Review

Turning Apple Pomace into Value: Sustainable Recycling in Food Production—A Narrative Review

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Abstract: Apple pomace is a significant by-product generated during the making of apple juice. It is frequently discarded as waste, harming the environment and making it risky for people’s health. The primary goals of this narrative review are to discuss the composition, functional bioactives, extraction techniques, and current food applications of apple pomace. Given the immediate positive economic effects, higher yields from novel extraction techniques were determined to be paramount. In addition to bioactive substances, apple pomace has a high dietary fiber content that could be utilized in newly created formulations. Additionally, this pomace can be added to food products to increase their nutritional content and marketability. For example, adding apple pomace to bread, confectionery, dairy, and meat products has increased their nutritional value and phytochemical and health-promoting qualities. Furthermore, the limitations associated with using this by-product in those products are addressed in this investigation. It is expected that the data presented in this work will serve as a helpful reference for food industry professionals in proposing an economical and sustainable extraction method that will convert apple waste into a functional product with added value. Along with validating potential bioactivity, additional research is required to determine the stability of bioactive substances and the mechanisms that regulate them.

Keywords: apple pomace; bioactive substances; polyphenols; vitamins and minerals; dietary fiber; extraction methods

1. Introduction

Apples are one of the most ancient fruits known to humans, extensively grown in temperate climates [1]. Apples are fourth in the world’s most eaten fruit crops, behind oranges, bananas, and grapes [2]. The yearly global production of apples has climbed by 48% over the last 20 years to reach 83.1 million metric tons in 2017, according to the most recent report from the FAO [3]. Asia, the apple’s native heartland, constitutes 65.4% of global apple production, with 41.4 million metric tons from China. The US, Turkey, and Poland are three other significant producers, accounting for 6.2%, 3.6%, and 2.9% of global production values, respectively [2].

Even though apples are grown more widely than ever, their global market share is mostly steady. About 70–75% of all apples are consumed fresh, with the remaining 25–30% being processed into diverse value-added products, like wine, juice, jams, and dried goods [4]. Nonetheless, with apple juice making up 65% of all processed apple products, it remains the most popular apple product [5]. During the juice extraction process, around 75% of the fresh weight of the apple is expected to be recovered as juice; the rest is gathered as pomace, a food waste [6].

Every year, millions of tons of apple pomace are produced, and they are primarily used as animal feed or waste [5]. However, apple pomace disposal as waste contributes to
environmental problems [7]. Also, composting produces greenhouse gasses, which leads to secondary pollution. This is why treatment and waste management costs for apple pomace are considerable. Additionally, composting forms surfaces where human disease vectors can grow and contaminate underground waters [8]. Apple pomace’s high water content gives it an excellent substrate for rapid fermentation, creating additional removal issues [9]. As a result, specialists recommended that apple juice facilities implement professional waste disposal to reduce environmental problems, which would necessitate further financial outlays [10].

The traditional extraction method formerly used to extract apple pomace involved maceration and Soxhlet coupled with organic materials. However, it is commonly acknowledged that plant material’s “green extraction” threatens the traditional extraction technique. The goal of demanding green extraction is to raise yield while lowering costs. Since organic solvents are not used, the risk of harmful residue formation is minimized. As a result, tremendous progress has been made in novel extraction technologies, including supercritical carbon dioxide, pulsed electric field (PEF), and microwave-assisted extraction (MAE) [11,12].

Apple pomace is an excellent source of carbohydrates, phenolic compounds, dietary fiber, and minerals [13]. Additionally, apple pomace has strong antiviral, antimicrobial, and antioxidant qualities [14,15]. Due to its high nutrient content, apple pomace is a promising resource with potential applications in the nutraceutical and pharmaceutical industries [16]. In light of the significance of bioactive compounds for human health and the general trend in the need for natural, healthful substances, this review aimed to investigate and evaluate all the existing research that uses apple pomace as an ingredient in various food products. Herein, we concentrated on all aspects that were not examined elsewhere by others, such as the composition, bioactive compounds, extraction, and application of apple pomace. This review also provides an informative overview of the opportunities and limitations, which may aid in the development of future studies that support the higher-level use of apple pomace.

2. Methods

In this narrative review, the main scientific databases, such as PubMed, ScienceDirect, Scopus, and Google Scholar, were screened to collect appropriate publications (1998—up to date as of July 2024). Since these databases are updated continually, it should be deemed that the revised data were confined to the information available during the preparation of this article. To find suitable papers, we used the keywords “apple pomace” combined with the terms “chemical composition”, “bioactive compounds”, “extraction”, “bioactivities”, “functional food”, and “limitations”. Full-text reports were collected if they were thought appropriate for an accurate evaluation.

