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Review

Sustainable Extraction of Bioactive Compounds and Nutrients from Agri-Food Wastes: Potential Reutilization of Berry, Honey, and Chicory Byproducts

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Abstract: Several agri-food byproducts represent valuable sources of compounds to be reutilized for nutritional, nutraceutical, and cosmetic purposes. Examples especially comprise byproducts from the processing of fruits such as pomace, because of their richness in nutrients (e.g., fibers) and bioactive compounds (e.g., polyphenols) that can be destined for animal and human use. However, in agreement with the principles of circular economy that are being promoted during the most recent years, other understudied agri-food byproducts of both plant and animal origin are being evaluated to assess their possible reutilization and valorization. In this review, we aim at summarizing the most recent research dealing with the extraction of nutrients and bioactive compounds from agri-food byproducts using innovative and sustainable approaches. Specifically, the review is focused on byproducts generated in large amounts (tons/year) by the food industry of Northeast Italy, namely, honey, red fruits (grapes and berries), and chicory, which are especially of interest for their content in phenolic acids, flavonoids, anthocyanins, and dietary fiber. The potential applications of these byproducts and extracts in cosmetic, nutraceutical, and nutritional fields are also discussed, referring to the published literature, as well as their potential utilization as sources of novel bioactive compounds with pharmacological applications.

Keywords: agri-food byproducts; honey; chicory; grape; berries; sustainable extraction

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1. Introduction

Roughly one-third of the edible parts of global food produced for human consumption is estimated to be lost or wasted [1], and these losses have been valued at USD 1 trillion [2]. The production of food waste worldwide is much higher in developed countries. According to Van der Werf and Gilliland [3], 198.9 kg/year per capita of food waste is produced in developed countries. The US Environmental Protection Agency (EPA) estimated that 66 million tons of wasted food was generated in US food retail, food service, and residential sectors in 2019, and an additional 40 million tons of wasted food was generated in the food and beverage manufacturing and processing sectors [4]. In the EU, over 59 million tons of food waste are generated annually [5]. North Africa and West and Central Asia account for 6–7% of total global food waste (200 kg per capita/year) [6], and in Latin America the food loss is estimated at 10–15% of total food production (approximately 127 million tons/year) [7]. On the other hand, the generation of agri-food byproducts is increasing progressively and proportionally with the increasing development of the food industry [8]. A large part of these products derives directly from the processing of crops such as oranges, grapes, apples, and tomato, which generates tons of pomace (i.e., peels and seeds mainly) per year [9–11]. However, wastes are also produced due to technical and management limits in the post-harvest, processing, and distribution steps and the high productivity and quality standards required by the market that frequently lead to food discharge by retailers [12,13].

The disposal of nonedible food waste and agri-food byproducts represents an economic, environmental, and social issue due mainly to the high amounts produced, their physicochemical characteristics, and their perishability. These products are frequently disposed of by incineration or landfilling, but this can cause soil, air, and water pollution. Efforts have been made to find alternative solutions in order to reduce the environmental impact of the agri-food chain and to increase its profitability. Many of these involve the reuse of agri-food byproducts and wastes as substrates for the production of biofuels [14] or the development of novel materials with potential utilization in medicine [15] and food technology [16], instead of their disposal. Residues obtained from fruits, cereal, and vegetables processing also represent valuable sources of bioactive compounds and nutrients (e.g., sugars, fats, dietary fibers, vitamins, and polyphenols) to be used in animal and human nutrition or as ingredients of nutraceuticals [17]. In this regard, one of the main issues that scientists and developers have to deal with is finding proper extraction methods for these compounds due to the chemical diversity and complexity of these materials. Extraction protocols should be selective for the compounds of interest in order to yield safe final products suitable for human use, but also environmentally sustainable and economically viable [18]. Also, they should not affect unstable compounds such as several plant secondary metabolites, which can be susceptible to thermal or oxidative degradation, for example. According to the literature, the main extraction techniques still involve the use of some sort of solvent, but the promotion of sustainable chemistry by government authorities all over the world is incentivizing the development of more environmentally friendly techniques, which are being increasingly employed nowadays [19]. Examples of these latter are supercritical fluid, ultrasound-assisted, subcritical water, and microwave-assisted extractions, along with the use of enzymes [20].

In this review, we aim at summarizing the most recent findings on the sustainable extraction of nutrients and bioactive compounds from some byproducts and wastes produced by the agri-food chain of Northeast Italy. Among these, some have been widely considered for their relevant content in bioactive metabolites, such as red fruits and grape (*Vitis vinifera*) pomace. These latter are particularly relevant: Italy leads wine production in the world, with an estimated production of 49.8 mhl of wine in 2022. This large-scale supply leads to a large-scale generation of grape pomace. Approximately 75% of produced grapes is intended for wine production, of which 20–30% represents waste products [21]. It has been estimated that the production of 1000 m^3 of wine generates 82.5 tons of grape pomace on a dry basis [22]. To note, northeastern regions of Italy are among the largest wine producers of the country, and this supply chain is responsible for producing more than 200,000 tons/year of byproducts comprising pomace and stalks [23]. Other byproducts, such as the residues of honey and fresh chicory production, have been less studied up to now, despite their potential content in several compounds of interest. In particular, the leafy chicory named "radicchio" (*Cichorium intybus* var. *foliosum*) is a typical product of Northeast Italy that assumes an important role at both a local and national level, as it characterizes a high proportion of the agricultural income of suited areas [24]. Commercial production of colored radicchio varieties involves a laborious procedure that includes the removal of many outer leaves from heads, with the aim of keeping the inner tissues that are better developed and characteristic of the product. This procedure generates large amounts (estimated annual production in in Northeast Italy: >100,000 tons) of byproducts rich in fibers and phenolic compounds [25].

2. Extraction of Phytochemicals and Volatile Compounds from Agri-Food Byproducts: An Overview of Traditional Techniques and Novel Sustainable Approaches

Several extraction procedures have been developed since ancient times, and these have been adapted to the characteristics of the matrices to extract and to the physicochemical properties of the compounds of interest. In this first part of the review, the main techniques used for the extraction of natural compounds with potential application as bioactive ingredients for food, nutraceutical, and cosmetic use will be introduced. To better understand the advantages and disadvantages of both traditional and novel approaches, a summary of the traditional extractive techniques will be presented first, and then the more innovative and sustainable methods will be discussed. The traditional techniques involve mainly extraction with solvents and include blending, solid–liquid extraction, Soxhlet extraction, and sonication [26]. The main advantages and disadvantages of these techniques are summarized in Table 1.

Table 1. Main advantages and disadvantages of traditional and innovative methods for the extraction of valuable compounds from agri-food byproducts. For each method, exemplificative applications are described in the manuscript.

Extraction Techniques	Advantages	Disadvantages
	Traditional techniques	
Maceration (solvent extraction)	- Simple, low-cost equipment. - Effective for a wide range of compounds (polar and nonpolar). - Adaptable to many plant materials.	- Time-consuming (hours to days). - Large solvent consumption. - Poor selectivity, may extract unwanted components. - Loss of volatile or thermolabile compounds.
Soxhlet extraction	- Efficient for continuous extraction with small solvent volumes. - Ideal for nonpolar substances like lipids. - High extraction yields.	- Long extraction times (up to 24 h). - Not suitable for thermally sensitive compounds. - Energy-intensive due to continuous heating.
Ultrasound-assisted extraction (UAE)	- Reduces extraction time and solvent use. - Enhances solvent penetration and extraction efficiency. - Low energy consumption.	- Ultrasound can cause degradation of thermolabile compounds. - Optimization of frequency and duration is essential to avoid undesired effects.
Hydro-distillation	- Widely used for essential oils extraction. - Simple process using water as solvent.	- High temperatures may degrade volatile compounds. - Long processing times. - Yields can be low for nonvolatile compounds.
	Innovative techniques	
Microwave-assisted extraction (MAE)	- Significant reduction in extraction time (minutes). - Less solvent required. - Uniform heating enhances efficiency. - Green and eco-friendly.	- High temperatures can degrade thermolabile compounds. - Requires specialized equipment. - Best suited for compounds stable at moderate to high temperatures.
Pressurized liquid extraction (PLE)	- Faster extraction with lower solvent use. - High pressure accelerates solvent penetration, reducing time. - Can use GRAS solvents like ethanol.	- High temperatures can degrade heat-sensitive compounds. - Equipment costs are higher. - Not suitable for small-scale labs due to complexity.
Supercritical CO_2 extraction (SFE-CO_2)	- Green solvent, no toxic residues. - High selectivity, adjustable for various compounds. - Ideal for thermolabile compounds due to mild conditions.	- High equipment costs. - Inefficient for polar compounds unless a cosolvent (e.g., ethanol) is used. - Requires optimization of pressure and temperature for each matrix.

Table 1. *Cont.*

Extraction Techniques	Advantages	Disadvantages
Enzyme-assisted extraction (EAE)	- Environmentally friendly. - Mild conditions prevent degradation of sensitive compounds. - Reduces solvent use. - High precision and selectivity.	- Enzyme costs can be high. - Requires specific enzyme optimization for different matrices. - Slower than physical methods (e.g., ultrasound).
Pulsed electric fields (PEF)	- Nonthermal technique preserves thermolabile compounds. - Enhances mass transfer for improved yields. - Low energy consumption.	- Expensive equipment. - Limited use as a standalone technique, mainly employed as a pretreatment. - Requires specific parameter optimization for each matrix.
Negative pressure Cavitation (NPC)	- Efficient and energy-saving. - No significant temperature increase, preventing degradation. - Promotes higher turbulence and mass transfer.	- Requires nitrogen flow. - Limited research and applications compared to other techniques. - Higher initial equipment cost.
High pressure homogenization (HPH)	- High pressure enhances solvent penetration, improving extraction efficiency. - Short processing time.	- Can cause degradation of some sensitive compounds (e.g., anthocyanins, vitamin C). - May require combination with other techniques for optimal extraction.
Instant controlled pressure drop (DIC)	- Fast extraction of volatile and heat-sensitive compounds. - Prevents degradation through rapid cooling and pressure drop.	- High equipment costs. - Mainly applicable to specific compounds like essential oils and volatile bioactives.

2.1. Traditional Approaches Involving the Use of Organic Solvents

2.1.1. Maceration

Maceration, also known as traditional solvent extraction, is an extractive technique that consists of immersing the matrix, typically herbal, in a solvent at room temperature for a variable time (hours or days) depending on the starting material and solvent used. It can also be assisted with stirring [27]. The initial matrix can be previously treated by drying or it can be used fresh, also depending on the desired compounds. Usually, the starting material is cut or milled into finer particle size to facilitate the penetration of the solvent and diffusion of the solutes. However, it is never reduced to too-fine particles or powder, because this can cause the loss of volatile compounds and the excessive absorption of solute in solid, making the separation by filtration of the extract more difficult.

The choice of the solvent is very important during the extraction; the solvent must be chosen based upon the chemical nature of the compounds of interest. Generally, alcohols (methanol and ethanol) are the most used solvents, due to their ability to extract a greater part of substances, including hydrophilic molecules and lipophilic ones [28,29]. A more selective extraction is also possible; in order to isolate only the lipophilic fraction, the extraction is performed using vegetable oils. Meanwhile, water is used to extract only hydrophilic ingredients.

At the end, the mixture is strained, the solid material is pressed to recover all of the product, and the combined liquids are filtered or decanted. An interesting study on the effects of long-term frozen storage on the nutraceutical compounds and antioxidant properties of blueberry (*Vaccinium corymbosum*), blackcurrant (*Ribes nigrum*), and raspberry (*Rubus idaeus*) was carried out in 2010 by Poiana et al. The fruits were extracted by maceration using an acidic ethanol solution. This extraction system allowed them to analyze the total phenolic content, total monomeric anthocyanins, vitamin C, antioxidant activity, and color indices. The results concluded that no significant loss of antioxidant activity happened within 4 months after the freezing of the samples and that blueberries contain the highest amounts of polyphenols, anthocyanins, and antioxidant activity between the three berries. On the other hand, raspberry showed the highest content of vitamin C [30].

The search for bioactive compounds is constant in the scientific community. A wide range of studies have been published about the isolation and characterization of polyphenols, pigments, fatty acids, and more, and several of them used the most traditional solvent extraction technique. For instance, polyphenols and other classes of bioactive substances extracted from strawberries (*Fragaria* × *ananassa*) were widely studied throughout the years. The extraction protocols with solvents were kept pretty much the same. For example, Heber's research team described a maceration extraction followed by several solvents partitions and chromatographic purification in order to yield the enriched anthocyanin and ellagitannin fractions [31]. More recently, Salas-Arias et al. extracted and characterized the polyphenol fraction of both strawberry leaves and fruits through maceration in hydroalcoholic mixtures. Extracts were then tested for possible photoprotective effects against UV damage in human melanoma cells (SK-MEL-28) and in murine embryo fibroblasts (NIH/3T3) [32].

2.1.2. Soxhlet Extraction

The Soxhlet technique was developed in 1879 by Franz von Soxhlet [33]. Generally, the Soxhlet extraction is used to obtain a specific compound (or class of compounds) that has a limited solubility in a certain solvent, and the impurity/undesired fractions are not soluble in that solvent. This method permits the extraction in a "self-acting" manner; meanwhile, the autofill system recycles the small amount of solvent that is necessary to perform the extraction. It was originally designed, and until today has been widely used, for the extraction of lipids from a solid matrix [34]. During the study of hypoglycemic properties of oat bran paste enriched with bioactive compounds from blueberry and blackcurrant, Hui et al. used a Soxhlet extraction method to determine the total fat content [35].

Even if the Soxhlet technique was developed over a century ago, it is still widely used in phytochemicals extraction. In 2020, the phytochemical characterization of *Punica granatum* (pomegranate) leaves was performed by Trabelsi et al. During that study, six plant extracts were obtained from the powdered leaves of pomegranate. Hexane, chloroform, ethyl acetate, and ethanol extracts were prepared by successive Soxhlet extraction of 6 h each; meanwhile, an extract enriched with total oligomer flavonoids was prepared by maceration in a mixture of acetone/water, and the sixth one was obtained by a decoction of the plant material in boiling water. The yield of extracts varied among extraction solvents and extraction methods between 0.5 and 20.07% [36].

In a comparison between the Soxhlet extraction technique with ethanol and hexane as solvents and supercritical CO_2 extraction, Wajs-Bonikowska et al. described that the highest extract yield of oil and bioactive compounds from blackberry (*Rubus fruticosus*) seeds was obtained by Soxhlet extraction using ethanol as a solvent (14.2%) [37]. The use of the Soxhlet technique was reported for the preparation of applicable nanofibers loaded with honeybee propolis extract (HBP) as a model drug. Among the studied extraction methods (maceration and ultrasound extraction), it was the Soxhlet technique that gave the highest yield of HBP [38].

2.1.3. Ultrasound-Assisted Extraction (UAE)

Sonication or ultrasonication is a procedure that involves the use of ultrasound frequencies that range from 20 kHz to 2000 kHz. This method uses the sound energy to increase the agitation of a sample's particles in order to extract several compounds [39]. During this process, the soundwaves diffuse through the solvent, provoking a pressure variation on the system that leads to the acoustic cavitation growth and collapse, thus enhancing the permeability of the solvent on the cell walls.

