: Extraction optimisation and analysis. *LWT Food Sci Technol, 93*, 583–591. https://doi.org/10.1016/j.lwt.2018.04.021
Kowalska, G., Baj, T., Kowalski, R., & Szymańska, J. (2021). Optimization of glycerol–water extraction of selected bioactive compounds from peppermint and common nettle. *Antioxidants, 10*(5), 817. https://doi.org/10.3390/antiox10050817
Kratchanova, M., Pavlova, E., & Panchev, I. (2004). The effect of microwave heating of fresh orange peels on the fruit tissue and quality of extracted pectin. *Carbohydr Polym, 56*, 181–185. https://doi.org/10.1016/j.carbpol.2004.01.009
Kumar, K., Srivastav, S., & Sharanagat, V. S. (2021). Ultrasound assisted extraction (UAE) of bioactive compounds from fruit and vegetable processing by-products: A review. *Ultrason Sonochem, 70*, Article 105325. https://doi.org/10.1016/j.ultsonch.2020.105325

Kumar, K., Yadav, A. N., Kumar, V., Vyas, P., & Dhaliwal, H. S. (2017). Food waste: A potential bioresource for extraction of nutraceuticals and bioactive compounds. *Bioresour Bioprocess, 4*, 18. https://doi.org/10.1186/s40643-017-0148-6

Kumar, M., Dahuja, A., Sachdev, A., Kaur, C., Varghese, E., Saha, S., & Sairam, K. V. S. S. (2019). Valorisation of black carrot pomace: Microwave assisted extraction of bioactive phytoceuticals and antioxidant activity using Box-Behnken design. *J Food Sci Technol, 56*, 995–1007. https://doi.org/10.1007/s13197-018-03566-9

Kumari, B., Tiwari, B. K., Hossain, M. B., Rai, D. K., & Brunton, N. P. (2017). Ultrasound-assisted extraction of polyphenols from potato peels: Profiling and kinetic modelling. *Int J Food Sci Technol, 52*, 1432–1439. https://doi.org/10.1111/ijfs.13404

Lack, E., Gamse, T., Marr, R. (2000). High pressure process technology: Fundamentals and applications. In Industrial Chemistry Library; Bertucco, A., Vetter, G., Eds.; Elsevier: Amsterdam, The Netherlands, 2000; Volume *9*, 378–395.

Landbo, A. K., & Meyer, A. S. (2001). Enzyme-Assisted Extraction of Antioxidative Phenols from Black Currant Juice Press Residues (Ribes nigrum). *J Agric Food Chem, 49*, 3169–3177. https://doi.org/10.1021/jf001443p

Lau, T., Harbourne, N., & Oruña-Concha, M. J. (2020). Optimization of enzyme-assisted extraction of ferulic acid from sweet corn cob by response surface methodology. *J Sci Food Agric, 100*(4), 1479–1485. https://doi.org/10.1002/jsfa.10155

Lecour, S., & Lamont, K. T. (2011). Natural polyphenols and cardioprotection. *Mini Rev Med Chem, 11*(14), 1191–1199. https://doi.org/10.2174/13895575111091191

Li, B. B., Smith, B., & Hossain, M. (2006). Extraction of phenolics from citrus peels. I. *Solvent extraction method. Sep Purif Technol, 48*, 182–188. https://doi.org/10.1016/j.seppur.2005.07.005

Li, Z., Fan, Y., & Xi, J. (2019). Recent advances in high voltage electric discharge extraction of bioactive ingredients from plant materials. *Food Chem, 277*, 246–260. https://doi.org/10.1016/j.foodchem.2018.10.119

Liazid, A., Barbero, G. F., Azaroual, L., Palma, M., & Barroso, C. G. (2014). Stability of anthocyanins from red grape skins under pressurized liquid extraction and ultrasound-assisted extraction conditions. *Molecules, 19*(12), 21034–21043. https://doi.org/10.3390/molecules191221034

Liazid, A., Palma, M., Brigui, J., & Barroso, C. G. (2007). Investigation on phenolic compounds stability during microwave-assisted extraction. *J Chromatogr A, 1140*, 29–34. https://doi.org/10.1016/j.chroma.2006.11.040

Lin, X., Gao, H., Ding, Z., Zhan, R., Zhou, Z., & Ming, J. (2021). Comparative metabolic profiling in pulp and peel of green and red pitayas (Hylocereus polyrhizus and Hylocereus undatus) reveals potential valorization in the pharmaceutical and food industries. *Biomed Res Int, 2021*, 6546170. https://doi.org/10.1155/2021/6546170

Loarce, L., Oliver-Simancas, R., Marchante, L., Díaz-Maroto, M. C., & Alañón, M. E. (2020). Implementation of subcritical water extraction with natural deep eutectic solvents for sustainable extraction of phenolic compounds from winemaking by-products. *Food Res Int, 137*, Article 109728. https://doi.org/10.1016/j.foodres.2020.109728. Epub 2020 Sep 22 PMID: 33233297.

Lobo, V., Patil, A., Phatak, A., & Chandra, N. (2010). Free radicals, antioxidants and functional foods: Impact on human health. *Pharmacogn Rev, 4*, 118–126. https://doi.org/10.4103/0973-7847.70902

Locke, B. R., Sato, M., Sunka, P., Hoffmann, M. R., & Chang, J. S. (2006). Electrohydraulic discharge and nonthermal plasma for water treatment. *Ind Eng Chem Res, 45*(3), 882–905. https://doi.org/10.1021/ie050981u

López-Fernández-Sobrino, R., Margalef, M., Torres-Fuentes, C., Ávila-Román, J., Aragonès, G., Muguerza, B., & Bravo, F. I. (2021). Enzyme-assisted extraction to obtain phenolic-enriched wine lees with enhanced bioactivity in hypertensive rats. *Antioxidants (Basel), 10*, 517. https://doi.org/10.3390/antiox10040517

Luengo, E., Álvarez, I., & Raso, J. (2013). Improving the pressing extraction of polyphenols of orange peel by pulsed electric fields. *Innov Food Sci Emerg Technol, 17*, 79–84. https://doi.org/10.1016/j.ifset.2012.10.005

Luque-Rodríguez, J. M., Luque de Castro, M. D., & Pérez-Juan, P. (2007). Dynamic superheated liquid extraction of anthocyanins and other phenolics from red grape skins of winemaking residues. *Bioresour Technol, 98*(14), 2705–2713. https://doi.org/10.1016/j.biortech.2006.09.019

Machado, A. P. F., Pasquel-Reátegui, J. L., Barbero, G. F., & Martínez, J. (2015). Pressurized liquid extraction of bioactive compounds from blackberry (*Rubus fruticosus* L.) residues: A comparison with conventional methods. *Food Res Int, 77*, 675–683. https://doi.org/10.1016/j.foodres.2014.12.042

Machado, A. P. F., Sumere, B. R., Mekaru, C., Martinez, J., Bezerra, R. M. N., & Rostagno, M. A. (2019). Extraction of polyphenols and antioxidants from pomegranate peel using ultrasound: Influence of temperature, frequency and operation mode. *Int J Food Sci Technol, 54*, 2792–2801. https://doi.org/10.1111/ijfs.14194

Mahnič-Kalamiza, S., Vorobiev, E., Miklavčič, D. (2014). Electroporation in food processing and biorefinery. *J Membr Biol, 247*, 12, 1279–304. https://doi.org/10.1007/s00232-014-9737-x.

