Molecular Science

http://www.aimspress.com/journal/Molecular

AIMS Molecular Science, 11(2): 150–188.
DOI: 10.3934/molsci.2024010
Received: 30 January 2024
Revised: 20 March 2024
Accepted: 29 March 2024
Published: 22 April 2024

Review

Bioactive compounds from plants and by-products: Novel extraction methods, applications, and limitations

Ahmed A. Zaky[1,2], **Muhammad Usman Akram**[3], **Katarzyna Rybak**[1], **Dorota Witrowa-Rajchert**[1] **and Malgorzata Nowacka**[1,*]

[1] Department of Food Engineering and Process Management, Institute of Food Sciences, Warsaw University of Life Sciences-SGGW, Warsaw, 02-787, Poland
[2] Department of Food Technology, Food Industries and Nutrition Research Institute, National Research Centre, Dokki, Cairo, 12622, Egypt
[3] Department of Food and Human Nutritional Sciences, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada

* **Correspondence:** Email: malgorzata_nowacka@sggw.edu.pl; Tel: +48225937579;
Fax: +48225937576.

Abstract: In recent years, numerous articles documenting bioactive components derived from diverse food sources have been published. Plant-based bioactive substances hold significant prospects for use as dietary supplements and functional foods because of their potential advantages for human health as antimicrobial, anticancer, anti-inflammatory, and antioxidant agents. Utilizing plant by-products as raw materials can also lower production costs and lessen environmental impacts. Thus, this review covered the bioactive substances found in plants and their by-products. The health benefits of bioactive compounds obtained from plant origins were also highlighted in this review. Furthermore, we concentrated on both conventional extraction techniques (e.g., Soxhlet, heat reflux, and maceration) and innovative extraction strategies for bioactive substances, including pulsed electric field (PEF), pressurized liquid, microwave-assisted, ultrasonic-assisted, and subcritical fluid methods. Higher yields obtained by novel extraction methods were found to be of primary interest, considering immediate beneficial economic outcomes. The potential applications of those bioactive substances in the food industry have been studied. Additionally, this investigation handled concerns regarding the challenges and limitations related to bioactive compounds. It is anticipated that the information covered in this review will prove to be a useful resource for the plant food processing sector in suggesting a cost-effective and environmentally friendly extraction technique that would turn plant wastes into a functional product with a high added value.

Keywords: plant sources; bioactive compounds; novel extraction technologies; applications; limitations

1. Introduction

Large volumes of agro-industry raw materials are produced worldwide, mostly for the generation of energy and the consumption of humans and animals [1]. However, the agri-food business produces over 190 million tons of by-products yearly [2]. These by-products include leaves, seeds, pomaces, brans, skins, oilseed meals, and other co-products of the production process. It is vital to manage, recycle, or dispose of these by-products [3,4]. Nevertheless, most food by-products could be valued for profit based on their nature and amount [5]. On the other hand, food by-products could be used as raw materials to make crucial components for the functional foods industry, which is one of the most well-liked food trends [6]. They are plentiful in lipids, carbs, fiber, vitamins, and phenolics and can be employed in various applications [7,8]. Consequently, extracting valuable compounds from these by-products may contribute to the economy, environment, and sustainability of food worldwide [2].

Bioactive compounds from plants have benefits over those obtained from animal sources because they are plentiful, cholesterol-free, targeting vegetarian consumers, and inexpensive [9]. Researchers have been increasingly interested in bioactive compound recovery processes from plant-origin by-products, particularly in developed and developing nations [10,11].

Bioactive compound extraction techniques should be carefully chosen, especially for food and pharmaceutical applications, since they can obviously affect the functional, organoleptic, and nutritional properties of phytochemicals [12]. Using chemical techniques to recover natural products presents many concerns such as safety risks, high energy requirements, low product quality, environmental effects, and toxicological impacts [13]. The development of thorough and optimal methods is required for the improved recovery of bioactive compounds, particularly from plants where the cell wall can reduce the effectiveness of extraction.

Many cutting-edge methods have been created and improved to make bioactive compounds extraction more accessible and productive [14]. To obtain functional plant extracts, ultrasound, microwaves, pulsed electric fields, and others can be used as green and sustainable extraction techniques [15]. Here, we highlight bioactive compounds from diverse plant sources and their by-products in terms of extraction, health effects, and potential applications as well as challenges and limitations. In this investigation, suitable reports (in English) were gathered through the search of the PubMed database and Google (2000; up to date as of March 20, 2024). To find the relevant papers, we employed the keywords “bioactive compounds” combined with the terms “plant sources”, “agri-food by-products”, “extraction”, “bioactivities”, “health benefits”, “food applications”, and “limitations”. We set the titles, keywords, and abstracts of the reports compiled from the database. Full-text articles were collected if they were deemed suitable for objective evaluation.

2. Bioactive compounds generated from plants

Bioactive components or secondary metabolites are produced from the metabolism of plants, which demonstrate promise as therapeutic agents, particularly in the area of antioxidation. Phenolics and carotenoids are thought to be the primary phytochemical or bioactive substances that can support improved human health [16]. Carotenoids are lipophilic substances found in abundance in most orange and yellow-colored fruits and vegetables [17]. These substances are highly valuable for usage in the food industry as colorings and nutritional additives that promote health [18]. Moreover, carotenoids are currently gaining a lot of attention since they may help lower the risk of chronic diseases because of their antioxidative activity [19]. Polyphenols, on the other hand, are natural antioxidants mostly found in food and medicinal plants, such as fruits, vegetables, grains, and spices. Polyphenols include categories such as anthocyanins, flavonoids, and phenolic acids. These compounds exhibit many biological characteristics, including anti-inflammatory, anti-aging, and anticancer effects [20] (Table 1).

Fruits, such as apples, kiwis, cherries, plums, and blueberries, are high in hydroxycinnamic acids, with values of 0.5–2 g/kg fresh weight. One of the most common phenolic acids is caffeic acid, which makes up between 75% and 100% of the hydroxycinnamic acids in some fruits [21]. Nonetheless, ferulic acid makes up 90% of the total polyphenol content (TPC) of wheat grains and is the most prevalent phenolic acid in cereal grains [20]. Also, fruit pulp and soluble cell wall fractions of bananas contain tannins and flavonoids including epicatechin, catechin, and gallocatechin [22]. As documented by Singh et al. [23], salicylic, vanillic, p-coumaric, ferulic, sinapic, p-hydroxybenzoic, syringic, and gallic acids are the primary phenolic compounds in bananas. It is advised to consume fruits and vegetables since they are a great source of natural antioxidants like vitamins C and E [24]. As a rule, medicinal and food plants are rich in polyphenols, including lignans, stilbenes, flavonoids, and phenolic acids. Hydroxycinnamic acids are present in food plants in greater amounts than hydroxybenzoic acids [20]. According to Erlund [25], the best sources of catechins are tea and red wine. Usually, catechins are present as aglycones or esterified with gallic acid. Furthermore, the two primary flavones that occur in the human diet are luteolin and apigenin, which are mostly found in celery and red pepper. Edible plants like berries, plums, and eggplants are rich in anthocyanins, which account for their red or blue colors [25]. As reported by Toufektsian et al. [26], maize seed is a good source of anthocyanins, particularly cyanidin and pelargonidin. In the same context, Faria et al. [27] have identified delphinidin, cyanidin, petunidin, peonidin, and malvidin from blueberry. In general, pelargonidin, cyanidin, delphinidin, and malvidin are the most prevalent anthocyanidins. Legumes are the leading source of the isoflavonoids daidzein and genistein. The greatest dietary source of these substances is soybean and its products [28]. A polyphenol-rich lettuce, containing chlorogenic acid, cyanidin, and quercetin, was documented by Cheng et al [29]. On the other hand, pumpkins contain the most investigated carotenoids, β-carotene and lycopene, which have been linked to a variety of biological and pharmacological impacts [30]. Numerous plants, including apples, onions, and tea, contain quercetin, a flavonoid of the flavonol group [31]. Natural flavanone, naringenin, is mostly present in grapes and citrus fruits, and it has been shown to have the ability to preserve insulin signaling in the brain and regulate cognitive performance [32].

Table 1. Bioactive compounds from different sources of plant materials and their health benefits.

Source	Bioactive constituents	Health benefits	References
Kiwis	Hydroxycinnamic acids (caffeic acid)	Antioxidant activity	[21]
Plums	Coumaric acid	Antioxidant activity	[21]
Wheat grains	Caffeic acid	Antioxidant activity	[22]
Bananas	Phenolic acids (salicylic, vanillic, p-coumaric, ferulic, sinapic, p-hydroxybenzoic, syringic, and gallic acids)	Antioxidant activity	[23]
Tea and red wine	Catechin and their gallates	Antioxidant activity	[25]
Celery and red pepper	Flavones (luteolin and apigenin)	Antioxidant and anti-inflammatory activities	[25]
Maize seed	Anthocyanins (cyanidin and pelargonidin)	Lowering of cardiovascular disease	[26]
Blueberry	Anthocyanins (delphinidin, cyanidin, petunidin, peonidin, and malvidin)	Anticancer activity	[27]
Soybean	Isoflavonoids (daidzein and genistein)	Anticancer, antioxidant, and anti-helminthic activities	[28]
Lettuce	Polyphenols (chlorogenic acid, cyanidin, and quercetin)	Antidiabetic activity	[29]
Pumpkin	Carotenoids (β-carotene and lycopene)	Anticancer and immunomodulatory activities	[30]
Grapes and citrus fruits	Flavanone (naringenin)	Maintain insulin signaling in the brain	[32]
Berries	Anthocyanins (cyanidin and delphinidin)	Antidiabetic, antiatherogenic, and antioxidant activities	[33]
Black currants	Anthocyanins (cyanidin-3-glucoside; delphinidin-3-glucoside)	Antidiabetic activity	[34]
Hazelnut	Flavonoids (myricetin and syringetin and proanthocyanidins A and B	Antibacterial, anti-inflammatory, and anti-tumor activities	[35]
Papaya peels	Phenolic acids (caffeic acid, p-coumaric acid, and ferulic acid); vitamin C	Antioxidant and anti-inflammatory activities	[36]
Mango peels	Polyphenols (gallic acid, chlorogenic acid, syringic acid, catechin, quercetin, and kaempferol	Antioxidant, antimicrobial, and anti-inflammatory activities	[37]
Apple pomace	Flavonoids (quercetin, isorhamnetin, procyanidin catechin); phenolic compounds (chlorogenic acid, p-coumaroylquinic acid)	Antioxidant activity	[38]

Continued on next page

Source	Bioactive constituents	Health benefits	References
Tomato peels	Carotenoids (lycopene); polyphenols (*p*-coumaric acid, chlorogenic acid, and quercetin)	Antioxidant and antimicrobial activities	[39]
Lemon seeds	Flavonoids (gallocatechin, caffeic acid, epicatechin, vitexin, quercetin, and hesperidin)	Enhancement in oxidative damage	[40]
Beetroot	Polyphenols (betagarin, betavulgarin, and cochliophilin A)	Antioxidant activity	[41]
Olive leaves	Phenolic compounds (rutin, tyrosol, luteolin, coumaric acid, ferulic acid, and quercetin)	Antioxidant and antimicrobial activities	[42]
Grape pomace	Flavonoids (quercetin, rutin, and epicatechin); phenolic acids (caffeic acid, gallic acid, and sinapic acid)	Antihypertensive, anti-atherosclerosis, and antioxidant activities	[43,44]
Potato peel	phenolic acids (caffeic acid, chlorogenic acid, gallic acid, isoferulic acid, and vanillic acid)	Antioxidant activity	[45]
Jujube peel	Flavonoids (rutin, quercetin)	Antioxidant, antimicrobial, and anti-melanogenesis	[46]
Pomegranate peel	Anthocyanins (cyanidin, delphinidin, and pelargonidin glycosides); flavonols (quercetin and kaempferol)	Anticancer, antioxidative and anti-inflammatory activities	[47]

3. Bioactive compounds derived from plant by-products

Several investigations have concentrated on the assessment of various bioactive components in fruit and vegetable peels [48–51]. It is well known that the phenolic content of several fruit peels, such as papaya, passion fruit, and pomegranate, is almost twice as high as that of the seeds and pulp. It has been found that the mineral composition, vitamin C content, and antioxidant activity of papaya peels are higher than those of seeds, even with intra-varietal variations [36]. It was discovered that bemyricetin, quercetin, kaempferol, morin, apigenin, and luteolin are the primary flavonoid components present in papaya peels and leaves [36]. In the same respect, the mango peel has noticeably higher phenolic acids (gallic acid) and flavonoids (quercetin) than other fruit peels [37]. Similarly, Sultana et al. [52] discovered that the peels of most tropical fruits (mango, mangosteen, and dragon fruit) have substantially higher gallotannins and total phenolic content than the pulp. Antioxidant activity and phytochemical content of apples were evaluated by Wolfe et al. [53]. They found that the peels have a higher proportion of flavonoids and phenolic compounds than the flesh of the fruit. Citrus peels have a phenolic content of up to 5000 mg/g, which is more than the fruit's edible part [54]. Overall, the principal bioactive substances found in citrus fruits are classified as phenolics and terpenoids [55]. Similar to fruits, many reports have shown that vegetable peels have much more bioactives than the edible parts [36,56]. Vegetable processing, such as that of tomato and eggplant, results in waste in the form of 60%–40% of peels and seeds. Thus, the extraction of useful molecules like lycopene from tomato peels and high-quality proteins, pigments, fibers, carotenoids, and organic acids from other sources is the advised and efficient way to handle vegetable peel waste [36]. According to a different study by Guuntekin et al. [57], the extract of tomato stalks contained the greatest number of phenolic components (7.14%) when compared with other plants. In the same trend, lemon seeds were confirmed to own flavonoid compounds such as gallocatechin, caffeic acid, epicatechin, vitexin, quercetin, and hesperidin [40]. As stated by Chhikara et al. [41] and Ravichandran et al. [58], root vegetable peels (beetroot, carrot) contain polyphenols (betagarin, betavulgarin, and cochliophilin A) and betalain (betacyanin and betaxanthin), which are beneficial antioxidants. According to Cartea et al. [59], the bioactive components found in cruciferous vegetables (broccoli, cauliflower) contain fiber, vitamin C, flavonoids (quercetin, kaempferol, and isorhamnetin), and phenolics (*p*-coumaric, sinapic, and ferulic acids). The efficient antioxidant action of potato peel extract prepared through lyophilization was demonstrated in a variety of *in vitro* systems [60]. The presence of phenolic and flavonoid compounds in discarded peels from the Cucurbitaceae family was found to reduce lipid peroxidation, according to Rajasree et al. [56]. Furthermore, olive leaves and by-products are excellent sources of bioactive substances such as rutin, tyrosol, hydroxytyrosol, and oleuropein [61]. Likewise, a study conducted by Talhaoui et al. [42] showed that a wide range of phenolic compounds including rutin, tyrosol, luteolin, quercetin, coumaric acid, ferulic acid, caffeic acid, and quercetin are present in olive leaves.

4. Health benefits of plant materials

Although plants have a variety of combinations of bioactive components that have therapeutic effects, they often include a single class of compounds that play common medicinal roles in human health. In this respect, the apple (*Malus domestica* L.) contains flavonoids such as epicatechin, phloretin, and quercetin and phenolic acids such as chlorogenic and coumaroylquinic acids that are antioxidative polyphenols [62]. The flesh of the mandarin fruit is rich in nutritional content of antioxidants (e.g., ascorbic acid, carotenoids, and phenolic compounds), and has sugars, minerals, and volatile amino acids [63]. Furthermore, peels are a great source of polyphenols [64]. The majority of the health advantages linked to mandarin fruits stem from the antioxidative properties of their bioactive constituents. In addition, prickly pear fruit (*Opuntia* spp.) has high concentrations of polyphenols, betalains, ascorbic acid, minerals, and amino acids [65]. These compounds have been linked to benefits for health, including antioxidant, antiatherogenic, and antiulcerogenic properties, as well as the prevention of low-density lipoprotein peroxidation [66,67] (Figure 1). Similarly, antioxidants can be found in high levels in the extracts of berry fruits like blueberries (*Vaccinium* sp.), blackberries (*Rubus* sp.), strawberries (*Fragaria ananassa*), and grape berries (*Vitis* sp.) [68].