There are two main sonication extraction mechanisms: the ultrasonic bath and the ultrasonic probe. The matrix is placed into contact with the solvent for a limited amount of time. Researchers have reported in the literature a significant reduction in the extraction time when the ultrasound-assisted method is used [40,41]. Because ultrasound technology is used to break the matrices and facilitate the extraction, its use has been applied outside the research community at an industrial level to increase the quality of fruit juices with a higher content of sugars and polyphenolic compounds [42].

A common feature reported in the literature is the use of ultrasonic-assisted extraction (UAE) to increase the solubility of compounds in the extraction with solvent, thus reducing the amount of solvent required to obtain the target compounds. For example, the optimization of the extraction of ellagitannins from raspberry, blackberry, strawberry (*Fragaria grandiflora*), and wild strawberry (*Fragaria vesca*) have been reported. The best conditions were obtained by UAE and using the response surface methodology (RSM) [43].

Since the sonication frequency is variable and, in some cases, it could cause undesirable effects on the target substances, the effect of UAE is constantly studied in articles published in the literature. These effects were studied for the characterization of the inhibitory effect of α-glucosidase on blackberry polysaccharide. This particular study concluded that the degradation by ultrasonic treatment decreased the molecular weight and particle size of the native polysaccharide; however, no significant structure change was observed [44].

2.1.4. Extraction of Volatile Compounds: Hydrodistillation

Another traditional method is hydrodistillation. This is usually used in the extraction of essential oils, and also in industrial contexts. In this technique, the matrix is confined in an extracting vessel with water and heated to a boil. The water and oil mixture travels in vapor form until it is condensed. The cooled mixture floods the separator, where the extracted oil (generally, essential oil) is separated from the water by their density difference.

Like the other traditional extraction methods mentioned before, hydrodistillation is still used to obtain bioactive compounds from several natural matrices and agri-food byproducts. For instance, Kirillov et al. reported, for the first time, the composition of the essential oils from leaves and fruits of green strawberry (*Fragaria viridis*). The oils were obtained by hydrodistillation, allowing the authors to predict a possible anti-inflammatory, antimicrobial, antioxidant, anticancer, antinociceptive, anxiolytic, and sedative activity [45].

A well-known issue with this technique is the degradation that the volatile compounds can suffer during hydrodistillation. An evaluation of four isolation techniques used to analyze and identify potential honey aroma compounds as markers revealed that the damaging effect of the conditions used caused the formation of undesired products mainly because of the effect of heat on the sugars present in the matrix, and also the degradation and oxidation of sensitive substances [46].

However, from a more ecological approach, the byproducts of hydrodistillation (hydrosol) are proven to be useful and rich in bioactive compounds. For instance, the hydrosol from *Hamamelis virginiana* (commonly known as "witch hazel") is widely used in cosmetics and medical treatments due to its vasodilator activity and topical relief [47]. On the other hand, hydrosols of aromatic plants with antioxidant properties, such as rosemary (*Salvia rosmarinus*), thyme (*Thymus vulgaris*), and sage (*Salvia officinalis*), are commonly used with alimentary purposes to marinate turkey [48].

2.2. Innovative and Sustainable Extraction Methods

2.2.1. Microwave-Assisted Extraction (MAE)

Microwave-assisted extraction (MAE) is considered a more modern, unconventional, and more sustainable extraction method. This technique provokes the disruption and/or changes of cell structures through the application of nonionizing electromagnetic waves. The frequency of the waves can range from 300 MHz to 300 GHz to a sample matrix; however, it is normally set between 0.915 and 2.45 GHz. The ionic conduction and dipole rotation mechanisms promote the energy transfer during an MAE, thus facilitating the migration of chemical compounds through a solution, and the heat in the media is caused by the resistance of the extraction solvent to the ionic migration when the electromagnetic waves are being applied [49]. It can be described, in a nutshell, as the use of microwave radiation to heat the extraction solvent, this way accelerating the dispersion of the solvent in the sample and assisting the diffusion of the target compounds from the sample into the solvent. This technique is also suitable for the extraction of volatile compounds, considering that the MAE equipment, which is simple and affordable, can be used as a distiller if properly configured with a condenser and a recovery vessel (Figure 1).

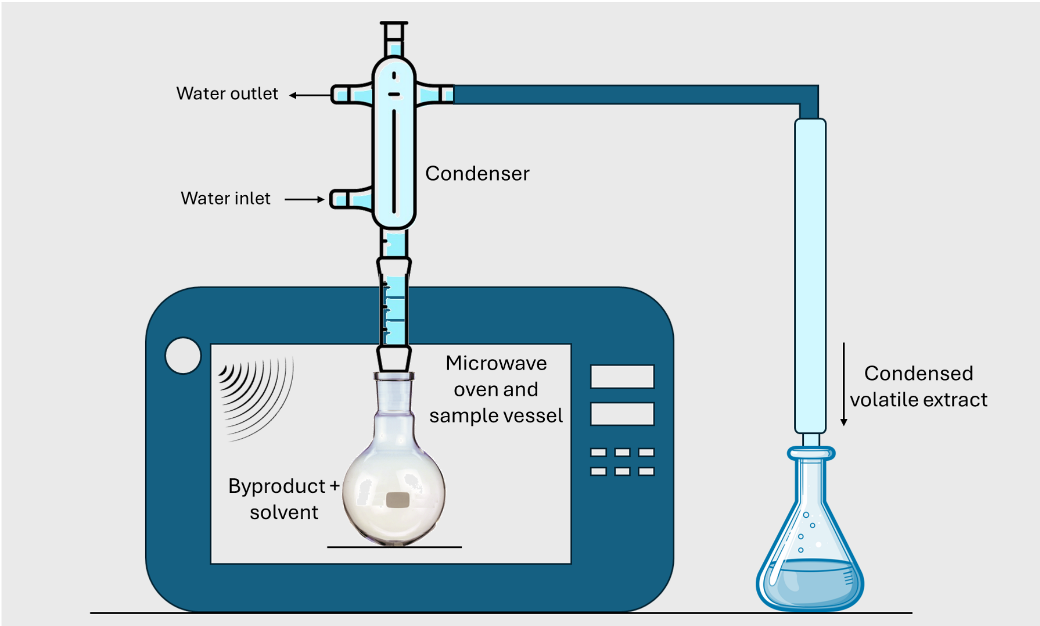

Figure 1. Scheme of an apparatus for microwave-assisted extraction (MAE) of volatile and nonvolatile compounds from agri-food byproducts. The matrix to be extracted is dispersed in the most appropriate solvent in a glass vessel, which is placed in the microwave oven. Application of microwaves heats the solvent and induces the extraction of chemical constituents. Volatile compounds are recovered upon distillation through a condenser, while nonvolatile compounds are recovered directly from the vessel.

Even though MAE is considered a more modern technique, it has been used by researchers for decades. In 2013, Zheng et al. published an investigation on the extraction characteristics and optimal parameters for the MAE of anthocyanin from blueberry powder. In that study, the chosen parameters were extraction temperature, solvent concentration, matrix–solvent ratio, and extraction time. With the optimized parameters, they were able to obtain an extraction rate of anthocyanin of 73.73% within an extraction time of 7 min [50].

The positive results reported in the literature led to more publications on the use of this technique, some of them focused on the optimization of the method using statistical tools, like the work carried out by Wen et al., where the optimal conditions for the extraction of antioxidant compounds from blackberry were obtained by Box–Behnken design (BBD) of response surface methodology (RSM). The obtained results included a microwave power of 469 W and an extraction time of 4 min yielding 2.18 $\pm$ 0.06 mg/g, a value 120% higher than the amount of extract obtained by ethanol leaching extraction, according to the authors [51].

A similar optimization protocol was used more recently to perform a comparison between the MAE and the UAE techniques [52]. The recovery of total phenolic compounds from *Camellia japonica* var. *Eugenia de Montijo* was studied with different parameters for each methodology. For UAE the chosen ones were solvent (acidified ethanol was switched from 0 to 100% v/v), power (30–80%), and time (5–45 min); meanwhile, the parameters solvent (0 to 100% v/v acidified ethanol), temperature (50–180 °C), and time (5–25 min) were optimized for the MAE. Overall, MAE provided better results than UAE at their respective optimum conditions (for MAE: maximum yield: 80% at 180 °C and 5 min), although a relevant yield was achieved with UAE (56% at 62% amplitude, 8 min, 39%

acidified ethanol) [52]. Studies using this methodology have evolved during the years, and its use as a pretreatment has yielded some interesting results for the enhancement of nutraceutical oils properties (e.g., [53]).

2.2.2. Pressurized Liquid Extraction (PLE)

Pressurized liquid extraction (PLE) is another technique that is considered more modern; however, it has been consolidated mainly as a high-throughput and green extraction technique. It is considered sustainable and adequate for the extraction of bioactive compounds from biological origins and for the characterization and determination of a wide variety of compounds of interest in food and other matrix samples [54]. Several authors consider the PLE as a pressurized and accelerated solvent extraction [55].

This methodology employs organic liquid solvents at high temperature (50 to 200 °C) and pressure (10 to 15 MPa) to implement a faster extraction of target compounds. The temperature and dielectric constant of the solvent have an inversely proportional relation; with the increase in the temperature, the dielectric constant decreases. Thus, the polarity of the solvent becomes lower [55]. Therefore, it is possible to tune the extraction temperature to the polarity of a solvent in order to recover the compounds of interest. Due to the high pressure, the matrix cells are saturated faster, which compels the solvent into the solid sample. This way, this technique is able to reduce the extraction time and the amount of solvents necessary, at the same time increasing the yields when compared with traditional solvent extraction [56]. Even if this method has some positive features, it also has clear drawbacks. It is not suitable for the extraction of thermolabile compounds, as high temperatures are necessary and they can cause degradation effects on the molecular structure of some desired compounds [57].

Some researchers use water and generally recognized safe solvents (e.g., ethanol) to obtain food-grade extracts using the PLE method. In a recent work, the PLE conditions for the recovery of bioactive compounds from fruit byproducts, mainly pomegranate (*Punica granatum*) peels, were studied in order to achieve the best conditions, using a solution of water and ethanol [58].

The use of extraction techniques to recover high-value substances from food industry waste is not a recent proposition, mainly because natural matrices are rich sources of important groups of compounds such as carotenoids, tocopherols, and polyphenols. Crop plants like red chicory have a considerable amount of waste (roots and steams) that are not consumed by either humans or animals. The mentioned characteristics led to the study performed by Lante et al., where the phenolic profile was characterized after the extraction by PLE [59]. In other works, the use of PLE had a considerable positive effect when compared to the traditional methods such as maceration and Soxhlet. Machado et al. studied the best conditions to achieve an enhancement in the antioxidant activities of the extracts from blackberry fruits [60].

2.2.3. Enzyme-Assisted Extraction (EAE)

The search for more and more environmentally friendly extraction methods has been recently focused on alternative methods such enzyme-assisted extraction (EAE). Based on the principle that enzymes are able to catalyze reactions with high precision, specificity, selectivity, and conversion, EAE has the potential to improve solvent extraction toward a greener path. One of the principles of EAE is that enzymes can break organic membranes and cell walls, facilitating the diffusion of the compounds of interest into the medium. A positive feature of EAE is the possibility to work with mild extraction conditions [61,62]. Enzymes are usually added to aqueous mixtures of byproduct at appropriate buffer conditions and temperature. After extraction, enzymes can be inactivated by heating and removed by centrifugation [61,62].

Studies in the literature have shown that EAE methods are able to achieve considerably high-yield extracts, especially for anthocyanin [63,64], carotenoids [65], lipids [66], proteins [67], and a wide variety of phenolic compounds [68]. A multistep process for the recovery of the lipophilic fractions of blackcurrant pomace after extraction with supercritical CO_2 showed some very positive results on the isolation of substances with higher polarity with pressurized liquid and EAE extractions. PLE and EAE yielded an additional 12.3–39.9% of extracts [69].

Recently, it was also reported that EAE helped to reduce the extraction time and enhance the quality of the extracts while reducing the amount of solvent necessary. The recovery of essential fatty acids, tocopherols, phytosterols, ellagitannins, and polyphenolics from raspberry pomace industrial waste using EAE is an exemplification of the sustainable potential that this technique can offer. In the work reported by Saad et al., the efficacies of the enzymes carbohydrases and proteases were evaluated, allowing the recovery of polyphenols and, consequently, antioxidant activity to reach 48% and 25%, respectively, higher than what was observed when the extractions were made with traditional extraction methods using solvents such as methanol, acetone, and water mixtures [70].

2.2.4. Pulsed Electric Fields (PEF)

The pulsed electric field (PFE) treatment technique is an emerging technology with its biggest advantage being that it is not a thermal technology; thus, it is a promising technique for the extraction of highly valued substances without the risk of thermal degradation. Some authors consider PEF treatment only as a pretreatment [71]. The PEF is applied to a plant matrix that is placed between two electrodes at room temperature, or, less commonly, at a temperature a bit higher than the ambient temperature [72]. The exposition of the organic cells to the given electric field generates a critical electrical potential across the cell membrane, causing an electrical breakdown, therefore provoking structural damage to the cell membrane. The electrical breakdown creates little holes (pores); this phenomenon is called electroporation, favoring the mass transfer from the organic matrix to the extraction medium [73].

The increase in the extraction kinetics with the assistance of PEF is constantly reported. Using an optimized number of pulses of the PEF technique, Rajha et al. achieved an intensification of polyphenols extraction from pomegranate peels. The results showed that this treatment was able to enhance the extraction kinetics of polyphenols along with their antiradical activities [74].

The positive effect of requiring milder temperatures has also been studied, with extractions being made at temperatures of 10 and 22 °C; an experimental design gave the conditions to perform PEF and achieved an increment of 19%, 45%, and 6% for total phenolic compounds, antioxidant activity, and total monomeric anthocyanins, respectively, in blackcurrant matrices [75]. A comparison between high-pressure, UAE, and PEF treatments on strawberry juices revealed that equivalent nonthermal processes had a different effect on strawberry juice quality. High pressure and PEF significantly stimulated the enhancement of the retention of total phenolic content and radical scavenging activity on the studied juices [76].

2.2.5. Negative Pressure Cavitation (NPC)

Negative pressure cavitation (NPC) is based on acoustic cavitation methods, a fluid mechanics phenomenon in which cavitation occurs due to negative pressure conditions. This method is considered cheaper than other innovative extraction techniques, and it is energy-efficient [77]. It is similar to UAE; however, it has the advantage of no or minimum increase in temperature during the process, and in some situations it can relatively lower the temperatures due to the presence of nitrogen bubbles. The extraction with NPC involves a continuous nitrogen flow into the liquid–solid extraction system. By causing an increase in the turbulence and increasing the collisions, cavitation causes corrosion on the surface of the solid and damage on the cell membranes. This effect promotes the mass transfer of nearby solid particles from the organic matrix and the extraction medium and facilitates the recovery of the compounds of interest [78].

Two correlated works from Wang et al. took advantage of the inherent properties of the NPC to extract phenolic compounds and chlorogenic acid from blueberry leaves. Both studies described the optimization of the extraction method, highlighting the potential to use negative-pressure cavitation on extraction and purification of the studied compounds in pilot or large-scale operations [79,80].