Maier, T., Göppert, A., Kammerer, D. R., Schieber, A., & Carle, R. (2008). Optimization of a process for enzyme-assisted pigment extraction from grape (Vitis vinifera L.) pomace. *EFRT, 227*, 267–275. https://doi.org/10.1007/s00217-007-0720-y

Makanjuola, S. A. (2017). Influence of particle size and extraction solvent on antioxidant properties of extracts of tea, ginger, and tea-ginger blend. *Food Sci Nutr, 5*(6), 1179–1185. https://doi.org/10.1002/fsn3.509

Makris, D. P., & Lalas, S. (2020). Glycerol and Glycerol-Based Deep Eutectic Mixtures as Emerging Green Solvents for Polyphenol Extraction: The Evidence So Far. *Molecules, 25*(24), 5842. https://doi.org/10.3390/molecules25245842

Mallek-Ayadi, S., Bahloul, N., & Kechaou, N. (2017). Characterization, phenolic compounds and functional properties of Cucumis melo L. peels. *Food Chem, 221*, 1691–1697. https://doi.org/10.1016/j.foodchem.2016.10.117

Manousaki, A., Jancheva, M., Grigorakis, S., & Makris, D. P. (2016). Extraction of antioxidant phenolics from agri-food waste biomass using a newly designed glycerol-based natural low-transition temperature mixture: A comparison with conventional eco-friendly solvents. *Recycling, 1*, 194. https://doi.org/10.3390/recycling1010194

Mariotti-Celis, M. S., Martínez-Cifuentes, M., Huamán-Castilla, N., Pedreschi, F., Iglesias-Rebolledo, N., & Pérez-Correa, J. R. (2018). Impact of an integrated process of hot pressurised liquid extraction–macroporous resin purification over the polyphenols, hydroxymethylfurfural and reducing sugars content of *Vitis vinifera* 'Carménère' pomace extracts. *Int J Food Sci Technol, 53*, 1072–1078. https://doi.org/10.1111/ijfs.13684

Marqués, J. L., Della Porta, G., Reverchon, E., Renuncio, J. A. R., & Mainar, A. M. (2013). Supercritical antisolvent extraction of antioxidants from grape seeds after vinification. *J Supercrit Fluids, 82*, 238–243. https://doi.org/10.1016/j.supflu.2013.07.005

Martillanes, S., Rocha-Pimienta, J., Delgado-Adámez, J. (2018). Agrifood by-products as a source of phytochemical compounds. In Descriptive Food Science, Valero Díaz, A., García-Gimeno, R. M. (Ed.). IntechOpen, https://doi.org/10.5772/intechopen.79434.

Mayanga-Torres, P., Lachos-Perez, D., Rezende, C., Prado, J., Ma, Z., Tompsett, G., … Forster-Carneiro, T. (2017). Valorization of cofee industry residues by subcritical water hydrolysis: Recovery of sugars and phenolic compounds. *J Supercrit Fluids, 120*, 75–85. https://doi.org/10.1016/j.supflu.2016.10.015

Medina-Meza, I. L., & Barbosa-Cánovas, G. V. (2015). Assisted extraction of bioactive compounds from plum and grape peels by ultrasonics and pulsed electric fields. *J Food Eng, 166*, 268–275. https://doi.org/10.1016/j.jfoodeng.2015.06.012

Medina-Torres, N., Ayora-Talavera, T., Espinosa-Andrews, H., Sánchez-Contreras, A., & Pacheco, N. (2017). Ultrasound assisted extraction for the recovery of phenolic compounds from vegetable sources. *Agronomy, 7*(3), 47. https://doi.org/10.3390/agronomy7030047

Meini, M. R., Cabezudo, I., Boschetti, C. E., & Romanini, D. (2019). Recovery of phenolic antioxidants from Syrah grape pomace through the optimization of an enzymatic extraction process. *Food Chem, 283*, 257–264. https://doi.org/10.1016/j.foodchem.2019.01.037

Mendiola, J. A., Herrero, M., Cifuentes, A., & Ibañez, E. (2007). Use of compressed fluids for sample preparation: Food applications. *J Chromatogr A, 1152*(1–2), 234–246. https://doi.org/10.1016/j.chroma.2007.02.046

Minatel, I. O., Vanz Borges, C., Ferreira, M. I., Gomez Gomez, H. A., Chen, C. Y.O., Pereira Lima, G. P. (2017). Phenolic compounds: Functional properties, impact of processing and bioavailability, In Phenolic Compounds - Biological Activity. Soto-Hernandez, M., Palma-Tenango, M., Garcia-Mateos, M.R. (Ed.). IntechOpen, DOI: 10.5772/66368. https://www.intechopen.com/chapters/53128.

Mirón, C., Sánchez, R., Prats, S., & Todolí, J. L. (2020). Total polyphenol content and metals determination in Spanish virgin olive oils by means of a dispersive liquid-liquid aerosol phase extraction method and ICP-MS. *Anal Chim Acta, 1094*, 34–46. https://doi.org/10.1016/j.aca.2019.10.009

Moldovan, M. L., Iurian, S., Puscas, C., Silaghi-Dumitrescu, R., Hanganu, D., Bogdan, C., … Benedec, D. (2019). A design of experiments strategy to enhance the recovery of polyphenolic compounds from Vitis vinifera by-products through heat reflux extraction. *Biomolecules, 9*(10), 529. https://doi.org/10.3390/biom9100529

Molino, A., Mehariya, S., Di Sanzo, G., Larocca, V., Martino, M., Leone, G. P., … Musmarra, D. (2020). Recent developments in supercritical fluid extraction of bioactive compounds from microalgae: Role of key parameters, technological achievements and challenges. *J CO_2 Util, 36*, 196–209. https://doi.org/10.1016/j.jcou.2019.11.014

Morgan, E. D. (2013). Natural products|supercritical fluid chromatography. *Reference Module in Chemistry, Molecular Sciences and Chemical Engineering*. Netherlands: Elsevier.

Motikar, P. D., More, P. R., & Arya, S. S. (2021). A novel, green environment-friendly cloud point extraction of polyphenols from pomegranate peels: A comparative assessment with ultrasound and microwave-assisted extraction. *Sep Sci Technol, 56*, 1014–1025. https://doi.org/10.1080/01496395.2020.1746969

Mouratoglou, E., Malliou, V., & Makris, D. P. (2016). Novel glycerol-based natural eutectic mixtures and their efficiency in the ultrasound-assisted extraction of antioxidant polyphenols from agri-food waste biomass. *Waste Biomass Valorization, 7*, 1377–1387. https://doi.org/10.1007/s12649-016-9539-8

Mourtzinos, I., Anastasopoulou, E., Petrou, A., Grigorakis, S., Makris, D., & Biliaderis, C. G. (2016). Optimization of a green extraction method for the recovery of polyphenols from olive leaf using cyclodextrins and glycerin as co-solvents. *J Food Sci Technol, 53*(11), 3939–3947. https://doi.org/10.1007/s13197-016-2381-y

Mrkonjić, Ž., Rakić, D., Kaplan, M., Teslić, N., Zeković, Z., & Pavlić, B. (2021). Pressurized-Liquid Extraction as an Efficient Method for Valorization of *Thymus serpyllum* Herbal Dust towards Sustainable Production of Antioxidants. *Molecules, 26*(9), 2548. https://doi.org/10.3390/molecules26092548

Müller, L. G., Pase, C. S., Reckziegel, P., Barcelos, R. C., Boufleur, N., Prado, A. C., Fett, R., Block, J. M., Pavanato, M. A., Bauermann, L. F., da Rocha, J. B. (2013). Burger ME. Hepatoprotective effects of pecan nut shells on ethanol-induced liver damage. *Exp Toxicol Pathol, 65*, 1-2, 165–171. https://doi.org/10.1016/j.etp.2011.08.002.