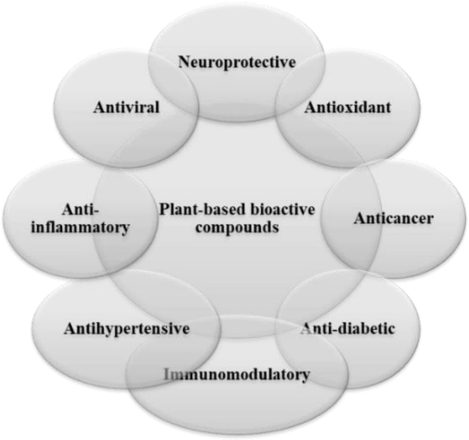

Figure 1. Health benefits of bioactive compounds from plant sources.

Generally, polyphenols and ascorbic acid have been demonstrated to have positive health effects on lung disorders, rheumatoid arthritis, cardiovascular disease, Parkinson's disease, and Alzheimer’s [69,70] (Table 1). *Allium* species, which include garlic, onions, chives, and leeks, are significant vegetable examples since they are recognized for their organosulfur compounds while having large concentrations of flavonoids, steroidal saponins, and phytosterols [71]. Among their many health advantages are their immunomodulatory, antiviral, antidiabetic, antioxidant, anticarcinogenic, anti-inflammatory, and neuroprotective qualities [72,73]. In the same line, Montesano et al. [30] stated that pumpkin (*Cucurbita* sp.) contains significant amounts of bioactive compounds, which are high in terpenoids, particularly carotenoids, which boost immunity, reduce the risk of cancer and heart disease, and expand the prostate gland. As confirmed by some researchers, rosemary (*Rosmarinus officinalis* L.) has bioactive compounds linked to antifungal, antidepressant, antidiabetic, anti-inflammatory, and antithrombotic health benefits [74,75]. Extracts from medicinal and aromatic plants are accepted as safe [Generally Recognized As Safe (GRAS) classification], which means they can be utilized as a natural alternative to chemical additions [76]. Sage (*Salvia officinalis* L.), for example, has been shown to have high potential as an additive for food production [77] and to have anti-inflammatory, anticancer, antibacterial, and antiproliferative activities [77,78]. As reported by Wu et al. [79], oregano (*Origanum vulgare*) consumption has been linked to antimicrobial and antioxidant effects. The main constituents of thyme (*Thymus vulgaris* L.) include thymol, carvacrol, geraniol, and p-cymene [80], which also have neuroprotective, respiratory, and antibacterial qualities [81]. Grape pomace, a by-product of winemaking that contains flavonoids, phenolic acids, and lignans among other polyphenolic antioxidants, is a valuable, economic source of bioactive compounds [44], with demonstrated therapeutic benefits in conditions such as hypertension, atherosclerosis, neurodegeneration, heart disease, and others [44]. Likewise, citrus by-products, which are rich in flavonoids and limonoids as well as essential oils, are also frequently left over after the manufacturing of citrus juice [82]. The antioxidant activity of citrus waste is mostly attributed to bioactive chemicals, whereas essential oils possess antibacterial, antimycotic, and antiviral properties [82]. Additionally, stevia is a great source of bioactive components like polyphenols, carotenoids, ascorbic acid, and chlorophylls. Its extracts are also rich in antioxidants, antimicrobials, hypotensive, anti-tumor, immunomodulatory, and anti-inflammatory qualities [83,84]. As reported by Bulotta et al. [85], olive leave extracts exhibit antiviral, anti-tumor, antioxidant, anticancer, antimicrobial, and cardiovascular health effects. In another study, Toufektsian et al. [26] assessed the cardioprotective benefits of anthocyanin-rich maize (20% seed diet) after feeding male Wistar rats for eight weeks. Anthocyanins may have cardioprotective properties, since a considerably ($p < 0.01$) lower infarct size, coronary occlusion, and reperfusion was found in rats fed an anthocyanin-rich maize diet compared with rats fed an anthocyanin-free diet [26]. Using the human gastric cancer cell line, Afshari et al. [86] studied the anticancer effects of eggplant extract. The researchers found that, compared with a normal cell line, eggplant extract had a more harmful effect on human gastric cancer cells. Because of its strong antioxidant qualities and abundance of phenolic components, eggplant may be useful in the detoxification of free radicals. As a result, eggplants may be consumed as a dietary supplement to lower the risk of cancer [86]. Plant derivatives, including polyphenols, can restore harmful or unfavorable epigenetic alterations in cancer cells, hinder the growth of tumors, stop the spread of metastases, and make tumor cells more sensitive to radiation and chemotherapy [87]. As stated by Sharma [88], numerous cancer types can be prevented and treated with pomegranate wastes and by-product extracts. Similarly, pomegranate extract has been shown to suppress the development of cancerous prostate cells and trigger apoptosis through the suppression of NF-kB activity, according to Rettig et al. [89]. In the same line, anthocyanin-pyruvic acid adduct extracts and blueberry extracts were tested for their potential as anticancer agents using MDA-MB-231 and MCF7 breast cancer cell lines. It was verified that these extracts, which function as cell anti-invasive factors and inhibit the growth of cancer cells, exhibit promising anticancer potential in the studied breast cancer cell lines [90]. Moreover, it has been established that terpenoids and carotenoids derived from plants have anti-inflammatory and anticancer properties. They inhibit the activation of NF-kB signaling pathways, which play a major role in regulating the development of inflammatory and tumorous conditions [91]. On the other hand, black currants with high anthocyanin content can control hyperglycemia using CaCo-2 cells, according to Barik et al. [92]. These findings showed that anthocyanins in black currants mainly inhibit α-glucosidase action to control postprandial hyperglycemia, while other phenolics affect salivary α-amylase, sugar transporters, and glucose uptake, all of which may lessen the associated risk of developing type-2 diabetes. Likewise, using STZ-induced diabetic mice models, Yang et al. [93] investigated the potential of puerarin (isoflavones) to reduce glucose levels. After four weeks of treatment, they discovered that the puerarin group had improved blood insulin levels and a considerable drop in blood glucose (hypoglycemic effects). In a previous investigation by Anhê et al. [94], the authors found that a cranberry extract high in polyphenols reduces intestinal inflammation in mice. The results showed that supplementing with a polyphenol-rich cranberry extract for eight weeks dramatically increased the population of

Akkermansia spp., which was linked to decreases in visceral adiposity, intestinal inflammation, and weight gain, all of which were elevated by a high-fat/high-sucrose diet [94]. Due to their high phenolic content and dietary fiber level, whole-cereal grains have been associated with favorable changes in gut microbiota, according to Gong et al. [95]. It has been proposed that high-cereal diets, when processed properly, may improve and perhaps treat many metabolic diseases. On the other hand, in a dose-dependent manner, avocado seed extracts have demonstrated anti-inflammatory and antiproliferative properties against the colon cancer cell line HCT-116 and the liver cancer cell line HepG-2 [96]. As documented by Mirza et al. [97] and Donga et al. [98], mango peels are considered a great source of polyphenols, particularly protocatechuic acid and mangiferin, which have antimicrobial, anti-diabetic, anti-inflammatory, and anticarcinogenic effects. Several fruit and vegetable by-products have demonstrated antimicrobial efficacy against *L. monocytogenes*, including those derived from apple [99], cauliflower [100], elderberry [101], citrus [102] and pomegranate [103]. Likewise, other fruits and vegetables can serve as antimicrobial agents upon *S. aureus*, like co-products obtained from artichoke [104], banana [105], grape [106], orange [107], pomegranate [108], and tomato [109].

5. Extraction of bioactive compounds

Generally, bioactive compounds within plant materials are unevenly distributed, existing in both soluble and insoluble forms. Therefore, it is crucial to employ a suitable solvent system for the optimum extraction of bioactive compounds from food materials. The selection of solvents, such as water, alcohols (propanol, methanol, and ethanol), acetone, or ethyl acetate, either in their pure form or mixtures, has a significant impact on both the quantity and quality of the extracted components [110]. Moreover, the process of obtaining bioactive compounds from plant-based foods is greatly influenced by the appropriate combination of time and temperature treatments [111]. It has been observed that prolonged extraction and higher temperatures enhance the solubility of the analyte. Nevertheless, these conditions can also result in the undesired degradation of bioactive compounds [112].

Solid-liquid extraction is a method of separation in which one or more components of a solid mixture are dissolved selectively in a liquid solvent. The process of removing precipitated solute from adsorbent material is usually referred to as leaching or elution [113]. Sequential extraction is another type of solid-liquid extraction that involves isolating compounds according to their differing polarities by performing multiple extractions on a solid sample aliquot using multiple solvents [114].

Liquid-liquid extraction, commonly referred to as partitioning or solvent extraction, is a method employed to separate constituents by utilizing their different solubilities in two incompatible liquids, usually polar (water) and nonpolar (organic) solvents [115]. On the other hand, the Folch and Bligh & Dyer method employs a two-step process, including solid-liquid and liquid-liquid extraction technologies. This technique efficiently transfers hydrophilic molecules into a phase that is rich in water, whereas hydrophobic lipids are gathered in a phase that is rich in organic solvent [116].

5.1. Conventional extraction techniques

Bioactive compounds are typically extracted from solid food materials using conventional techniques, including mainly Soxhlet extraction, heated reflux extraction, and maceration. The Soxhlet extraction technique was initially invented in 1879 by a German scientist (Frans Ritter von Soxhlet), being mainly used for the extraction of lipids [117]. The Soxhlet extraction is also important due to its ability to compare the efficiency of various novel extraction protocols. In this context, the Soxhlet extraction method was used by Kodal and Aksu [118] to recover carotenoid pigments from orange peel. The authors stated that the greatest carotene pigment in the range of 4.5 mg carotene/g dry peel was obtained by treating frozen peel at 79 ℃ with ethanol at a liquid-to-solid ratio of 40:1. Nevertheless, because of lipid oxidation, it was discovered that the extract readily broke down into its terpene monomer units. Similarly, Caldas et al. [119] have extracted phenolics (catechin, rutin, and epicatechin) from grape peel using the Soxhlet technique. The heat reflux extraction method utilizes a reflux extractor as the reactor to enhance efficiency and optimize the mass transfer between the solvent and solute at an elevated temperature. This is achieved by allowing the heated solvent vapors to flow through the solute and ensuring consistent regeneration through the condenser [120]. Although these extraction methods are cheap and simple, they may jeopardize the integrity of heat-sensitive components. Therefore, maceration is usually employed to extract heat-labile components after reducing the size of solid samples. Romero-Cascales et al. [121] found that the maceration method with methanol at 25 ℃ produced the greatest amount of anthocyanin pigment (300 mg/g) from grape skin. Also, earlier research on the extraction of flavonoid components from different citrus peels by Sultana et al. [122] showed that the maceration process using methanol was the most effective in terms of yield and purity. Flavonoids (catechin) have also been isolated by maceration from the fruits of *Arbutus unedo* L. at an increased temperature of 79.6 ℃ in 3.7% diluted ethanol [123]. The maceration process typically involves extracting substances at room temperature for a prolonged period, while the Soxhlet and heated reflux extraction can be accomplished in a few hours at a temperature of 90 ℃ [124].

From the authors' point of view, conventional extraction methods have significant limitations despite their ease of use, cost-effectiveness, and ability to produce favorable outcomes in the extraction of bioactive compounds. These limitations include the requirement for extended extraction duration, the use of large volumes of potentially hazardous organic solvents, and the susceptibility to interference and deterioration from external factors including air, light, temperature, etc.

5.2. Novel extraction techniques

In addition to conventional extraction techniques, several novel approaches are commonly employed to increase the yield of extractable bioactive compounds, including ultrasound-assisted extraction, microwave-assisted extraction, infrared-assisted extraction, pulsed electric field extraction, pressurized liquid extraction, supercritical fluid extraction, subcritical fluid extraction, and enzyme-assisted extraction.

5.2.1. Ultrasound-assisted extraction (UAE)

Over the past few decades, a large amount of research has focused on the potential of UAE as a low-impact, environmentally friendly, and economically feasible alternative to conventional extraction methods. Ultrasound waves within the frequency range of 20 kHz to 100 MHz have been widely used to improve the processing of food due to their ability to pass through any medium, causing expansion and compression and inducing cavitation or bubble formation. The collapse of these bubble-like structures causes microturbulence, significant extractant agitation, and sample particle collisions between extractant particles. The utilization of an ultrasound-assisted technique to extract chlorogenic acid from artichoke leaves (*Cynara scolymus* L.) in 15 min at room temperature with 80% methanol demonstrated a substantial increase in yield of up to 50% when compared with maceration [112]. According to Altemimi et al. [125], this process has been demonstrated to accelerate the breakdown of cell tissue and boost the rate at which lutein and β-carotene are extracted from spinach. To extract phenolic compounds from purple eggplant peel, Ferarsa et al. [126] performed UAE and found that the ideal conditions for maximum carotenoid yield were 60 °C for 60 min at pH 2.0. Besides, the best conditions for gallic acid extraction from goji berry peels by UAE, which have strong antibacterial properties, were found to be 55 °C for 25 min at 220 W/cm^2, according to Skenderidis et al. [127]. The recovery of flavonoids (neohesperidin, tangeritin, hesperidin, and diosmin) from citrus peel was shown to be effectively achieved with the use of UAE, as reported by Londoño-Londoño et al. [128]. Similarly, Zhu et al. [129] also discovered a great enhancement in polyphenols, mainly flavonoids (rutin, quercetin 3-β-D-glucoside, and kaempferol-3-O-rutinosid) from jujube peels employing UAE treatment. Recently, Sulejmanović et al. [130] studied the impact of UAE to maximize the use and recovery of phenolic compounds from ginger herbal dust. It was discovered that the extract exhibited elevated levels of TPC, 6-gingerol (44.57 mg/gDE), 8-gingerol (8.62 mg/gDE), and 6-shogaol (6.92 mg/gDE). According to a similar investigation by Raj and Dash [131], the UAE is superior to other methods for the extraction of flavonoid (betacyanin) from dragon fruit peel. Likewise, diverse functional molecules, such as lycopene from tomatoes [132], quercetin from onion wastes [133], carotenoids from pomegranate wastes [134], and anthocyanins from plum and grape peels [135] have been effectively recovered using UAE.

From the experience of the authors, using the ultrasonic technique might be considered a cost-effective substitute for increasing the extraction of bioactive chemicals from plant sources.

5.2.2. Infrared-assisted extraction

Infrared radiation is subdivided into near, mid, and far wavelengths, ranging from 0.78–1000 µm; their ability to penetrate decreases as the energy level increases. Infrared radiation induces vibrations of the atoms or molecules in the plant material, leading to the generation of thermal energy. This leads to an elevation in the temperature, causing the liquid to evaporate and break the structure of the material to promote the extraction of specific target molecules.