3. Apple Pomace

3.1. Composition of Apple Pomace

Apple pomace typically contains 70–85% moisture. Apple pomace consists of the peel and flesh (95%) and a negligible amount of seeds (2–4%) and stems (1%) [17]. It has substantial amounts of carbohydrates, small amounts of proteins, vitamins, and minerals, and is an excellent source of phytochemicals [10]. Along with simple sugars, like glucose, fructose, and galactose, the insoluble sugars in apple pomace comprise primarily cellulose, hemicellulose, and lignin [8]. Apple pomace is well known for providing a good natural antioxidant content. These natural antioxidants include procyanidins, quercetin glycosides, phlorizin, phloretin glycosides, caffeic acid, and catechins [18]. Furthermore, apple pomace is still a dependable supply of pectic components and a crucial, novel, raw material for the industry’s manufacture of pectin [19]. As a result, apple pomace has a high nutritional content and health advantages. In addition to helping to avoid hypertension and constipation, many studies have shown that apple pomace can scavenge certain dangerous compounds found in the human body, like free radicals [10].
Apple pomace is a cheap source of bioactive substances and phytochemicals, like dietary fiber, polyphenols, vitamins, and polysaccharides (Figure 1). However, given its significance in the food and pharmaceutical industries, this by-product is not being utilized to its full potential [20]. Here, we will focus on the bioactive compounds found in apple pomace, especially polyphenols, and fiber, which will be further discussed.

### Figure 1. Valuable compounds in apple pomace.

#### 3.2. Bioactive Compounds in Apple Pomace

##### 3.2.1. Polyphenols in Apple Pomace

Apple pomace is rich in phenolics (i.e., dihydrochalcones, anthocyanins, flavonols, and phenolic acids), accounting for several health benefits [13]. The polyphenolic chemicals included in pomace have been shown to possess antioxidant and anti-inflammatory effects [21]. Likewise, a higher quantity of antioxidant substances, such as quercetin glycosides, phloridzin, and other polyphenols with substantial antioxidant action have already been demonstrated to be present in apple pomace [17]. Also, studies have shown that chlorogenic acid is crucial for preventing specific types of diabetes disorders [22,23]. Moreover, quercetin may have anti-diabetic effects, particularly on type 2 diabetes in its early stages [24]. According to Kapoor et al. [25], apple pomace is a good source of flavonoids, phenolics, and carotenoids that benefit human health. In vitro tumor-cell growth has been confirmed to be inhibited by polyphenols found in apple extracts [26]. Angiotensin-converting enzyme activity was suppressed in vitro by an apple peel extract, primarily flavonoids and certain quercetin derivatives [27]. In an earlier investigation, scientists showed that endothelial nitric oxide synthase in EA.hy926 cells could be activated by a combination extracted from apple pomace that contains quercetin and many triterpenoid acids [20]. Given that these two molecular pathways are linked to vasodilation effects, they may both have physiological significance. On the other hand, when compared to vitamins C and E, apple pomace polyphenols were discovered to be efficient superoxide scavengers; nevertheless, procyanidins were found to be better than quercetin 3-glycosides, chlorogenic acid, 3-hydroxy phloridzin, and phloridzin [28].

##### 3.2.2. Vitamins and Minerals in Apple Pomace

Apple pomace is abundant in vitamins A and C, which are strong antioxidants. According to Pieszka et al. [29], apple pomace contains 22.4 mg of vitamin C per 100 g and 5.5 mg of vitamin E per 100 g, indicating its potential as a source of antioxidant compounds. However, apple pomace also contains minerals such as sodium, phosphorus, potassium, manganese, calcium, magnesium, zinc, copper, and iron [17,30]. These minerals are necessary for bone health (calcium and phosphorus), neutralize acidic effects due to alkaline precursors (potassium, calcium, and magnesium), and help with iron deficiency and anemia. Moreover, apple pomace (especially the peel) contains more minerals than...
whole apples [30]. The consumption of apples, including their by-products, like apple pomace, has been associated with beneficial effects on human health, especially on vascular function, blood pressure, lipids, inflammation, and hyperglycemia [31].

3.2.3. Polysaccharides and Dietary Fibers in Apple Pomace

Apple pomace contains approximately 14% carbohydrates, mainly fructose and glucose, however it also contains more complex carbohydrates, such as polysaccharides. The polysaccharides found in apple pomace include cellulose, hemicellulose [32], and pectin [33]. According to Kruczek et al. [34], dietary fibers found in apple pomace possess well-adjusted resolvable and unresolvable fibers, indicating high-quality components compared to typical cereal ones. While apple pomace can be utilized directly as a functional component in food items, the fiber extract from the pomace is anticipated to impact fiber enrichment significantly. Pectin, cellulose, and lignin are dietary fibers added to various food and pharmaceutical items through fiber extract.

Pectin is a structural heteropolysaccharide found in the middle lamella and primary and secondary cell walls of plants, such as apples. Apple pomace is rich in complex polysaccharides. It is composed mainly of chains of $\alpha$-(1–4)-linked d-galacturonic acid units (49–64%), and contains arabinose (14–23%) and galactose (6–15%), along with smaller quantities of rhamnose, xylose, and glucose [17]. Galacturonic acid may be methylated and acetylated to varying degrees. Pectin serves as a structural component in plant cell walls, while in the food industry, it is widely used as a gelling agent, thickener, and stabilizer in jams, jellies, fruit preserves, and other processed foods [35].