Murga, R., Ruiz, R., Beltran, S., & Cabezas, J. L. (2000). Extraction of natural complexphenols and tannins from grape seeds by using supercritical mixtures of carbon di-oxide and alcohol. *J Agric Food Chem, 48*, 3408–3412. https://doi.org/10.1021/jf9912506

Mustafa, A., & Turner, C. (2011). Pressurized liquid extraction as a green approach in food and herbal plants extraction: A review. *Anal Chim Acta, 703*(1), 8–18. https://doi.org/10.1016/j.aca.2011.07.018

Nadar, S. S., Rao, P., & Rathod, V. K. (2018). Enzyme assisted extraction of biomolecules as an approach to novel extraction technology: A review. *Food Res Int, 108*, 309–330. https://doi.org/10.1016/j.foodres.2018.03.006

Nastić, N., Lozano-Sánchez, J., Borrás-Linares, I., Švarc-Gajić, J., & Segura-Carretero, A. (2020). New technological approaches for recovering bioactive food constituents from sweet cherry (Prunus avium L.) stems. *Phytochem Anal, 31, 1*, 119–130. https://doi.org/10.1002/pca.2872

Nieto, J. A., Santoyo, S., Prodanov, M., Reglero, G., & Jaime, L. (2020). Valorisation of grape stems as a source of phenolic antioxidants by using a sustainable extraction methodology. *Foods, 9*, 604. https://doi.org/10.3390/foods9050604

Nipornram, S., Tochampa, W., Rattanatraiwong, P., & Singanusong, R. (2018). Optimization of low power ultrasound-assisted extraction of phenolic compounds from mandarin (Citrus reticulata Blanco cv. Sainampueng) peel. *Food Chem, 241*, 338–345. https://doi.org/10.1016/j.foodchem.2017.08.114

Nishad, J., Saha, S., Dubey, A. K., Varghese, E., & Kaur, C. (2019). Optimization and comparison of non-conventional extraction technologies for Citrus paradisi L. peels: A valorization approach. *J Food Sci Technol, 56*, 1221–1233. https://doi.org/10.1007/s13197-019-03585-0

Noorolahi, Z., Sahari, M. A., Barzegar, M., & Ahmadi Gavlighi, H. (2020). Tannin fraction of pistachio green hull extract with pancreatic lipase inhibitory and antioxidant activity. *J Food Biochem, 44*(6), Article e13208. https://doi.org/10.1111/jfbc.13208

Nutrizio, M., Kljusurić, J. G., Sabolović, M. B., Kovačević, D. B., Šupljika, F., Putnik, P., … Jambrak, A. R. (2020). Valorization of sage extracts (Salvia officinalis L.) obtained by high voltage electrical discharges: Process control and antioxidant properties. *Innov Food Sci Emerg Technol, 60*, Article 102284. https://doi.org/10.1016/j.ifset.2019.102284

Nutter, J., Fernandez, M. V., Jagus, R. J., & Agüero, M. V. (2021). Development of an aqueous ultrasound-assisted extraction process of bioactive compounds from beet leaves: A proposal for reducing losses and increasing biomass utilization. *J Sci Food Agric, 101*(5), 1989–1997. https://doi.org/10.1002/jsfa.10815

Nzekoue, F. K., Angeloni, S., Navarini, L., Angeloni, C., Freschi, M., Hrelia, S., … Caprioli, G. (2020). Coffee silverskin extracts: Quantification of 30 bioactive compounds by a new HPLC-MS/MS method and evaluation of their antioxidant and antibacterial activities. *Food Res Int, 133*, Article 109128. https://doi.org/10.1016/j.foodres.2020.109128

Oancea, S. (2021). A review of the current knowledge of thermal stability of anthocyanins and approaches to their stabilization to heat. *Antioxidants, 10*, 1337. https://doi.org/10.3390/antiox10091337

Okiyama, D. C. G., Navarro, S. L. B., & Rodrigues, C. E. C. (2017). Cocoa shell and its compounds: Applications in the food industry. *Trends Food Sci Technol, 63*, 103–112. https://doi.org/10.1016/j.tifs.2017.03.007

Osorio-Tobón, J. F. (2020). Recent advances and comparisons of conventional and alternative extraction techniques of phenolic compounds. *J Food Sci Technol, 57*(12), 4299–4315. https://doi.org/10.1007/s13197-020-04433-2

Osorio, L. L. D. R., Flórez-López, E., & Grande-Tovar, C. D. (2021). The potential of selected agri-food loss and waste to contribute to a circular economy: Applications in the food, cosmetic and pharmaceutical industries. *Molecules, 26*, 515. https://doi.org/10.3390/molecules26020515

Otero-Pareja, M. J., Casas, L., Fernández-Ponce, M. T., Mantell, C., & Martínez de la Ossa, E. J. (2015). Green extraction of antioxidants from different varieties of red grape pomace. *Molecules, 20*(6), 9686–9702. https://doi.org/10.3390/molecules20069686

Ozturk, B., Parkinson, C., & Gonzalez-Miquel, M. (2018). Extraction of polyphenolic antioxidants from orange peel waste using deep eutectic solvents. *Sep Purif Technol, 206*, 1–13. https://doi.org/10.1016/j.seppur.2018.05.052

Pagliarulo, C., De Vito, V., Picariello, G., Colicchio, R., Pastore, G., Salvatore, P., & Volpe, M. G. (2016). Inhibitory effect of pomegranate (Punica granatum L.) polyphenol extracts on the bacterial growth and survival of clinical isolates of pathogenic Staphylococcus aureus and Escherichia coli. *Food Chem, 190*, 824–831. https://doi.org/10.1016/j.foodchem.2015.06.028

Pal, C. B. T., & Jadeja, G. C. (2019). Deep eutectic solvent-based extraction of polyphenolic antioxidants from onion (Allium cepa L.) peel. *J Sci Food Agric, 99, 4*, 1969–1979. https://doi.org/10.1002/jsfa.9395

Paleologou, I., Vasiliou, A., Grigorakis, S., & Makris, D. P. (2016). Optimisation of a green ultrasound-assisted extraction process for potato peel (Solanum tuberosum) polyphenols using bio-solvents and response surface methodology. *Biomass Conv. Biorefinery, 6*, 289–299. https://doi.org/10.1007/s13399-015-0181-7

Palma, M., Piñeiro, Z., & Barroso, C. G. (2001). Stability of phenolic compounds during extraction with superheated solvents. *J Chromatogr A, 921*(2), 169–174. https://doi.org/10.1016/s0021-9673(01)00882-2

Palmeri, R., Restuccia, C., Monteleone, J. I., Sperlinga, E., Siracusa, L., Serafini, M., … Spagna, G. (2017). Bioactivity improvement of Olea europaea leaf extract biotransformed by Wickerhamomyces anomalus enzymes. *Plant Foods Hum Nutr, 72*(2), 211–218. https://doi.org/10.1007/s11130-017-0612-7

Pandey, K. B., & Rizvi, S. I. (2009). Plant polyphenols as dietary antioxidants in human health and disease. *Oxid Med Cell Longev, 2*(5), 270–278. https://doi.org/10.4161/oxim.2.5.9498

Panja, P. (2018). Green extraction methods of food polyphenols from vegetable materials. *Curr Opin Food Sci, 23*, 173–182. https://doi.org/10.1016/j.cofs.2017.11.012

Panzella, L., Moccia, F., Nasti, R., Marzorati, S., Verotta, L., & Napolitano, A. (2020). Bioactive phenolic compounds from agri-food wastes: An update on green and sustainable extraction methodologies. *Front Nutr, 7*, 60. https://doi.org/10.3389/fnut.2020.00060

Papillo, V. A., Vitaglione, P., Graziani, G., Gokmen, V., & Fogliano, V. (2014). Release of antioxidant capacity from five plant foods during a multistep enzymatic digestion protocol. *J Agric Food Chem, 62*, 4119–4126. https://doi.org/10.1021/jf500695a