Far-infrared extraction technology is commonly utilized, since water and most organic molecules absorb at wavelengths higher than 2.5 µm. Infrared-assisted extraction has been used to create a quick, easy, and affordable way to extract quercitrin, iso-quercitrin, and rutin from *Magnolia officinalis* leaves [136]. The benefits include simplicity, high concentrations of key flavonoid components, and high extraction yield. In another study, Wang et al. [137] introduced a novel, easy, and rapid method of infrared-assisted self-enzymolysis extraction for obtaining total flavonoid aglycones, particularly oroxylin A, wogonin, and baicalein from *Scutellariae radix* with improved efficiency. El Kantar et al. [138] utilized infrared-assisted extraction as a preliminary step to extract polyphenols from fresh orange peel. Their study has shown that this technique significantly increased the yield of obtained polyphenols with reduced extraction time. In a study by Cheaib et al. [139], the effectiveness of several methods was examined in terms of polyphenol yield and bioactivity from apricot pomace, including ultrasounds, microwaves, and infrared. Infrared was the most successful technique with the greatest polyphenol (10 mg GAE/g DM), flavonoid (6 mg CE/g DM), and tannin (3.6 mg/L) yields. In addition, compared with other methods, infrared extracts exhibited the highest levels of epicatechin, catechin, and rutin. In comparison to solid-liquid ones, the infrared extraction of polyphenols from *Salviae miltiorrhizae* (danshen) demonstrated an improvement in antioxidant capacity from 47% to 79% and an increase from 0.12 to 0.19 mM after 30 min, according to Chen et al. [140]. They also separated eight polyphenol compounds from danshen, particularly danshensu, protocatechuic acid, protocatechuic aldehyde, salvianolic acid B, dihydrotanshinone, cryptotanshinone, tanshinone I, and tanshinone IIA. Similarly, Abi-Khattar et al. [141] used an infrared-assisted extraction strategy to obtain polyphenols (oleuropein and hydroxytyrosol) from olive leaves. The TPC was improved by more than 30% using infrared as compared with the water bath method, which needed 27% more ethanol consumption.

From the authors' viewpoint and compared with other traditional extraction techniques, infrared-assisted extraction is quick, cheap, effective, and environmentally friendly, as radiation heat spreads within the sample uniformly to improve heat efficiency and reduce energy waste.

5.2.3. Microwave-assisted extraction (MAE)

Microwave-assisted extraction is also an effective green technology that has evolved to be one of the main methods of extracting bioactive components from complex herbal formulations [142]. Microwaves, as electromagnetic waves having a frequency ranging from 300 MHz to 300 GHz, are responsible for heating the substances by means of the combination of ionic conduction and dipole movement [143]. Solvents, such as water, possessing a high dielectric constant, can absorb and release microwave energy, consequently raising the temperature needed for an enhanced rate of extraction. A novel approach for extracting and purifying alkaloids from *Sophora flavescens* Ait. utilizing focused microwave-assisted aqueous extraction in conjunction with inverse micellar extraction was proposed by Zhang et al. [144]. Similarly, different natural deep eutectic solvents combined with MAE were used to extract bioactive components such as iridoids, phenylpropanoids, and flavonoids from *Lippia citriodora* compared with conventional methanol [145]. In another study by Simsek et al. [146], phenolic components (syringic, vanillic, epicatechin, gentisic, and quercetin) were isolated from sour cherry pomace by using MAE. According to Asghari's [147] research, MAE is a quicker and simpler technique than conventional extraction processes for removing bioactive components (tannin and cinnamaldehyde) from a range of medicinal Asian plants (*C. mukul*, *Q. infectoria*, and *C. verum* J.S. Presl). Condensed tannins and polyphenols have been effectively extracted from grape wastes using optimized MAE [148]. Pure extracts of the polyphenolic pigment betalain were obtained from the peel of *Opuntia ficus-indica* fruits by Ciriminna et al. [149] using MAE (1 h at 70 ℃). Liazid et al. [150] utilized MAE to extract anthocyanin pigment from grape peels and found that the anthocyanin extract exhibited greater stability at a temperature of 100 ℃. However, above this temperature, the extract yield and stability declined, suggesting a breakdown of the molecule. Likewise, Torres-León et al. [151] demonstrated that MAE could extract a high concentration of bioactive substances from mango seeds at optimum conditions of a solid-to-solvent ratio of 1/60 g/mL. The study also stated that ethyl gallate, pent-O-galloyl-glucoside (PGG), and hamnetin-3-[6-2-butenoil-hexoside] were the main antioxidants present in mango seeds. In addition, Araújo et al. [152] demonstrated that acetone (72.18 ℃ and 19.01 min) and ethanol (71.64 ℃ and 14.69 min), two different solvents, could be used to extract the largest amount of bioactive substances (e.g., procyanidins dimer B, catechin, and epicatechin) from avocado seeds employing MAE.

Along with this, solvent-free microwave extraction can also be performed by using the residual water of plant material, thus minimizing the additional hydrolysis reactions. Solvent-free extraction of oxygenated compounds from cardamom oil (*Elletaria cardamomum* L.) was performed and optimized by Lucchesi et al. [153]. In another work, a direct irradiation-based MAE was performed by Michel et al. [154] to isolate the polar antioxidant components from sea berries (*Hippophae rhamnoides*) using residual water contents. In comparison to the conventional Soxhlet extraction, a quick method of extracting the two main capsaicinoids from habanero peppers using ultrasound, near-infrared, or microwave radiation–based novel extraction techniques resulted in higher overall yields and a higher ratio of capsaicin to dihydrocapsaicin [155].

From the authors' experience, MAE has been considered a valuable alternative to conventional methods for the extraction of numerous biologically active compounds from raw plants and by-products. The main advantages of MAE are (1) higher extraction yield and (2) shorter extraction times.

5.2.4. Pulsed electric field extraction (PEF)

Pulse electric field is an innovative technology that can be considered green and environmentally safe and does not require any thermal energy. It is applied by passing food for a short time in between two electrodes containing a high-voltage electric field. The electric pulses with 20 to 1000 µs intervals with high electric field strength are generally employed for improved preservation of food quality [156]. The strength of the electric field is a critical factor in determining the level of extraction, as it directly influences the physical characteristics of the molecule being targeted, including solubility, diffusivity, viscosity, and surface tension [157].

The PEF treatment is an ideal nonthermal method for extracting phenols and flavonoids from onions while minimizing any notable degradation in quality. Its application causes irreversible structural changes in the cell membrane by inducing cellular tissue disintegration, which increases the mass transfer rate and membrane permeability [158,159]. In the same trend, Yu et al. [160,161] demonstrated that the PEF method helped the extraction of polyphenols and proteins from rapeseed stems and leaves, resulting in higher polyphenol purity. As reported by Medina-Meza and Barbosa-Canovas [135], the use of PEF also increased the recovery of anthocyanins, flavonoids, and phenols from plum and grape peels. In another study, the phenolic compounds were extracted from apple peels by subjecting them to a pulsed electric field with varying electric intensities and times [162]. According to its findings, the intensity of the electric field and the cell integration index affected the extraction process. Parniakov et al. [163] also documented that PEF was used to extract bioactive components from papaya seeds. Additionally, Koubaa et al. [164] discovered that the application of PEF resulted in a noticeably greater extraction yield of red colorants (isobetanin and betanin) found in pear peel. Comparably, Luengo et al. [165] declared that the polyphenols and flavonoid components (naringin and hesperin) in orange peel could be effectively extracted using an electric-field treatment with an intensity of 7 kV/cm and a pulse rate of 20 in 60 ms. As stated by Corrales et al. [166], anthocyanins from grape by-products are typically extracted using an industrial batch PEF process.

5.2.5. Pressurized liquid extraction

In pressurized liquid extraction, the extraction of bioactive phytochemicals typically requires a pressure ranging from 100 to 1000 MPa. This pressure is usually applied to increase the temperature of the solvent beyond its boiling point, causing a decrease in its viscosity and an increase in its penetration and solubility to improve the efficiency of extraction as compared with conventional methods. The temperature is often regarded as the principal regulating factor in pressurized liquid extraction, as it has the potential to either positively or adversely influence the selective extraction of molecules based on their chemical composition. The increase in temperature can also improve the extraction efficiency by enhancing the solvent diffusivity in the food matrix. In a study, Gòmez-Mejìa et al. [167] reported improved extraction yield of bioactive polyphenols (t-ferulic acid, p-coumaric acid, rutin, and hesperidin) from citrus peel waste with pressurized liquid extraction at a temperature of 90 ℃. This phenomenon was also observed by Benito-Román et al. [168] while optimizing the extraction of phenols and β-glucans from waxy barley at elevated temperatures (135–175 ℃). Nevertheless, temperature had a positive influence on the yield of total phenolics while negatively influencing the glucan yield. According to Markom et al. [169], a pressurized liquid extraction was used to extract the tannins from *Phyllanthus niruri* at 100 ℃ and 107 Pa. The pressurized liquid extraction produced the highest total yield of tannin and corilagin in the shortest time when compared with the Soxhlet method. In an additional investigation by Mohd et al. [170], hydrolysable tannins from *Phyllanthus tenellus* Roxb. were separated by pressurized liquid extraction.

5.2.6. Supercritical fluid extraction (SFE)

A fluid is referred to its critical state when it is subjected to pressure and heat beyond its critical pressure and temperature levels. Supercritical fluid extraction is widely recognized as an ecologically sustainable technique owing to its application of a renewable solvent such as carbon dioxide, non-toxic and suitable for usage in the supercritical state. The primary benefit of using a solvent in the supercritical phase is that the fluid displays characteristics of both a gas and a liquid. CO_2 is nonpolar; therefore, mixing a minimal amount of polar solvent can considerably increase the overall yield of extraction [171].

The amount of monoterpene content shows a direct relationship with pressure, which can be explained by an increase in density. Similarly, elevating the temperature leads to a rise in the vapor pressure of the analytes, facilitating the sequential extraction of compounds with varying densities. On the other hand, Montañés et al. [172] investigated tocopherol extraction from apple seed oil using supercritical carbon dioxide, finding that increased pressure improved extraction yield, while higher temperatures decreased tocopherol content. The impact of temperature and pressure on the recovery of monoterpenes from the sage herbal dust was investigated by Pavlić et al. [173] using SFE. Kitrytė et al. [174] optimized parameters such as temperature, pressure, and time duration for supercritical carbon dioxide extraction to isolate the non-polar fraction of elderberry pomace. Also, subcritical water extraction is an effective method for recovering phenolic substances from potato peels (gallic acid, chlorogenic acid, caffeic acid, protocatechuic acid, syringic acid, p-hydroxyl benzoic acid, ferulic acid, and coumaric acid) and pomegranate wastes, as well as antioxidants from winery by-products [175–177]. As reported by Jiao and Kermanshahi [178], anthocyanins were recovered successfully from haskap berries using subcritical CO_2 under the following conditions: 45 MPa, 65 ℃, 15–20 min. The phenolic component punicic acid was extracted from pomegranate seeds using SFE at 60 ℃ and 320 bars, according to Natolino and Da Porto [179]. In the same regard, various studies discovered that supercritical extraction using CO_2 was effective in extracting phenolic compounds, including terpene, γ-element, germacrene from Brazilian cherries and ellagitannins, and flavanols from strawberry seeds [180,181]. In terms of extraction yields and duration, SFE with CO_2 was generally less efficient than novel pressurized liquid extraction and ultrasonic-assisted extraction but more efficient than conventional Soxhlet and solid-liquid extraction.

5.2.7. Subcritical fluid extraction

Subcritical fluid extraction is an innovative method that employs a selected extraction solvent at a temperature exceeding its boiling point but below its critical temperature, with the pressure carefully adjusted to keep the solvent in a liquid state during the process. This is performed at a lower temperature and pressure than in supercritical fluid extraction, making this technique safe and effective without degrading the heat-liable components of the food materials [182].

It is much more advantageous to extract economically important phenolic compounds from food products using water rather than organic solvents. In a study by Abdelmoez et al. [183], water-based subcritical extraction has been employed for the extraction of bioactive phenolic compounds from wheat straw, revealing the optimal conditions for hydrolysis as 30 min of hydrolysis time at 190 ℃, 180–355 µm particle size, and a water to wheat-straw ratio of 6:1. Subcritical water extraction was found to be a highly effective alternative to conventional solvent extraction utilizing ethanol for the extraction of bioactive components from onion peel [184]. According to Rodrigues et al. [185], the papaya seed extracts might be isolated using subcritical water extraction in 5 min at 150 ℃. The main components of phenolic classes were discovered to be ferulic, mandelic, and vanillic acids, which are substantially greater than with the Soxhlet extraction at 40 ℃ for 6 h. Another work revealed that tocopherols, strong antioxidants utilized in chemical and pharmaceutical applications, are present in sweet passion fruit seed oil. A considerably higher yield was obtained from oil extracted using subcritical propane extraction at 60 ℃ and 6 MPa pressure than from Soxhlet procedure at 65 ℃ for 4 h utilizing n-hexane solvent [186]. Similar research on the extraction of polyphenols from grape pomace using subcritical water extraction in semi-continuous mode shows that heating water to 80–120 ℃ and under 100 MPa of pressure yields in total 44.3–77 mg/g of polyphenol and 44–124 mg/g from pomace [187].

5.2.8. Enzyme-assisted extraction

Another innovative approach is enzyme-assisted extraction, which involves the use of enzymes in the extraction medium to enhance the recovery of target molecules. This technique is gaining popularity over solvent extraction due to its enhanced safety, environmental tolerance, and performance.

The primary constituents of the plant cell wall are cellulose, hemicellulose, and pectin, which are the primary constraints to the extraction of bioactive phytochemicals. Application of various enzymes such as α-amylase, cellulase, hemicellulose, or pectinase promotes the efficiency and yield of extraction by dissolving the main components of the cell wall, ultimately improving the interaction between target compounds and solvents [188]. Deng et al. [189] optimized the efficiency of the enzyme-assisted aqueous extraction for an improved yield of peanut oil by preheating the peanuts using short-wave infrared radiation. In another study, it was observed that applying the glycosidase enzyme to the freeze-dried tomato material before CO_2-based supercritical extraction can increase the amount of lycopene by three-fold [190]. Boulila et al. [191] stated that the yield of essential oil extraction from bay leaves can be increased by employing the cellulase, hemicellulose, xylanase, and ternary mixture of them. Other researchers were also able to extract more curcumin from turmeric by utilizing a combination of α-amylase and amyloglucosidase enzymes [192]. In another study, Xu et al. [193] compared the extraction of polysaccharides from grape peels using ethanol as a solvent and a mixture of enzymes such as cellulase, pectinase, and β-glucosidase. According to this study, a larger yield of pectin containing phenolic compounds like anthocyanin was obtained with a shorter extraction time using enzyme-assisted extraction as opposed to solvent extraction. Likewise, Vasco-Correa and Zapata [194] found that the proto-pectinase enzyme yields a higher amount of pectin from passion fruit peels than traditional chemical extraction. Moreover, enzymes including cellulase, hemicellulase, and pectinase can be used to extract vinegar from pineapple peels, which is employed in the manufacturing of sugar [195].

While these innovative techniques possess the capability to enhance extraction yields, they also result in the excessive disruption of bonding forces within the targeted bioactive compounds [196,197]. The combination of conventional and novel extraction techniques is also another trend being applied in modern research. Both conventional and novel extraction techniques are compared in Table 2, along with their advantages and disadvantages in Table 3.

6. Economical cost evaluations

An economic comparison of traditional extraction methods and modern extraction approaches is necessary. However, there are very few reports that have addressed this point. For example, the economic costs of ethanol extraction and subcritical water extraction of bioactive kanuka leaves were studied by Essien et al. [202]. The outcomes showed that the costs of manufacturing and unit production for subcritical water extraction were NZ$ 4.49 million and NZ$ 2.14/kg, whereas the costs for ethanol extraction were NZ$ 4.7 million and NZ$ 5.57/kg, respectively. In the same respect, Lopeda-Correa et al. [203] assessed the economic costs of using the Soxhlet technique versus the UAE when separating polyphenols from *Adenaria floribunda* stems. Manufacturing costs for the UAE are US$ 3.86/flask, and less than US$ 5.8/flask for the Soxhlet process. It is identifiable that new extraction processes are more cost-effective than traditional techniques.

Table 2. Application of conventional and novel technologies for the extraction of bioactive compounds from plant sources.