Apple pomace produces a notable quantity of total dietary fibers, typically ranging from 45% to 51%, according to Sudha et al. [36]. Despite being regarded as waste in the apple processing industry, 36.8% of dried apple pomace fiber is composed of water-soluble and insoluble fractions. As reported by Issar et al. [37], when fiber is added, yogurt’s lipid content and acidity drop, but the content of the fiber increases. In addition, sensory tests were used to optimize apple fiber-containing yogurt, resulting in fiber-enriched acidophilus yogurt with desired quality and sensory attributes. Similarly, apple pomace was added to biscuits to increase their fiber content [38]. Pomace fiber extract can also be utilized to substitute fat in meat products, enhancing the product’s emulsion stability and rheological characteristics [39]. On the other hand, it has been shown that soluble dietary fibers, such as pectin, can lower blood glucose levels [40]. Contrary to commercial apple pectin, the subcritical water-extracted apple pectin surprisingly demonstrated higher rates of HT-29 cell growth inhibition [35]. According to Aprikian et al. [41], the administration of apple pectin, along with an apple concentrate rich in polyphenols, led to a considerable reduction in plasma cholesterol and triglyceride levels and intestinal cholesterol absorption. The importance of dietary fiber in supporting human health is well known, and apple pomace, which is high in dietary fiber, may be a great source of this material. However, efficient methods for obtaining and applying this fiber must be used to ensure people’s well-being. Overall, the value-added substances mentioned above suggest that apple pomace has the potential to be used as a component in the food sector.

4. Extraction of Bioactive Compounds from Apples and Its By-Products

The key metabolites of apples are phenols, which, when consumed, may have health-promoting properties. To optimize the quantity of desired chemicals and their antioxidant activity, the phenolic extraction process needs to be accurate. Hence, the extraction process may be the most important when analyzing the metabolites of apples because good extraction should recover all of the desired metabolites without chemical additions [42]. Figure 2 presents a biorefinery scheme that allows the recovery of several bioactive compounds from apple pomace.
Figure 2. Biorefinery scheme for the recovery of bioactive compounds from apple pomace.

The main advantages and disadvantages of conventional and novel extraction techniques for bioactive compounds are summarized in Table 1 and described later.

Table 1. Advantages and disadvantages of conventional and novel extraction techniques.

<table>
<thead>
<tr>
<th>Extraction Techniques</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>References</th>
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<td>Conventional techniques</td>
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<td>Soxhlet extraction/maceration</td>
<td>- A solid understanding of the underlying processes and how the operation</td>
<td>- Longer extraction times</td>
<td>[43,44]</td>
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<td>- parameters impact the phenolic compound profile, extraction yield, and</td>
<td>- Prolonged extraction time leads to the breakdown of bioactive compounds</td>
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<td>- extraction time</td>
<td>- High solvent need, resulting in equipment corrosion</td>
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<td>- Provides acceptable yields and extraction rates if process parameters are optimized</td>
<td>- Certain solvents are toxic and flammable</td>
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<td>- Poor selectivity</td>
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<td>Novel techniques</td>
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<td>Ultrasound-assisted extraction</td>
<td>- Shorter extraction time, which increases process efficiency and reduces</td>
<td>- Extended sonication periods cause bioactive compounds to breakdown, lowering the yield</td>
<td>[45,46]</td>
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<td>- adverse environmental consequences</td>
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<td>- Lower operating temperatures</td>
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<td>- Simple to use at industrial, laboratory, and pilot scales</td>
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<td>Microwave-assisted extraction</td>
<td>- Quick and effective</td>
<td>- Bioactive compounds may deteriorate due to high microwave power or prolonged exposure</td>
<td>[44,47]</td>
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<td></td>
<td>- Increased extraction yield</td>
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<td>Pulsed electric-field extraction</td>
<td>- Les solvents needed, making it more sustainable</td>
<td>- Challenging to scale up</td>
<td>[48,49]</td>
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<td>- Improves yield and extraction efficiency</td>
<td>- Require conductivity</td>
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<td>Pressurized liquid extraction</td>
<td>- Increased solubility of water/solvents</td>
<td>- High cost</td>
<td>[46,47]</td>
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<td>- Enhanced rate of extraction</td>
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<td>- Reduced solvent requirements lead to lower chemical and effluent treatment expenses as well as reduced environmental effects</td>
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<td>Supercritical fluid extraction</td>
<td>- Shorter extraction time, increasing process effectiveness and reducing</td>
<td>- Challenging to scale up</td>
<td>[47,50]</td>
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<td>- harmful ecological consequences</td>
<td>- Ineffective for extracting polar polyphenols due to the non-polar nature of CO₂</td>
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<td>- CO₂ has a low critical temperature (about 31 °C), is nontoxic, and is</td>
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<td>- The lack of light and air during extraction decreases degradation</td>
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<td>- Increased extraction yield</td>
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4.1. Conventional Extractions