Papoutsis, K., Pristijono, P., Golding, J. B., Stathopoulos, C. E., Bowyer, M. C., Scarlett, C. J., & Vuong, Q. V. (2018). Screening the effect of four ultrasound-assisted extraction parameters on hesperidin and phenolic acid content of aqueous citrus pomace extracts. *Food Biosci, 21*, 20–26. https://doi.org/10.1016/j.fbio.2017.11.001

Paradiso, V. M., Squeo, G., Pasqualone, A., Caponio, F., & Summo, C. (2019). An easy and green tool for olive oils labelling according to the contents of hydroxytyrosol and tyrosol derivatives: Extraction with a natural deep eutectic solvent and direct spectrophotometric analysis. *Food Chem, 291*, 1–6. https://doi.org/10.1016/j.foodchem.2019.03.139

Parniakov, O., Barba, F. J., Grimi, N., Lebovka, N., & Vorobiev, E. (2016). Extraction assisted by pulsed electric energy as a potential tool for green and sustainable recovery of nutritionally valuable compounds from mango peels. *Food Chem, 192*, 842–848. https://doi.org/10.1016/j.foodchem.2015.07.096

Parniakov, O., Barba, F. J., Grimi, N., Lebovka, N., Vorobiev, E. (2014). Impact of pulsed electric fields and high voltage electrical discharges on extraction of high-added value compounds from papaya peels. *Food Res Int, 65*, Part C, 337–343. https://doi.org/10.1016/j.foodres.2014.09.015.

Pasrija, D., & Anandharamakrishnan, C. (2015). Techniques for extraction of green tea polyphenols: A review. *Food Bioproc Technol, 8*, 935–950. https://doi.org/10.1007/s11947-015-1479-y

Paulo, F., & Santos, L. (2021). Deriving valorization of phenolic compounds from olive oil by-products for food applications through microencapsulation approaches: A comprehensive review. *Crit Rev Food Sci Nutr, 61*, 920–945. https://doi.org/10.1080/10408398.2020.1748563

Peiró, S., Luengo, E., Segovia, F., Raso, J., & Almajano, M. P. (2019). Improving Polyphenol Extraction from Lemon Residues by Pulsed Electric Fields. *Waste Biomass Valor, 10*, 889–897. https://doi.org/10.1007/s12649-017-0116-6

Percevault, L., Limanton, E., Nicolas, P., Paquin, L., & Lagrost, C. (2021). Electrochemical determination and antioxidant capacity modulation of polyphenols in deep eutectic solvents. *ACS Sustainable Chem Eng, 9*(2), 776–784. https://doi.org/10.1021/acssuschemeng.0c07023

Pereira, D. T. V., Tarone, A. G., Cazarin, C. B. B., Barbero, G. F., & Martínez, J. (2019). Pressurized liquid extraction of bioactive compounds from grape marc. *J Food Eng, 240*, 105–113. https://doi.org/10.1016/j.jfoodeng.2018.07.019

Pérez-Jiménez, J., Neveu, V., Vos, F., & Scalbert, A. (2010). Identification of the 100 richest dietary sources of polyphenols: An application of the Phenol-Explorer database. *Eur J Clin Nutr, 64. Suppl, 3*, S112–S120. https://doi.org/10.1038/ejcn.2010.221

Perussello, C. A., Zhang, Z., Marzocchella, A., & Tiwari, B. K. (2017). Valorization of apple pomace by extraction of valuable compounds. *Compr Rev Food Sci Food Saf, 16*, 776–796. https://doi.org/10.1111/1541-4337.12290

Petrotos, K., Giavasis, I., Gerasopoulos, K., Mitsagga, C., Papaioannou, C., & Gkoutsidis, P. (2021). Optimization of vacuum-microwave-assisted extraction of natural polyphenols and flavonoids from raw solid waste of the orange juice producing industry at industrial scale. *Molecules, 26*, 246. https://doi.org/10.3390/molecules26010246

Pimentel-Moral, S., Borrás-Linares, I., Lozano-Sánchez, J., Arráez-Román, D., Martínez-Férez, A., & Segura-Carretero, A. (2019). Supercritical CO2 extraction of bioactive compounds from Hibiscus sabdariffa. *J Supercrit Fluids, 147*, 213–221. https://doi.org/10.1016/j.supflu.2018.11.005

Pimentel-Moral, S., Cádiz-Gurrea, M. L., Rodríguez-Pérez, C., Segura-Carretero, A. (2020). Recent advances in extraction technologies of phytochemicals applied for the revaluation of agri-food by-products. In Functional and Preservative Properties of Phytochemicals. Prakash, B. (Ed.). Academic Press. https://doi.org/10.1016/b978-0-12-818593-3.00007-5.

Piñeiro, Z., Marrufo-Curtido, A., Serrano, M. J., & Palma, M. (2016). Ultrasound-assisted extraction of stilbenes from grape canes. *Molecules, 21*, 784. https://doi.org/10.3390/molecules21060784

Pinela, J., Prieto, M. A., Barreiro, M. F., Carvalho, A. M., Oliveira, M. B. P. P., Curran, T. P., & Ferreira, I. C. F. R. (2017). Valorisation of tomato wastes for development of nutrient-rich antioxidant ingredients: A sustainable approach towards the needs of the today's society. *Innov Food Sci Emerg Technol, 41*, 160–171. https://doi.org/10.1016/j.ifset.2017.02.004

Pinelo, M., Arnous, A., & Meyer, A. S. (2006). Upgrading of grape skins: Significance of plant cell-wall structural components and extraction techniques for phenol release. *Trends Food Sci Technol, 17*, 579–590. https://doi.org/10.1016/j.tifs.2006.05.003

Pinelo, M., Del Fabbro, P., Manzocco, L., Nunez, M. J., & Nicoli, M. C. (2005). Optimization of continuous phenol extraction from Vitis vinifera byproducts. *Food Chem, 92*, 109–117. https://doi.org/10.1016/j.foodchem.2004.07.015

Pinelo, M., Ruiz, R. A., Sineiro, J., Senorans, F. J., Reglero, G., & Nunez, M. J. (2007). Super-criticalfluid and solid–liquid extraction of phenolic antioxidants from grape pom-ace: A comparative study. *Eur Food Res Technol, 226*, 199–205. https://doi.org/10.1007/s00217-006-0526-3

Pinelo, M., Zornoza, B., & Meyer, A. S. (2008). Selective release of phenols from apple skin: Mass transfer kinetics during solvent and enzyme-assisted extraction. *Sep Purif Technol, 63*, 620–627. https://doi.org/10.1016/j.seppur.2008.07.007

Plaza, M., Abrahamsson, V., & Turner, C. (2013). Extraction and neoformation of antioxidant compounds by pressurized hot water extraction from apple byproducts. *J Agric Food Chem, 61*(23), 5500–5510. https://doi.org/10.1021/jf400584f

Plaza, M., & Turner, C. (2015). Pressurized hot water extraction of bioactives. *Trends Anal Chem, 71*, 39–54. https://doi.org/10.1016/j.trac.2015.02.022

Pradal, D., Vauchel, P., Decossin, S., Dhulster, P., & Dimitrov, K. (2016). Kinetics of ultrasound-assisted extraction of antioxidant polyphenols from food by-products: Extraction and energy consumption optimization. *Ultrason Sonochem, 32*, 137–146. https://doi.org/10.1016/j.ultsonch.2016.03.001

Radošević, K., Ćurko, N., Srček, V. G., Bubalo, M. C., Tomašević, M., Ganić, K. K., & Redovniković, I. R. (2016). Natural deep eutectic solvents as beneficial extractants

for enhancement of plant extracts bioactivity. *LWT, 73*, 45–51. https://doi.org/10.1016/j.lwt.2016.05.037

Rajha, H. N., Boussetta, N., Louka, N., Maroun, R. G., & Vorobiev, E. (2014). A comparative study of physical pretreatments for the extraction of polyphenols and proteins from vine shoots. *Food Res Int, 65*, 462–468. https://doi.org/10.1016/j.foodres.2014.04.024