Extraction techniques	Source	Extracted compound	References
Conventional techniques			
Soxhlet extraction	Orange peel	Carotene pigment	[118]
	Grape peel	Catechin, rutin, and epicatechin	[119]
Maceration	Grape skin	Anthocyanin pigment	[121]
	Kinnow peels	Flavonoids (glycosides)	[198]
	Arbutus unedo L. Fruits	Flavonoid (catechin)	[123]
Novel techniques			
Ultrasound-assisted extraction	Artichoke leaves	Chlorogenic acid	[112]
	Spinach	Lutein and β-carotene	[125]
	Purple eggplant peel	Carotenoid	[126]
	Goji berry peels	Gallic acid	[127]
	Citrus peel	Neohesperidin, tangeritin, hesperidin, and diosmin	[128]

Continued on next page

Extraction techniques	Source	Extracted compound	References
Novel techniques			
Ultrasound-assisted extraction	Jujube peels	Rutin, quercetin 3-β-D-glucoside, and kaempferol-3-O-rutinosid	[129]
	Ginger herbal dust	6-gingerol, 8-gingerol, and 6-shogaol	[130]
	Dragon peel	Betacyanin	[131]
	Tomatoes	Lycopene	[132]
	Onion wastes	Quercetin	[133]
	Plum and grape peels	Anthocyanins	[135]
Infrared-assisted extraction	*Magnolia officinalis* leaves	Quercitrin, iso-quercitrin, and rutin	[136]
	Scutellariae Radix	Oroxylin A, wogonin, and baicalein	[137]
	Orange peels	Polyphenols	[138]
	Apricot pomace	Epicatechin, catechin, and rutin	[139]
	Salviae miltiorrhizae (danshen)	Danshensu, protocatechuic acid, protocatechuic aldehyde, salvianolic acid B, dihydrotanshinone, cryptotanshinone, tanshinone I, and tanshinone IIA	[140]
	Olive leaves	Oleuropein and hydroxytyrosol	[141]
Microwave-assisted extraction	*Lippia citriodora*	Iridoids, phenylpropanoids, and flavonoids	[145]
	Sour cherry pomace	Syringic, vanillic, epicatechin, gentisic, and quercetin	[146]
	Asian plants (*C. mukul*, *Q. infectoria*, and *C. verum* J. S. Presl)	Tannin and cinnamaldehyde	[147]
	Grape waste	Tannins and polyphenols	[148]
	Opuntia ficus-indica	Betalain	[149]
	Grape peels	Anthocyanin	[150]
	Mango seeds	Ethyl gallate, pent-O-galloyl-glucoside (PGG), and hamnetin-3-[6-2-butenoil-hexoside]	[151]
	Avocado seeds	Procyanidins dimer B, catechin, and epicatechin	[152]
Pulsed electric field extraction	Rapeseed stems	Polyphenols and proteins	[160]
	Plum and grape peels	Anthocyanins, flavonoids, and phenols	[135]
	Apple peels	Total phenolic acids	[162]
	Papaya seeds	Total phenolic acids, proteins, carbohydrates, and isothiocyanates	[163]

Continued on next page

Extraction techniques	Source	Extracted compound	References
Novel techniques			
Pulsed electric field extraction	Pear peel	Isobetanin and betanin	[164]
	Orange peel	Naringin and hesperin	[165]
	Grape by-products	Anthocyanins	[166]
Pressurized liquid extraction	Citrus peel waste	t-ferulic acid, p-coumaric acid, rutin, and hesperidin	[167]
	Waxy barley	Phenols and β-glucans	[168]
	Phyllanthus niruri	Tannin and corilagin	[169]
	Phyllanthus tenellus	Hydrolysable tannins	[170]
Supercritical fluid extraction	Apple seed oil	Tocopherol	[172]
	Sage herbal dust	Monoterpenes	[173]
	Elderberry pomace	Total phenolic acids	[174]
	Pomegranate seed	Total phenolic acids	[175]
	Potato peels	Gallic acid, chlorogenic acid, caffeic acid, protocatechuic acid, syringic acid, *p*-hydroxyl benzoic acid, ferulic acid, and coumaric acid	[176]
	Winery by-products	Total polyphenols and flavonoids	[177]
	Haskap berries pulp	Anthocyanins	[178]
	Pomegranate seeds	Punicic acid	[179]
	Brazilian cherries	Terpene, γ-element, and germacrene	[180]
	Strawberry seeds	Ellagitannins and flavanols	[181]
Subcritical fluid extraction	Wheat straw	Phenolic compounds	[183]
	Papaya seeds	Ferulic, mandelic, and vanillic acids	[185]
	Sweet passion fruit seeds	Tocopherols	[186]
	Grape pomace	Polyphenols	[187]
Enzyme-assisted extraction	Tomato	Lycopene	[190]
	Bay leaves	Essential oil	[191]
	Turmeric	Curcumin	[192]
	Grape peels	Pectin	[193]
	Passion fruit peels	Pectin	[194]
	Pineapple peels	Vinegar	[195]

Table 3. Advantages and disadvantages of conventional and novel extraction techniques.

Extraction techniques	Advantages	Disadvantages	References
Conventional techniques			
Soxhlet extraction	Simple and reproducible	High temperature Large solvent consumption	[15,199]
Heated reflux extraction	High efficiency Low solvent usage	Thermal degradation	[120]
Maceration	Extraction of heat labile compounds	Large organic waste Long duration of extraction	[188]
Novel techniques			
Ultrasound-assisted extraction	High yield in short duration Easy to utilize at pilot, industrial, and laboratory scales	Energy consumption Swelling of plant material	[14,200]
Microwave-assisted extraction	Rapid and efficient High extraction yield	Need of solvent with ability to absorb microwave radiation Lower selectivity	[15,199]
Infrared-assisted extraction	Environmentally friendly Energy efficient Uniform heating	Limited penetration	[189]
Pulsed electric field extraction	Non-thermal process Short processing time Extraction of thermolabile components	Equipment cost Need of conductivity	[158,201]
Pressurized liquid extraction	Increased rate of extraction Low solvent consumption	High cost	[167]
Supercritical fluid extraction	High efficiency Rapid extraction	High equipment cost	[15,199]
Subcritical fluid extraction	Cost-effective processing	Accelerated hydrolysis of compounds Hard-to-clean equipment	[15,184]
Enzyme-assisted extraction	Environmentally friendly Improved food safety	Sensitive to external factors like temperature, pH, etc.	[188,189]

7. Food applications

The utilization of plants and their by-products to gain bioactive compounds is encouraged by the growing need for foods that are healthy and sustainable [204]. Bioactive compounds are used in food in a variety of ways, including as texture modifiers, antioxidants, antimicrobials, natural dyes, and enhancing ingredients [205]. Numerous research studies document the incorporation of bioactive compounds derived from by-products into diverse food models. These compounds are utilized as agents to enhance the nutritious and functional value of food products, including yogurt [206], dry frozen fish [207], bread [208], petit Suisse cheese [209], beef patties [210], and cured sausage [211].

Overall, by-product extracts are commonly employed in food applications, and their antioxidant capacity has been primarily linked to the amount of total phenolic compounds they contain, which may be found by using several techniques [206,210,211]. In this context, pomegranate peel extract (1000 mg/100 g) was added to beef meatballs by Turgut et al. [212]. Following an 8-day storage period at 4 °C, the 1% extract and artificial antioxidant (BHT) samples showed 53% and 50% reduction in thiobarbituric acid–reactive substances (TBARS), a marker of secondary lipid oxidation products, compared with the control. According to Choe et al. [213], persimmon peel extract was used to reinforce ground pork meat. Meats enriched with extract (200 mg/100 g) and BHT had reduced levels of primary lipid oxidation products, as measured by peroxide values (PV) and conjugated dienes (CD), following a 12-day storage period at 3 °C. In comparison with the ground pork without antioxidants, the PV lowering was 43% and 34%, respectively, and the extract group was the most successful in postponing CD production. In another work, Ergezer and Serdaroglu [214] investigated the effects of incorporating BHT and extract produced from artichoke by-products into beef patties. The addition of the extract (27 mg/100 g) significantly reduced lipid and protein oxidation during storage compared with BHT treatment. By the end of storage, these samples demonstrated a 42% and 114% boost to TPC and scavenging capacity against the DPPH radical, respectively, compared with the control, whereas these values stood at 4% and 9% for BHT samples. The authors assigned these results to the TPC and antioxidant abilities of artichoke by-products. On the other hand, lamb patties were enhanced with grape, olive, tomato, and pomegranate pomace extract by Andrés et al. [215]. All meats enriched with plant extracts had between 10% and 21% lower mesophilic microbe microbiological counts after seven days in chilled storage as compared with the control group. Additionally, pomegranate peel–enhanced beef sausages and shrimp immersed in a solution having this coproduct exhibited comparable microbiological findings [216,217]. As mentioned by Nishad et al. [218], meatballs treated with nutmeg and citrus peel extracts (100 mg/100 g) retarded lipid and protein oxidation as well as enhanced sensory evaluations for color, odor, taste, and overall acceptability after storage when compared with control samples. In a different study, the addition of 2.5 g/100 g and 2 g/100 g of apple and banana peels, respectively, were sufficient to improve the sensory properties of chicken meat wafers [219]. According to Abid et al. [220], tomato pomace extracts were added to butter. Supplemented butter (40 mg/100 g) showed the lowest PV during storage, probably as a result of the extract's high lycopene and phenolic content. As reported by Bertolino et al. [221], the addition of skin hazelnuts powder to yoghurt increased the yoghurt's DPPH capability and TPC (3000 mg/100 g) by 96% and 31%, respectively, as compared with the control. On the other hand, probiotic development was increased when yoghurts containing powdered pineapple peel were stored at 4 °C [222]. Compared with the non-fortified juice, reinforced fresh orange juice with a banana peel extract (500 mg/100 mL) displayed growth of approximately 21% and 150% for DPPH and FRAP tests, respectively [223]. In a recent study by Zaky et al. [224], different concentrations (3%, 6%, and 9%) of sunflower meal protein isolate (SMPI) rich in active components were added to pasta. The results showed that the nutritional value of pasta was improved, and the samples were acceptable to consumers, especially those enriched with 3% and 6% SMPI. According to Kampuse et al. [225], adding pumpkin pomace powder (5.5 g/100 g dough) to wheat bread increased the quantity of carotenoids by a factor of 13. In general, many other plant-based sources have demonstrated their ability to increase the TPC and antioxidant efficacy in bakery products including grape pomace [226,227], plantain peel [228], mango peel [229], potato peel [45], raspberry and cranberry pomaces [230], beetroot pomace [231], apple pomace [232], and rosehip, blackcurrant, and elderberry pomaces [233]. Several studies on the incorporation of bioactive ingredients into food products are displayed in Table 4.

Table 4. Application of bioactive compounds obtained from plant sources in the food industry.

Source	Product	Function	References
Camu-camu (*Myrciaria dubia*) seed	Yogurt	Increasing antioxidant activity	[206]
Pomegranate and grape seeds	Minced fish muscle	Controlling lipid oxidation	[207]
Grape seed	Bread	Increasing antioxidant activity Acceptable color change	[208]
Grape seed	Petit Suisse cheese	Increasing antioxidant activity 73% sensory acceptance	[209]
Hull, bur, and leaf chestnut	Beef patties	Reducing lipid oxidation; it did not impact sensory acceptance	[210]
Grape seed	Dry cured sausage “chorizo”	Decreasing lipid oxidation Improving the sensory quality	[211]
Pomegranate peel	Beef meatballs	Inhibiting lipid and protein oxidation	[212]
Persimmon peel	Ground pork meat	Reducing lipid and protein oxidation	[213]
Artichoke by-products	Beef patties	Lowering lipid and protein oxidation	[214]
Grape, olive, tomato, and pomegranate pomace	Lamb patties	Lowering mesophilic microbe microbiological counts	[215]
Pomegranate peel	Beef sausages and white shrimp	Increasing antimicrobial activity	[216,217]
Nutmeg and citrus peel	Meatballs	Retarding lipid and protein oxidation Enhancing sensory evaluations	[218]
Apple and banana peels	Chicken meat wafers	Improving the sensory properties	[219]
Tomato pomace	Butter	Decreasing lipid oxidation	[220]
Hazelnut skins	Yogurt	Increasing antioxidant activity	[221]
Pineapple peel	Yogurt	Enhancing probiotic viability	[222]
Banana peel	Fresh orange juice	Increasing antioxidant activity Enhancing sensory evaluations	[223]
Sunflower meal protein isolate	Pasta	Enhancing nutritional value	[224]
Pumpkin pomace	Wheat bread	Increasing carotenoid content Enhancing sensory evaluations	[225]
Grape pomace	Bread	Increasing antioxidant activity Improving the sensory properties	[226]
Grape pomace	Biscuits	Reducing lipid peroxidation	[227]
Nendran peel	Cookies	Increasing antioxidant dietary fiber	[228]
Mango peel	Biscuits	Inhibiting lipid peroxidation	[229]
Potato peel	Biscuits	Reducing lipid peroxidation	[45]
Red beetroot pomace	Biscuits	Enhancing nutritional characteristics Increasing antioxidant activity	[231]
Apple pomace	Rice-based cracker	Increasing antioxidant activity Enhancing sensory attributes	[232]
Rosehip, blackcurrant, and elderberry pomaces	Cookies	Boosting antioxidant activity Enhancing sensory attributes	[233]

8. Challenges and limitations

Global food markets are witnessing an increase in the production of food; to meet industry demands, extraction processes must be improved to provide high-grade extracts that can be utilized as raw materials. Although the primary method for getting bioactive compounds is still conventional extraction, this technique is not in line with "green" and sustainable manufacturing because it frequently involves significant costs and the disposal of hazardous chemicals and energy. Furthermore, this thermal method works by harming bioactive molecules that are thermally unstable and should be generated in the first place. However, innovative solutions are frequently quicker, more selective, environmentally friendly, and sensitive to temperature, but still lack adequate testing for use in industry [234]. Numerous other arguments characterize them as costly and unsuitable for industrial use because of the high cost of industrial equipment, which for certain technologies is still in the prototype stage or needs to be specially designed for each application. In general, greater industrial production and application solutions are anticipated in the future for the food-manufacturing sector.

On the other hand, there is a sharp rise in demand for nutrient-rich food and the food industry as a result of consumers' growing consciousness of their physical health and willingness to pay for nutritious meals, especially those of plant origin. Nowadays, a wide range of plant extracts are easily accessible for use in the food processing industry. Before being employed, the bioactive components or active substances from plant extracts are purified or concentrated. Those plant extracts' purified forms are now easily found on the market as premium goods, dietary supplements, and nutraceuticals. These present several health benefits, including lowering LDLs and blood pressure, managing atherosclerosis, boosting memory, minimizing oxidative stress, and having anticancer action [235]. Commercial grape seed extracts with the trade name ORAC-15 M (80% polyphenols and 15,000 oxygen radical absorption capacity) were prepared by Natural Products Insiders Inc. in California, USA, and were suggested for use in reducing the body's oxidative stress. Applied Food Science Inc. also offers a broad variety of commercial plant extract preparations, including green coffee extract (GCE-50% chlorogenic acids from raw coffee beans), organic ginger powder (PureGinger with 2% gingerol), cascara fruit extract (CoffeeNectar from coffee cherry), green tea (Purtea) caffeine, and so on [236].

Due to their high phenolic content, plant extracts have an increased chance of causing bitterness or aftertaste as well as a darker color in the final product at greater inclusion or concentration levels. It is always preferable to investigate and utilize plant extracts because of their higher antioxidant capacity with the lowest impact on the sensory characteristics of food products [237]. However, there is still a long way to go before plant-based antioxidant extracts become widely used. The dearth of human clinical trials and animal model studies has impeded the advancement of bioavailability evaluation and its subsequent market applicability. Therefore, further investigation into the potential effects of plant extracts *in vivo* is required. Generally, ensuring plant extract safety, including the lack of toxicity, cytotoxicity, and allergenicity, is crucial [14]. To safeguard consumers from misleading products, strict and precise laws are needed.