2.2.6. High-Pressure Homogenization (HPH)

Another emerging extraction assistance technology based on the breaking of the organic cell wall is high-pressure homogenization (HPH). Also considered as a pretreatment or an assistance for solvent extraction, this method provokes the rupture/modification of the cell walls, facilitating the migration of the solvent into the cellular membrane of the matrix by high-intensity mechanical stress. This is possible because the liquid (extraction solvent) flows through the homogenization chamber at high pressure (40 or 350 MPa), generating high intramaterial shear forces that disintegrate the plant matrix [81].

HPH is widely used as a treatment against microbial contamination, similar to a nonthermal pasteurization [82]. Some studies have investigated the combination of both effects of the technique in a variety of organic matrices. In a study about the quality of pomegranate juice, HPH was compared to thermal pasteurization techniques, and their effects on microbial, nutritional, and organoleptic properties were reported. The total polyphenol content and antioxidant activity were also measured, and, in both treatments, they were higher [83].

The negative effects of this technique have been also reported in the literature: for instance, it has been observed to negatively affect the stability against the sedimentation of strawberry juice and to increase its viscosity. However, even if color and anthocyanin content were slightly affected by the high pressure levels, the total polyphenol concentration was increased up to 30% compared to the control juice (filtered) [84]. In a more recent work, blackcurrant was treated with HPH at different values of pressure, number of passes, and inlet temperature to investigate the effect on total phenolic content and other properties. The results showed a significant degradation of vitamin C and anthocyanin [85].

2.2.7. Instant Controlled Pressure Drop (DIC)

A potential treatment within the more modern techniques is the instant controlled pressure drop, abbreviated as DIC from the French expression: *Détente Instantanée Contrôlée* (instant controlled relaxation). DIC, which was developed at the end of the 1980s, is mainly used for the extraction of essential oils and volatile molecules by autovaporization, because its principle is based on steam extraction. The DIC apparatus (Figure 2) is composed of four compartments: (1) the extraction vessel where the sample is placed and treated: the sample is exposed to a saturated stem for a short period of time; (2) a controlled instant-pressure-drop valve that makes possible the quick release of the steam under pressure into the vacuum chamber; (3) the vacuum chamber, which has a volume 50 times higher than the extraction vessel and is surrounded by a cooling jacket; (4) a trap connected to the vacuum chamber, where the pressure is suddenly dropped and the extract is recovered [86]. Therefore, the temperature exchange rate between the matrix surface and the saturated vapor is so fast that it causes an almost immediate vaporization of the water inside the cell. Due to the presence of air and water, evaporation/condensation creates some openings. The heat flow is used to evaporate water and essential oils through product openings.

Most of the more modern methods or emergent technologies have been developed to eliminate, or at least reduce, common issues of traditional techniques such as thermal degradation and leaching of more volatile components, always searching for higher extraction yield and reduced processing time and energy demands. The potential of DIC as an extraction technique has been reported for the recovery of polyphenolic compounds in pomegranate peels. In 2016, Ranjbar et al. pretreated pomegranate peels with DIC to enhance extraction efficiency. That work involved the optimization of the method where the longest extraction time was 60 s [87]. In a comparison between superheated solvent extraction and instant controlled pressure drop-assisted solvent extraction (DIC-SE) on total phenolic, flavonoids, and anthocyanins compounds from pomegranate peels, DIC-SE proved to be more effective in the flavonoid extraction, which took only 5 s [88].

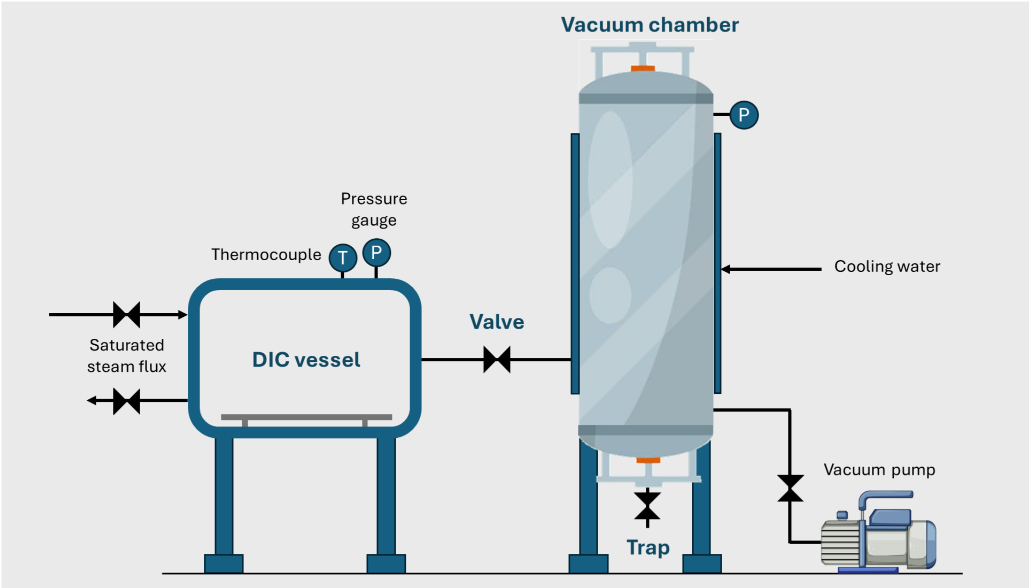

Figure 2. Scheme of an apparatus for instant controlled pressure drop extraction. The main compartments of the instrumentation are the DIC chamber where the sample is placed and extracted, the pressure-drop valve that releases the pressurized steam into the vacuum chamber, and a trap where the extract is recovered.

2.2.8. Supercritical CO_2

Carbon dioxide (CO_2) is widely employed as chemical feedstocks for a variety of applications because it is nontoxic, nonflammable, abundant, economical, and intrinsically renewable. Among the applications of carbon dioxide in science, green extraction technologies like supercritical fluid extraction (SCFE) can conform to all the current, as well as likely future, regulations pertaining to safety, health, and the environment [89]. Advantages of using CO_2 as a solvent include chemical inertness, nontoxicity, nonflammability, nonexplosiveness, and availability with high purity at a reasonable cost; moreover, thanks to its physical properties, any further solvent removal procedure is not needed, making it interesting for industrial application [90,91]. Furthermore, relatively low critical properties (Tc = 304.1 K, Pc = 73.8 bars) make CO_2 an ideal solvent when it comes to the extraction of thermally labile components such as terpenes and carotenoids (and represent a good aspect for further industrial application involving lower plant costs), allowing excellent handling properties and recovery of solvent [92,93]. With these remarks, supercritical fluid extraction based on carbon dioxide (SFE-CO_2) has been evaluated as a solvent for the recovering of interesting and added-value compounds, especially from wastes of the agri-food industry. In this application, SFE-CO_2 turns out to be a very advantageous technique considering the particular supercritical state properties: in fact, it is characterized by both gas and liquid properties, i.e., gas-like viscosity and diffusivity and liquid-like density and solvating properties, which allow the fluid to diffuse easily through the matrix, giving faster extraction yield [93]. Additionally, the density of supercritical CO_2 (scCO_2) can be modified by changing its pressure and/or temperature, modifying the solvent strength of the fluid [92,94]. A general scheme of an apparatus for SFE-CO_2 is shown in Figure 3.

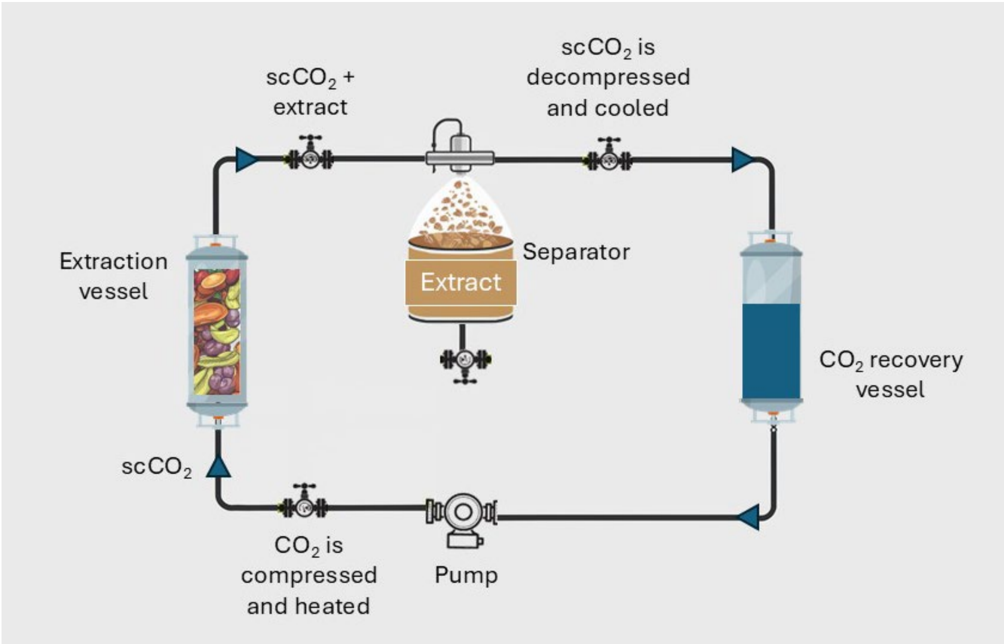

Figure 3. General scheme of an apparatus for SFE-CO_2 extraction. The extraction vessel is filled with dried agri-food byproducts. The pump forces compressed and heated CO_2 at the supercritical state (scCO_2) into the extraction vessel, where extraction of lipophilic compounds is carried out. The extract is recovered in the separator, where the pressure is decreased and the scCO_2 separates from the extract. The CO_2 is finally recovered and is recycled for further extraction cycles.

Focusing on scCO_2 as extraction solvent, thanks to its sustainability and tunable-solvation properties, it has been studied over the years to valorize byproducts from the agri-food industry, enhancing the circular economy standpoint [95]. Natural bioactive compounds from agri-food waste constitute a wide variety of molecules with different structures and functionalities to produce nutraceuticals, functional foods, and cosmetics. Even if scCO_2 is an apolar solvent, it is shown to be an effective solvent for a very large class of compounds such as polyphenols, lycopene, anthocyanins, lipids, sugars, alkaloids, proteins, dietary fibers, and flavors, because the extraction selectivity can be tuned by the use of cosolvent (ethanol, water), forming tailorable solvent mixtures with different polarities [96]. In a recent work carried out by our group, scCO_2 turned out to be the best solvent for the selective recovery of fatty acids (FAs) from discarded waste pomace [97]. In this study, six different processed wastes were considered: blackberry, raspberry, blackcurrant, wild strawberry, pomegranate, and blueberry. To investigate scCO_2 efficiency as a green solvent for the recovery of such compounds (especially FAs), it was compared with traditional Soxhlet liquid extractions using hexane as solvent. The extraction conditions for SFE-CO_2 (P, T, CO_2 flow, time) were optimized based on the recovered yield, showing that 300 bar and 70 °C with a flow of 5 mL/min for 5 h were the best conditions to recover the highest amount of target compounds from all the matrices. All the SCF-CO_2 experiments were performed with these parameters, while Soxhlet extraction was performed at 68 °C (reflux) for 24 h. The results showed that the extraction yields of the wild strawberry, blueberry, pomegranate, and blackcurrant pomace obtained by using hexane as the solvent were generally higher than with SFE-CO_2, but the selectivity towards FAs was always significantly higher with the latter.

3. Agri-Food Byproducts as Valuable Sources of Bioactive Compounds: Chemical Composition of Chicory, Honey, and Red Fruit Byproducts

3.1. Lettuce and Chicory Byproducts

Lettuce (*Lactuca sativa*) and chicory (*Cichorium* spp.) are commercialized as both whole lettuce heads and as fresh-cut products. Nowadays, there has been a great development of the fresh-cut vegetable industry, with fresh-cut lettuce being one of the most important products. The packing houses dealing with these vegetables produce large amounts of byproducts, mainly outer leaves, stems, and roots. Sometimes these byproducts can reach 50% of the harvested material as in lettuce production. Different approaches have been taken for the valorization of the byproducts, including animal feedstuff and fiber production [98,99]. In addition, studies have demonstrated that vegetable byproducts are an interesting and cheap source of health-promoting antioxidant polyphenols [100]. Lettuce and chicory byproducts are rich sources of hydroxycinnamic acids and flavonoids, such as caffeoylquinic and caffeoyltartaric acid derivatives, and luteolin, quercetin, and kampferol derivatives, respectively [100]. Sesquiterpene lactones are characteristic constituents of leaves, and they are responsible for the bitterness of chicory. Ferioli et al. evaluated the content in sesquiterpene lactones of several chicory species, reporting 11(S),13-dihydrolactucin, lactucin, 8-deoxylactucin, 11(S),13-dihydro-8-deoxylactucin, 11(S),13-dihydrolactucopicrin, and lactucopicrin as main components [101]. On the other hand, roots are characterized by high amounts of inulin (starch-like polysaccharide), coumarins, flavonoids, sesquiterpene lactones (lactucin and lactucopicrin), tannins, alkaloids, vitamins, minerals, and volatile oils [102].

Red chicory leaves (*C. intybus* var. *foliosum*) have been extensively characterized for their phenolic profile, characterized by several hydroxylated benzoic acid and p-coumaric acid derivatives, chlorogenic acids, and flavonoids, among which are quercetin, kaempferol, and apigenin derivatives (e.g., rutin, quercetin-3,4-O-diglucoside, quercetin-3-O-glucoside and quercetin-3-O-(6′′-malonyl-glucoside), apigenin-7-O-glucoside, kaempferol-7-O-glucoside). Important constituents of red chicory leaves are the anthocyanins, which are responsible for their dark-red color. Among these, several cyanidin (e.g., cyanidin-3-O-glucoside, cyanidin-3-O-(6′′-malonyl-glucoside) and cyanidin-3,5-di-O-(6′′-O-malonyl-glucoside)), delphinidin (delphinidin 3-O-(6′′ malonyl)-glucoside), and pelargonidin (pelargonidin-3-O-monoglucuronide) derivatives have been reported [103,104], and they have been associated with the antioxidant and antiproliferative activities of red chicory [105–107].

Red chicory whole leaves and polyphenol-rich extracts have already been evaluated for their nutraceutical potential, showing significant antioxidant, cytoprotective, and antiproliferative effects in vitro [105,106]. Chicory fermented with *L. plantarum* and *L. hilgardii* shows an increase in antioxidant and antimicrobial activities due to the release of phenolic compounds, such as gallic acid protocatechic acid, chicoric acid, chlorogenic acid, and several degradation products of these phenolics [25]. Red chicory extract has also been evaluated as a natural antioxidant for the food and feed industries, showing an effective reduction in lipid peroxidation of different oils [59].

Green Extraction of Bioactive Compounds from Chicory Byproducts

In a work published by Baiano et al., the authors compared the extraction efficacy of MAE in water with conventional solvent extraction performed under heating, focusing on total polyphenols [108]. The MAE was performed with a domestic microwave oven at 750 W for 2 or 4 min, assaying different solid-to-liquid ratios. Although, in any case, the extraction efficacy of MAE was lower than conventional solvent extraction, the MAE performed at 750 W for 4 min achieved a total phenolic yield of almost 400 mg/kg of fresh material. Furthermore, the obtained extract showed an antioxidant capacity of 0.21 and 31679 mmol Trolox eq/kg of fresh material, measured by DPPH and ABTS assays, respectively.