Apple fruit is used to make a wide range of products. Depending on the type of product, the protocol may change. For liquid samples, like apple juice, liquid–liquid extraction (LLE) using common solvents, like acetone, ethanol, and methanol, can be performed, or the sample can be evaluated immediately upon filtering and/or centrifugation [42,51]. Most prior investigations used solid–liquid extraction (SLE) to create phenolics from apple peel, pomace, and whole fruit using ethanol, acetone, methanol, or water [52–54]. The use of ethanol and water was safer and more environmentally friendly than methanol, despite most research showing that methanol consumption increased phenolic production, according to Casazza et al. [54] and Quang et al. [55]. That said, ethanol released higher flavonoids during the 4 h phenolic extraction of whole apple fruit compared to methanol and acetone [56]. Rana et al. [57] reported that extracting apple pomace with 50% acetone (30 min at 60 °C) was more effective than extracting it with 50% methanol and 50% ethanol. According to Çam’s and Aaby’s [53] study, the best extraction method for phenolics from pomace using water as a solvent was 100 °C for 37 min and 100 mL/g of the solvent to solid ratio. This yielded an optimal total phenolic content (TPC) output and limited 5-hydroxymethylfurfural. In addition, an investigation found that the best TPC was obtained from the SLE of apple pomace at a concentration of 1.14% in water, 104 mL/g of the solvent to material ratio, a pH of 3.8, and an extraction time of 65 min employing Tween 80 as a surfactant [58].

From the author’s experience, one type of solvent may not be sufficient to extract all the polyphenols since fewer polar phenolics may stay inside the matrix, and other hydrophilic chemicals may also be extracted. Conventional extraction also has certain disadvantages that should be taken into consideration. These include the lengthy extraction period, the high solvent amount needed, the flammability issue, poor selectivity, and the potential impact on food safety. To avoid those issues, novel extraction techniques, such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), supercritical fluid extraction (SFE), and pulsed electric field extraction (PEF), have been developed.

4.2. Novel Extraction Strategies

4.2.1. Microwave-Assisted Extraction

Microwave-assisted extraction (MAE) has been acknowledged as an eco-friendly and fast-heating technology with less solvent use. Additionally, it decreased waste, increased automation, provided a better yield with higher purity, and had appropriate reproducibility [59]. This method’s basic idea is the quick transfer of microwave energy to the materials through molecular interactions with electromagnetic fields, which degrades apple tissue and increases the yield of phenolic compounds during solvent extraction [47]. The phenolics from apple peel and pomace were extracted using the MAE [54,60–62]. According to Casazza et al. [54], compared to traditional SLE (which used methanol, 0.2 gDM/mL of solvent, at 25 °C, for 19 h), MAE (using methanol, 0.2 gDM/mL of solvent, at 110 °C for 60 min) produced a higher TPC in apple peel. In a different study, Casazza et al. [60] used ethanol to extract the phenolic content from Jonagold peel. They discovered that the ideal conditions, as determined by TPC, TFC, and antioxidant activity, were ethanol (32% water concentration), a 90 min extraction time, and the possibility that an inert atmosphere could limit the degradation caused by high temperatures (up to 150 °C). Chandrasekar et al. [61] used the response surface methodology (RSM) to investigate the ideal phenolic extraction conditions from two apple pomace varieties using MAE with 70% acetone and 60% ethanol. The authors utilized the extraction time of 30–180 s, solvent to sample ratio of 4–12 mL/g of dry pomace, and microwave power of 100–900 W. They discovered that, when using 70% acetone, increasing the microwave power (265 to 735 W) significantly raised the TPC of both types. They also found that extending the extraction time (61 to 149 s) boosted the phenolics output of the pomace. Moreover, longer exposure times and a higher microwave power may raise the temperature of the solution, which would subsequently break down the phenolics [47]. In the same manner, Rezaei et al. [62] demonstrated that a higher power
(above 90 W) and longer extraction times (above 15 min) resulted in a decrease in the TPC of apple pomace.

4.2.2. Ultrasound-Assisted Extraction

Ultrasound-assisted extraction (UAE) involves applying sonic waves to apple fruits, which can break plant cells and release more phenolic substances into the media [47]. Research has indicated that UAE offers prospective industrial applications for phenolic extraction due to its shorter extraction time, improved process efficiency, and greater sustainability [46]. Using several solvents, UAE was conducted to extract phenolic compounds from apples and their by-products [63]. Much research has been reported on using ultrasound during extraction; however, it has also occasionally been employed to pretreat samples before extraction [64,65]. Wiktor et al. [66] used immersion and contact ultrasound therapy as a pretreatment for apple flesh. It was discovered that the extract had the highest TPC and antioxidant capacity employing the immersion method. In a different study, UAE extracted catechin from the peel and flesh of several apples [67]. Apple cultivars may impact the relative amount of catechin in TPC, which represents the selectivity of catechin extraction compared to other phenolics in addition to the flesh and skin. As stated by Pingret et al. [68], apple pomace has a significant amount of polyphenols that UAE achieves. Higher antioxidant activity was also observed in ultrasonic extracts. An industrial application for the ultrasonic technique was discovered through extensive testing. Pectin was also extracted from apple pomace using UAE [69]. According to Perussello et al. [47], an extended sonication period may cause the phenolics to deteriorate and reduce the yield. Phenolics were removed from the apple fruit by optimizing UAE (with 70% ethanol) using RSM [56]. The maximum TFC concentration of the extract was determined by analyzing the impacts of optimizing temperature, extraction time, and ultrasonic power. Ideal UAE was achieved with 480 W of ultrasonic power for 26.90 min at 44.61 °C. The measured amount of TFC (6.58 mg of rutin equivalent (RE)/g) was close to the expected value (6.69 mg RE/g) under these ideal conditions.