9. Conclusions and future prospects

The advantages and functions of bioactive compounds derived from plants and their waste products were highlighted in this review. Owing to their biological activities, such as antioxidant, antimicrobial, antiviral, antidiabetic, and anti-inflammatory attributes, these compounds have gained much attention due to their beneficial impacts on human health. The extraction of bioactive compounds using conventional and environmentally friendly extraction techniques was also covered. The selection of the extraction procedure is essential as it impacts the dependability and caliber of the analytical tasks that follow. The primary goals of extraction are to maximize the yields of bioactive substances while maintaining biological activity and achieving economic viability, environmental friendliness, and shorter extraction times. Reports indicate that green extraction strategies are becoming a more effective and efficient approach for extracting bioactive substances than conventional techniques. Conventional extraction methods exhibit several drawbacks, including extended extraction times, increased solvent requirements, potential damage to bioactivity, and reduced yield. On the contrary, novel methods have various benefits such as shorter extraction times, lower solvent demands, maintenance of biological activity, higher yields, and lower energy use. As food additives, plant-based bioactive components can be added to fatty products to improve oxidative stability and extend shelf life. Overall, the usage of plant food by-products as raw materials can aid in decreasing the production cost and contribute to recycling waste as well as creating a more environmentally friendly atmosphere. More investigation is needed into the stability of bioactive compounds and their regulatory factors, in addition to the confirmation of possible bioactivity. To find out which doses are safe, their dosage-response relationship, bioavailability, and whether they may be consumed with food, preclinical and clinical research is also necessary.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

This work was funded by the Polish National Agency for Academic Exchange (NAWA) under the Ulam programme (Agreement No. BPN/ULM/2022/1/00059/U/00001).

Conflict of interest

The authors declare no conflict of interest.

References

1. Sadh PK, Duhan S, Duhan JS (2018) Agro-industrial wastes and their utilization using solid state fermentation: A review. *Bioresour Bioprocess* 5: 1. https://doi.org/10.1186/s40643-017-0187-z
2. Kumari B, Tiwari BK, Hossain MB, et al. (2018) Recent advances on application of ultrasound and pulsed electric field technologies in the extraction of bioactives from agro-industrial byproducts. *Food Bioprocess Technol* 11: 223–241. https://doi.org/10.1007/s11947-017-1961-9
3. de Los Ángeles Fernández M, Espino M, Gomez FJV, et al. (2018) Novel approaches mediated by tailor-made green solvents for the extraction of phenolic compounds from agro-food industrial byproducts. *Food Chem* 239: 671–678. https://doi.org/10.1016/j.foodchem.2017.06.150

4. Ng HS, Kee PE, Yim HS, et al. (2020) Recent advances on the sustainable approaches for conversion and reutilization of food wastes to valuable bioproducts. *Bioresource Technol* 302: 122889. https://doi.org/10.1016/j.biortech.2020.122889
5. Cecilia JA, García-Sancho C, Maireles-Torres PJ, et al. (2019) Industrial food waste valorization: A general overview. In: *Biorefinery*. Springer, Cham. 253–277. https://doi.org/10.1007/978-3-030-10961-5_11
6. Varzakas T, Zakynthinos G, Verpoort F (2016) Plant food residues as a source of nutraceuticals and functional foods. *Foods* 5: 88. https://doi.org/10.3390/foods5040088
7. Coman V, Teleky BE, Mitrea L, et al. (2020) Bioactive potential of fruit and vegetable wastes, *In Advances in food and nutrition research*. Academic Press, 91: 157–225. https://doi.org/10.1016/bs.afnr.2019.07.001
8. Lopes FC, Ligabue-Braun R (2021) Agro-industrial residues: Eco-friendly and inexpensive substrates for microbial pigments production. *Front Sustain Food Syst* 5: 589414. https://doi.org/10.3389/fsufs.2021.589414
9. Lemes AC, Egea MB, de Oliveira Filho JG, et al. (2022) Biological approaches for extraction of bioactive compounds from agro-industrial by-products: A review. *Front Bioeng Biotechnol* 9: 802543. https://doi.org/10.3389/fbioe.2021.802543
10. Sobhy R, Zou X, Morsy OM, et al. (2023) Date seed polyphenol pills as renewable raw materials showed anti-obesity effects with high digestible antioxidants in 3T3-L1 cells. *Appl Sci* 13: 12533. https://doi.org/10.3390/app132212533
11. Zaky AA, Chen Z, Qin M, et al. (2020) Assessment of antioxidant activity, amino acids, phenolic acids and functional attributes in defatted rice bran and rice bran protein concentrate. *Progr Nutr* 22: e2020069. https://doi.org/10.23751/pn.v22i4.8971
12. Rifna EJ, Misra NN, Dwivedi M (2021) Recent advances in extraction technologies for recovery of bioactive compounds derived from fruit and vegetable waste peels: A review. *Crit Rev Food Sci Nutr* 63: 719–752. https://doi.org/10.1080/10408398.2021.1952923
13. Ünlü AE (2021) Green and non-conventional extraction of bioactive compounds from olive leaves: Screening of novel natural deep eutectic solvents and investigation of process parameters. *Waste Biomass Valori* 12: 5329–5346. https://doi.org/10.1007/s12649-021-01411-3
14. Zaky AA, Simal-Gandara J, Eun JB, et al. (2022) Bioactivities, applications, safety, and health benefits of bioactive peptides from food and by-products: A review. *Front Nutr* 8: 815640. https://doi.org/10.3389/fnut.2021.815640
15. Jha AK, Sit N (2022) Extraction of bioactive compounds from plant materials using combination of various novel methods: A review. *Trends Food Sci Tech* 119: 579–591. https://doi.org/10.1016/j.tifs.2021.11.019
16. Singh JP, Kaur A, Shevkani K, et al. (2015) Influence of jambolan (*Syzygium cumini*) and xanthan gum incorporation on the physicochemical, antioxidant and sensory properties of gluten-free eggless rice muffins. *Int J Food Sci Technol* 50: 1190–1197. https://doi.org/10.1111/ijfs.12764
17. Ahmed F, Fanning K, Netzel M, et al. (2014) Profiling of carotenoids and antioxidant capacity of microalgae from subtropical coastal and brackish waters. *Food Chem* 165: 300–306. https://doi.org/10.1016/j.foodchem.2014.05.107
18. Cooperstone J, Schwartz S (2016) Recent insights into health benefits of carotenoids. In: *Handbook on natural pigments in food and beverages*, Cambridge, UK: Woodhead Publishing, 473–497. https://doi.org/10.1016/B978-0-08-100371-8.00020-8

19. Gürbüz N, Uluisik S, Frary A, et al. (2018) Health benefits and bioactive compounds of eggplant. *Food Chem* 268: 602–610. https://doi.org/10.1016/j.foodchem.2018.06.093
20. Xu DP, Li Y, Meng X, et al. (2017) Natural antioxidants in foods and medicinal plants: Extraction, assessment and resources. *Int J Mol Sci* 18: 96. https://doi.org/10.3390/ijms18010096
21. Claudine M, Augustin S, Christine M, et al. (2004) Polyphenols: Food sources and bioavailability. *Am J Clin Nutr* 79: 727–747. https://doi.org/10.1093/ajcn/79.5.727
22. Bennett RN, Shiga TM, Hassimotto NMA, et al. (2010) Phenolics and antioxidant propertiesof fruit pulp and cell wall fractions of postharvest banana (*Musa acuminata* Juss.) cultivars. *J Agric Food Chem* 58: 7991–8003. https://doi.org/10.1021/jf1008692
23. Singh B, Singh JP, Kaur A, et al. (2016) Bioactive compounds in banana and their associated health benefits-A review. *Food Chem* 206: 1–11. https://doi.org/10.1016/j.foodchem.2016.03.033
24. Kim MJ, Moon Y, Tou JC, et al. (2016) Nutritional value, bioactive compounds and health benefits of lettuce (*Lactuca sativa* L.). *J Food Compos Anal* 49: 19–34. https://doi.org/10.1016/j.jfca.2016.03.004
25. Erlund I (2004) Review of the flavonoids quercetin, hesperetin, and naringenin. Dietary sources, bioactivities, bioavailability, and epidemiology. *Nutr Res* 24: 851–874. https://doi.org/10.1016/j.nutres.2004.07.005
26. Marie-Claire T, Michel de L, Norbert N, et al. (2008) Chronic dietary intake of plant-derived anthocyanins protects the rat heart against ischemia-reperfusion injury. *J Nutr* 138: 747–752. https://doi.org/10.1093/jn/138.4.747
27. Faria A, Pestana D, Teixeira D, et al. (2010) Blueberry anthocyanins and pyruvic acid adducts: Anticancer properties in breast cancer cell lines. *Phytother Res* 24: 1862–1869. https://doi.org/10.1002/ptr.3213
28. Liggins J, Bluck LJC, Runswick S, et al. (2000) Daidzein and genistein contents of vegetables. *Br J Nutr* 84: 717–725. https://doi.org/10.1017/S0007114500002075
29. Cheng DM, Pogrebnyak N, Kuhn P, et al. (2014) Polyphenol-rich rutgers scarlet lettuce improves glucose metabolism and liver lipid accumulation in diet-induced obese C57BL/6 mice. *Nutrition* 30: S52–S58. https://doi.org/10.1016/j.nut.2014.02.022
30. Montesano D, Rocchetti G, Putnik P, et al. (2018) Bioactive profile of pumpkin: An overview on terpenoids and their health-promoting properties. *Curr Opin Food Sci* 22: 81–87. https://doi.org/10.1016/j.cofs.2018.02.003
31. D'Andrea G (2015) Quercetin: A flavonol with multifaceted therapeutic applications? *Fitoterapia* 106: 256–271. https://doi.org/10.1016/j.fitote.2015.09.018
32. Ghofrani S, Joghataei MT, Mohseni S, et al. (2015) Naringenin improves learning and memory in an Alzheimer's disease rat model: Insights into the underlying mechanisms. *Eur J Pharmacol* 764: 195–201. https://doi.org/10.1016/j.ejphar.2015.07.001
33. Nyman NA, Kumpulainen JT (2001) Determination of anthocyanidins in berries and red wine by high-performance liquid chromatography. *J Agric Food Chem* 49: 4183–4187. https://doi.org/10.1021/jf010572i
34. Barik SK, Russell WR, Moar KM, et al. (2020) The anthocyanins in black currants regulate postprandial hyperglycaemia primarily by inhibiting α-glucosidase while other phenolics modulate salivary α-amylase, glucose uptake and sugar transporters. *J Nutr Biochem* 78: 108325. https://doi.org/10.1016/j.jnutbio.2019.108325

35. Sorrenti V, Burò I, Consoli V, et al. (2023) Recent advances in health benefits of bioactive compounds from food wastes and by-products: Biochemical aspects. *Int J Mol Sci* 24: 2019. https://doi.org/10.3390/ijms24032019
36. Rifna EJ, Misra NN, Dwivedi M (2023) Recent advances in extraction technologies for recovery of bioactive compounds derived from fruit and vegetable waste peels: A review. *Crit Rev Food Sci Nutr* 63: 719–752. https://doi.org/10.1080/10408398.2021.1952923
37. Suleria HAR, Barrow CJ, Dunshea FR (2020) Screening and characterization of phenolic compounds and their antioxidant capacity in different fruit peels. *Foods* 9: 1206. https://doi.org/10.3390/foods9091206
38. Gumul D, Ziobro R, Korus J, et al. (2021) Apple pomace as a source of bioactive polyphenol compounds in gluten-free breads. *Antioxidants* 10: 807. https://doi.org/10.3390/antiox10050807
39. Martí R, Roselló S, Cebolla-Cornejo J (2016) Tomato as a source of carotenoids and polyphenols targeted to cancer prevention. *Cancers* 8: 58. https://doi.org/10.3390/cancers8060058
40. Yang D, Jiang Y, Wang Y, et al. (2020) Improvement of flavonoids in lemon seeds on oxidative damage of human embryonic kidney 293T cells induced by H_2O_2. *Oxid Med Cell Longev* 2020: 3483519. https://doi.org/10.1155/2020/3483519
41. Chhikara N, Kushwaha K, Sharma P, et al. (2019) Bioactive compounds of beetroot and utilization in food processing industry: A critical review. *Food Chem* 272: 192–200. https://doi.org/10.1016/j.foodchem.2018.08.022
42. Talhaoui N, Gómez-Caravaca AM, Roldán C, et al. (2015) Chemometric analysis for the evaluation of phenolic patterns in olive leaves from six cultivars at different growth stages. *J Agric Food Chem* 63: 1722–1729. https://doi.org/10.1021/jf5058205
43. Wani TA, Majid D, Dar BN, et al. (2023) Utilization of novel techniques in extraction of polyphenols from grape pomace and their therapeutic potential: A review. *J Food Meas Charact* 17: 5412–5425. https://doi.org/10.1007/s11694-023-02040-1
44. Forbes-Hernandez TY, Giampieri F, Gasparrini M, et al. (2014) The effects of bioactive compounds from plant foods on mitochondrial function: A focus on apoptotic mechanisms. *Food Chem Toxicol* 68: 154–182. https://doi.org/10.1016/j.fct.2014.03.017
45. Rowayshed G, Sharaf AM, El-Faham SY, et al. (2015) Utilization of potato peels extract as source of phytochemicals in biscuits. *J Basic Appl Res Int* 8: 190–201.
46. Zhu J, Lu Y, He Q (2024) Recent advances on bioactive compounds, health benefits, and potential applications of jujube (*Ziziphus Jujuba* Mill.): A perspective of by-products valorization. *Trends Food Sci Tech* 145: 104368. https://doi.org/10.1016/j.tifs.2024.104368
47. Pirzadeh M, Caporaso N, Rauf A, et al. (2021) Pomegranate as a source of bioactive constituents: A review on their characterization, properties and applications. *Crit Rev Food Sci Nutr* 61: 982–999. https://doi.org/10.1080/10408398.2020.1749825
48. Ben-Othman S, Joudu I, Bhat R (2020) Bioactives from agri-food wastes: Present insights and future challenges. *Molecules* 25: 510. https://doi.org/10.3390/molecules25030510
49. Deo S, Sakhale BK (2018) A review on potential of bioactive compounds obtained from processing waste of various fruits and vegetables. *Int J Pure Appl Biosci* 6: 680–686. https://doi.org/10.18782/2320-7051.6742
50. Singh JP, Kaur A, Shevkani K, et al. (2016) Composition, bioactive compounds and antioxidant activity of common Indian fruits and vegetables. *J Food Sci Technol* 53: 4056–4066. https://doi.org/10.1007/s13197-016-2412-8

51. Jeon YA, Chung SW, Kim SC, et al. (2022) Comprehensive assessment of antioxidant and anti-inflammatory properties of papaya extracts. *Foods* 11: 3211. https://doi.org/10.3390/foods11203211
52. Sultana B, Hussan Z, Asif M, et al. (2012) Investigation on the antioxidant activity of leaves, peels, stems bark, and kernel of mango (*Mangifera indica* L.). *J Food Sci* 77: C849–C852. https://doi.org/10.1111/j.1750-3841.2012.02807.x
53. Wolfe K, Wu X, Liu RH (2003) Antioxidant activity of apple peels. *J Agric Food Chem* 51: 609–614. https://doi.org/10.1021/jf020782a
54. Matsuo Y, Miura LA, Araki T, et al. (2019) Proximate composition and profiles of free amino acids, fatty acids, minerals and aroma compounds in Citrus natsudaidai peel. *Food Chem* 279: 356–363. https://doi.org/10.1016/j.foodchem.2018.11.146
55. Zou Z, Xi W, Hu Y, et al. (2016) Antioxidant activity of *Citrus* fruits. *Food Chem* 196: 885–896. https://doi.org/10.1016/j.foodchem.2015.09.072
56. Rajasree RS, Sibi PI, Francis F, et al. (2016) Phytochemicals of Cucurbitaceae family-A review. *Int J Pharmacogn Phytochem Res* 8: 113–123.
57. Guuntekin E, Uner B, Karakus B (2009) Chemical composition of tomato (*Solanum lycopersicum*) stalk and suitability in the particleboard production. *J Env Biol* 30: 731–734.
58. Ravichandran K, Saw NMMT, Mohdaly AAA, et al. (2013) Impact of processing of red beet on betalain content and antioxidant activity. *Food Res Int* 50: 670–675. https://doi.org/10.1016/j.foodres.2011.07.002
59. Cartea ME, Francisco M, Soengas P, et al. (2010) Phenolic compounds in *Brassica* vegetables. *Molecules* 16: 251–280. https://doi.org/10.3390/molecules16010251
60. Al-Weshahy A, El-Nokety M, Bakhete M, et al. (2013) Effect of storage on antioxidant activity of freeze-dried potato peels. *Food Res Int* 50: 507–512. https://doi.org/10.1016/j.foodres.2010.12.014
61. Sahin S, Samli R, Tan ASB, et al. (2017) Solvent-free microwave-assisted extraction of polyphenols from olive tree leaves: Antioxidant and antimicrobial properties. *Molecules* 22: 1056. https://doi.org/10.3390/molecules22071056
62. Alberti A, Zielinski AAF, Zardo DM, et al. (2014) Optimisation of the extraction of phenolic compounds from apples using response surface methodology. *Food Chem* 149: 151–158. https://doi.org/10.1016/j.foodchem.2013.10.086
63. Putnik P, Barba FJ, Lorenzo JM, et al. (2017) An integrated approach to mandarin processing: Food safety and nutritional quality, consumer preference and nutrient bioaccessibility. *Compr Rev Food Sci Food Saf* 16: 1345–1358. https://doi.org/10.1111/1541-4337.12310
64. Anticona M, Lopez-Malo D, Frigola A, et al. (2022) Comprehensive analysis of polyphenols from hybrid Mandarin peels by SPE and HPLC-UV. *LWT* 165: 113770. https://doi.org/10.1016/j.*LWT*.2022.113770
65. Jménez-Aguilar DM, López-Martínez JM, Hernández-Brenes C, et al. (2015) Dietary fiber, phytochemical composition and antioxidant activity of Mexican commercial varieties of cactus pear. *J Food Compos Anal* 41: 66–73. https://doi.org/10.1016/j.jfca.2015.01.017
66. Chang SF, Hsieh CL, Yen GC (2008) The protective effect of *Opuntia dillenii* Haw fruit against low-density lipoprotein peroxidation and its active compounds. *Food Chem* 106: 569–575. https://doi.org/10.1016/j.foodchem.2007.06.017