In a more recent work by Cova et al., the authors aimed at investigating the influence of UAE, MAE, and their combination on the recovery of the polyphenolic fraction from industrial chicory leftovers [109]. Results showed the highest extraction yield (87% *w*/*w*) using the MW/US technique in an EtOH 60% *v*/*v* solution for 15 min, although the highest phenolic content over dried extract (67.5 mg GAE/g DE) was obtained using MAE in subcritical H_2O for 15 min. Overall, the phenolic profile was not changing when using different extraction techniques, and major constituents were the phenolic acids chlorogenic, p-coumaric, p-hydroxybenzoic and caffeic acids, and the flavonoids luteolin-3-glucoside and apigenin-3-glucoside.

In another work by Baixinho et al., the authors developed an $scCO_2$ method for the extraction of sesquiterpene lactones from chicory root waste, for possible human health-promoting applications [110]. By performing a DoE, the best operating conditions were achieved at 350 bar, 40 °C, and 10% EtOH as a cosolvent in a 15 g/min flow rate for 120 min. Results showed a yield of 1.68% mass and 0.09% sesquiterpenes, and two sesquiterpene lactones not commercially available (8-deoxylactucin and 11β,13-dihydro-8-deoxylactucin) were isolated. Results from anti-inflammatory assays on yeast calcineurin/Crz1 pathway showed a pathway inhibition of 61.74% with 50 µg/mL of $scCO_2$ extract, and 53.38% with 10 µg/mL of purified fraction containing 8-deoxylactucin and 11β,13-dihydro-8-deoxylactucin. Overall, these data show the applicability of sustainable extraction technology to recover potential bioactive compounds from chicory byproducts.

During recent years, several works have been focused on the extraction of inulin from chicory roots produced as industrial byproduct. Inulin is a soluble fiber that is widely used in the food industry and has various pharmacological effects, such as lowering the blood glucose level, reducing LDL cholesterol and serum lipids, and enhancing calcium absorption [111]. Due to its content in fructose, this fiber can also be used to produce fructose-rich solutions to be used for different purposes. For these reasons, it is considered a valuable material. Stökle et al. developed two different acid-assisted approaches to extract inulin from chicory roots: the first method (one-step process) allows the direct hydrolyzation of inulin in the course of the extraction process, since chicory roots are extracted at 80 °C at pH 2 using buffer solutions; the second approach (two-step process) is an aqueous extraction at neutral pH followed by nitric acid hydrolysis of the extract at 80 °C under pH 2. The first approach leads to 56% of fructose yield, while the two-step approach has a yield of 95% [112].

3.2. Honey and Other Bee Byproducts

Since ancient times, bees have been precious allies for mankind, and their products have represented incredibly valuable sources of nutrients, bioactive compounds, and materials. Bee products such as honey and royal jelly have found usage as food, thanks to their high content of sugars, minerals, and fats, being among the most important [113]. On the other hand, propolis has been used as a natural remedy due to its content in flavonoids and phenolic acids [114], and, in the same way, royal jelly has also been used for health-promoting purposes due mainly to its content of peculiar hydroxylated fatty acids deriving from bee metabolism of fats [115]. Also, honey is not devoid of bioactivity, and some varieties, such as the stingless bee honey, show anti-inflammatory, antioxidant, antitumor, and antidiabetic properties [116]. The beneficial role of honey is attributed to its antioxidant compounds like amino acids, proteins, enzymes, carotenoids (beta-carotene, lycopene), organic acids, and polyphenols, especially flavonoids and phenolic acids [117,118]. The phenolic composition of honey mainly depends on its floral origin; however, among phenolic acids, hydroxybenzoic derivatives (such as methyl syringate, gallic acid, ellagic acid, protocatechuic acid, syringic acid, benzoic acid and 4-hydroxybenzoic acid), hydroxycinnamic acids (such as chlorogenic, vanillic, caffeic, p-coumaric and ferulic acids), and hydroxy-phenylacetic acids (such as homogentisic and phenylacetic acids) have been reported in several honey varieties, and, hence, they could be regarded as the main representative compounds [119]. Among flavonoids, the most abundant ones in honey are flavones, flavanols, and flavonols [120], and apigenin, genistein, pinocembrin, pinobanksin, galangin, kaempferol, quercetin, luteolin, and chrysin can be regarded as the most representative of these classes [121]. Amino acids have been reported as main constituents of honey, and 22 free amino acids have been previously described in honey samples from different harvesting areas [122]. The main amino acids found for these honeys were proline, phenylalanine, tyrosine, and lysine, although lower, but also important, amounts of arginine, glutamic acid, histidine, and valine were present [123]. Finally, a number of organic acids are known to occur in honey, including acetic, butyric, citric, formic, lactic, malic, pyroglutamic, and succinic, although the major organic acid is gluconic acid (accounting for 64.6 to 99.8% of total acids [124]), which is produced in honey by the action of the enzyme glucose-oxidase on glucose [125].

The word "propolis" derives from Greek, in which the morpheme "Pro" means "in front of" and the morpheme "polis" means "community" or "city". Hence, the name indicates that propolis has a hive defensive property [126]. Propolis is composed mainly of resin (50%), wax (30%), essential oils (10%), pollen (5%), and other organic compounds (5%) [127]. Phenolic compounds, esters, flavonoids, terpenes, beta-steroids, aromatic aldehydes, and alcohols are the important organic compounds present in propolis [128]. Among flavonoids, pinocembrin, acacetin, chrysin, rutin, luteolin, kaempferol, apigenin, myricetin, catechin, naringenin, galangin, and quercetin have been reported as the main constituents, while the main phenolic acids are caffeic acid and cinnamic acid. Propolis also contains important vitamins, such as vitamins B1, B2, B6, C, and E, and useful minerals such as magnesium (Mg), calcium (Ca), potassium (K), sodium (Na), copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) [127].

Only a few works focusing on the potential reutilization of byproducts from honey production have been published up to now. Zhao et al. investigated the physicochemical properties, chemical composition, and nutritional value of honeycomb, the residence for honeybee species used for honey and pollen storage that is discarded as waste in the bee product industry [129]. In this study, the authors reported more than 70 chemical constituents, among which were 10 nitrogen-containing compounds (e.g., the amino acids proline, isoleucine, leucine, phenylalaninepyridoxine; the vitamins B6, nicotinamide, and nicotinic acid; the nucleosides uridine, adenine, and guanine), and 28 polyphenols, comprising 14 phenolic acids (e.g., methoxysalicylic, shikimic, benzoic, gallic, protocatechuic, vanillic and p-hydroxybenzoic acids), and 14 flavonoids (e.g., chrysin, luteolin, quercetin, galangin, kaempferol, and pinocembrin). Fatty acid composition was also evaluated, and several short-chain (isocitric, succinic, 2,2-dimethylsuccinic, maleic, and malic acids) and long-chain (e.g., palmitic, stearic, 10-hydroxydecenoic, hydroxyhexadecanoic, 13-hydroxy-9,11,15-octadecatrienoic, 9-hydroxy-10,12-octadecadienoic, and 12-hydroxy-9-octadecenoic acids) fatty acids were identified. The same residue was evaluated for its antioxidant activity and antibacterial effect against Gram-negative (*Escherichia coli* and *Pseudomonas aeruginosa*) and Gram-positive bacteria (*Staphylococcus aureus* and *Bacillus subtilis*), shown to effectively exert both biological effects [129]. In a previous study, Giampieri et al. evaluated the proximal, nutritional, and phytochemical composition of beeswax recycling byproducts [130]. These authors reported several potentially bioactive constituents, such as flavonoids (isorhamnetin, kaempferol, myricetin and quercetin derivatives), chlorogenic acid, proteins, and minerals. Furthermore, beeswax byproducts also exerted significant biological activities. Using three different assays (DPPH, FRAP, and TEAC), the byproducts were shown to exert significant antioxidant activity, and they were also effective as proapoptotic agents in a human liver cancer cell (HepG2) model [130]. More recently, our group achieved comparable results from the assessment of chemical composition and antibacterial activity of a beeswax processing byproduct from Northeast Italy [131]. The purification of raw beeswax by melting produces a semisolid beeswax byproduct, composed of honey, resins, and other constituents, which is usually considered as a waste. The main constituents of the residue were carbohydrates, hydrocarbons, and minerals, but bioactive secondary metabolites typical of honey and propolis were revealed at 1.5% w/w, mainly flavonoids and phenolic acids. The residue was active against several Gram-negative and Gram-positive bacteria, namely, *Klebsiella pneumoniae*, *Salmonella enterica*, *Enterococcus faecalis*, methicillin-resistant *S. aureus*, and *P. aeruginosa*.

3.3. Red Fruits and Grape

The term "red fruits" comprises several species characterized by typical red–blue color. Among red fruits, strawberries and other berries such as bilberry (*Vaccinium myrtillus*), raspberry, and elderberry (*Sambucus nigra*) are widely used for the preparation of jams and juices. On the other hand, grape (*Vitis vinifera*) is widely used for the preparation of wines upon alcoholic fermentation. The typical color of these fruits is mainly due to anthocyanins, a class of chemical compounds that represents one of the largest and most important group of pigments in the plant kingdom. Apart from red fruits and grapes, they are largely responsible for diverse pigmentation from orange to red, pink, purple, and blue in flowers of many plants [132]. Chemically, anthocyanins are flavonoids and are consequently based on a C15 skeleton with a chromane ring, bearing a second aromatic ring B in position 2 (C_6–C_3–C_6) and with one or more sugar molecules bonded at different hydroxylated positions of the basic structure. They are typically linked to a saccharide molecule such as glucose, galactose, arabinose, rhamnose, or rutinose, as either 3-glycosides or 3,5-diglycosides [133,134]. The basic C_6–C_3–C_6 anthocyanin structure is the origin of all the different colors resulting from its chemical combination with glycosides and/or acyl groups and from its interaction with other molecules. Anthocyanidins are the sugarfree counterparts of anthocyanins. More than 20 anthocyanidins have been reported, with differences in the number and position of the hydroxyl and/or methyl ether groups, but six of them (cyanidin, malvidin, peonidin, delphinidin, pelargonidin, and petunidin) are the most common in nature, being present in 80% of pigmented leaves, 69% of fruits, and 50% of flowers [135,136].

Apart from anthocyanins, other typical constituents of red fruits and grapes are hydroxycinnamic acids and flavonoids, which are used by the plants to prevent the fruits from undergoing oxidation due to environmental factors, such as light, air, oxygen, and microbiological attacks [137]. On the other hand, dietary polyphenols have been widely studied for their biological properties in humans, and a wide range of beneficial effects, from anti-inflammatory to immunomodulatory and antimicrobial, have been described, and have been exhaustively resumed in recent papers [138,139]. In red fruits and grapes, polyphenols are concentrated mainly in the peel and pulp, where other abundant nutrients such as carbohydrates, fibers, and vitamins (especially ascorbic acid) are present [140].

Peels and seeds represent the most abundant byproducts obtained from the processing of red fruits and grapes for jam and juice production and wine making (20–30% of total fruit weight) [141]. Seeds are rich sources of other nutrients such as fatty acids. All berry seed oils have a high content of polyunsaturated fatty acids (PUFAs), mostly linoleic acid (33.68–71.10%) and α-linolenic acid (0.5–36.48%) [142], providing essential fatty acids (EFAs). EFAs are fatty acids that cannot be synthesized within an organism from other components by any known chemical pathway; therefore, they must be obtained from the diet. On the other hand, peels are a good source of polyphenols such as flavonoids, catechins, phenolic acids, and anthocyanins, which are, as extensively reported, attractive for their antioxidant properties [143].

Considering this information, red fruit and grape pomaces have been widely considered as valuable sources of bioactive compounds and nutrients. Berries are commonly eaten fresh or, due to their short shelf life, are kept frozen or dried or, again, processed to obtain food products such as jams, jellies, juices, canned fruits, and extracts [144]. Strawberry, raspberry, blueberry, and blackberry pomaces have been evaluated for their content in polyphenols, and authors showed that, among these, blueberry byproduct has the highest content of extractable flavonoids (17.10 mg/g), anthocyanins (509.13 mg/g), and proanthocyanidins (34.33 mg/g), followed by blackberry (2.91, 25.17, and 20.66 mg/g, respectively) and strawberry (3.26, 15.98, and 19.70 mg/g, respectively) [145]. Overall, the phenolic profile of pomaces resembles those of fresh fruits. Regarding other valuable constituents, the analysis of fatty acids content of wild strawberry, blueberry, blackberry, and raspberry showed an average content of FFAA of 27.3%, and the qualitative profile was dominated by mono- and polyunsaturated FFAA, with linoleic acid, oleic acid, and α-linolenic being the most representative [97].

Considering the value of berry and grape byproducts as sources of nutrients and polyphenols, a massive volume of works dealing with the extraction of these classes of compounds from pomace has been published during the last decade. An exhaustive overview of these works can be found in recent review papers [143,146,147].

Green Extraction of Bioactive Compounds from Red Fruit and Grape Pomace

Recently, $scCO_2$ has been widely employed for the extraction of the apolar fraction of berry pomace, consisting mainly of fatty acids contained in the seeds. As an example, an optimized SFE-CO_2 extraction protocol allowed the extraction of the lipophilic fraction of blackcurrant pomace with a yield of 14.6%, and this extract was rich in polyunsaturated fatty acids such as linoleic (46.89%) and γ-linolenic (14.02%) acids, and tocopherols (in total, 2468 μg/g oil) [69]. Similar results were obtained from a more recent work, where the same extractive approach was used to extract the lipophilic fraction of elderberry pomace, leading to a yield of 14.05%. This extract was also rich in polyunsaturated linoleic (42.0%) and α-linolenic (34.1%) fatty acids [148]. Gustinelli et al. obtained oils enriched in PUFAs (66.8%–75.9% *w*/*w*), vitamin E (range: 113.0–241.8 mg/100 g oil), and carotenoids (range: 11.5–32.3 mg/100 g oil) from SFE-CO_2 of blackcurrant seeds, and this composition was positively correlated to its antioxidant activity observed in vitro [149].

