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Title:

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Date:

2020-03-01

Citation:

Lyu, F., Luiz, S. F., Azeredo, D. R. P., Cruz, A. G., Ajlouni, S. & Ranadheera, C. S. (2020). Apple pomace as a functional and healthy ingredient in food products: A review. *Processes*, 8 (3), <https://doi.org/10.3390/pr8030319>.

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Review

Apple Pomace as a Functional and Healthy Ingredient in Food Products: A Review

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Received: 5 February 2020; Accepted: 4 March 2020; Published: 9 March 2020



Abstract: Apple pomace is a major by-product obtained during apple juice processing. Several million metric tons of apple pomace are estimated to be generated worldwide every year. However, the recovery rate of this by-product is low. Pomace is commonly disposed and thrown away as a waste, which results in environmental problems and even public health hazards. As a by-product of the apple juice processing industries, pomace contains plenty of different varieties of nutritionally important compounds, such as carbohydrates, phenolic compounds, dietary fiber and minerals. These important compounds can be recovered from apple pomace, or there is even a possibility of using apple pomace in the food systems directly or after minimal processing. Therefore, apple pomace can be utilized in food products to improve their health benefits and commercial values. This review focuses on the current food applications and influence of apple pomace on the characteristics of various food products.

Keywords: apple pomace; food processing wastes; bioactives; functional ingredients

1. Introduction

Apple (*Malus domestica* Borkh.) is one of the earliest fruit known to humans and is widely cultivated in temperate regions [1]. Following oranges, bananas and grapes, apples are the fourth most consumed fruit crop in the world [2]. It has been reported that the global per capita consumption of apples exceeded 9 kg in 2013 [1] and has been further increased over time. According to the latest report by FAO [3], the annual world production of apples has increased by 48% over the last two decades and reached 83.1 million metric tons in 2017. As the original center for apples, Asia accounted for 65.4% of the world production, with China producing 41.4 million metric tons. Other major producers include the US, Turkey and Poland, representing 6.2%, 3.6% and 2.9% of the total worldwide production, respectively.

Although the global apple production continues to grow, the share of its consumption is relatively stable. Apples used for fresh consumption account for 70%–75% while the rest (25%–30%) of world total production is processed to various value-added products including juice, wine, jams and dried product [4,5]. However, apple juice is still the most demanded apple product, accounting for 65% of the total amount of processed apple [6]. Generally, nearly 75% of apple fresh weight is supposed to be extracted as juice during juice production, and the left-over is collected as a food waste, the so-called pomace [7].

Considering the worldwide mass production of juice, a total of several million metric tons of the pomace is estimated to be generated every year [6]. The approximate quantity of apple pomace production in certain countries is given in Table 1, which is expected to have a further increase in future. However, the recovery rate of this by-product is quite low. In India, for example, only approximately 1% of the apple pomace can be utilized as animal feed or dry product [5]. The most common disposal method for this by-product is to discard it directly to the soil in a landfill, which is suggested to cause serious environmental problems associated with pollution [4,5,8,9]. This is mainly due to the rich water content (>70%) and the high biodegradable organic load (chemical and biochemical oxygen demand) of apple pomace. The former leads to a great susceptibility to microbial decomposition, resulting in unpredictable fermentation while the latter contributes to environmental pollution and even public health hazards [4]. Consequently, researchers suggested that professional waste disposal should be applied in apple juice plants to reduce environmental problems, which may require additional economic investments [10]. Therefore, it is necessary to explore safe and efficient treatments of apple pomace and its effective utilization in the food and nutraceutical industries. Considering the large volume of this by-product generated from production and processing of juice, the commercial applications of pomace can create great economic impact [5]. Some success has been achieved in transforming a variety of agricultural and food processing waste into commercially viable products including bio-fuels, nutrients and multifunctional ingredients [11]. Similarly, in recent years, various applications of apple pomace have been considered in order to raise its recovery rate.

Table 1. Quantities of apple pomace production in certain countries.

Country	Quantity (Metric Tons)	Ref.
Brazil	800,000	[7]
China	1,000,000	[12]
Germany	250,000	[13]
India	1,000,000	[5]
Iran	97,000	[14]
Japan	160,000	[15]
United States	27,000	[16]

Currently, apple pomace is used as a functional ingredient in food products due to its high nutrient content [17]. Most of the previous reviews on utilization of apple pomace have been focused on the recovery of functional bioactive compounds from apple pomace and applications of these compounds in various nutraceutical products. However, there is an increasing interest in utilizing apple pomace directly or with minimal processing in food products. Therefore, this review mainly summarizes the current food applications of apple pomace as direct ingredient or after minimum processing in food manufacturing with special reference to the influence of apple pomace on the characteristics of various food products. Utilization of apple pomace as a substrate to produce food and beverages is also briefly discussed.