67. Galati EM, Mondello MR, Giuffrida D, et al. (2003) Chemical characterization and biological effects of Sicilian *Opuntia ficus indica* (L.) Mill. fruit juice: Antioxidant and antiulcerogenic activity. *J Agric Food Chem* 51: 4903–4908. https://doi.org/10.1021/jf030123d
68. Lorenzo JM, Pateiro M, Domínguez R, et al. (2018) Berries extracts as natural antioxidants in meat products: A review. *Food Res Int* 106: 1095–1104. https://doi.org/10.1016/j.foodres.2017.12.005
69. Lorenzo JM, Munekata P, Putnik P, et al. (2019) Sources, chemistry and biological potential of ellagitannins and ellagic acid derivatives. In: *Studies in natural products chemistry*, Amsterdam, The Netherlands: Elsevier, 60: 189–221. https://doi.org/10.1016/B978-0-444-64181-6.00006-1
70. Szajdek A, Borowska EJ (2008) Bioactive compounds and health-promoting properties of berry fruits: A review. *Plant Food Hum Nutr* 63: 147–156. https://doi.org/10.1007/s11130-008-0097-5
71. Nishimura T, Egusa AS, Nagao A, et al. (2016) Phytosterols in onion contribute to a sensation of lingering of aroma, a *koku* attribute. *Food Chem* 192: 724–728. https://doi.org/10.1016/j.foodchem.2015.06.075
72. Bisen PS, Emerald M (2016) Nutritional and therapeutic potential of garlic and onion (*Allium* sp.). *Curr Nutr Food Sci* 12: 190–199. https://doi.org/10.2174/1573401312666160608121954
73. Nile SH, Nile AS, Keum YS, et al. (2017) Utilization of quercetin and quercetin glycosides from onion (*Allium cepa* L.) solid waste as an antioxidant, urease and xanthine oxidase inhibitors. *Food Chem* 235: 119–126. https://doi.org/10.1016/j.foodchem.2017.05.043
74. Ribeiro-Santos R, Carvalho-Costa D, Cavaleiro C, et al. (2015) A novel insight on an ancient aromatic plant: The rosemary (*Rosmarinus officinalis* L.). *Trends Food Sci Tech* 45: 355–368. https://doi.org/10.1016/j.tifs.2015.07.015
75. Sueishi Y, Sue M, Masamoto H (2018) Seasonal variations of oxygen radical scavenging ability in rosemary leaf extract. *Food Chem* 245: 270–274. https://doi.org/10.1016/j.foodchem.2017.10.085
76. Nieto G (2017) Biological activities of three essential oils of the Lamiaceae family. *Medicines* 4: 63. https://doi.org/10.3390/medicines4030063
77. Berdahl DB, McKeague J (2015) Rosemary and sage extracts as antioxidants for food preservation. In: *Handbook of antioxidants for food preservation*. Cambridge, UK: Woodhead Publishing, 177–217. https://doi.org/10.1016/B978-1-78242-089-7.00008-7
78. Kolac UK, Ustuner MC, Tekin N, et al. (2017) The anti-inflammatory and antioxidant effects of Salvia officinalis on lipopolysaccharide-induced inflammation in rats. *J Med Food* 20: 1193–1200. https://doi.org/10.1089/jmf.2017.0035
79. Wu J, Ge S, Liu H, et al. (2014) Properties and antimicrobial activity of silver carp (*Hypophthalmichthys molitrix*) skin gelatin-chitosan films incorporated with oregano essential oil for fish preservation. *Food Packaging Shelf* 2: 7–16. https://doi.org/10.1016/j.fpsl.2014.04.004
80. Tohidi B, Rahimmalek M, Arzani A (2017) Essential oil composition, total phenolic, flavonoid contents, and antioxidant activity of *Thymus* species collected from different regions of Iran. *Food Chem* 220: 153–161. https://doi.org/10.1016/j.foodchem.2016.09.203
81. Moghimi R, Ghaderi L, Rafati H, et al. (2016) Superior antibacterial activity of nanoemulsion of *Thymus daenensis* essential oil against *E. coli*. *Food Chem* 194: 410–415. https://doi.org/10.1016/j.foodchem.2015.07.139
82. Sharma K, Mahato N, Cho MH, et al. (2017) Converting citrus wastes into value-added products: Economic and environmently friendly approaches. *Nutrition* 34: 29–46. https://doi.org/10.1016/j.nut.2016.09.006

83. Criado MN, Barba FJ, Frigola A, et al. (2014) Effect of *Stevia rebaudiana* on oxidative enzyme activity and its correlation with antioxidant capacity and bioactive compounds. *Food Bioprocess Technol* 7: 1518–1525. https://doi.org/10.1007/s11947-013-1208-3
84. Koubaa M, Roselló-Soto E, Žlabur JS, et al. (2015) Current and new insights in the sustainable and green recovery of nutritionally valuable compounds from *Stevia rebaudiana* Bertoni. *J Agric Food Chem* 63: 6835–6846. https://doi.org/10.1021/acs.jafc.5b01994
85. Bulotta S, Celano M, Lepore SM, et al. (2014) Beneficial effects of the olive oil phenolic components oleuropein and hydroxytyrosol: Focus on protection against cardiovascular and metabolic diseases. *J Transl Med* 12: 219. https://doi.org/10.1186/s12967-014-0219-9
86. Afshari F, Seraj H, Hashemi ZS, et al. (2017) The cytotoxic effects of eggplant peel extract on human gastric adenocarcinoma cells and normal cells. *Mod Med Lab J* 1: 77–83. https://doi.org/10.30699/mmlj17.1.2.77
87. Berghe WV (2012) Epigenetic impact of dietary polyphenols in cancer chemoprevention: Lifelong remodeling of our epigenomes. *Pharmacol Res* 65: 565–576. https://doi.org/10.1016/j.phrs.2012.03.007
88. Sharma P, McClees SF, Afaq F (2017) Pomegranate for prevention and treatment of cancer: An update. *Molecules* 22: 177. https://doi.org/10.3390/molecules22010177
89. Rettig MB, Heber D, An J, et al. (2008) Pomegranate extract inhibits androgen-independent prostate cancer growth through a nuclear factor-κB-dependent mechanism. *Mol Cancer Ther* 7: 2662–2671. https://doi.org/10.1158/1535-7163.MCT-08-0136
90. Faria A, Pestana D, Teixeira D, et al. (2010) Blueberry anthocyanins and pyruvic acid adducts: Anticancer properties in breast cancer cell lines. *Phytother Res* 24: 1862–1869. https://doi.org/10.1002/ptr.3213
91. Salminen A, Lehtonen M, Suuronen T, et al. (2008) Terpenoids: Natural inhibitors of NF-κB signaling with anti-inflammatory and anticancer potential. *Cell Mol Life Sci* 65: 2979–2999. https://doi.org/10.1007/s00018-008-8103-5
92. Barik SK, Russell WR, Moar KM, et al. (2020) The anthocyanins in black currants regulate postprandial hyperglycaemia primarily by inhibiting α-glucosidase while other phenolics modulate salivary α-amylase, glucose uptake and sugar transporters. *J Nutr Biochem* 78: 108325. https://doi.org/10.1016/j.jnutbio.2019.108325
93. Yang L, Shu L, Yao DD, et al. (2014) Study on the glucose-lowering effect of puerarin in STZ-induced diabetic mice. *Chin J Hosp Pharm* 34: 1338–1342.
94. Anhê FF, Roy D, Pilon G, et al. (2015) A polyphenol-rich cranberry extract protects from diet-induced obesity, insulin resistance and intestinal inflammation in association with increased Akkermansia spp. population in the gut microbiota of mice. *Gut* 64: 872–883. https://doi.org/10.1136/gutjnl-2014-307142
95. Gong L, Cao W, Chi H, et al. (2018) Whole cereal grains and potential health effects: Involvement of the gut microbiota. *Food Res Int* 103: 84–102. https://doi.org/10.1016/j.foodres.2017.10.025
96. Velderrain-Rodríguez GR, Quero J, Osada J, et al. (2021) Phenolic-rich extracts from avocado fruit residues as functional food ingredients with antioxidant and antiproliferative properties. *Biomolecules* 11: 977. https://doi.org/10.3390/biom11070977
97. Mirza B, Croley CR, Ahmad M, et al. (2021) Mango (*Mangifera indica* L.): A magnificent plant with cancer preventive and anticancer therapeutic potential. *Crit Rev Food Sci Nutr* 61: 2125–2151. https://doi.org/10.1080/10408398.2020.1771678

98. Donga S, Bhadu GR, Chanda S (2020) Antimicrobial, antioxidant and anticancer activities of gold nanoparticles green synthesized using *Mangifera indica* seed aqueous extract. *Artif Cell Nanomed Biotechnol* 48: 1315–1325. https://doi.org/10.1080/21691401.2020.1843470
99. Agourram A, Ghirardello D, Rantsiou K, et al. (2013) Phenolic content, antioxidant potential, and antimicrobial activities of fruit and vegetable by-product extracts. *Int J Food Prop* 16: 1092–1104. https://doi.org/10.1080/10942912.2011.576446
100. Sanz-Puig M, Pina-Pérez MC, Martínez-López A, et al. (2016) *Escherichia coli* O157: H7 and *Salmonella Typhimurium* inactivation by the effect of mandarin, lemon, and orange by-products in reference medium and in oat-fruit juice mixed beverage. *LWT-Food Sci Technol* 66: 7–14. https://doi.org/10.1016/j.lwt.2015.10.012
101. Coman MM, Oancea AM, Verdenelli MC, et al. (2018) Polyphenol content and in vitro evaluation of antioxidant, antimicrobial and prebiotic properties of red fruit extracts. *Eur Food Res Technol* 244: 735–745. https://doi.org/10.1007/s00217-017-2997-9
102. Ramadan H, Min B, Tiwari AK, et al. (2015) Antibacterial activity of Pomegranate, Orange and Lemon peel extracts against food-borne pathogens and spoilage bacteria *in vitro* and on poultry skin. *Int J Poult Sci* 14: 229–239. https://doi.org/10.3923/ijps.2015.229.239
103. Wu J, Goodrich, KM, Eifert JD, et al. (2018). Inhibiting foodborne pathogens Vibrio parahaemolyticus and Listeria monocytogenes using extracts from traditional medicine: Chinese gallnut, pomegranate peel, Baikal skullcap root and forsythia fruit. *Open Agric* 3: 163–170. https://doi.org/10.1515/opag-2018-0017
104. Zhu X, Zhang H, Lo R, et al. (2005) Antimicrobial activities of *Cynara scolymus* L. leaf, head, and stem extracts. *J Food Sci* 70: M149–M152. https://doi.org/10.1111/j.1365-2621.2005.tb07106.x
105. Mordi RC, Fadiaro AE, Owoeye TF, et al. (2016) Identification by GC-MS of the components of oils of banana peels extract, phytochemical and antimicrobial analyses. *Res J Phytochem* 10: 39–44. https://doi.org/10.3923/rjphyto.2016.39.44.
106. Xu C, Yagiz Y, Hsu WY, et al. (2014) Antioxidant, antibacterial, and antibiofilm properties of polyphenols from muscadine grape (*Vitis rotundifolia* Michx.) pomace against selected foodborne pathogens. *J Agric Food Chem* 62: 6640–6649. https://doi.org/10.1021/jf501073q
107. Casquete R, Castro SM, Martín A, et al. (2015) Evaluation of the effect of high pressure on total phenolic content, antioxidant and antimicrobial activity of citrus peels. *Innov Food Sci Emerg Technol* 31: 37–44. https://doi.org/10.1016/j.ifset.2015.07.005
108. de Almeida Rochelle SL, de Cássia Orlandi Sardi J, Freires IA, et al. (2016) The anti-biofilm potential of commonly discarded agro-industrial residues against opportunistic pathogens. *Ind Crop Prod* 87: 150–160. https://doi.org/10.1016/j.indcrop.2016.03.044
109. Gaafar AA, Asker MS, Salama ZA, et al. (2015) In-vitro, antiviral, antimicrobial and antioxidant potential activity of tomato pomace. *Int J Pharm Sci Res* 32: 262–272. https://doi.org/10.31083/j.fbl2709259
110. Garcia-Salas P, Morales-Soto A, Segura-Carretero A, et al. (2010) Phenolic-compound-extraction systems for fruit and vegetable samples. *Molecules* 15: 8813–8826. https://doi.org/10.3390/molecules15128813
111. Andersson AAM, Dimberg L, Åman P, et al. (2014) Recent findings on certain bioactive components in whole grain wheat and rye. *J Cereal Sci* 59: 294–311. https://doi.org/10.1016/j.jcs.2014.01.003