4.2.3. Pressurized Liquid Extraction

Pressurized liquid extraction (PLE) is another novel approach that employs solvents at high temperatures, above their boiling point and below their critical point. The pressure is required to keep the solvent in the liquid state [70]. According to Deen et al. [71], in PLE, apples and other solid samples are extracted employing a solvent at 40–200 °C, 500–3000 psi, for 5–15 min. PLE was used in previous research to remove phenolics from the pomace [21] and apple fruit [72]. It was found that phenolic chemicals from apple pomace may be obtained using a combination of solid-phase extraction and PLE [21]. The study examined many parameters, including the initial water volume (0–120 mL), temperature (60–80 °C), solid-phase extraction adsorbent (Sepra, Isolute, Strata X, and Oasis), and activation/elution solvent (methanol and ethanol). While the temperature did not affect recovery, there were notable variations between phlorizin and a quercetin derivative. The outcomes showed that ethanol might be utilized as an activation, extraction, and elution solvent instead of methanol. Similar or higher yields of flavonoids (0.97 mg/g) and acids (2.85 mg/g) were obtained with this approach compared to Soxhlet extraction utilizing green solvents (ethanol, water, or a tiny amount of reused methanol) [21]. In contrast to MAE and classic SLE, Casazza et al. [54] examined the phenolics of peels from four distinct apple cultivars (Golden Delicious, Jonagold, Renetta Canada, and Raventze) using high-pressure and high-temperature extraction (HPTE). It was revealed that, across all cultivars, the extract produced by HPTE had greater antioxidant activity (DPPH assay) than MAE and SLE. Overall, PLE enhanced the antioxidant activity 2.4 times compared to traditional SLE, suggesting that the technique may be a good substitute for current antioxidant extraction protocols [73]. However, the application of PLE is restricted because of the high expense of the equipment required to sustain the high pressure employed [71].
4.2.4. Pulsed Electric-Field Treatment in Extraction

Pulsed electric field (PEF) is cutting-edge technology that does not require thermal energy and is harmless to the environment. This approach applies brief high-power electrical pulses (μs or ms) between electrodes to the food sample [74]. The PEF is an outstanding nonthermal technique for extracting phenols and flavonoids from apples and their wastes while reducing any marked degradation in the quality. In this context, Lohani and Muthukumarappan [75] used mild PEF to liberate the powdered apple pomace’s bound phenolics. Based on the TPC and antioxidant capacity findings, several pomace powder to water ratios (FWRs 5–12.5%, w/v), treatment times (500–1250 μs), and electric field intensities (1–3 kV/cm) were optimized. The researchers observed that the TPC and antioxidant capability levels were higher at 37.4% and 86%, respectively, under the optimal conditions (12.5% FWR, 500 μs, 2 kV/cm) instead of the control. In an in vitro simulated digestion investigation, PEF treatment (0 and 24 h after 0.01, 1.8, and 7.3 kJ/kg of energy input) was carried out on the bioaccessible and non-bioaccessible fractions of phenolic compounds of apple fruit, and the results were compared with the untreated apple [76]. The outcomes showed that, in comparison to the untreated apple, 0.01 kJ/kg of treatment after 24 h enhanced bioaccessible (61%) and non-bioaccessible (35%) 5-caffeoylquinic acid as well as the TPC of bioaccessible (26%) and non-bioaccessible phenolic compounds (19%).

In summary, several variables, including the apple’s composition, processing settings, and solvent types, influence how well apple phenolic extraction works. More research is still required to improve the conditions, particularly for apple cultivars.