Ramón-Gonçalves, M., Gómez-Mejía, E., Rosales-Conrado, N., León-González, M. E., & Madrid, Y. (2019). Extraction, identification and quantification of polyphenols from spent coffee grounds by chromatographic methods and chemometric analyses. *Waste Manag, 96*, 15–24. https://doi.org/10.1016/j.wasman.2019.07.009

Ramos, L., Kristenson, E. M., & Brinkman, U. A. T. (2002). Current use of pressurised liquid extraction and subcritical water extraction in environmental analysis. *J Chromatogr A, 975*, 3–29. https://doi.org/10.1016/S0021-9673(02)01336-5

Redha, A. A. (2021). Review on Extraction of Phenolic Compounds from Natural Sources Using Green Deep Eutectic Solvents. *J Agric Food Chem, 69*(3), 878–912. https://doi.org/10.1021/acs.jafc.0c06641

Reverchon, E., & De Marco, I. (2006). Supercritical extraction and fractionation of natural matter. *J Supercrit Fluids, 38*, 146–166. https://doi.org/10.1016/j.supflu.2006.03.020

Reynoso-Camacho, R., Rodríguez-Villanueva, L. D., Sotelo-González, A. M., Ramos-Gómez, M., & Pérez-Ramírez, I. F. (2021). Citrus decoction by-product represents a rich source of carotenoid, phytosterol, extractable and non-extractable polyphenols. *Food Chem, 350*, Article 129239. https://doi.org/10.1016/j.foodchem.2021.129239

Ribeiro Sarkis, J., Boussetta, N., Blouet, C., Tessaro, I. C., Ferreira Marczak, L. D., & Vorobiev, E. (2015). Effect of pulsed electric fields and high voltage electrical discharges on polyphenol and protein extraction from sesame cake. *Innov Food Sci Emerg Technol, 29*, 170–177. https://doi.org/10.1016/j.ifset.2015.02.011

Riciputi, Y., Diaz-de-Cerio, E., Akyol, H., Capanoglu, E., Cerretani, L., Caboni, M. F., & Verardo, V. (2018). Establishment of ultrasound-assisted extraction of phenolic compounds from industrial potato by-products using response surface methodology. *Food Chem, 269*, 258–263. https://doi.org/10.1016/j.foodchem.2018.06.154

Roda-Serrat, M. C., Lundsfryd, C., Rasmussen, S., Bahij, R., Lund, P., & Christensen, K. (2019). Enzyme-assisted extraction and ultrafiltration of value-added compounds from sour cherry wine pomace. *Chem Eng Trans, 74*, 811–816. https://doi.org/10.3303/CET1974136

Rodríguez De Luna, S. L., Ramírez-Garza, R. E., & Serna Saldívar, S. O. (2020). Environmentally friendly methods for flavonoid extraction from plant material: Impact of their operating conditions on yield and antioxidant properties. *Sci World J, 2020*, 6792069. https://doi.org/10.1155/2020/6792069

Rodríguez-Morgado, B., Candiracci, M., Santa-María, C., Revilla, E., Gordillo, B., Parrado, J., Castaño, A. (2015). Obtaining from grape pomace an enzymatic extract with anti-inflammatory properties. *Plant Foods Hum Nutr 2015; 70*, 1, 42-9. https://doi.org/10.1007/s11130-014-0459-0.

Rodsamran, P., & Sothornvit, R. (2019). Extraction of phenolic compounds from lime peel waste using ultrasonic-assisted and microwave-assisted extractions. *Food Biosci, 28*, 66–73. https://doi.org/10.1016/j.fbio.2019.01.017

Roggia Ruviaro, A., de Paula Menezes Barbosa, P., Barbosa, M., & Alves Macedo, G. (2018). Enzyme-assisted biotransformation increases hesperetin content in citrus juice by-products. *Food Res Int, 124*, 213–221. https://doi.org/10.1016/j.foodres.2018.05.004

Rojo-Poveda, O., Barbosa-Pereira, L., Mateus-Reguengo, L., Bertolino, M., Stévigny, C., & Zeppa, A. G. (2019). Effects of particle size and extraction methods on cocoa bean shell functional beverage. *Nutrients, 11*(4), 867. https://doi.org/10.3390/nu11040867

Román, G. C., Jackson, R. E., Gadhia, R., Román, A. N., & Reis, J. (2019). Mediterranean diet: The role of long-chain ω-3 fatty acids in fish; polyphenols in fruits, vegetables, cereals, coffee, tea, cacao and wine; probiotics and vitamins in prevention of stroke, age-related cognitive decline, and Alzheimer disease. *Rev Neurol (Paris), 175*(10), 724–741. https://doi.org/10.1016/j.neurol.2019.08.005

Roselló-Soto, E., Koubaa, M., Moubarik, A., Lopes, R. P., Saraiva, J. A., Boussetta, N., … Barba, F. J. (2015). Emerging opportunities for the effective valorization of wastes and by-products generated during olive oil production process: Non-conventional methods for the recovery of high-added value compounds. *Trends Food Sci Technol, 45*, 296–310. https://doi.org/10.1016/j.tifs.2015.07.003

Ross, K. A., Beta, T., & Arntfield, S. D. (2009). A comparative study on the phenolic acids identified and quantified in dry beans using HPLC as affected by different extraction and hydrolysis methods. *Food Chem, 113*, 336–344. https://doi.org/10.1016/j.foodchem.2008.07.064

Routray, W., & Orsat, V. (2012). Microwave-assisted extraction of flavonoids: A review. *Food Bioproc Technol, 5*, 409–424. https://doi.org/10.1007/s11947-011-0573-z

Ruesgas-Ramón, M., Figueroa-Espinoza, M. C., & Durand, E. (2017). Application of deep eutectic solvents (DES) for phenolic compounds extraction: Overview, challenges, and opportunities. *J Agric Food Chem, 65*(18), 3591–3601. https://doi.org/10.1021/acs.jafc.7b01054

Rusu, M. E., Fizeşan, I., Pop, A., Gheldiu, A. M., Mocan, A., Crişan, G., … Popa, D. S. (2019). Tomuta I. Enhanced recovery of antioxidant compounds from hazelnut (*Corylus avellana* L.) involucre based on extraction optimization: Phytochemical profile and biological activities. *Antioxidants (Basel), 8, 10*, 460. https://doi.org/10.3390/antiox8100460

Rusu, M. E., Fizesan, I., Pop, A., Mocan, A., Gheldiu, A. M., Babota, M., … Popa, D. S. (2020). Walnut (*Juglans regia* L.) septum: Assessment of bioactive molecules and in vitro biological effects. *Molecules, 25, 9*, 2187. https://doi.org/10.3390/molecules25092187

Rusu, M. E., Gheldiu, A. M., Mocan, A., Moldovan, C., Popa, D. S., Tomuta, I., Vlase, L. (2018). Process optimization for improved phenolic compounds recovery from walnut (*Juglans regia* L.) septum: Phytochemical profile and biological activities. *Molecules, 23*, 11, 2814. https://doi.org/10.3390/molecules23112814.