112. Saleh IA, Vinatoru M, Mason TJ, et al. (2016) A possible general mechanism for ultrasound-assisted extraction (UAE) suggested from the results of UAE of chlorogenic acid from *Cynara scolymus* L. (artichoke) leaves. *Ultrason Sonochem* 31: 330–336. https://doi.org/10.1016/j.ultsonch.2016.01.002
113. Berk Z (2009) Extraction. In: *Food process engineering and technology*. Academic Press, 259–277. https://doi.org/10.1016/B978-0-12-373660-4.00011-9
114. Kühn S, Temelli F (2017) Recovery of bioactive compounds from cranberry pomace using ternary mixtures of CO_2+ethanol+water. *J Supercrit Fluids* 130: 147–155. https://doi.org/10.1016/j.supflu.2017.07.028
115. Hammad SF, Abdallah IA, Bedair A, et al. (2022) Homogeneous liquid–liquid extraction as an alternative sample preparation technique for biomedical analysis. *J Sep Sci* 45: 185–209. https://doi.org/10.1002/jssc.202100452
116. Breil C, Vian MA, Zemb T, et al. (2017) “Bligh and Dyer” and Folch methods for solid–liquid–liquid extraction of lipids from microorganisms. Comprehension of solvatation mechanisms and towards substitution with alternative solvents. *Int J Mol Sci* 18: 708. https://doi.org/10.3390/ijms18040708
117. Chen SY, Urban PL (2015) On-line monitoring of Soxhlet extraction by chromatography and mass spectrometry to reveal temporal extract profiles. *Anal Chim Acta* 881: 74–81. https://doi.org/10.1016/j.aca.2015.05.003
118. Kodal SP, Aksu Z (2001) Optimization of carotene pigment production by Soxhlet extraction from waste orange peels. *Food Chem* 72: 145–171.
119. Caldas TW, Mazza KEL, Teles ASC, et al. (2018) Phenolic compounds recovery from grape skin using conventional and non-conventional extraction methods. *Ind Crops Prod* 111: 86–91. https://doi.org/10.1016/j.indcrop.2017.10.012
120. Tian B, Qiao YY, Tian YY, et al. (2016) Effect of heat reflux extraction on the structure and composition of a high-volatile bituminous coal. *Appl Therm Eng* 109: 560–568. https://doi.org/10.1016/j.applthermaleng.2016.08.104
121. Romero-Cascales I, Fernández-Fernández JI, López-Roca JM, et al. (2005) The maceration process during winemaking extraction of anthocyanins from grape skins into wine. *Eur Food Res Technol* 221: 163–167. https://doi.org/10.1007/s00217-005-1144-1
122. Sultana B, Anwar F, Asi MR, et al. (2008) Antioxidant potential of extracts from different agro wastes: Stabilization of corn oil. *Grasas Aceites* 59: 205–217.
123. Albuquerque BR, Prieto MA, Barreiro MF, et al. (2017) Catechin-based extract optimization obtained from *Arbutus unedo* L. fruits using maceration/microwave/ultrasound extraction techniques. *Ind Crops Prod* 95: 404–415. https://doi.org/10.1016/j.indcrop.2016.10.050
124. Khoddami A, Wilkes MA, Roberts TH (2013) Techniques for analysis of plant phenolic compounds. *Molecules* 18: 2328–2375. https://doi.org/10.3390/molecules18022328
125. Altemimi A, Lightfoot DA, Kinsel M, et al. (2015) Employing response surface methodology for the optimization of ultrasound assisted extraction of lutein and β-carotene from spinach. *Molecules* 20: 6611–6625. https://doi.org/10.3390/molecules20046611
126. Ferarsa S, Zhang W, Moulai-Mostefa N, et al. (2018) Recovery of anthocyanins and other phenolic compounds from purple eggplant peels and pulps using ultrasonic-assisted extraction. *Food Bioprod Process* 109: 19–28. https://doi.org/10.1016/j.fbp.2018.02.006

127. Skenderidis P, Mitsagga C, Giavasis I, et al. (2019) The in vitro antimicrobial activity assessment of ultrasound assisted *Lycium barbarum* fruit extracts and pomegranate fruit peels. *J Food Meas Charact* 13: 2017–2031. https://doi.org/10.1007/s11694-019-00123-6
128. Londoño-Londoño J, de Lima VR, Lara O, et al. (2010) Clean recovery of antioxidant flavonoids from citrus peel: Optimizing an aqueous ultrasound-assisted extraction method. *Food Chem* 119: 81–87. https://doi.org/10.1016/j.foodchem.2009.05.075
129. Zhu J, Kou X, Wu C, et al. (2022) Enhanced extraction of bioactive natural products using ultrasound-assisted aqueous two-phase system: Application to flavonoids extraction from jujube peels. *Food Chem* 395: 133530. https://doi.org/10.1016/j.foodchem.2022.133530
130. Sulejmanović M, Milić N, Mourtzinos I, et al. (2024) Ultrasound-assisted and subcritical water extraction techniques for maximal recovery of phenolic compounds from raw ginger herbal dust toward in vitro biological activity investigation. *Food Chem* 437: 137774. https://doi.org/10.1016/j.foodchem.2023.137774
131. Raj GB, Dash KK (2020) Ultrasound-assisted extraction of phytocompounds from dragon fruit peel: Optimization, kinetics and thermodynamic studies. *Ultrason Sonochem* 68: 105180. https://doi.org/10.1016/j.ultsonch.2020.105180
132. Kumcuoglu S, Yilmaz T, Tavman S (2014) Ultrasound assisted extraction of lycopene from tomato processing wastes. *J Food Sci Technol* 51: 4102–4107. https://doi.org/10.1007/s13197-013-0926-x
133. Jang M, Asnin L, Nile SH, et al. (2013) Ultrasound-assisted extraction of quercetin from onion solid wastes. *Int J Food Sci Technol* 48: 246–252. https://doi.org/10.1111/j.1365-2621.2012.03180.x
134. Goula AM, Ververi M, Adamopoulou A, et al. (2017) Green ultrasound-assisted extraction of carotenoids from pomegranate wastes using vegetable oils. *Ultrason Sonochem* 34: 821–830. https://doi.org/10.1016/j.ultsonch.2016.07.022
135. Medina-Meza IG, Barbosa-Canovas GV (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
136. Huang G, Zhang M, Sun J, et al. (2020) Determination of flavonoids in *magnolia officinalis* leaves based on response surface optimization of infrared assisted extraction followed by high-performance liquid chromatography (HPLC). *Anal Lett* 53: 2145–2159. https://doi.org/10.1080/00032719.2020.1732401
137. Wang L, Duan H, Jiang J, et al. (2017) A simple and rapid infrared-assisted self enzymolysis extraction method for total flavonoid aglycones extraction from *Scutellariae Radix* and mechanism exploration. *Anal Bioanal Chem* 409: 5593–5602. https://doi.org/10.1007/s00216-017-0497-1
138. El Kantar S, Rajha HN, Maroun RG, et al. (2020) Intensification of polyphenols extraction from orange peels using infrared as a novel and energy saving pretreatment. *J Food Sci* 85: 414–420. https://doi.org/10.1111/1750-3841.15016
139. Cheaib D, El Darra N, Rajha HN, et al. (2018) Study of the selectivity and bioactivity of polyphenols using infrared assisted extraction from apricot pomace compared to conventional methods. *Antioxidants* 7: 174. https://doi.org/10.3390/antiox7120174

140. Chen Y, Duan G, Xie M, et al. (2010) Infrared-assisted extraction coupled with high-performance liquid chromatography for simultaneous determination of eight active compounds in *Radix Salviae miltiorrhizae*. *J Sep Sci* 33: 2888–2897. https://doi.org/10.1002/jssc.201000234
141. Abi-Khattar AM, Rajha HN, Abdel-Massih RM, et al. (2019) Intensification of polyphenol extraction from olive leaves using Ired-Irrad®, an environmentally-friendly innovative technology. *Antioxidants* 8: 227. https://doi.org/10.3390/antiox8070227
142. Zhou T, Xiao X, Li G, et al. (2011) Study of polyethylene glycol as a green solvent in the microwave-assisted extraction of flavone and coumarin compounds from medicinal plants. *J Chromatog A* 1218: 3608–3615. https://doi.org/10.1016/j.chroma.2011.04.031
143. Horikoshi S, Schiffmann RF, Fukushima J, et al. (2018) Electromagnetic fields and electromagnetic waves. In: *Microwave chemical and materials processing*. Singapore: Springer, 33–45. https://doi.org/10.1007/978-981-10-6466-1_3
144. Zhang W, Liu X, Fan H, at al. (2016) Separation and purification of alkaloids from *Sophora flavescens* Ait. by focused microwave-assisted aqueous two-phase extraction coupled with reversed micellar extraction. *Ind Crops Prod* 86: 231–238. https://doi.org/10.1016/j.indcrop.2016.03.052
145. Ivanović M, Alañón ME, Arráez-Román D, et al. (2018) Enhanced and green extraction of bioactive compounds from *Lippia citriodora* by tailor-made natural deep eutectic solvents. *Food Res Int* 111: 67–76. https://doi.org/10.1016/j.foodres.2018.05.014
146. Simsek M, Sumnu G, Sahin S (2012) Microwave assisted extraction of phenolic compounds from sour cherry pomace. *Sep Sci Technol* 47: 1248–1254. https://doi.org/10.1080/01496395.2011.644616
147. Asghari J, Ondruschka B, Mazaheritehrani M (2011) Extraction of bioactive chemical compounds from the medicinal Asian plants by microwave irradiation. *J Med Plant Res* 5: 495–506.
148. Brahim M, Gambier F, Brosse N (2014) Optimization of polyphenols extraction from grape residues in water medium. *Ind Crops Prod* 52: 18–22. https://doi.org/10.1016/j.indcrop.2013.10.030
149. Ciriminna R, Fidalgo A, Avellone G, et al. (2019) Integral extraction of opuntia ficus-indica peel bioproducts via microwave-assisted hydrodiffusion and hydrodistillation. *ACS Sustain Chem Eng* 7: 7884–7891. https://doi.org/10.1021/acssuschemeng.9b00502
150. Liazid A, Guerrero RF, Cantos E, et al. (2011) Microwave assisted extraction of anthocyanins from grape skins. *Food Chem* 124: 1238–1243. https://doi.org/10.1016/j.foodchem.2010.07.053
151. Torres-León C, Rojas R, Serna-Cock L, et al. (2017) Extraction of antioxidants from mango seed kernel: Optimization assisted by microwave. *Food Bioprod Process* 105: 188–196. https://doi.org/10.1016/j.fbp.2017.07.005
152. Araújo RG, Rodriguez-Jasso RM, Ruiz HA, et al. (2020) Process optimization of microwave-assisted extraction of bioactive molecules from avocado seeds. *Ind Crops Prod* 154: 112623. https://doi.org/10.1016/j.indcrop.2020.112623
153. Lucchesi ME, Smadja J, Bradshaw S, et al. (2007) Solvent free microwave extraction of *Elletaria cardamomum* L.: A multivariate study of a new technique for the extraction of essential oil. *J Food Eng* 79: 1079–1086. https://doi.org/10.1016/j.jfoodeng.2006.03.029
154. Michel T, Destandau E, Elfakir C, et al. (2011) Evaluation of a simple and promising method for extraction of antioxidants from sea buckthorn (*Hippophaë rhamnoides* L.) berries: Pressurised solvent-free microwave assisted extraction. *Food Chem* 126: 1380–1386. https://doi.org/10.1016/j.foodchem.2010.09.112

155. Martínez J, Rosas J, Pérez J, et al. (2019) Green approach to the extraction of major capsaicinoids from habanero pepper using near-infrared, microwave, ultrasound and Soxhlet methods, a comparative study. *Nat Prod Res* 33: 447–452. https://doi.org/10.1080/14786419.2018.1455038
156. Yogesh K (2016) Pulsed electric field processing of egg products: A review. *J Food Sci Technol* 53: 934–945. https://doi.org/10.1007/s13197-015-2061-3
157. Sánchez-Vega R, Elez-Martínez P, Martín-Belloso O, et al. (2015) Influence of high-intensity pulsed electric field processing parameters on antioxidant compounds of broccoli juice. *Innov Food Sci Emerg Technol* 29: 70–77. https://doi.org/10.1016/j.ifset.2014.12.002
158. Kim HS, Ko MJ, Park CH, et al. (2022) Application of pulsed electric field as a pre-treatment for subcritical water extraction of quercetin from onion skin. *Foods* 11: 1069. https://doi.org/10.3390/foods11081069
159. Tantamacharik T, Leong SY, Leus MJ, et al. (2019) Structural changes induced by pulsed electric fields increase the concentration of volatiles released in red onion (*Allium cepa* L. Var. Red pearl) bulbs. *Foods* 8: 368. https://doi.org/10.3390/foods8090368
160. Yu X, Bals O, Grimi N (2015) A new way for the oil plant biomass valorization: Polyphenols and proteins extraction from rapeseed stems and leaves assisted by pulsed electric fields. *Ind Crops Prod* 74: 309–318. https://doi.org/10.1016/j.indcrop.2015.03.045
161. Yu X, Gouyo T, Grimi N, et al. (2016) Pulsed electric field pretreatment of rapeseed green biomass (stems) to enhance pressing and extractives recovery. *Bioresour Technol* 199: 194–201. https://doi.org/10.1016/j.biortech.2015.08.073
162. Wang L, Boussetta N, Lebovka N, et al. (2020) Cell disintegration of apple peels induced by pulsed electric field and efficiency of bio-compound extraction. *Food Bioprod Process* 122: 13–21. https://doi.org/10.1016/j.fbp.2020.03.004
163. Parniakov O, Rosello-Soto E, Barba FJ, et al. (2015) New approaches for the effective valorization of papaya seeds: Extraction of proteins, phenolic compounds, carbohydrates, and isothiocyanates assisted by pulsed electric energy. *Food Res Int* 77: 711–717. https://doi.org/10.1016/j.foodres.2015.03.031
164. Koubaa M, Barba FJ, Grimi N, et al. (2016) Recovery of colorants from red prickly pear peels and pulps enhanced by pulsed electric field and ultrasound. *Innov Food Sci Emerg Technol* 37: 336–344. https://doi.org/10.1016/j.ifset.2016.04.015
165. Luengo E, Alvarez 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
166. Corrales M, Toepfl S, Butz P, et al. (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: 85–91. https://doi.org/10.1016/j.ifset.2007.06.002
167. Gómez-Mejía E, Rosales-Conrado N, León-González ME, et al. (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
168. Benito-Román Ó, Alvarez VH, Alonso E, et al. (2015) Pressurized aqueous ethanol extraction of β-glucans and phenolic compounds from waxy barley. *Food Res Int* 75: 252–259. https://doi.org/10.1016/j.foodres.2015.06.006

169. Markom M, Hasan M, Daud WRW, et al. (2007) Extraction of hydrolysable tannins from *Phyllanthus niruri* Linn.: effects of solvents and extraction methods. *Sep Purif Technol* 52: 487–496. https://doi.org/10.1016/j.seppur.2006.06.003
170. Mohd Jusoh NH, Subki A, Yeap SK, et al. (2019) Pressurized hot water extraction of hydrosable tannins from *Phyllanthus tenellus* Roxb. *BMC Chem* 13: 134. https://doi.org/10.1186/s13065-019-0653-0
171. Wrona O, Rafińska K, Możeński C, et al. (2017) Supercritical fluid extraction of bioactive compounds from plant materials. *J AOAC Int* 100: 1624–1635. https://doi.org/10.5740/jaoacint.17-0232
172. Montañés F, Catchpole OJ, Tallon S, et al. (2018) Extraction of apple seed oil by supercritical carbon dioxide at pressures up to 1300 bar. *J Supercrit Fluid* 141: 128–136. https://doi.org/10.1016/j.supflu.2018.02.002
173. Pavlić B, Bera O, Teslić N, et al. (2018) Chemical profile and antioxidant activity of sage herbal dust extracts obtained by supercritical fluid extraction. *Ind Crops Prod* 120: 305–312. https://doi.org/10.1016/j.indcrop.2018.04.044
174. Kitrytė V, Laurinavičienė A, Syrpas M, et al. (2020) Modeling and optimization of supercritical carbon dioxide extraction for isolation of valuable lipophilic constituents from elderberry (*Sambucus nigra* L.) pomace. *J CO2 Util* 35: 225–235. https://doi.org/10.1016/j.jcou.2019.09.020
175. He L, Zhang X, Xu H, et al. (2011) Subcritical water extraction of phenolic compounds from pomegranate (*Punica granatum* L.) seed residues and investigation into their antioxidant activities with HPLC–ABTS$\cdot^{+}$ assay. *Food Bioprod Process* 90: 215–223. https://doi.org/10.1016/j.fbp.2011.03.003
176. Singh PP, Saldaña MDA (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
177. Aliakbarian B, Fathi A, Perego P, et al. (2012) Extraction of antioxidants from winery wastes using subcritical water. *J Supercrit Fluids* 65: 18–24. https://doi.org/10.1016/j.supflu.2012.02.022
178. Jiao G, Kermanshahi A (2018) Extraction of anthocyanins from haskap berry pulp using supercritical carbon dioxide: influence of co-solvent composition and pretreatment. *LWT* 98: 237–244. https://doi.org/10.1016/j.lwt.2018.08.042
179. Natolino A, Da Porto C (2019) Supercritical carbon dioxide extraction of pomegranate (*Punica granatum* L.) seed oil: Kinetic modelling and solubility evaluation. *J Supercrit Fluids* 151: 30–39. https://doi.org/10.1016/j.supflu.2019.05.002
180. e Santos DN, de Souza LL, Ferreira NJ, et al. (2015) Study of supercritical extraction from Brazilian cherry seeds (*Eugenia uniflora* L.) with bioactive compounds. *Food Bioprod Process* 94: 365–374. https://doi.org/10.1016/j.fbp.2014.04.005
181. Grzelak-Błaszczyk K, Karlińska E, Grzęda K, et al. (2017) Defatted strawberry seeds as a source of phenolics, dietary fiber and minerals. *LWT* 84: 18–22. https://doi.org/10.1016/j.lwt.2017.05.014
182. Liu J, Chen P, He J, et al. (2014) Extraction of oil from *Jatropha curcas* seeds by subcritical fluid extraction. *Ind Crops Prod* 62: 235–241. https://doi.org/10.1016/j.indcrop.2014.08.039
183. Abdelmoez W, Nage SM, Bastawess A, et al. (2014) Subcritical water technology for wheat straw hydrolysis to produce value added products. *J Clean Prod* 70: 68–77. https://doi.org/10.1016/j.jclepro.2014.02.011