4.2.5. Supercritical Fluid Extraction

To extract the phenolics from apple products using supercritical fluid extraction (SFE), the primary solvent utilized is the safe and nontoxic gas CO\textsubscript{2} (which has a low critical temperature of about 31 °C) [77]. This method’s limitation is that it can only be applied to removing non-polar substances. Adding ethanol/methanol as a modifier to SC-CO\textsubscript{2} is one way to develop a strategy for extracting polar molecules [78]. The SFE procedure was employed to obtain the phenolic content from apple waste [79,80]. Additionally, a study conducted by Ferrentino et al. [81] examined the TPC and antioxidant capability of apple seed oil by SFE. Ferrentino et al. [79] optimized the SFE of fresh, freeze-dried, and oven-dried apple pomace under controlled conditions, including temperature (45 and 55 °C), pressure (20 and 30 MPa), and time (2 h). They also tested the effects of adding 5% ethanol as a co-solvent. The researchers discovered that greater TPC and antioxidant activities were obtained from the freeze-dried pomace extracted under ideal conditions (45 °C, 30 MPa, and 5% ethanol). These findings were also compared to traditional Soxhlet and maceration methods. The SFE extract had a greater TPC and antioxidant capacity than conventional procedures. Likewise, Ferrentino et al. [81] used SFE (24 MPa, 40 °C, 1 L/h flow rate, 140 min) to remove oils from apple seeds. This method produced oil with elevated TPC and antioxidant actions than the Soxhlet extraction. According to Perussello et al. [47], SFE was carried out at a lower temperature without exposure to light or air, which could reduce phenolic degradation and retain the phenolic quality compared to standard extraction methods. Triterpene acids, which also have anti-inflammatory, antioxidant, and anticancer properties, may be selectively extracted and isolated using the SFE approach in addition to phenolics [82].

5. Use of Apple Pomace in Food Applications

Owing to its elevated concentration of phenolic compounds, dietary fiber, and other nutrients, apple pomace is considered a valuable functional component for incorporation into a range of food products (Figure 3). Nevertheless, it has been noted that adding apple pomace to food products can lower several of its quality indicators. Therefore, pomace should only be used in small amounts as a functional element [16], and these additional levels must be closely watched.
Figure 3. Use of apple pomace in food products.

5.1. Bakery Products

For hundreds of years, people have been consuming and accepting various bakery products, such as bread, cakes, and biscuits [16]. The use of apple pomace in baked goods is thought to increase the amount of dietary fiber and provide health advantages. Apple pomace has been attempted to be used as a dietary fiber supplement in bread production in recent years [83]. According to this study, wheat bread was made using 2, 5, 8, and 11% apple pomace. The results showed that, in the neutralized and un-neutralized dough, the loaf of bread mass rose by 3 and 7%, respectively, when the pomace level rose to 11%. In neutralized and un-neutralized doughs, the loaf volume decreased by 26.6 and 42.8%, respectively. As the pomace level increased, improvements were also noted in the crust’s color and bread’s hardness. Similar results have been revealed by Kteniousdaki et al. [84], who concentrated mainly on the dough’s rheological characteristics. It was discovered that adding apple pomace to wheat flour increased the biaxial extensional viscosity, but decreased the uniaxial extensibility. It caused the bread to have a thick structure and a low volume. However, Jannati et al. [85] reported the opposite result of adding apple pomace regarding bread toughness. They assessed the quality of Sangak bread, a customary Iranian bread made with 1 to 7% w/w apple pomace powder. The findings showed that adding apple pomace can reduce the bread’s hardness and slow the staling process. They found that the best addition was 3% apple pomace, which could enhance the bread’s overall acceptability, texture, and aroma. Furthermore, several studies have documented using apple pomace instead of wheat flour in muffins and biscuits. Also, it was shown that muffins with less than 20% apple pomace maintained their shape and scored highly on taste, texture, and color evaluations [86]. Conversely, the assessment of the color of the crust and crumb revealed a notable decrease from a creamier yellow to a brown at replacement levels above 20%. These outcomes concurred with the conclusions stated by Jung et al. [87]. It has been demonstrated that apple pomace improves flavor while increasing total dietary fiber (TDF), TPC, and antioxidant activity [86,87]. Moreover, apple pomace utilization in scones was investigated by Reis et al. [9]. They discovered that adding 20% apple pomace considerably raised the scones’ total flavonoid content (TFC), TPC, and proanthocyanidin content (PAC) by 4-, 3.3-, and 3.1-fold, respectively. Alongi et al. [88] reported that adding apple pomace to cookies can reduce their glycemic index. In line with de Toledo et al.’s [89] findings, Kohajdová et al. [90] found that adding 5% apple pomace did not significantly alter the sensory characteristics of the cookies. On the other hand, Mir et al. [91] created a
gluten-free cracker using brown rice flour and 3, 6, or 9% apple pomace. It was documented that adding pomace considerably increased the amount of minerals, like potassium and chlorine, as well as the antioxidant power; TDF and TPC levels also went up. Thus, apple pomace could be assumed as a nutritional and functional component in bakery products.