A huge amount of work dealing with green extraction of phenolics from berry and grape pomace can be found in the literature, where the application of different extraction techniques is reported (Table 2). As an example, the group of Lončarić et al. used PEF and UAE to extract anthocyanins and other polyphenols from blueberry pomace, using alcohols (methanol and ethanol) as solvents. The highest total polyphenols content (TPC) [10.52 mg of gallic acid equivalent (GAE) per g of dry weight (dw)] and antioxidant activity (AA) (0.83 mmol TE/g dw) were obtained by PEF-assisted extraction in the ethanol-based solvent after 100 pulses and 20 kV/cm, which corresponds to an energy input of 41.03 kJ/kg. A total of eighteen individual polyphenols were identified in all investigated blueberry pomace extracts, using high-performance liquid chromatography with the diode-array detector (HPLC-DAD) (JASCO International Co., Ltd., Tokyo, Japan) and liquid chromatography electrospray ionization tandem mass spectrometry (LC-(HESI)-MS/MS) (Thermo Scientific Inc., San Jose, CA, USA). The highest anthocyanin (1757.32 μg/g of dw) and flavanol (297.86 μg/g of dw) yields were obtained in the methanol-based solvent, while the highest phenolic acid (625.47 μg/g of dw) and flavonol (157.54 μg/g of dw) yields were obtained in the ethanol-based solvent by PEF-assisted extraction at the energy input of 41.03 kJ/kg [150]. In another recent work, Saad et al. used an aqueous EAE (AEAE) to simultaneously recover lipophilic compounds and polyphenols from raspberry pomace, testing different combinations of carbohydrases and proteases [70]. Under optimized conditions (1.2 units of thermostable alkaline protease/100 g pomace, pH 9, 60 °C, and 2 h hydrolysis), more than 38% of the total lipophilic content of raspberry residue was recovered in the aqueous medium. The recovery of polyphenols and antioxidant activity was, respectively, 48% and 25% higher than those obtained by extraction with a methanol/acetone/water mixture. Recently, Vázquez-González et al. reported the application of deep eutectic solvents for the recovery of bioactive compounds from strawberry and raspberry byproducts [151]. The best performing eutectic solvent consisted of a mixture of choline chloride, glycolic acid, and oxalic acid in a ratio of 1:1.7:0.3, and this was able to lead to anthocyanin and polyphenol recovery from raspberry and strawberry extracts. Overall, the best yield was obtained using raspberry pomace, which gave a final extract containing 36.53% of total soluble phenols (compared to 31.74% of acetone extract) and 0.01% of anthocyanins (compared with 0% of acetone extract).

Table 2. Overview of extraction and utilization of valuable compounds from red fruit and grape pomace.

Byproduct (Pomace)	Compound(s)	Extraction Method	Yield	Extraction Conditions	Proposed Use of Extracts	Ref.
Grape	Polyphenols, anthocyanins, tannins.	EAE, MWE, UAE, Soxhlet.	Up to 2.98 mg/g total phenolics.	Cellulase is used as enzyme. Solvent: ethanol (50% water).	Antioxidant and antibacterial agents in food packaging and products.	[152]
Grape	Catechin, gallic acid, flavan-3-ols.	EAE with tannase, UAE.	439 g/kg GAE total phenolics, 43.5 g/kg catechin, 4.5 g/kg quercetin.	Enzyme: tannase; solvent: water.	Enhanced antioxidant activity.	[153]
Grape	Flavanols and anthocyanins.	PLE using an intermittent process.	Total phenolic content: 97.4 GAE/g dry basis.	Solvent: 40% ethanol.	Antioxidant for applications in food, cosmetics, and pharmaceuticals.	[154]
Grape	Total phenolics, anthocyanins.	UAE, MAE.	Higher yields with MAE (at 1000 W for 10 min).	UAE: 450 W, 15 min; MAE: 1000 W, 10 min.	Antioxidant potential, food industries.	[155]
Grape	Polyphenols, anthocyanins.	Accelerated Solvent Extraction (ASE), SFE.	ASE at 50:50 ethanol/water at 80–140 °C yielded highest procyanidins.	ASE: 80–140 °C, ethanol/water (50:50), SFE: 2000 psi.	Nutraceuticals, food additives.	[156]
Blackcurrant	Anthocyanins, phenolic acids.	Freeze-drying, Soxhlet extraction.	Not specified.	Water and alcohol (60:40).	Antioxidant and prebiotic.	[157]
Blackcurrant	Anthocyanins, flavonoids.	MAE, solid-liquid extraction (SLE).	Total phenolics: 18.45 mg/g.	Solvent: methanol (40%); conditions: 70–80 °C, 15 min.	Antioxidant products.	[158]
Cranberry	Anthocyanins, flavonols, procyanidins.	Alcohol extraction, freeze-drying.	Not specified.	Ethanol: water (70:30).	Antibacterial effects against *Salmonella* in food.	[157]
Strawberry	Quercetin-3-glucuronide, ellagic acid, malic acid, p-coumaric acid.	SLE, PLE.	Quercetin: 15.60 mg/g, Total phenolics: 15.34 mg/g.	Solvent: ethanol (50%); conditions: 60 °C, 90 min.	Nutraceuticals, food additives.	[159]
Blueberry	Anthocyanins, flavonoids (e.g., chlorogenic acid).	UAE, SFE.	Anthocyanins: 72.27 mg/g, Polyphenols: 900–1300 mg/g.	Solvent: ethanol, $scCO_2$; conditions: 20 °C, 2000 psi for SFE.	Functional foods, dietary supplements.	[160]
Chokeberry	Polyphenols (e.g., chlorogenic acid, flavonoids), ascorbic acid.	Fermentation, UAE.	Not specified.	Solvent: ethanol (50%); fermentation with yeast cultures.	Fortified foods, natural colorants.	[161]
Raspberry	Gallic, p-coumaric, caffeic, quercitrin, chlorogenic, ellagic acids, total phenolics, flavonoids, anthocyanins.	UAE, maceration.	TPC: 27.79 mg GAE/L, TFC: 8.02 mg QE/g, TAC: 7.13 mg C3G Eq/L.	UAE: 450 W for 15 min; maceration: conventional organic solvent extraction.	Antioxidants, dietary supplements.	[162]

4. Valorization of Agrifood Byproducts Through Extraction and Recovery of Valuable Compounds: Limitations and Future Directions

While traditional methods like solvent extraction remain widely used for their simplicity and relatively low upfront costs, they often fall short in terms of environmental sustainability and extraction efficiency. Traditional techniques may require large quantities of toxic and nonsustainable solvents, and high temperatures. These latter can degrade unstable compounds, limiting both the purity and yield of recovered extracts. In contrast, innovative methods such as SFE-CO_2, UAE, and MAE offer a more sustainable approach by reducing solvent use, minimizing thermal degradation, and often achieving higher yields in shorter timeframes. However, these novel approaches come with their own set of limitations, such as higher operational costs and technical complexity, which present significant barriers to their economic viability and scalability. For example, SFE-CO_2 requires expensive equipment and precise control over pressure and temperature, making it less accessible to small- to medium-scale producers. Additionally, the specialized equipment and energy requirements of MAE and UAE, though potentially less resource-intensive per batch, require substantial upfront investments that might not be justifiable without high throughput to offset costs.

In terms of effectiveness, innovative methods generally outperform traditional methods in both extraction yield and selectivity. For instance, SFE-CO_2 and UAE can recover higher concentrations of bioactive compounds with greater specificity, thanks to their accurate control over process variables. This allows the extraction of targeted compounds without the same level of thermal or oxidative degradation common in solvent-based extractions. Thus, for high-value compounds, innovative methods may, indeed, be more cost-effective in the long term due to their higher-quality outputs. Yet, when it comes to large-scale applications, the substantial upfront and operational costs associated with these novel technologies still make traditional methods more economically viable in some contexts, especially where the initial quality of the byproduct does not necessitate highly selective extraction techniques.

Scaling these methods for industrial use introduces additional challenges, particularly for innovative approaches. Traditional methods, already in widespread use, have established supply chains, well-documented processes, and regulatory approvals, making them easier to scale and implement. Conversely, scaling innovative methods like SFE-CO_2 requires not only significant capital investment but also skilled labor to operate complex machinery and maintain rigorous process conditions. Additionally, the energy demands of techniques like MAE and UAE can increase disproportionately at larger scales, raising questions about their net environmental benefits when applied at industrial levels.

To address these limitations and enhance the practicality of innovative methods, future research should focus on optimizing these processes to reduce costs and improve efficiency. For example, developing hybrid techniques that combine aspects of traditional and innovative methods (such as solvent-assisted SFE-CO_2) could bridge the gap by improving yield and purity while keeping costs and energy consumption manageable. Furthermore, future studies should evaluate the use of eco-friendly, biobased solvents to make traditional solvent extraction more sustainable.

5. Conclusions

A huge amount of published data demonstrates the usefulness of berry and grape byproducts as valuable sources of bioactive secondary metabolites and pigments. Extracts from these materials or isolated compounds can find possible applications in the food industry or can be used as functional ingredients of nutraceuticals or cosmetics thanks to their biological properties. Nowadays, innovative and sustainable extraction methods have been developed for the efficient extraction of red fruit pomace, at least at the laboratory scale. However, future efforts need to be made to scale up the processes to a higher industrial scale, and to reduce the operational costs. These limitations and future directions have been exhaustively discussed above. The northeastern region of Italy can represent a suitable operational area, considering that it hosts several national and international companies that produce tons of red fruit and grape pomace per year. Also, several productive companies operating in the nutraceutical and cosmetic sectors reside in the same area, and they may represent possible stakeholders from the perspective of developing novel sustainable products.

The number of studies regarding the valorization of chicory byproducts through the extraction of secondary metabolites and inulin is also increasing in the literature, indicating that both scientists and industrial partners are paying more attention to this kind of material. Similarly to what was stated above, the northeastern region of Italy can potentially represent a leading actor in the valorization and reuse of these byproducts, taking into account the high amount of red chicory that it produces annually.

On the other hand, studies on bee byproducts are still scarce. Authors have recently shown that different bee byproducts represent valuable reservoirs of nutrients and bioactive compounds, which can also be efficiently isolated using sustainable approaches. The main issue of these byproducts may reside in their complex chemical composition and their poor standardization. As was already stated in a recent article dealing with the characterization of a beeswax processing byproduct [131], appropriate clean-up procedures should be developed in order to selectively isolate compounds of interest, depending on their physicochemical properties. To this aim, scCO_2 extraction would be a feasible and sustainable approach to remove lipophilic compounds, such as waxes and fatty acids, and concentrate more polar ones, such as carbohydrates, amino acids, and polyphenols.

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References

1. European Commission. Food Waste. 2024. Available online: https://food.ec.europa.eu/food-safety/food-waste_en (accessed on 16 November 2024).
2. Amicarelli, V.; Lagioia, G.; Bux, C. Global warming potential of food waste through the life cycle assessment: An analytical review. *Environ. Impact Assess. Rev.* **2021**, *91*, 106677. [CrossRef]
3. Van Der Werf, P.; Gilliland, J.A. A systematic review of food losses and food waste generation in developed countries. *Proc. Inst. Civ. Eng. Waste Resour. Manag.* **2017**, *170*, 66–77. [CrossRef]
4. United States Environmental Protection Agency. United States 2030 Food Loss and Waste Reduction Goal. Available online: https://www.epa.gov/sustainable-management-food/united-states-2030-food-loss-and-waste-reduction-goal (accessed on 31 October 2024).
5. Eurostat. Food Waste and Food Waste Prevention-Estimates-Statistics Explained. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates (accessed on 31 October 2024).
6. Chatti, C.B.; Hassen, T.B.; El Bilali, H. Closing the Loop: Exploring Food Waste Management in the Near East and North Africa (NENA) Region During the COVID-19 Pandemic. *Sustainability* **2024**, *16*, 3772. [CrossRef]
7. Food and Agriculture Organization of the United Nations (FAO). Food Losses and Waste in Latin America and the Caribbean. Newsletter #3 February 2016. Available online: https://openknowledge.fao.org/server/api/core/bitstreams/5569e764-205c-4165-9251-1cbc78f7e0fb/content (accessed on 5 November 2024).
8. Ribeiro, T.B.; Voss, G.B.; Coelho, M.C.; Pintado, M.E. *Chapter 33—Food Waste and By-Product Valorization as an Integrated Approach with Zero Waste: Future Challenges*; Bhat, R., Ed.; Academic Press: Cambridge, MA, USA, 2022; pp. 569–596. ISBN 978-0-323-91001-9.

9. Zannini, D.; Dal Poggetto, G.; Malinconico, M.; Santagata, G.; Immirzi, B. Citrus Pomace Biomass as a Source of Pectin and Lignocellulose Fibers: From Waste to Upgraded Biocomposites for Mulching Applications. *Polymers* **2021**, *13*, 1280. [CrossRef] [PubMed]
10. Farinon, B.; Felli, M.; Sulli, M.; Diretto, G.; Savatin, D.V.; Mazzucato, A.; Merendino, N.; Costantini, L. Tomato pomace food waste from different variants as a high antioxidant potential resource. *Food Chem.* **2024**, *452*, 139509. [CrossRef]
11. Kauser, S.; Murtaza, M.A.; Hussain, A.; Imran, M.; Kabir, K.; Najam, A.; An, Q.U.; Akram, S.; Fatima, H.; Batool, S.A.; et al. Apple pomace, a bioresource of functional and nutritional components with potential of utilization in different food formulations: A review. *Food Chem. Adv.* **2024**, *4*, 100598. [CrossRef]
12. Fidelis, M.; de Moura, C.; Kabbas Junior, T.; Pap, N.; Mattila, P.; Mäkinen, S.; Putnik, P.; Bursać Kovačević, D.; Tian, Y.; Yang, B.; et al. Fruit Seeds as Sources of Bioactive Compounds: Sustainable Production of High Value-Added Ingredients from By-Products Within Circular Economy. *Molecules* **2019**, *24*, 3854. [CrossRef]
13. Hadj Saadoun, J.; Bertani, G.; Levante, A.; Vezzosi, F.; Ricci, A.; Bernini, V.; Lazzi, C. Fermentation of Agri-Food Waste: A Promising Route for the Production of Aroma Compounds. *Foods* **2021**, *10*, 707. [CrossRef]
14. Philippini, R.R.; Martiniano, S.E.; Ingle, A.P.; Franco Marcelino, P.R.; Silva, G.M.; Barbosa, F.G.; dos Santos, J.C.; da Silva, S.S. Agroindustrial Byproducts for the Generation of Biobased Products: Alternatives for Sustainable Biorefineries. *Front. Energy Res.* **2020**, *8*, 152. [CrossRef]
15. Torres-León, C.; Ramírez-Guzman, N.; Londoño-Hernandez, L.; Martinez-Medina, G.A.; Díaz-Herrera, R.; Navarro-Macias, V.; Alvarez-Pérez, O.B.; Picazo, B.; Villarreal-Vázquez, M.; Ascacio-Valdes, J.; et al. Food Waste and Byproducts: An Opportunity to Minimize Malnutrition and Hunger in Developing Countries. *Front. Sustain. Food Syst.* **2018**, *2*, 52. [CrossRef]
16. Dilucia, F.; Lacivita, V.; Conte, A.; Del Nobile, M.A. Sustainable Use of Fruit and Vegetable By-Products to Enhance Food Packaging Performance. *Foods* **2020**, *9*, 857. [CrossRef] [PubMed]
17. Teshome, E.; Teka, T.A.; Nandasiri, R.; Rout, J.R.; Harouna, D.V.; Astatkie, T.; Urugo, M.M. Fruit By-Products and Their Industrial Applications for Nutritional Benefits and Health Promotion: A Comprehensive Review. *Sustainability* **2023**, *15*, 7840. [CrossRef]
18. Yadav, S.; Malik, K.; Moore, J.M.; Kamboj, B.R.; Malik, S.; Malik, V.K.; Arya, S.; Singh, K.; Mahanta, S.; Bishnoi, D.K. Valorisation of Agri-Food Waste for Bioactive Compounds: Recent Trends and Future Sustainable Challenges. *Molecules* **2024**, *29*, 2055. [CrossRef]
19. Chemat, F.; Abert Vian, M.; Fabiano-Tixier, A.-S.; Nutrizio, M.; Režek Jambrak, A.; Munekata, P.E.S.; Lorenzo, J.M.; Barba, F.J.; Binello, A.; Cravotto, G. A review of sustainable and intensified techniques for extraction of food and natural products. *Green Chem.* **2020**, *22*, 2325–2353. [CrossRef]
20. Arshadi, M.; Attard, T.M.; Lukasik, R.M.; Brncic, M.; da Costa Lopes, A.M.; Finell, M.; Geladi, P.; Gerschenson, L.N.; Gogus, F.; Herrero, M.; et al. Pre-treatment and extraction techniques for recovery of added value compounds from wastes throughout the agri-food chain. *Green Chem.* **2016**, *18*, 6160–6204. [CrossRef]
21. Maicas, S.; Mateo, J.J. Sustainability of Wine Production. *Sustainability* **2020**, *12*, 559. [CrossRef]
22. Ioannidou, S.M.; Filippi, K.; Kookos, I.K.; Koutinas, A.; Ladakis, D. Techno-economic evaluation and life cycle assessment of a biorefinery using winery waste streams for the production of succinic acid and value-added co-products. *Bioresour. Technol.* **2022**, *348*, 126295. [CrossRef]
23. Ente Nazionale per la Meccanizzazione Agricola (ENAMA). Biomasse ed Energia & Disponibilità delle Biomasse. 2008. Available online: https://www.progettobiomasse.it/it/pdf/studio/p1c2.pdf (accessed on 5 November 2024).
24. Barcaccia, G.; Ghedina, A.; Lucchin, M. Current Advances in Genomics and Breeding of Leaf Chicory (*Cichorium intybus* L.). *Agriculture* **2016**, *6*, 50. [CrossRef]
25. Kagkli, D.M.; Corich, V.; Bovo, B.; Lante, A.; Giacomini, A. Antiradical and antimicrobial properties of fermented red chicory (*Cichorium intybus* L.) by-products. *Ann. Microbiol.* **2016**, *66*, 1377–1386. [CrossRef]
26. Sridhar, A.; Ponnuchamy, M.; Kumar, P.S.; Kapoor, A.; Vo, D.-V.N.; Prabhakar, S. Techniques and modeling of polyphenol extraction from food: A review. *Environ. Chem. Lett.* **2021**, *19*, 3409–3443. [CrossRef]
27. Zhang, Q.-W.; Lin, L.-G.; Ye, W.-C. Techniques for extraction and isolation of natural products: A comprehensive review. *Chin. Med.* **2018**, *13*, 20. [CrossRef] [PubMed]
28. Plaskova, A.; Mlcek, J. New insights of the application of water or ethanol-water plant extract rich in active compounds in food. *Front. Nutr.* **2023**, *10*, 1118761. [CrossRef] [PubMed]
29. Bitwell, C.; Indra, S.S.; Luke, C.; Kakoma, M.K. A review of modern and conventional extraction techniques and their applications for extracting phytochemicals from plants. *Sci. Afr.* **2023**, *19*, e01585. [CrossRef]
30. Poiana, M.-A.; Raba, D.; Viorica-Mirela, P. The effect of long-term frozen storage on the nutraceutical compounds, antioxidant properties and color indices of different kinds of berries. *J. Food Agric. Environ.* **2010**, *8*, 54–58.
31. Zhang, Y.; Seeram, N.P.; Lee, R.; Feng, L.; Heber, D. Isolation and Identification of Strawberry Phenolics with Antioxidant and Human Cancer Cell Antiproliferative Properties. *J. Agric. Food Chem.* **2008**, *56*, 670–675. [CrossRef] [PubMed]
32. Salas-Arias, K.; Irías-Mata, A.; Sánchez-Kopper, A.; Hernández-Moncada, R.; Salas-Morgan, B.; Villalta-Romero, F.; Calvo-Castro, L.A. Strawberry Fragaria x ananassa cv. Festival: A Polyphenol-Based Phytochemical Characterization in Fruit and Leaf Extracts. *Molecules* **2023**, *28*, 1865. [CrossRef]
33. Jensen, W. The Origin of the Soxhlet Extractor. *J. Chem. Educ.* **2007**, *84*, 1913. [CrossRef]