184. Munir MT, Kheirkhah H, Baroutian S, et al. (2018) Subcritical water extraction of bioactive compounds from waste onion skin. *J Clean Prod* 183: 487–494. https://doi.org/10.1016/j.jclepro.2018.02.166
185. Rodrigues LGG, Mazzutti S, Vitali L, et al. (2019) Recovery of bioactive phenolic compounds from papaya seeds agroindustrial residue using subcritical water extraction. *Biocatal Agric Biotechnol* 22: 101367. https://doi.org/10.1016/j.bcab.2019.101367
186. Pereira MG, Hamerski F, Andrade EF, et al. (2017) Assessment of subcritical propane, ultrasound-assisted and Soxhlet extraction of oil from sweet passion fruit (*Passiflora alata* Curtis) seeds. *J Supercrit Fluids* 128: 338–348. https://doi.org/10.1016/j.supflu.2017.03.021
187. Duba KS, Casazza AA, Mohamed HB, et al. (2015) Extraction of polyphenols from grape skins and defatted grape seeds using subcritical water: Experiments and modeling. *Food Bioprod Process* 94: 29–38. https://doi.org/10.1016/j.fbp.2015.01.001
188. Awad AM, Kumar P, Ismail-Fitry MR, et al. (2021) Green extraction of bioactive compounds from plant biomass and their application in meat as natural antioxidant. *Antioxidants* 10: 1465. https://doi.org/10.3390/antiox10091465
189. Deng BX, Li B, Li XD, et al. (2018) Using short-wave infrared radiation to improve aqueous enzymatic extraction of peanut oil: Evaluation of peanut cotyledon microstructure and oil quality. *Eur J Lipid Sci Technol* 120: 1700285. https://doi.org/10.1002/ejlt.201700285
190. Lenucci MS, De Caroli M, Marrese PP, et al. (2015) Enzyme-aided extraction of lycopene from high-pigment tomato cultivars by supercritical carbon dioxide. *Food Chem* 170: 193–202. https://doi.org/10.1016/j.foodchem.2014.08.081
191. Boulila A, Hassen I, Haouari L, et al. (2015) Enzyme-assisted extraction of bioactive compounds from bay leaves (*Laurus nobilis* L.). *Ind Crops Prod* 74: 485–493. https://doi.org/10.1016/j.indcrop.2015.05.050
192. Sahne F, Mohammadi M, Najafpour GD, et al. (2017) Enzyme-assisted ionic liquid extraction of bioactive compound from turmeric (*Curcuma longa* L.): Isolation, purification and analysis of curcumin. *Ind Crops Prod* 95: 686–694. https://doi.org/10.1016/j.indcrop.2016.11.037
193. Xu C, Yagiz Y, Borejsza-Wysocki W, et al. (2014) Enzyme release of phenolics from muscadine grape (*Vitis rotundifolia* Michx.) skins and seeds. *Food Chem* 157: 20–29. https://doi.org/10.1016/j.foodchem.2014.01.128
194. Vasco-Correa J, Zapata ADZ (2017) Enzymatic extraction of pectin from passion fruit peel (*Passiflora edulis f. flavicarpa*) at laboratory and bench scale. *LWT* 80: 280–285. https://doi.org/10.1016/j.lwt.2017.02.024
195. Roda A, De Faveri DM, Giacosa S, et al. (2016) Effect of pre-treatments on the saccharification of pineapple waste as a potential source for vinegar production. *J Clean Prod* 112: 4477–4484. https://doi.org/10.1016/j.jclepro.2015.07.019
196. Ameer K, Shahbaz HM, Kwon JH, et al. (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
197. Dzah CS, Duan Y, Zhang H, et al. (2020) Latest developments in polyphenol recovery and purification from plant by-products: A review. *Trends Food Sci Technol* 99: 375–388. https://doi.org/10.1016/j.tifs.2020.03.003

198. Safdar MN, Kausar T, Jabbar S, et al. (2017) Extraction and quantification of polyphenols from kinnow (*Citrus reticulate* L.) peel using ultrasound and maceration techniques. *J Food Drug Anal* 25: 488–500. https://doi.org/10.1016/j.jfda.2016.07.010
199. Patra A, Abdullah S, Pradhan RC, et al. (2022) Review on the extraction of bioactive compounds and characterization of fruit industry by-products. *Bioresour Bioprocess* 9: 14. https://doi.org/10.1186/s40643-022-00498-3
200. Khadhraoui B, Ummat V, Tiwari BK, et al. (2021) Review of ultrasound combinations with hybrid and innovative techniques for extraction and processing of food and natural products. *Ultrason Sonochem* 76: 105625. https://doi.org/10.1016/j.ultsonch.2021.105625
201. Khan MK, Ahmad K, Hassan S, et al. (2018) Effect of novel technologies on polyphenols during food processing. *Innov Food Sci Emerg Technol* 45: 361–381. https://doi.org/10.1016/j.ifset.2017.12.006
202. Essien SO, Udugama I, Young B, et al. (2021) Recovery of bioactives from kanuka leaves using subcritical water extraction: Techno-economic analysis, environmental impact assessment and technology readiness level. *J Supercrit Fluids* 169: 105119. https://doi.org/10.1016/j.supflu.2020.105119
203. Lopeda-Correa M, Valdes-Duque BE, Osorio-Tobon JF (2022) Ultrasound-assisted extraction of phenolic compounds from *Adenaria floribunda* stem: Economic assessment. *Foods* 11: 2904. https://doi.org/10.3390/foods11182904
204. Vilas-Boas AA, Pintado M, Oliveira ALS (2021) Natural bioactive compounds from food waste: Toxicity and safety concerns. *Foods* 10: 1564. https://doi.org/10.3390/foods10071564
205. Veneziani G, Novelli E, Esposto S, et al. (2017) Applications of recovered bioactive compounds in food products, In: *Olive mill waste*. Academic Press, 231–253. https://doi.org/10.1016/b978-0-12-805314-0.00011-x.
206. Fidelis M, de Oliveira SM, Sousa JS, et al. (2020) From byproduct to a functional ingredient: Camu-cmu (*Myrciaria Dubia*) seed extract as an antioxidant agent in a yogurt model. *J Dairy Sci* 103: 1131–1140. https://doi.org/10.3168/jds.2019-17173
207. Özen BO, Eren M, Pala A, et al. (2011) Effect of plant extracts on lipid oxidation during frozen storage of minced fish muscle. *Int J Food Sci Technol* 46: 724–731. https://doi.org/10.1111/j.1365-2621.2010.02541.x
208. Peng X, Ma J, Cheng KW, et al. (2010) The effects of grape seed extract fortification on the antioxidant activity and quality attributes of bread. *Food Chem* 119: 49–53. https://doi.org/10.1016/j.foodchem.2009.05.083
209. Deolindo CTP, Monteiro PI, Santos JS, et al. (2019). Phenolic-rich *petit suisse* cheese manufactured with organic bordeaux grape juice, skin, and seed extract: Technological, sensory, and functional properties. *LWT* 115: 108493. https://doi.org/10.1016/j.lwt.2019.108493
210. Zamuz S, López-Pedrouso M, Barba FJ, et al. (2018) Application of hull, bur and leaf chestnut extracts on the shelf-life of beef patties stored under MAP: Evaluation of their impact on physicochemical properties, lipid oxidation, antioxidant, and antimicrobial potential. *Food Res Int* 112: 263–273. https://doi.org/10.1016/j.foodres.2018.06.053
211. Lorenzo JM, González-Rodríguez RM, Sánchez M, et al. (2013) Effects of natural (grape seed and chestnut extract) and synthetic antioxidants (buthylatedhydroxytoluene, BHT) on the physical, chemical, microbiological and sensory characteristics of dry cured sausage "chorizo". *Food Res Int* 54: 611–620. https://doi.org/10.1016/j.foodres.2013.07.064

212. Turgut SS, Soyer A, Işıkçı F (2016) Effect of pomegranate peel extract on lipid and protein oxidation in beef meatballs during refrigerated storage. *Meat Sci* 116: 126–132. https://doi.org/10.1016/j.meatsci.2016.02.011
213. Choe JH, Kim HY, Kim CJ (2017) Effect of persimmon peel (*Diospyros kaki* thumb.) extracts on lipid and protein oxidation of raw ground pork during refrigerated storage. *Korean Soc Food Sci Anim Resour* 37: 254–263. https://doi.org/10.5851/kosfa.2017.37.2.254
214. Ergezer H, Serdaroğlu M (2018) Antioxidant potential of artichoke (*Cynara scolymus* L.) byproducts extracts in raw beef patties during refrigerated storage. *J Food Meas Charact* 12: 982–91. https://doi.org/10.1007/s11694-017-9713-0
215. Andrés AI, Petron MJ, Delgado-Adamez J, et al. (2017) Effect of tomato pomace extracts on the shelf-life of modified atmosphere-packaged lamb meat. *J Food Process Pres* 41: e13018. https://doi.org/10.1111/jfpp.13018
216. Basiri S, Shekarforoush SS, Aminlari M, et al. (2015) The effect of pomegranate peel extract (PPE) on the polyphenol oxidase (PPO) and quality of pacific white shrimp (*Litopenaeus vannamei*) during refrigerated storage. *LWT-Food Sci Technol* 60: 1025–1033. https://doi.org/10.1016/j.lwt.2014.10.043
217. Ebied AS, Morshdy AEM, Abd-El-Salam EH, et al. (2017) Effect of pomegranate peel powder on the hygienic quality of beef sausage. *J Microbiol Biotechnol Food Sci* 6: 1300–1304. https://doi.org/10.15414/jmbfs.2017.6.6.1300-1304
218. Nishad J, Koley TK, Varghese E, et al. (2018) Synergistic effects of nutmeg and citrus peel extracts in imparting oxidative stability in meat balls. *Food Res Int* 106: 1026–1036. https://doi.org/10.1016/j.foodres.2018.01.075
219. Biswas AK, Beura CK, Yadav AS, et al. (2015) Influence of novel bioactive compounds from selected fruit by-products and plant materials on the quality and storability of microwave-assisted cooked poultry meat wafer during ambient temperature storage. *LWT-Food Sci Technol* 62: 727–733. https://doi.org/10.1016/j.lwt.2014.09.024
220. Abid Y, Azabou S, Jridi M, et al. (2017) Storage stability of traditional Tunisian butter enriched with antioxidant extract from tomato processing by-products. *Food Chem* 233: 476–482. https://doi.org/10.1016/j.foodchem.2017.04.125
221. Bertolino M, Belviso S, Dal Bello B, et al. (2015) Influence of the addition of different hazelnut skins on the physicochemical, antioxidant, polyphenol and sensory properties of yogurt. *LWT-Food Sci Technol* 63: 1145–1154. https://doi.org/10.1016/j.lwt.2015.03.113
222. Sah BNP, Vasiljevic T, McKechnie S, et al. (2015) Effect of refrigerated storage on probiotic viability and the production and stability of antimutagenic and antioxidant peptides in yogurt supplemented with pineapple peel. *J Dairy Sci* 98: 5905–5916. https://doi.org/10.3168/jds.2015-9450
223. Ortiz L, Dorta E, Lobo MG, et al. (2017) Use of banana peel extract to stabilise antioxidant capacity and sensory properties of orange juice during pasteurisation and refrigerated storage. *Food Bioprocess Technol* 10: 1883–1891. https://doi.org/10.1007/s11947-017-1964-6
224. Zaky AA, Hussein AS, Mostafa S, et al. (2022) Impact of sunflower meal protein isolate supplementation on pasta quality. *Separations* 9: 429. https://doi.org/10.3390/separations9120429
225. Kampuse S, Ozola L, Straumite E, et al. (2015) Quality parameters of wheat bread enriched with pumpkin (*Cucurbita moschata*) by-products. *Acta Univ Cibiniensis Ser E: Food Technol* 19: 3–14. https://doi.org/10.1515/aucft-2015-0010

226. Šporin M, Avbelj M, Kovač B, et al. (2018) Quality characteristics of wheat flour dough and bread containing grape pomace flour. *Food Sci Technol Int* 24: 251–263. https://doi.org/10.1177/1082013217745398
227. Zaky AA, Asiamah E, El-Faham SY, et al. (2020) Utilization of grape pomace extract as a source of natural antioxidant in biscuits. *Eur Acad Res* 8: 108–126.
228. Arun KB, Persi F, Aswathy PS, et al. (2015) Plantain peel—A potential source of antioxidant dietary fibre for developing functional cookies. *J Food Sci Tech*nol 52: 6355–6364. https://doi.org/10.1007/s13197-015-1727-1
229. El-Faham SY, Mohsen MSA, Sharaf AM, et al. (2016) Utilization of mango peels as a source of polyphenolic antioxidants. *Curr Sci Int* 5: 529–542.
230. Mildner-Szkudlarz S, Bajerska J, Górnaś P, et al. (2016) Physical and bioactive properties of muffins enriched with raspberry and cranberry pomace powder: A promising application of fruit by-products rich in biocompounds. *Plant Foods Hum Nutr* 71: 165–173. https://doi.org/10.1007/s11130-016-0539-4
231. Hidalgo A, Brandolini A, Čanadanović-Brunet J, et al. (2018) Microencapsulates and extracts from red beetroot pomace modify antioxidant capacity, heat damage and colour of pseudocerealsenriched einkorn water biscuits. *Food Chem* 268: 40–48. https://doi.org/10.1016/j.foodchem.2018.06.062
232. Mir SA, Bosco SJD, Shah MA, et al. (2017) Effect of apple pomace on quality characteristics of brown rice based cracker. *J Saudi Soc Agric Sci* 16: 25–32. https://doi.org/10.1016/j.jssas.2015.01.001
233. Tańska M, Roszkowska B, Czaplicki S, et al. (2016) Effect of fruit pomace addition on shortbread cookies to improve their physical and nutritional values. *Plant Foods Hum Nutr* 71: 307–313. https://doi.org/10.1007/s11130-016-0561-6
234. Putnik P, Lorenzo JM, Barba FJ, et al. (2018) Novel food processing and extraction technologies of high-added value compounds from plant materials. *Foods* 7: 106. https://doi.org/10.3390/foods7070106
235. Zawistowski J (2008) Chapter 24-Regulation of functional foods in selected Asian countries in the pacific rim. In: *Nutraceutical and functional food regulations in the united states and around the world*. San Diego, CA, USA: Academic Press, 419–463. https://doi.org/10.1016/B978-0-12-405870-5.00024-4
236. Plant extracts market size and forecast. Available online: https://www.verifiedmarketresearch.com/product/global-plantextracts-market-size-and-forecast-to-2025/.
237. Beya MM, Netzel ME, Sultanbawa Y, et al. (2021) Plant-based phenolic molecules as natural preservatives in comminuted meats: A review. *Antioxidants* 10: 263. https://doi.org/10.3390/antiox10020263

AIMS Press