5.2. Extruded Food Products

Adding apple pomace to extruded snack products has been demonstrated to increase their nutritional content without materially impairing the snacks’ physical attributes [92]. By using a single-screw extrusion process, Singha and Muthukumarakappan [93] created an extruded snack made of corn grits, defatted soy flour, and apple pomace. The bulk density, antioxidant ability, and TPC increased significantly as the pomace content increased from 0% to 20%. The 5% treatment resulted in a rise in the expansion ratio, whereas the 10 and 20% addition levels showed an opposite tendency. Apple pomace was also incorporated into an extruded food item made with corn flour by O’Shea et al. [94]. The product’s optimal specifications have been described as follows: 69 rpm screw speed, 150 °C die head temperature, and 7.7% pomace. It was also noted that adding pomace decreased the radical expansion ratio, adversely affecting the snack’s texture. Nevertheless, Masli et al. [95], who created cornstarch-based extrudates with 15 and 30% apple pomace concentrations, reported inconsistent results. The addition of 15% pomace resulted in higher initial and stable expansion indices at a lower mechanical energy cost. Moreover, increased shrinkage was noted, and this increased in significance with the degree of addition. The results of the sensory attributes for the corn-extruded snacks with apple pomace added were published by Ačkar et al. [96]. Most sensory qualities, such as flavor, chewiness, and exterior appearance, were considerably reduced when apple pomace was added to the extruded snacks. As the percentage of pomace increased from 5% to 15%, these alterations became more apparent. Overall quality showed the same drop, but was still within tolerable limits. Likewise, Reis et al. [9] created extruded products of rice and wheat semolina flour with 10, 20, and 30% apple pomace inclusions, focusing on the nutritional characteristics. The nitrogen solubility index decreased by 23% when the pomace level rose to 30%, indicating low protein denaturation. It was found that TPC, TFC, and PAC had increased by 2.8, 4, and 1.8 times, respectively. In contrast, Lohani and Muthukumarappan [97] observed that food products made with apple pomace and sorghum flour that were CO2-extruded had improved crispness and reduced hardness. These results, obtained using CO2-extruded food, point to a promising area for further investigation.

5.3. Meat Products

Most recent research focuses on using apple pomace in meat products to help with the meat’s nutritional fiber deficit. In this respect, efforts have been made in numerous meat products, such as chicken sausages, chicken chunks, mutton chunks, and mutton goshtaba [98,99]. Depending on the source for creating meat patties, buffalo meat was added to apple pomace in amounts ranging from 2 to 8%. With an increase in apple pomace powder incorporation, there was an improvement in the water-holding capacity, cooking yield, and meat emulsion stability. The pH of the patties decreased while the amounts of moisture, water activity, fat, and crude fiber rose after cooking. The patty’s textural attributes (i.e., firmness, toughness, and hardness) were more affected [99]. In another study, pomace fiber extract was used as a fat alternative to improve the rheological properties of meat meals and stabilize emulsions [39]. According to Choi et al. [100], sausages were made in a controlled trial, where 1 or 2% apple pomace fiber was combined instead of 5 or 10% pork fat. Chicken sausages with an enhanced nutritional fiber content, excellent acceptability, and room temperature storage durability for up to 15 days were produced using dried apple pomace powder at a 6% level [98]. A study by Jung et al. [87] found that enriched chicken products with 10% and 20% apple pomace added as a meat substitute in chicken patties had reduced hardness. In the same trend, Verma et al. [101] reported that low-fat chicken nuggets with 8 to 12% (w/w) of pomace showed a comparable decrease in
hardness. From the authors’ point of view, even though meat products are regarded as a rich source of protein, adding apple pomace in various forms to meat items may help to increase their dietary fiber content and other bioactive ingredients.

5.4. Confectionery and Snack Products

According to Lyu et al. [2], apple pomace is deemed the ideal component for making a variety of confectionery since it has an elevated concentration of pectin and flavorings. It should be noted that most jelly goods are created due to studies conducted using apple pomace [102]. As Hussein et al. [103] mentioned, apple pomace, carrot, banana, and mandarin peels are among the fruit by-products used to make jam. Apple pomace jam was discovered to have a moderately high phosphorus content, TPC, and TFC, with values of 220 mg/100 g, 82.5 mg/100 g, and 30.1 mg CAT/100 g, respectively. Along the same line, the study conducted by Kapoor et al. [25] revealed that apple pomace jams exhibit elevated levels of phenolic compounds, carotenoids, dietary fiber, and antioxidant properties. According to Goranova et al. [104], apple pomace powder was added to a sponge cake recipe in 10, 25, and 50% increments. The cakes’ flavor was enhanced by adding apple pomace, which also gave them a richer, more vibrant brown color. The semi-finished sponge cakes with 25 and 50% apple pomace had excellent sensory characteristics, an attractive brown color, and tiny, uniformly spaced crumb pores. It can be concluded that powdered apple pomace might be a valuable and nutritious replacement for wheat flour without materially lowering the technological quality of the products. Some examples of the possible use of apple pomace in confectionery and snack products are presented in Figure 4.