34. Saini, R.K.; Prasad, P.; Shang, X.; Keum, Y.-S. Advances in Lipid Extraction Methods—A Review. *Int. J. Mol. Sci.* **2021**, *22*, 13643. [CrossRef]
35. Hui, X.; Wu, G.; Han, D.; Gong, X.; Stipkovits, L.; Wu, X.; Tang, S.; Brennan, M.A.; Brennan, C.S. Bioactive compounds from blueberry and blackcurrant powder alter the physicochemical and hypoglycaemic properties of oat bran paste. *LWT* **2021**, *143*, 111167. [CrossRef]
36. Trabelsi, A.; El Kaibi, M.A.; Abbassi, A.; Horchani, A.; Chekir-Ghedira, L.; Ghedira, K. Phytochemical Study and Antibacterial and Antibiotic Modulation Activity of *Punica granatum* (Pomegranate) Leaves. *Scientifica* **2020**, *2020*, 8271203. [CrossRef]
37. Wajs-Bonikowska, A.; Stobiecka, A.; Bonikowski, R.; Krajewska, A.; Sikora, M.; Kula, J. A comparative study on composition and antioxidant activities of supercritical carbon dioxide, hexane and ethanol extracts from blackberry (*Rubus fruticosus*) growing in Poland. *J. Sci. Food Agric.* **2017**, *97*, 3576–3583. [CrossRef] [PubMed]
38. Sharaf, S. Eco-friendly technology for preparation, characterization and promotion of honey bee propolis extract loaded cellulose acetate nanofibers in medical domains. *Cellulose* **2018**, *25*, 5195–5204. [CrossRef]
39. Chemat, F.; Rombaut, N.; Sicaire, A.-G.; Meullemiestre, A.; Fabiano-Tixier, A.-S.; Abert-Vian, M. Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. *Ultrason. Sonochem.* **2017**, *34*, 540–560. [CrossRef] [PubMed]
40. Shen, L.; Pang, S.; Zhong, M.; Sun, Y.; Qayum, A.; Liu, Y.; Rashid, A.; Xu, B.; Liang, Q.; Ma, H.; et al. A comprehensive review of ultrasonic assisted extraction (UAE) for bioactive components: Principles, advantages, equipment, and combined technologies. *Ultrason. Sonochem.* **2023**, *101*, 106646. [CrossRef]
41. Kumar, K.; Srivastav, S.; Sharanagat, V.S. Ultrasound assisted extraction (UAE) of bioactive compounds from fruit and vegetable processing by-products: A review. *Ultrason. Sonochem.* **2021**, *70*, 105325. [CrossRef]
42. Abid, M.; Jabbar, S.; Wu, T.; Hashim, M.M.; Hu, B.; Lei, S.; Zeng, X. Sonication enhances polyphenolic compounds, sugars, carotenoids and mineral elements of apple juice. *Ultrason. Sonochem.* **2014**, *21*, 93–97. [CrossRef]
43. Agnieszka, M.; Michał, S.; Robert, K. Selection of Conditions of Ultrasound-Assisted, Three-Step Extraction of Ellagitannins from Selected Berry Fruit of the Rosaceae Family Using the Response Surface Methodology. *Food Anal. Methods* **2020**, *13*, 1650–1665. [CrossRef]
44. Dou, Z.; Chen, C.; Fu, X. The effect of ultrasound irradiation on the physicochemical properties and α-glucosidase inhibitory effect of blackberry fruit polysaccharide. *Food Hydrocoll.* **2019**, *96*, 568–576. [CrossRef]
45. Kirillov, V.; Stikhareva, T.; Atazhanova, G.; Makubayeva, A.; Serafimovich, M.; Kabanova, S.; Rakhimzhanov, A.; Adekenov, S. Composition of essential oil of leaves and fruits of green strawberry (*Fragaria viridis* Weston) growing wild in Northern Kazakhstan. *J. Appl. Bot. Food Qual.* **2019**, *92*, 39–48. [CrossRef]
46. Alissandrakis, E.; Tarantilis, P.; Harizanis, P.; Polissiou, M. Evaluation of four isolation techniques for honey aroma compounds. *J. Sci. Food Agric.* **2005**, *85*, 91–97. [CrossRef]
47. Piazza, S.; Martinelli, G.; Magnavacca, A.; Fumagalli, M.; Pozzoli, C.; Terno, M.; Canilli, L.; Angarano, M.; Maranta, N.; Dell'Agli, M.; et al. Unveiling the Ability of Witch Hazel (*Hamamelis virginiana* L.) Bark Extract to Impair Keratinocyte Inflammatory Cascade Typical of Atopic Eczema. *Int. J. Mol. Sci.* **2022**, *23*, 9279. [CrossRef] [PubMed]
48. Mielnik, M.B.; Sem, S.; Egelandsdal, B.; Skrede, G. By-products from herbs essential oil production as ingredient in marinade for turkey thighs. *LWT-Food Sci. Technol.* **2008**, *41*, 93–100. [CrossRef]
49. Destandau, E.; Michel, T.; Elfakir, C. Microwave-assisted Extraction. In *Natural Product Extraction: Principles and Applications*; Rostagno, M.A., Prado, J.M., Eds.; The Royal Society of Chemistry: London, UK, 2013; pp. 113–156, ISBN 978-1-84973-606-0.
50. Zheng, X.; Xu, X.; Liu, C.; Sun, Y.; Lin, Z.; Liu, H. Extraction characteristics and optimal parameters of anthocyanin from blueberry powder under microwave-assisted extraction conditions. *Sep. Purif. Technol.* **2013**, *104*, 17–25. [CrossRef]
51. Wen, Y.; Chen, H.; Zhou, X.; Deng, Q.; Zhao, Y.; Zhao, C.; Gong, X. Optimization of the microwave-assisted extraction and antioxidant activities of anthocyanins from blackberry using a response surface methodology. *RSC Adv.* **2015**, *5*, 19686–19695. [CrossRef]
52. Pereira, A.G.; Cruz, L.; Cassani, L.; Chamorro, F.; Lourenço-Lopes, C.; Freitas, V.; Otero, P.; Fraga-Corral, M.; Prieto, M.A.; Simal-Gandara, J.; et al. Comparative Study of Microwave-Assisted Extraction and Ultrasound-Assisted Extraction Techniques (MAE vs. UAE) for the Optimized Production of Enriched Extracts in Phenolic Compounds of *Camellia japonica* var Eugenia de Montijo. *Eng. Proc.* **2023**, *37*, 124. [CrossRef]
53. Rezvankhah, A.; Emam-Djomeh, Z.; Safari, M.; Askari, G.; Salami, M. Microwave-assisted extraction of hempseed oil: Studying and comparing of fatty acid composition, antioxidant activity, physiochemical and thermal properties with Soxhlet extraction. *J. Food Sci. Technol.* **2019**, *56*, 4198–4210. [CrossRef]
54. Oubannin, S.; Bijla, L.; Ahmed, M.N.; Ibourki, M.; El Kharrassi, Y.; Devkota, K.; Bouyahya, A.; Maggi, F.; Caprioli, G.; Sakar, E.H.; et al. Recent advances in the extraction of bioactive compounds from plant matrices and their use as potential antioxidants for vegetable oils enrichment. *J. Food Compos. Anal.* **2024**, *128*, 105995. [CrossRef]
55. Barp, L.; Višnjevec, A.M.; Moret, S. Pressurized Liquid Extraction: A Powerful Tool to Implement Extraction and Purification of Food Contaminants. *Foods* **2023**, *12*, 2017. [CrossRef] [PubMed]
56. Višnjevec, A.M.; Barp, L.; Lucci, P.; Moret, S. Pressurized liquid extraction for the determination of bioactive compounds in plants with emphasis on phenolics. *TrAC Trends Anal. Chem.* **2024**, *173*, 117620. [CrossRef]