Saad, N., Louvet, F., Tarrade, S., Meudec, E., Grenier, K., Landolt, C., … Bressollier, P. (2019). Enzyme-assisted extraction of bioactive compounds from raspberry (Rubus idaeus L.) pomace. *J Food Sci, 84, 6*, 1371–1381. https://doi.org/10.1111/1750-3841.14625

Salarbashi, D., Bazzaz, B., Karimkhani, M. M., Sabeti Noghabi, Z., Khanzadeh, F., & Sahebkar, A. (2014). Oil stability index and biological activities of Achillea biebersteinii and Achillea wilhelmsii extracts as influenced by various ultrasound intensities. *Ind Crops Prod, 55*, 163–172. https://doi.org/10.1016/j.indcrop.2014.01.044

Santana, A. L., & Macedo, G. A. (2019). Effects of hydroalcoholic and enzyme-assisted extraction processes on the recovery of catechins and methylxanthines from crude and waste seeds of guarana (Paullinia cupana). *Food Chem, 281*, 222–230. https://doi.org/10.1016/j.foodchem.2018.12.091

Santos-Buelga, C., González-Paramás, A. M., Oludemi, T., Ayuda-Durán, B., & González-Manzano, S. (2019). Plant phenolics as functional food ingredients. *Adv Food Nutr Res, 90*, 183–257. https://doi.org/10.1016/bs.afnr.2019.02.012

Sanz, V., Flórez-Fernández, N., Domínguez, H., & Torres, M. D. (2020). Clean technologies applied to the recovery of bioactive extracts from Camellia sinensis leaves agricultural wastes. *Food Bioprod Process, 122*, 214–221. https://doi.org/10.1016/j.fbp.2020.05.007

Saptarini, N. M., Wardati, Y. (2020). Effect of extraction methods on antioxidant activity of papery skin extracts and fractions of Maja Cipanas onion (*Allium cepa* L. var. *ascalonicum*). *Sci World J, 2020*, 3280534. https://doi.org/10.1155/2020/3280534.

Saulis, G., Rodaitė-Riševičienė, R., Dainauskaitė, V. S., Saulė, R. (2015). Electrochemical processes during high-voltage electric pulses and their Importance in food processing technology. In Advances in Food Biotechnology, R. Rai V (Ed.). https://doi.org/10.1002/9781118864463.ch35.

Schwarz, L. J., Danylec, B., Harris, S. J., Boysen, R. I., & Hearn, M. T. (2016). Sequential molecularly imprinted solid-phase extraction methods for the analysis of resveratrol and other polyphenols. *J Chromatogr A, 1438*, 22–30. https://doi.org/10.1016/j.chroma.2016.02.028

Schwingshackl, L., Hoffmann, G., Iqbal, K., Schwedhelm, C., & Boeing, H. (2018). Food groups and intermediate disease markers: A systematic review and network meta-analysis of randomized trials. *Am J Clin Nutr, 108*(3), 576–586. https://doi.org/10.1093/ajcn/nqy151

Selvamuthukumaran, M., Shi, J. (2017). Recent advances in extraction of antioxidants from plant by-products processing industries, Food Quality and Safety, Volume 1, Issue 1, 1 March 2017, Pages 61–81, https://doi.org/10.1093/fqsafe/fyx004.

Shams, K. A., Abdel-azim, N. S., Saleh, I. A., Hegazy, M. F., El-missiry, M. M., Hammouda, F. M., Bohouth, E., Tahrir, E. (2015). Green technology: economically and environmentally innovative methods for extraction of medicinal & aromatic plants (MAP) in Egypt. *J Chem Pharm Res, 7*, 1050–1074. CODEN(USA): JCPRC5.

Shehata, E., Grigorakis, S., Loupassaki, S., & Makris, D. P. (2015). Extraction optimization using water/glycerol for the efficient recovery of polyphenolic antioxidants from two Artemisia species. *Sep Purif Technol, 149*, 462–469. https://doi.org/10.1016/j.seppur.2015.06.017

Shi, J., Nawaz, H., Pohorly, J., Mittal, G., Kakuda, Y., & Jiang, Y. (2005). Extraction of polyphenolics from plant material for functional foods-engineering and technology. *Food Rev Int, 21*, 139–166. https://doi.org/10.1081/FRI-200040606

Silva, A. M., Pinto, D., Fernandes, I., Freitas, V., Cádiz-Gurrea, M. L., Costa, P., … Rodrigues, F. (2021a). An insight into kiwiberry leaf valorization: Phenolic composition, bioactivity and health benefits. *Molecules, 26*, 2314. https://doi.org/10.3390/molecules26082314

Silva, L. O., Garrett, R., Monteiro, M. L. G., Conte-Junior, C. A., & Torres, A. G. (2021b). Pomegranate (Punica granatum) peel fractions obtained by supercritical CO_2 increase oxidative and colour stability of bluefish (Pomatomus saltatrix) patties treated by UV-C irradiation. *Food Chem, 362*, Article 130159. https://doi.org/10.1016/j.foodchem.2021.130159

Silva, M., García, J. C., & Ottens, M. (2018). Polyphenol liquid-liquid extraction process development using NRTL-SAC. *Ind Eng Chem Res, 57*(28), 9210–9221. https://doi.org/10.1021/acs.iecr.8b00613

Silva, R. P. F. F., Rocha-Santos, T. A. P., & Duarte, A. C. (2016). Supercritical fluid extraction of bioactive compounds. *Trends Anal Chem, 76*, 40–51. https://doi.org/10.1016/j.trac.2015.11.013

Singh, P. P., & Saldaña, M. D. A. (2011). Subcritical water extraction of phenolic compounds from potato peel. *Food Res Int, 44*, 2452–2458. https://doi.org/10.1016/j.foodres.2011.02.006

Skenderidis, P., Leontopoulos, S., Petrotos, K., & Giavasis, I. (2020). Optimization of vacuum microwave-assisted extraction of pomegranate fruits peels by the evaluation of extracts' phenolic content and antioxidant activity. *Foods, 9*, 1655. https://doi.org/10.3390/foods9111655

Smith, R. M. (2002). Extractions with superheated water. *J Chromatogr A, 975*, 31–46. https://doi.org/10.1016/S0021-9673(02)01225-6

Socas-Rodríguez, B., Torres-Cornejo, M., Alvarez-Rivera, G., & Mendiola, J. (2021). Deep eutectic solvents for the extraction of bioactive compounds from natural sources and agricultural by-products. *Appl Sci, 11*, 4897. https://doi.org/10.3390/app11114897

Soliva-Fortuny, R., Balasa, A., Knorr, D., & Martín Belloso, O. (2009). Effects of pulsed electric fields on bioactive compounds in foods: A review. *Trends Food Sci Technol, 20*, 544–556. https://doi.org/10.1016/j.tifs.2009.07.003

Soquetta, M. B., Tonato, D., Quadros, M. M., Boeira, C. P., Cichoski, A. J., Terra, L. M., & Kühn, R. C. (2019). Ultrasound extraction of bioactive compounds from Citrus reticulata peel using electrolyzed water. *J Food Proc Preserv, 43*, Article e14236. https://doi.org/10.1111/jfpp.14236

Soria, A. C., & Villamiel, M. (2010). Effect of ultrasound on the technological properties and bioactivity of food: A review. *Trends Food Sci Technol, 21*, 323–331. https://doi.org/10.1016/j.tifs.2010.04.003

Sosa-Ferrera, Z., Mahugo-Santana, C., & Santana-Rodríguez, J. J. (2013). Analytical methodologies for the determination of endocrine disrupting compounds in biological and environmental samples. *Biomed Res Int, 2013*, Article 674838. https://doi.org/10.1155/2013/674838

Stalikas, C. D. (2007). Extraction, separation, and detection methods for phenolic acids and flavonoids. *J Sep Sci, 30*(18), 3268–3295. https://doi.org/10.1002/jssc.200700261

Sumere, B. R., & de Souza, M. C. (2018). Dos Santos MP, Bezerra RMN, da Cunha DT, Martinez J, Rostagno MA. Combining pressurized liquids with ultrasound to improve the extraction of phenolic compounds from pomegranate peel (Punica granatum L.). *Ultrason Sonochem, 48*, 151–162. https://doi.org/10.1016/j.ultsonch.2018.05.028