![Examples of confectionery and snack products with the addition of apple pomace](own unpublished data)

**Figure 4.** Examples of confectionery and snack products with the addition of apple pomace (own unpublished data).

5.5. Dairy Products

The usage of apple pomace as a natural texturizer and stabilizer in set-type yogurt has been investigated by Wang et al. [105]. Apple pomace at different quantities (0.1%, 0.5%, and 1% w/w) was mixed with fermented products and skim milk. The outcomes demonstrated that adding 1% pomace resulted in a much higher pH at the beginning and a shorter gelation time. Furthermore, after being stored for 28 days, all enriched yogurts showed increased cohesion and consistency. Additionally, it was found that the addition of apple pomace powder to fiber-fortified yogurt resulted in a decrease in acidity and an increase in total soluble solids. Furthermore, El Sayed et al. [106] found that apple fiber improved the yogurt’s color, texture consistency, and flavor, among other sensory attributes. Apple pomace was successfully added to acidophilus yogurt to increase its fiber content to a 10% level without causing any degradation in its quality [37]. According to Tanuja’s and Goswami’s [107] research, burfi, a dairy product with apple pomace added, is more nutritious than the original recipe. Further studies are required to examine the viability and acceptance of such products because there is a shortage of information on the direct application of apple pomace to dairy products.
6. Limitations Associated with Apple Pomace Consumption

The research on the potential health risks associated with apple pomace is currently lacking and requires more studies. Previous reports have identified two possible hazards associated with consuming apple pomace: ingesting natural plant toxins and pesticide residue [30]. Plant toxin investigations still focus on amygdalin from apple seeds, which can cause sharp cyanide poisoning. On the other hand, current research indicates that apple seeds have a typically safe amount of amygdalin for human intake [108]. According to Skinner et al. [30], sharp cyanide poisoning in humans requires the eating of about 800 g of apple pomace, an occurrence that is extremely unlikely [30]. Apple pomace may also contain pesticide residues, of which neonicotinoids are of particular concern since conventional procedures are thought to be unable to eliminate them by Chen et al. [109]. Neonicotinoid residues were evaluated in eight apple cultivars by Chen et al. [109], who found that most neonicotinoids were small. Two apple cultivars were found to contain acetamiprid, however the toxicity risk associated with these amounts is negligible [30]. Moreover, fungicides are being utilized increasingly to enhance the quality and production of apple fruit, which presents serious safety concerns. In this respect, Liu et al. [110] reported that thiophanate, carbendazim, and pyrimethanil, three fungicides, were found in apple fruits. Thiophanate and carbendazim were shown to have low acute toxicity, according to the US Environmental Protection Agency (EPA) [110]. Additionally, the residue of plant growth regulators, such as diphenylamine and naphthaleneacetic acid, was also highlighted in some studies, and the EPA considers them to have low toxicity and not dangerous [111]. There is no proof that eating apple pomace poses any health risks. However, as pesticides and other chemical agents evolve, more research will be needed to understand this issue better.

7. Conclusions and Future Directions

Apple pomace is the waste product that remains after processing apples and includes the peel, stem, seeds, and pulp. This review examined the nutritional value and bioactive components of apple pomace in detail, as well as the safety and potential health advantages. The standard practices for disposing apple pomace can pollute the environment and possibly pose health risks to the general public. Considering that apple pomace is an excellent source of pectin and polyphenols, the extraction of these bioactive substances utilizing traditional and eco-friendly extraction methods was also discussed in this review. The choice of extraction process is crucial since it affects the quality and dependability of the subsequent analytical procedures. According to the reports, using green extraction technologies instead of traditional ones is turning out to be a more prosperous and efficient way to extract bioactive compounds from apple by-products. From different extraction methods, apple pomace is an essential functional ingredient in a wide range of industrial, nutritional, and environmental products. As mentioned above, apple pomace can enhance bakery goods’ nutritional value and fiber content, including bread and sweet baked goods. Extruded food and meat products can benefit from adding apple pomace to increase their nutritional content. Furthermore, it has been discovered that the use of apple pomace in dairy and confectionery goods influences the quality attributes of the final product. Additionally, various useful bioactive substances that can be isolated from apple pomace, such as fiber, phenol, and pectin, can be added to food products to enhance their nutritional value and overall quality. Even though apple pomace contains pesticide residues and natural plant toxins that are thought to present health dangers, recent research indicates that consuming apple pomace does not present a significant risk to human health. For future studies, techno-economic analyses and life cycle assessments are necessary for assessing the commercial use of apple pomace with the best technologies, which is promising for cutting economic costs and environmental pollution. Along with validating potential bioactivity, additional research is required to understand the stability of bioactive substances and the mechanisms that regulate them. Additionally, preclinical and clinical studies are necessary for increased safety.
Author Contributions: Conceptualization, A.A.Z.; writing—original draft preparation, A.A.Z., M.N. and D.W.-R.; writing—review and editing, A.A.Z., M.N. and D.W.-R.; visualization, A.A.Z. and M.N.; supervision, M.N. and D.W.-R.; project administration, A.A.Z. and M.N.; funding acquisition, D.W.-R. All authors have read and agreed to the published version of the manuscript.

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

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding authors.

Acknowledgments: The first author is highly grateful to the Polish National Agency for Academic Exchange (NAWA) for their financial support under the Ulam programme, Agreement No. BPN/ULM/2022/1/00059/U/00001.

Conflicts of Interest: The authors declare no conflicts of interest.

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