57. Tena, N.; Asuero, A.G. Up-To-Date Analysis of the Extraction Methods for Anthocyanins: Principles of the Techniques, Optimization, Technical Progress, and Industrial Application. *Antioxidants* **2022**, *11*, 286. [CrossRef]
58. García, P.; Fredes, C.; Cea, I.; Lozano-Sánchez, J.; Leyva-Jiménez, F.J.; Robert, P.; Vergara, C.; Jimenez, P. Recovery of Bioactive Compounds from Pomegranate (*Punica granatum* L.) Peel Using Pressurized Liquid Extraction. *Foods* **2021**, *10*, 203. [CrossRef] [PubMed]
59. Lante, A.; Nardi, T.; Zocca, F.; Giacomini, A.; Corich, V. Evaluation of Red Chicory Extract as a Natural Antioxidant by Pure Lipid Oxidation and Yeast Oxidative Stress Response as Model Systems. *J. Agric. Food Chem.* **2011**, *59*, 5318–5324. [CrossRef]
60. Machado, A.P.D.F.; Pasquel-Reátegui, J.L.; Barbero, G.F.; Martínez, J. Pressurized liquid extraction of bioactive compounds from blackberry (*Rubus fruticosus* L.) residues: A comparison with conventional methods. *Food Res. Int.* **2015**, *77*, 675–683. [CrossRef]
61. Guo, P.; Chen, H.; Ma, J.; Zhang, Y.; Chen, H.; Wei, T.; Gao, D.; Li, J. Enzyme-assisted extraction, characterization, and in vitro antioxidant activity of polysaccharides from *Potentilla anserina* L. *Front. Nutr.* **2023**, *10*, 1216572. [CrossRef]
62. Wang, D.; Wang, B.; Jin, X.; Peng, Y.; Zhao, J.; Zhang, M.; Wei, Y.; Long, Z.; Chen, Q. Microwave-enzyme-assisted extraction of pectin from feijoa (*Acca sellowiana*) fruit: Extraction optimization, physicochemical and functional properties. *LWT* **2024**, *204*, 116445. [CrossRef]
63. Amulya, P.R.; ul Islam, R. Optimization of enzyme-assisted extraction of anthocyanins from eggplant (*Solanum melongena* L.) peel. *Food Chem. X* **2023**, *18*, 100643. [CrossRef]
64. Granato, D.; Fidelis, M.; Haapakoski, M.; dos Santos Lima, A.; Viil, J.; Hellström, J.; Rätsep, R.; Kaldmäe, H.; Bleive, U.; Azevedo, L.; et al. Enzyme-assisted extraction of anthocyanins and other phenolic compounds from blackcurrant (*Ribes nigrum* L.) press cake: From processing to bioactivities. *Food Chem.* **2022**, *391*, 133240. [CrossRef] [PubMed]
65. Ricarte, G.N.; Coelho, M.A.Z.; Marrucho, I.M.; Ribeiro, B.D. Enzyme-assisted extraction of carotenoids and phenolic compounds from sunflower wastes using green solvents. *3 Biotech* **2020**, *10*, 405. [CrossRef]
66. Zuorro, A.; Maffei, G.; Lavecchia, R. Optimization of enzyme-assisted lipid extraction from Nannochloropsis microalgae. *J. Taiwan Inst. Chem. Eng.* **2016**, *67*, 106–114. [CrossRef]
67. Vergara-Barberán, M.; Lerma-García, M.J.; Herrero-Martínez, J.M.; Simó-Alfonso, E.F. Use of an enzyme-assisted method to improve protein extraction from olive leaves. *Food Chem.* **2015**, *169*, 28–33. [CrossRef]
68. Gligor, O.; Mocan, A.; Moldovan, C.; Locatelli, M.; Crișan, G.; Ferreira, I.C.F.R. Enzyme-assisted extractions of polyphenols—A comprehensive review. *Trends Food Sci. Technol.* **2019**, *88*, 302–315. [CrossRef]
69. Basegmez, H.I.O.; Povilaitis, D.; Kitrytė, V.; Kraujalienė, V.; Šulniūtė, V.; Alasalvar, C.; Venskutonis, P.R. Biorefining of blackcurrant pomace into high value functional ingredients using supercritical CO_2, pressurized liquid and enzyme assisted extractions. *J. Supercrit. Fluids* **2017**, *124*, 10–19. [CrossRef]
70. Saad, N.; Louvet, F.; Tarrade, S.; Meudec, E.; Grenier, K.; Landolt, C.; Ouk, T.S.; Bressollier, P. Enzyme-Assisted Extraction of Bioactive Compounds from Raspberry (*Rubus idaeus* L.) Pomace. *J. Food Sci.* **2019**, *84*, 1371–1381. [CrossRef] [PubMed]
71. Blikra, M.J.; Skipnes, D.; Skåra, T. On the use of pulsed electric field technology as a pretreatment to reduce the content of potentially toxic elements in dried Saccharina latissima. *LWT* **2022**, *169*, 114033. [CrossRef]
72. Ranjha, M.M.A.N.; Kanwal, R.; Shafique, B.; Arshad, R.N.; Irfan, S.; Kieliszek, M.; Kowalczewski, P.Ł.; Irfan, M.; Khalid, M.Z.; Roobab, U.; et al. A Critical Review on Pulsed Electric Field: A Novel Technology for the Extraction of Phytoconstituents. *Molecules* **2021**, *26*, 4893. [CrossRef]
73. Bocker, R.; Silva, E.K. Pulsed electric field assisted extraction of natural food pigments and colorings from plant matrices. *Food Chem. X* **2022**, *15*, 100398. [CrossRef]
74. Rajha, H.N.; Abi-Khattar, A.-M.; El Kantar, S.; Boussetta, N.; Lebovka, N.; Maroun, R.G.; Louka, N.; Vorobiev, E. Comparison of aqueous extraction efficiency and biological activities of polyphenols from pomegranate peels assisted by infrared, ultrasound, pulsed electric fields and high-voltage electrical discharges. *Innov. Food Sci. Emerg. Technol.* **2019**, *58*, 102212. [CrossRef]
75. Gagneten, M.; Leiva, G.; Salvatori, D.; Schebor, C.; Olaiz, N. Optimization of Pulsed Electric Field Treatment for the Extraction of Bioactive Compounds from Blackcurrant. *Food Bioprocess Technol.* **2019**, *12*, 1102–1109. [CrossRef]
76. Yildiz, S.; Pokhrel, P.R.; Unluturk, S.; Barbosa-Cánovas, G. V Changes in Quality Characteristics of Strawberry Juice After Equivalent High Pressure, Ultrasound, and Pulsed Electric Fields Processes. *Food Eng. Rev.* **2021**, *13*, 601–612. [CrossRef]
77. Roohinejad, S.; Koubaa, M.; Barba, F.J.; Greiner, R.; Orlien, V.; Lebovka, N.I. Negative pressure cavitation extraction: A novel method for extraction of food bioactive compounds from plant materials. *Trends Food Sci. Technol.* **2016**, *52*, 98–108. [CrossRef]
78. Panda, D.; Manickam, S. Cavitation Technology—The Future of Greener Extraction Method: A Review on the Extraction of Natural Products and Process Intensification Mechanism and Perspectives. *Appl. Sci.* **2019**, *9*, 766. [CrossRef]
79. Wang, T.; Guo, N.; Wang, S.-X.; Kou, P.; Zhao, C.-J.; Fu, Y.-J. Ultrasound-negative pressure cavitation extraction of phenolic compounds from blueberry leaves and evaluation of its DPPH radical scavenging activity. *Food Bioprod. Process.* **2018**, *108*, 69–80. [CrossRef]
80. Wang, T.; Xu, W.-J.; Wang, S.-X.; Kou, P.; Wang, P.; Wang, X.-Q.; Fu, Y.-J. Integrated and sustainable separation of chlorogenic acid from blueberry leaves by deep eutectic solvents coupled with aqueous two-phase system. *Food Bioprod. Process.* **2017**, *105*, 205–214. [CrossRef]
81. Comuzzo, P.; Calligaris, S. Potential Applications of High Pressure Homogenization in Winemaking: A Review. *Beverages* **2019**, *5*, 56. [CrossRef]

82. Chauhan, O.P.; Chandel, A.; Smitha, P.M.; Semwal, A.D. High pressure homogenization and retention of bioactive compounds in fruits and vegetables products. *Food Humanit.* **2023**, *1*, 1559–1569. [CrossRef]
83. Benjamin, O.; Gamrasni, D. Microbial, nutritional, and organoleptic quality of pomegranate juice following high-pressure homogenization and low-temperature pasteurization. *J. Food Sci.* **2020**, *85*, 592–599. [CrossRef]
84. Moscovici Joubran, A.; Katz, I.H.; Okun, Z.; Davidovich-Pinhas, M.; Shpigelman, A. The effect of pressure level and cycling in high-pressure homogenization on physicochemical, structural and functional properties of filtered and non-filtered strawberry nectar. *Innov. Food Sci. Emerg. Technol.* **2019**, *57*, 102203. [CrossRef]
85. Kruszewski, B.; Zawada, K.; Karpiński, P. Impact of High-Pressure Homogenization Parameters on Physicochemical Characteristics, Bioactive Compounds Content, and Antioxidant Capacity of Blackcurrant Juice. *Molecules* **2021**, *26*, 1802. [CrossRef]
86. Pech-Almeida, J.L.; Téllez-Pérez, C.; Alonzo-Macías, M.; Teresa-Martínez, G.D.; Allaf, K.; Allaf, T.; Cardador-Martínez, A. An Overview on Food Applications of the Instant Controlled Pressure-Drop Technology, an Innovative High Pressure-Short Time Process. *Molecules* **2021**, *26*, 6519. [CrossRef]
87. Ranjbar, N.; Eikani, M.H.; Javanmard, M.; Golmohammad, F. Impact of instant controlled pressure drop on phenolic compounds extraction from pomegranate peel. *Innov. Food Sci. Emerg. Technol.* **2016**, *37*, 177–183. [CrossRef]
88. Rahnemoon, P.; Sarabi-Jamab, M.; Javanmard, M.; Bostan, A.; Safari, O. Comparison of two methods of solvent extraction of phenolic compounds from pomegranate (*Punica granatum* L.) peels. *J. Agric. Sci. Technol.* **2018**, *20*, 939–952.
89. Gandhi, K.; Arora, S.; Kumar, A.; Kamal Gandhi, C. Industrial applications of supercritical fluid extraction: A review. *Int. J. Chem. Stud.* **2017**, *5*, 235–243.
90. Carpentieri, S.; Soltanipour, F.; Ferrari, G.; Pataro, G.; Donsì, F. Emerging Green Techniques for the Extraction of Antioxidants from Agri-Food By-Products as Promising Ingredients for the Food Industry. *Antioxidants* **2021**, *10*, 1417. [CrossRef]
91. RAMSEY, E.; SUN, Q.; ZHANG, Z.; ZHANG, C.; GOU, W. Mini-Review: Green sustainable processes using supercritical fluid carbon dioxide. *J. Environ. Sci.* **2009**, *21*, 720–726. [CrossRef]
92. Budisa, N.; Schulze-Makuch, D. Supercritical Carbon Dioxide and Its Potential as a Life-Sustaining Solvent in a Planetary Environment. *Life* **2014**, *4*, 331–340. [CrossRef] [PubMed]
93. Uwineza, P.A.; Waśkiewicz, A. Recent Advances in Supercritical Fluid Extraction of Natural Bioactive Compounds from Natural Plant Materials. *Molecules* **2020**, *25*, 3847. [CrossRef]
94. Liu, H.; Chen, B.-Q.; Pan, Y.-J.; Fu, C.-P.; Kankala, R.K.; Wang, S.-B.; Chen, A.-Z. Role of supercritical carbon dioxide (scCO_2) in fabrication of inorganic-based materials: A green and unique route. *Sci. Technol. Adv. Mater.* **2021**, *22*, 695–717. [CrossRef]
95. Freitas, L.C.; Barbosa, J.R.; da Costa, A.L.C.; Bezerra, F.W.F.; Pinto, R.H.H.; Carvalho Junior, R.N. de From waste to sustainable industry: How can agro-industrial wastes help in the development of new products? *Resour. Conserv. Recycl.* **2021**, *169*, 105466. [CrossRef]
96. Gondo, T.F.; Jönsson, M.; Karlsson, E.N.; Sandahl, M.; Turner, C. Extractability, selectivity, and comprehensiveness in supercritical fluid extraction of seaweed using ternary mixtures of carbon dioxide, ethanol, and water. *J. Chromatogr. A* **2023**, *1706*, 464267. [CrossRef]
97. Campalani, C.; Amadio, E.; Zanini, S.; Dall'Acqua, S.; Panozzo, M.; Ferrari, S.; De Nadai, G.; Francescato, S.; Selva, M.; Perosa, A. Supercritical CO_2 as a green solvent for the circular economy: Extraction of fatty acids from fruit pomace. *J. CO2 Util.* **2020**, *41*, 101259. [CrossRef]
98. Sanchez-Salvador, J.L.; Marques, M.P.; Brito, M.S.C.A.; Negro, C.; Monte, M.C.; Manrique, Y.A.; Santos, R.J.; Blanco, A. Valorization of Vegetable Waste from Leek, Lettuce, and Artichoke to Produce Highly Concentrated Lignocellulose Micro- and Nanofibril Suspensions. *Nanomaterials* **2022**, *12*, 4499. [CrossRef] [PubMed]
99. Pinotti, L.; Manoni, M.; Fumagalli, F.; Rovere, N.; Luciano, A.; Ottoboni, M.; Ferrari, L.; Cheli, F.; Djuragic, O. Reduce, Reuse, Recycle for Food Waste: A Second Life for Fresh-Cut Leafy Salad Crops in Animal Diets. *Animals* **2020**, *10*, 1082. [CrossRef] [PubMed]
100. Llorach, R.; Tomás-Barberán, F.A.; Ferreres, F. Lettuce and Chicory Byproducts as a Source of Antioxidant Phenolic Extracts. *J. Agric. Food Chem.* **2004**, *52*, 5109–5116. [CrossRef] [PubMed]
101. Ferioli, F.; Manco, M.A.; D'Antuono, L.F. Variation of sesquiterpene lactones and phenolics in chicory and endive germplasm. *J. Food Compos. Anal.* **2015**, *39*, 77–86. [CrossRef]
102. Nwafor, I.C.; Shale, K.; Achilonu, M.C. Chemical Composition and Nutritive Benefits of Chicory (*Cichorium intybus*) as an Ideal Complementary and/or Alternative Livestock Feed Supplement. *Sci. World J.* **2017**, *2017*, 7343928. [CrossRef]
103. Bergantin, C.; Maietti, A.; Cavazzini, A.; Pasti, L.; Tedeschi, P.; Brandolini, V.; Marchetti, N. Bioaccessibility and HPLC-MS/MS chemical characterization of phenolic antioxidants in Red Chicory (*Cichorium intybus*). *J. Funct. Foods* **2017**, *33*, 94–102. [CrossRef]
104. Frond, A.D.; Iuhas, C.I.; Stirbu, I.; Leopold, L.; Socaci, S.; Andreea, S.; Ayvaz, H.; Andreea, S.; Mihai, S.; Diaconeasa, Z.; et al. Phytochemical Characterization of Five Edible Purple-Reddish Vegetables: Anthocyanins, Flavonoids, and Phenolic Acid Derivatives. *Molecules* **2019**, *24*, 1536. [CrossRef]
105. D'evoli, L.; Morroni, F.; Lombardi-Boccia, G.; Lucarini, M.; Hrelia, P.; Cantelli-Forti, G.; Tarozzi, A. Red Chicory (*Cichorium intybus* L. cultivar) as a Potential Source of Antioxidant Anthocyanins for Intestinal Health. *Oxid. Med. Cell. Longev.* **2013**, *2013*, 704310. [CrossRef]