Sun, S., Huang, S., Shi, Y., Shao, Y., Qiu, J., Sedjoah, R. A., … Xin, Z. (2021). Extraction, isolation, characterization and antimicrobial activities of non-extractable polyphenols from pomegranate peel. *Food Chem, 351*, Article 129232. https://doi.org/10.1016/j.foodchem.2021.129232

Suslick, K. S., & Flannigan, D. J. (2008). Inside a collapsing bubble: Sonoluminescenceand the conditions during cavitation. *Annu Rev Phys Chem, 59*, 659–683. https://doi.org/10.1146/annurev.physchem.59.032607.093739

Talmaciu, A. I., Volf, I., & Popa, V. I. (2015). A comparative analysis of the "green" techniques applied for polyphenols extraction from bioresources. *Chem Biodivers, 12*, 1635–1651. https://doi.org/10.1002/cbdv.201400415

Tamkutė, L., Liepuoniūtė, R., Pukalskienė, M., & Venskutonis, P. R. (2020). Recovery of valuable lipophilic and polyphenolic fractions from cranberry pomace by consecutive supercritical CO2 and pressurized liquid extraction. *J Supercrit Fluids, 159*, Article 104755. https://doi.org/10.1016/j.supflu.2020.104755

Tapia-Quirós, P., Montenegro-Landívar, M. F., Reig, M., Vecino, X., Alvarino, T., Cortina, J. L., … Granados, M. (2020). Olive mMill and winery wastes as viable sources of bioactive compounds: A study on polyphenols recovery. *Antioxidants (Basel), 9*(11), 1074. https://doi.org/10.3390/antiox9111074

Toro-Uribe, S., Ibañez, E., Decker, E. A., Villamizar-Jaimes, A. R., & López-Giraldo, L. J. (2020). Food-safe process for high recovery of flavonoids from cocoa beans: Antioxidant and HPLC-DAD-ESI-MS/MS analysis. *Antioxidants (Basel), 9*(5), 364. https://doi.org/10.3390/antiox9050364

Trasanidou, D., Apostolakis, A., & Makris, D. P. (2016). Development of a green process for the preparation of antioxidant and pigment-enriched extracts from winery solid wastes using response surface methodology and kinetics. *Chem Eng Comm, 203*, 1317–1325. https://doi.org/10.1080/00986445.2016.1189416

Trujillo-Mayol, I., Céspedes-Acuña, C., Silva, F. L., & Alarcón-Enos, J. (2019). Improvement of the polyphenol extraction from avocado peel by assisted ultrasound and microwaves. *J Food Process Eng, 42*, Article e13197. https://doi.org/10.1111/jfpe.13197

Tsao, R. (2010). Chemistry and biochemistry of dietary polyphenols. *Nutrients, 2*(12), 1231–1246. https://doi.org/10.3390/nu2121231

Tsubaki, S., Sakamoto, M., & Azuma, J. I. (2010). Microwave-assisted extraction of phenolic compounds from tea residues under autohydrolytic conditions. *Food Chem, 123*, 1255–1258. https://doi.org/10.1016/j.foodchem.2010.05.088

Tuladhar, P., Sasidharan, S., Saudagar, P. (2021). 17 - Role of phenols and polyphenols in plant defense response to biotic and abiotic stresses. In Biocontrol Agents and Secondary Metabolites, Ed.: Jogaiah, S. (Ed.), Woodhead Publishing, Pages 419–441. https://doi.org/10.1016/B978-0-12-822919-4.00017-X.

Tunchaiyaphum, S., Eshtiaghi, M., & Yoswathana, N. (2013). Extraction of bioactive compounds from mango peels using green technology. *Int J Chem Eng Appl, 4*, 194. https://doi.org/10.7763/IJCEA.2013.V4.293

Tyśkiewicz, K., Konkol, M., & Rój, E. (2018). The application of supercritical fluid extraction in phenolic compounds isolation from natural plant materials. *Molecules, 23*(10), 2625. https://doi.org/10.3390/molecules23102625

Uwineza, P. A., & Waśkiewicz, A. (2020). Recent advances in supercritical fluid extraction of natural eioactive compounds from natural plant materials. *Molecules, 25*(17), 3847. https://doi.org/10.3390/molecules25173847

Valente, I. M., Maia, M. R. G., Malushi, N., Oliveira, H. M., Papa, L., & Rodrigues, J. A. (2018). Fonseca AJM, Cabrita ARJ. Profiling of phenolic compounds and antioxidant properties of European varieties and cultivars of Vicia faba L. pods. *Phytochemistry, 152*, 223–229. https://doi.org/10.1016/j.phytochem.2018.05.011

Van Hung, P., Yen Nhi, N. H., Ting, L. Y., Lan Phi, N. T., & Loman, A. A. (2020). Chemical composition and biological activities of extracts from pomelo peel by-products under enzyme and ultrasound-assisted extractions. *J Chem, 2020*, 1043251. https://doi.org/10.1155/2020/1043251

Varadharajan, V., Shanmugam, S., & Ramaswamy, A. (2017). Model generation and process optimization of microwave-assisted aqueous extraction of anthocyanins from grape juice waste. *J Food Process Eng, 40*, Article e12486. https://doi.org/10.1111/jfpe.12486

Vatai, T., Skerget, M., & Knez, Z. (2009). Extraction of phenolic compounds from elderberry and different grape marc varieties using organic solvents and/or supercriticalcarbon dioxide. *J Food Eng, 90*, 246–254. https://doi.org/10.1016/j.jfoodeng.2008.06.028

Vella, F. M., Laratta, B., La Cara, F., & Morana, A. (2018). Recovery of bioactive molecules from chestnut (Castanea sativa Mill.) by-products through extraction by different solvents. *Nat Prod Res, 32, 9*, 1022–1032. https://doi.org/10.1080/14786419.2017.1378199

Vergara-Salinas, J.R., Cuevas-Valenzuela, J., Pérez-Correa, J. R. (2015). Chapter 3. Pressurized hot water extraction of polyphenols from plant material. In: Biotechnology of Bioactive Compounds (Eds. Gupta, V. K., Tuohy, M. G.). https://doi.org/10.1002/9781118733103.ch3.

Vieira, G. S., Cavalcanti, R. N., Meireles, M. A. A., & Hubinger, M. D. (2013). Chemical and economic evaluation of natural antioxidant extracts obtained by ultrasound-assisted and agitated bed extraction from jussara pulp (Euterpe edulis). *J Food Eng, 119*, 196–204. https://doi.org/10.1016/j.jfoodeng.2013.05.030

Viganó, J., Brumer, I. Z., de Campos Braga, P. A., da Silva, J. K., Maróstica Júnior, M. R., Reyes Reyes, F. G., Martínez, J. (2016). Pressurized liquids extraction as an alternative process to readily obtain bioactive compounds from passion fruit rinds. *Food Bioprod Process, 100*, Part A, 382–390. https://doi.org/10.1016/j.fbp.2016.08.011.

Viganó, J., de Paula Assis, B. F., Náthia-Neves, G., dos Santos, P., Meireles, M. A. A., Carvalho Veggi, P., & Martínez, J. (2020). Extraction of bioactive compounds from defatted passion fruit bagasse (Passiflora edulis sp.) applying pressurized liquids assisted by ultrasound. *Ultrason Sonochem, 64*, Article 104999. https://doi.org/10.1016/j.ultsonch.2020.104999

Vilkhu, K., Mawson, R., Simons, L., & Bates, D. (2008). Applications and opportunities for ultrasound-assisted extraction in the food industry — a review. *Innov Food Sci Emerg Technol, 9*(2), 161–169. https://doi.org/10.1016/j.ifset.2007.04.014

Virot, M., Tomao, V., Le Bourvellec, C., Renard, C. M. C. G., & Chemat, F. (2010). Towards the industrial production of antioxidants from food processing by-products with ultrasound-assisted extraction. *Ultrason Sonochem, 17*, 1066–1074. https://doi.org/10.1016/j.ultsonch.2009.10.015

Vladić, J., Jakovljević, M., Molnar, M., Vidović, S., Tomić, M., Drinić, Z., & Jokić, S. (2020). Valorization of Yarrow (*Achillea millefolium* L.) By-Product through Application of Subcritical Water Extraction. *Molecules, 25, 8*, 1878. https://doi.org/10.3390/molecules25081878

Vorobiev, E., Lebovka, N. I. (2006). Extraction of Intercellular Components by Pulsed Electric Fields. In: Raso J., Heinz V. (eds) Pulsed Electric Fields Technology for the Food Industry. Food Engineering Series. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-31122-7_6.