106. Migliorini, A.A.; Piroski, C.S.; Daniel, T.G.; Cruz, T.M.; Escher, G.B.; Vieira do Carmo, M.A.; Azevedo, L.; Marques, M.B.; Granato, D.; Rosso, N.D. Red Chicory (*Cichorium intybus*) Extract Rich in Anthocyanins: Chemical Stability, Antioxidant Activity, and Antiproliferative Activity In Vitro. *J. Food Sci.* **2019**, *84*, 990–1001. [CrossRef]
107. Sinkovič, L.; Demšar, L.; Žnidarčič, D.; Vidrih, R.; Hribar, J.; Treutter, D. Phenolic profiles in leaves of chicory cultivars (*Cichorium intybus* L.) as influenced by organic and mineral fertilizers. *Food Chem.* **2015**, *166*, 507–513. [CrossRef]
108. Baiano, A.; Bevilacqua, L.; Terracone, C.; Contò, F.; Del Nobile, M.A. Single and interactive effects of process variables on microwave-assisted and conventional extractions of antioxidants from vegetable solid wastes. *J. Food Eng.* **2014**, *120*, 135–145. [CrossRef]
109. Cova, C.M.; Boffa, L.; Pistocchi, M.; Giorgini, S.; Luque, R.; Cravotto, G. Technology and Process Design for Phenols Recovery from Industrial Chicory (*Chicorium intybus*) Leftovers. *Molecules* **2019**, *24*, 2681. [CrossRef] [PubMed]
110. Baixinho, J.P.; Anastácio, J.D.; Ivasiv, V.; Cankar, K.; Bosch, D.; Menezes, R.; de Roode, M.; dos Santos, C.N.; Matias, A.A.; Fernández, N. Supercritical CO_2 Extraction as a Tool to Isolate Anti-Inflammatory Sesquiterpene Lactones from *Cichorium intybus* L. Roots. *Molecules* **2021**, *26*, 2583. [CrossRef]
111. El-Kholy, W.M.; Aamer, R.A.; Ali, A.N.A. Utilization of inulin extracted from chicory (*Cichorium intybus* L.) roots to improve the properties of low-fat synbiotic yoghurt. *Ann. Agric. Sci.* **2020**, *65*, 59–67. [CrossRef]
112. Stökle, K.; Jung, D.; Kruse, A. Acid-assisted extraction and hydrolysis of inulin from chicory roots to obtain fructose-enriched extracts. *Biomass Convers. Biorefinery* **2023**, *13*, 159–170. [CrossRef]
113. Kieliszek, M.; Piwowarek, K.; Kot, A.M.; Wojtczuk, M.; Roszko, M.; Bryła, M.; Trajkovska Petkoska, A. Recent advances and opportunities related to the use of bee products in food processing. *Food Sci. Nutr.* **2023**, *11*, 4372–4397. [CrossRef]
114. Altuntaş, Ü.; Güzel, İ.; Özçelik, B. Phenolic Constituents, Antioxidant and Antimicrobial Activity and Clustering Analysis of Propolis Samples Based on PCA from Different Regions of Anatolia. *Molecules* **2023**, *28*, 1121. [CrossRef]
115. Collazo, N.; Carpena, M.; Nuñez-Estevez, B.; Otero, P.; Simal-Gandara, J.; Prieto, M.A. Health Promoting Properties of Bee Royal Jelly: Food of the Queens. *Nutrients* **2021**, *13*, 543. [CrossRef]
116. Ávila, S.; Hornung, P.S.; Teixeira, G.L.; Malunga, L.N.; Apea-Bah, F.B.; Beux, M.R.; Beta, T.; Ribani, R.H. Bioactive compounds and biological properties of Brazilian stingless bee honey have a strong relationship with the pollen floral origin. *Food Res. Int.* **2019**, *123*, 1–10. [CrossRef]
117. Ávila, S.; Beux, M.R.; Ribani, R.H.; Zambiazi, R.C. Stingless bee honey: Quality parameters, bioactive compounds, health-promotion properties and modification detection strategies. *Trends Food Sci. Technol.* **2018**, *81*, 37–50. [CrossRef]
118. Chuttong, B.; Chanbang, Y.; Sringarm, K.; Burgett, M. Physicochemical profiles of stingless bee (Apidae: Meliponini) honey from South East Asia (Thailand). *Food Chem.* **2016**, *192*, 149–155. [CrossRef] [PubMed]
119. Hossen, M.S.; Ali, M.Y.; Jahurul, M.H.A.; Abdel-Daim, M.M.; Gan, S.H.; Khalil, M.I. Beneficial roles of honey polyphenols against some human degenerative diseases: A review. *Pharmacol. Reports* **2017**, *69*, 1194–1205. [CrossRef] [PubMed]
120. Moniruzzaman, M.; Yung An, C.; Rao, P.V.; Hawlader, M.N.I.; Azlan, S.A.B.M.; Sulaiman, S.A.; Gan, S.H. Identification of Phenolic Acids and Flavonoids in Monofloral Honey from Bangladesh by High Performance Liquid Chromatography: Determination of Antioxidant Capacity. *Biomed Res. Int.* **2014**, *2014*, 737490. [CrossRef]
121. Cianciosi, D.; Forbes-Hernández, T.Y.; Afrin, S.; Gasparrini, M.; Reboredo-Rodriguez, P.; Manna, P.P.; Zhang, J.; Bravo Lamas, L.; Martínez Flórez, S.; Agudo Toyos, P.; et al. Phenolic Compounds in Honey and Their Associated Health Benefits: A Review. *Molecules* **2018**, *23*, 2322. [CrossRef] [PubMed]
122. Łozowicka, B.; Kaczyński, P.; Iwaniuk, P. Analysis of 22 free amino acids in honey from Eastern Europe and Central Asia using LC-MS/MS technique without derivatization step. *J. Food Compos. Anal.* **2021**, *98*, 103837. [CrossRef]
123. Hermosín, I.; Chicón, R.M.; Dolores Cabezudo, M. Free amino acid composition and botanical origin of honey. *Food Chem.* **2003**, *83*, 263–268. [CrossRef]
124. Suto, M.; Kawashima, H.; Nakamura, Y. Determination of Organic Acids in Honey by Liquid Chromatography with Tandem Mass Spectrometry. *Food Anal. Methods* **2020**, *13*, 2249–2257. [CrossRef]
125. Kornecki, J.F.; Carballares, D.; Tardioli, P.W.; Rodrigues, R.C.; Berenguer-Murcia, Á.; Alcántara, A.R.; Fernandez-Lafuente, R. Enzyme production of d-gluconic acid and glucose oxidase: Successful tales of cascade reactions. *Catal. Sci. Technol.* **2020**, *10*, 5740–5771. [CrossRef]
126. Anjum, S.I.; Ullah, A.; Khan, K.A.; Attaullah, M.; Khan, H.; Ali, H.; Bashir, M.A.; Tahir, M.; Ansari, M.J.; Ghramh, H.A.; et al. Composition and functional properties of propolis (bee glue): A review. *Saudi J. Biol. Sci.* **2019**, *26*, 1695–1703. [CrossRef]
127. Pasupuleti, V.R.; Sammugam, L.; Ramesh, N.; Gan, S.H. Honey, Propolis, and Royal Jelly: A Comprehensive Review of Their Biological Actions and Health Benefits. *Oxid. Med. Cell. Longev.* **2017**, *2017*, 1259510. [CrossRef]
128. Huang, S.; Zhang, C.-P.; Wang, K.; Li, G.Q.; Hu, F.-L. Recent Advances in the Chemical Composition of Propolis. *Molecules* **2014**, *19*, 19610–19632. [CrossRef] [PubMed]
129. Zhao, H.; Zhu, M.; Wang, K.; Yang, E.; Su, J.; Wang, Q.; Cheng, N.; Xue, X.; Wu, L.; Cao, W. Identification and quantitation of bioactive components from honeycomb (*Nidus vespae*). *Food Chem.* **2020**, *314*, 126052. [CrossRef] [PubMed]
130. Giampieri, F.; Quiles, J.L.; Orantes-Bermejo, F.J.; Gasparrini, M.; Forbes-Hernandez, T.Y.; Sánchez-González, C.; Llopis, J.; Rivas-García, L.; Afrin, S.; Varela-López, A.; et al. Are by-products from beeswax recycling process a new promising source of bioactive compounds with biomedical properties? *Food Chem. Toxicol.* **2018**, *112*, 126–133. [CrossRef] [PubMed]

131. Peron, G.; Carmo dos Santos, N.A.; Ferrarese, I.; Rizzo, F.; Bernabè, G.; Paccagnella, M.; Panozzo, M.; Francescato, S.; Castagliuolo, I.; Dall'Acqua, S.; et al. The beeswax processing by-product: A potential antibacterial ingredient for food and nutraceutical applications. *Int. J. Food Sci. Technol.* **2023**, *58*, 5549–5556. [CrossRef]
132. Fernández-López, J.A.; Fernández-Lledó, V.; Angosto, J.M. New insights into red plant pigments: More than just natural colorants. *RSC Adv.* **2020**, *10*, 24669–24682. [CrossRef]
133. Alappat, B.; Alappat, J. Anthocyanin Pigments: Beyond Aesthetics. *Molecules* **2020**, *25*, 5500. [CrossRef]
134. Zhao, C.L.; Chen, Z.J.; Bai, X.S.; Ding, C.; Long, T.J.; Wei, F.G.; Miao, K.R. Structure–activity relationships of anthocyanidin glycosylation. *Mol. Divers.* **2014**, *18*, 687–700. [CrossRef]
135. Mannino, G.; Gentile, C.; Ertani, A.; Serio, G.; Bertea, C.M. Anthocyanins: Biosynthesis, Distribution, Ecological Role, and Use of Biostimulants to Increase Their Content in Plant Foods—A Review. *Agriculture* **2021**, *11*, 212. [CrossRef]
136. Saigo, T.; Wang, T.; Watanabe, M.; Tohge, T. Diversity of anthocyanin and proanthocyanin biosynthesis in land plants. *Curr. Opin. Plant Biol.* **2020**, *55*, 93–99. [CrossRef]
137. Hidalgo, G.-I.; Almajano, M.P. Red Fruits: Extraction of Antioxidants, Phenolic Content, and Radical Scavenging Determination: A Review. *Antioxidants* **2017**, *6*, 7. [CrossRef]
138. El-Saadony, M.T.; Yang, T.; Saad, A.M.; Alkafaas, S.S.; Elkafas, S.S.; Eldeeb, G.S.; Mohammed, D.M.; Salem, H.M.; Korma, S.A.; Loutfy, S.A.; et al. Polyphenols: Chemistry, bioavailability, bioactivity, nutritional aspects and human health benefits: A review. *Int. J. Biol. Macromol.* **2024**, *277*, 134223. [CrossRef] [PubMed]
139. Rudrapal, M.; Rakshit, G.; Singh, R.P.; Garse, S.; Khan, J.; Chakraborty, S. Dietary Polyphenols: Review on Chemistry/Sources, Bioavailability/Metabolism, Antioxidant Effects, and Their Role in Disease Management. *Antioxidants* **2024**, *13*, 429. [CrossRef] [PubMed]
140. Zhang, X.; Ahuja, J.K.C.; Burton-Freeman, B.M. Characterization of the nutrient profile of processed red raspberries for use in nutrition labeling and promoting healthy food choices. *Nutr. Health Aging* **2019**, *5*, 225–236. [CrossRef]
141. Struck, S.; Plaza, M.; Turner, C.; Rohm, H. Berry pomace—A review of processing and chemical analysis of its polyphenols. *Int. J. Food Sci. Technol.* **2016**, *51*, 1305–1318. [CrossRef]
142. Piasecka, I.; Wiktor, A.; Górska, A. Alternative Methods of Bioactive Compounds and Oils Extraction from Berry Fruit By-Products—A Review. *Appl. Sci.* **2022**, *12*, 1734. [CrossRef]
143. Kandemir, K.; Piskin, E.; Xiao, J.; Tomas, M.; Capanoglu, E. Fruit Juice Industry Wastes as a Source of Bioactives. *J. Agric. Food Chem.* **2022**, *70*, 6805–6832. [CrossRef]
144. Nile, S.H.; Park, S.W. Edible berries: Bioactive components and their effect on human health. *Nutrition* **2014**, *30*, 134–144. [CrossRef] [PubMed]
145. Reynoso-Camacho, R.; Sotelo-González, A.M.; Patiño-Ortiz, P.; Rocha-Guzmán, N.E.; Pérez-Ramírez, I.F. Berry by-products obtained from a decoction process are a rich source of low- and high-molecular weight extractable and non-extractable polyphenols. *Food Bioprod. Process.* **2021**, *127*, 371–387. [CrossRef]
146. Athanasiadis, V.; Chatzimitakos, T.; Kotsou, K.; Kalompatsios, D.; Bozinou, E.; Lalas, S.I. Polyphenol Extraction from Food (by) Products by Pulsed Electric Field: A Review. *Int. J. Mol. Sci.* **2023**, *24*, 15914. [CrossRef]
147. Zhou, M.; Fakayode, O.A.; Li, H. Green Extraction of Polyphenols via Deep Eutectic Solvents and Assisted Technologies from Agri-Food By-Products. *Molecules* **2023**, *28*, 6852. [CrossRef]
148. Kitrytė, V.; Laurinavičienė, A.; Syrpas, M.; Pukalskas, A.; Venskutonis, P.R. Modeling and optimization of supercritical carbon dioxide extraction for isolation of valuable lipophilic constituents from elderberry (*Sambucus nigra* L.) pomace. *J. CO2 Util.* **2020**, *35*, 225–235. [CrossRef]
149. Gustinelli, G.; Eliasson, L.; Svelander, C.; Andlid, T.; Lundin, L.; Ahrné, L.; Alminger, M. Supercritical Fluid Extraction of Berry Seeds: Chemical Composition and Antioxidant Activity. *J. Food Qual.* **2018**, *2018*, 6046074. [CrossRef]
150. Lončarić, A.; Celeiro, M.; Jozinović, A.; Jelinić, J.; Kovač, T.; Jokić, S.; Babić, J.; Moslavac, T.; Zavadlav, S.; Lores, M. Green Extraction Methods for Extraction of Polyphenolic Compounds from Blueberry Pomace. *Foods* **2020**, *9*, 1521. [CrossRef] [PubMed]
151. Vázquez-González, M.; Fernández-Prior, Á.; Bermúdez Oria, A.; Rodríguez-Juan, E.M.; Pérez-Rubio, A.G.; Fernández-Bolaños, J.; Rodríguez-Gutiérrez, G. Utilization of strawberry and raspberry waste for the extraction of bioactive compounds by deep eutectic solvents. *LWT* **2020**, *130*, 109645. [CrossRef]
152. Chamorro, S.; Viveros, A.; Alvarez, I.; Vega, E.; Brenes, A. Changes in polyphenol and polysaccharide content of grape seed extract and grape pomace after enzymatic treatment. *Food Chem.* **2012**, *133*, 308–314. [CrossRef] [PubMed]
153. Drosou, C.; Kyriakopoulou, K.; Bimpilas, A.; Tsimogiannis, D.; Krokida, M. A comparative study on different extraction techniques to recover red grape pomace polyphenols from vinification byproducts. *Ind. Crops Prod.* **2015**, *75*, 141–149. [CrossRef]
154. Silva, J.T.; Borges, M.H.; de Souza, C.A.; Fávaro-Trindade, C.S.; Sobral, P.J.; de Oliveira, A.L.; Martelli-Tosi, M. Grape Pomace Rich-Phenolics and Anthocyanins Extract: Production by Pressurized Liquid Extraction in Intermittent Process and Encapsulation by Spray-Drying. *Foods* **2024**, *13*, 279. [CrossRef]
155. da Rocha, C.B.; Noreña, C.P.Z. Microwave-Assisted Extraction and Ultrasound-Assisted Extraction of Bioactive Compounds from Grape Pomace. *Int. J. Food Eng.* **2020**, *16*, 20190191. [CrossRef]
156. Fontana, A.R.; Antoniolli, A.; Bottini, R. Grape Pomace as a Sustainable Source of Bioactive Compounds: Extraction, Characterization, and Biotechnological Applications of Phenolics. *J. Agric. Food Chem.* **2013**, *61*, 8987–9003. [CrossRef]

157. Rubinskiene, M.; Viskelis, P.; Jasutiene, I.; Viskeliene, R.; Bobinas, C. Impact of various factors on the composition and stability of black currant anthocyanins. *Food Res. Int.* **2005**, *38*, 867–871. [CrossRef]
158. Yüksekkaya, Ş.; Başyiğit, B.; Sağlam, H.; Pekmez, H.; Cansu, Ü.; Karaaslan, A.; Karaaslan, M. Valorization of fruit processing by-products: Free, esterified, and insoluble bound phytochemical extraction from cherry (*Prunus avium*) tissues and their biological activities. *J. Food Meas. Charact.* **2021**, *15*, 1092–1107. [CrossRef]
159. Pukalskienė, M.; Pukalskas, A.; Dienaitė, L.; Revinytė, S.; Pereira, C.V.; Matias, A.A.; Venskutonis, P.R. Recovery of Bioactive Compounds from Strawberry (*Fragaria* × *ananassa*) Pomace by Conventional and Pressurized Liquid Extraction and Assessment Their Bioactivity in Human Cell Cultures. *Foods* **2021**, *10*, 1780. [CrossRef] [PubMed]
160. Piechowiak, T.; Skóra, B.; Grzelak-Błaszczyk, K.; Sójka, M. Extraction of Antioxidant Compounds from Blueberry Fruit Waste and Evaluation of Their In Vitro Biological Activity in Human Keratinocytes (HaCaT). *Food Anal. Methods* **2021**, *14*, 2317–2327. [CrossRef]
161. Sady, S.; Ligaj, M.; Pachołek, B.; Błaszczyk, A.; Płaczek, Z.; Dłużniewska, N.; Kawałek, P.; Pakuła, K.; Konopelski, A.; Gołaszewski, E. Designing the Quality Characteristics of Berry Processing Byproducts Using Fermentation. *Appl. Sci.* **2024**, *14*, 3110. [CrossRef]
162. Krivokapić, S.; Vlaović, M.; Damjanović Vratnica, B.; Perović, A.; Perović, S. Biowaste as a Potential Source of Bioactive Compounds—A Case Study of Raspberry Fruit Pomace. *Foods* **2021**, *10*, 706. [CrossRef]