Vorobiev, E., & Lebovka, N. (2010). Enhanced Extraction from Solid Foods and Biosuspensions by Pulsed Electrical Energy. *Food Eng Rev., 2*, 95–108. https://doi.org/10.1007/s12393-010-9021-5

Wajs-Bonikowska, A., Stobiecka, A., Bonikowski, R., Krajewska, A., Sikora, M., & Kula, J. (2017). A comparative study on composition and antioxidant activities of supercritical carbon dioxide, hexane and ethanol extracts from blackberry (Rubus fruticosus) growing in Poland. *J Sci Food Agric, 97*(11), 3576–3583. https://doi.org/10.1002/jsfa.8216

Wang, H. F., Shao, S. J., Xin, X. R., Wang, M., & Wei, J. L. (2017a). Research on extraction and antibacterial activity of flavonoids in potato peel. *J North Univ China, 38*, 6660–6665. https://doi.org/10.3969/j.issn.1673-3193.2017.06.018

Wang, L., Wu, Y., Liu, Y., & Wu, Z. (2017b). Complex enzyme-assisted extraction releases antioxidative phenolic compositions from guava leaves. *Molecules, 22*, 1648. https://doi.org/10.3390/molecules22101648

Wang, Q., Qin, X., Liang, Z., Li, S., Cai, J., Zhu, Z., & Liu, G. (2018). HPLC–DAD–ESI–MS2 analysis of phytochemicals from Sichuan red orange peel using ultrasound-assisted extraction. *Food Biosci, 25*, 15–20. https://doi.org/10.1016/j.fbio.2018.07.001

Wang, W., Jung, J., Tomasino, E., & Zhao, Y. (2016). Optimization of solvent and ultrasoundassisted extraction for different anthocyanin rich fruit and their effects on anthocyanin compositions. *LWT Food Sci Technol, 72*, 229–238. https://doi.org/10.1016/j.lwt.2016.04.041

Wenzel, J., Storer Samaniego, C., Wang, L., Burrows, L., Tucker, E., Dwarshuis, N., … Zand, A. (2016). Antioxidant potential of Juglans nigra, black walnut, husks extracted using supercritical carbon dioxide with an ethanol modifier. *Food Sci Nutr, 5*, 223–232. https://doi.org/10.1002/fsn3.385

Wenzel, J., Wang, L., Horcasitas, S., Warburton, A., Constine, S., Kjellson, A., … Samaniego, C. S. (2020). Influence of supercritical fluid extraction parameters in preparation of black chokeberry extracts on total phenolic content and cellular viability. *Food Sci Nutr, 8*, 3626–3637. https://doi.org/10.1002/fsn3.1645

Wijngaard, H., Hossain, M. B., Rai, D. K., & Brunton, N. (2012). Techniques to extract bioactive compounds from food by-products of plant origin. *Food Res Int, 46*, 505–513. https://doi.org/10.1016/j.foodres.2011.09.027

Wrona, O., Rafińska, K., Możeński, C., & Buszewski, B. (2017). Supercritical Fluid Extraction of Bioactive Compounds from Plant Materials. *J AOAC Int, 100*(6), 1624–1635. https://doi.org/10.5740/jaoacint.17-0232

Wu, D., Gao, T., Yang, H., Du, Y., Li, C., Wei, L., … Bi, H. (2015). Simultaneous microwave/ultrasonic-assisted enzymatic extraction of antioxidant ingredients from Nitraria tangutorun Bobr. *Juice by-products. Ind Crop Prod, 66*, 229–238. https://doi.org/10.1016/j.indcrop.2014.12.054

Xi, J. (2017). Ultrahigh pressure extraction of bioactive compounds from plants-A review. *Crit Rev Food Sci Nutr, 57*, 1097–1106. https://doi.org/10.1080/10408398.2013.874327

Xi, J., & Wang, B. S. (2013). Optimization of ultrahigh-pressure extraction of polyphenolic antioxidants from green tea by response surface methodology. *Food Bioprocess Tech, 6*, 2538–2546. https://doi.org/10.1007/s11947-012-0891-9

Xu, L., He, W., Lu, M., Yuan, B., Zeng, M., Tao, G., … He, Z. (2018). Enzyme-assisted ultrasonicmicrowave synergistic extraction and UPLC-QTOF-MS analysis of flavonoids from Chinese water chestnut peels. *Ind Crop Prod, 117*, 179–186. https://doi.org/10.1016/j.indcrop.2018.03.012

Xu, B. J., & Chang, S. K. (2007). A comparative study on phenolic profiles and antioxidant activities of legumes as affected by extraction solvents. *J Food Sci, 72*, S159–166. https://doi.org/10.1111/j.1750-3841.2006.00260.x

Yammine, S., Delsart, C., Vitrac, X., Mietton Peuchot, M., & Ghidossi, R. (2020). Characterisation of polyphenols and antioxidant potential of red and white pomace by-product extracts using subcritical water extraction. *OENO One, 54*, 263–278. https://doi.org/10.20870/oeno-one.2020.54.2346

Yan, B., Chen, Z. S., Hu, Y., & Yong, Q. (2021). Insight in the recent application of polyphenols from biomass. *Front Bioeng Biotechnol, 9*, Article 753898. https://doi.org/10.3389/fbioe.2021.753898

Zakaria, S. M., & Kamal, S. M. M. (2016). Subcritical water extraction of bioactive compounds from plants and algae: Applications in pharmaceutical and food ingredients. *Food Eng Rev, 8*, 23–34. https://doi.org/10.1007/s12393-015-9119-x

Zhang, H.-F., Yang, X.-H., & Wang, Y. (2011). Microwave assisted extraction of secondary metabolites from plants: Current status and future directions. *Trends Food Sci Technol, 22*, 672–688. https://doi.org/10.1016/j.tifs.2011.07.003

Zhang, Q. W., Lin, L. G., & Ye, W. C. (2018). Techniques for extraction and isolation of natural products: A comprehensive review. *Chin Med, 13*, 20. https://doi.org/10.1186/s13020-018-0177-x

Zhang, R., Su, D., Hou, F., Liu, L., Huang, F., Dong, L., … Zhang, M. (2017). Optimized ultra-high-pressure-assisted extraction of procyanidins from lychee pericarp improves the antioxidant activity of extracts. *Biosci Biotechnol Biochem, 81*, 1576–1585. https://doi.org/10.1080/09168451.2017.1321953

Zhao, Z., Liu, P., Wang, S., & Ma, S. (2017). Optimization of ultrasound, microwave and Soxhlet extraction of flavonoids from *Millettia speciose* Champ. and evaluation of antioxidant activities in vitro. *Food Meas, 11*, 1947–1958. https://doi.org/10.1007/s11694-017-9577-3

Zhou, J., Gullón, B., Wang, M., Gullón, P., Lorenzo, J. M., & Barba, F. J. (2021). The application of supercritical fluids technology to recover healthy valuable compounds from marine and agricultural food processing by-products: A review. *Processes, 9*(2), 357. https://doi.org/10.3390/pr9020357