2. Composition and Nutritional Value of Apple Pomace

Apple pomace is a heterogeneous mixture consisting mainly of skin and flesh (95%), with a tiny proportion of seeds (2%–4%) and stems (1%) [4,18]. Its physical–chemical composition has been determined by numerous studies (Table 2) and it shows a variation according to the variety and processing type used in apple juice production [7].

Table 2. Different physical–chemical compositions of apple pomace.

Composition (%) ¹	Wang et al. (2019) [19]	Jin et al. (2002) [20]	Jannati et al. (2018) [21]	Ktenioudaki et al. (2013) [22]
Moisture	4.4	5.8	10.5	7.1
Protein	3.8	4.7	1.2	2.4
Lipids	3.8	4.2	0.6	2.7
Total Dietary Fiber	26.5	NR ²	14.5	42.5
Ash	1.8	1.5	2.5	1.7
Carbohydrates	45.1	83.8	NR ²	NR ²

¹ Dry weight basis. ² Not reported.

Despite the differences in content, the variety of nutrients in apple pomace is rich. It is a good source of phytochemicals and contain significant amounts of carbohydrate as well as small amounts of proteins, vitamins and minerals [4]. The apple pomace carbohydrates consist mainly of insoluble sugars including cellulose (127.9 g/kg DW), hemicellulose (7.2 to 43.6 g/kg DW) and lignin (15.3 to 23.5 g/kg DW), with simple sugars such as glucose (22.7%), fructose (23.6%) and galactose (6% to 15%) [23]. In addition to carbohydrates, some minerals were also determined in apple pomace, such as P (0.07% to 0.076%), Ca (0.06% to 0.1%), Mg (0.02% to 0.36%) and Fe (31.8 to 38.3 mg/kg, dry weight basis). Apple pomace is also characterized by a high proportion of polyphenols (31% to 51%), especially cinnamate esters, dihydrochalcones and flavonols [24]. Furthermore, it has been proven that apple pomace has a broad content of natural antioxidants such as quercetin glycosides, phloridzin and other phenolic constituents that have strong antioxidant activity [25,26]. Therefore, apple pomace is of great nutritional value, providing health benefits. Several studies indicated that apple pomace not only helps in the prevention of constipation and hypertension but also can scavenge certain harmful substances in the human body such as free radicals [4]. The existence of these value-added compounds also indicates the potential of apple pomace being utilized as an ingredient in the food industry.

3. Use of Apple Pomace as a Functional Ingredient in Food Products

Due to the high content of dietary fiber, phenolic compounds and other nutrients, apple pomace is regarded as a good functional ingredient to be incorporated in various food products. However, the addition of apple pomace is reported to cause a decline in certain quality parameters of food products. Therefore, the addition level of pomace as a functional ingredient is relatively low [17], and these amounts should be carefully monitored.

3.1. Bakery Products

Various bakery products including bread, cakes and cookies have been consumed by humans for hundreds of years and are widely accepted [17]. The application of apple pomace in bakery foods is considered to improve the dietary fiber content and health benefits [27,28]. However, pomace addition results in a decrease in quality and sensory properties of baked products in the majority of cases [29–31]. Therefore, efforts have been undertaken to evaluate the effects of apple pomace on each individual bakery product and optimize the utilization level to incorporate.

3.1.1. Bread

Efforts have been made to apply apple pomace as a supplement of dietary fiber in bread making over the last few decades [17,27,31,32]. A study by Masoodi and Chauhan examined the application of 2%, 5%, 8% and 11% apple pomace in wheat bread making [27]. Their results showed that with the pomace level increasing from 0% to 11%, the loaf weight increased by 3.1% in the neutralized dough (dough with acidity-neutralized apple pomace) and by 7% in the un-neutralized one. The loaf volume was observed to be reduced by 26.6% and 42.8% in neutralized and un-neutralized doughs, respectively. The crust color and bread hardness were also found to increase with the pomace level. Moreover, although the overall score of the organoleptic evaluation was gradually decreased, the bread

made with 5% pomace was considered to be acceptable and obtained the highest scores in respect of odor and taste. Similar findings have been demonstrated in depth by Ktenioudaki et al. (2013), with a particular focus on the rheological properties of dough [22]. The incorporation of apple pomace to wheat flour was found to reduce the uniaxial extensibility while raising the biaxial extensional viscosity of dough. It led to the low volume and dense structure of the bread. Nevertheless, the opposite effect of adding apple pomace on bread hardness was described by Jannati et al. (2018). They evaluated the quality of Sangak bread (a traditional Iranian bread) that included apple pomace powder (1% to 7% w/w of flour) [21]. The results indicated that adding apple pomace can reduce the hardness of bread texture and delayed its staling progress. They concluded that adding apple pomace at 3% was the most effective. In addition, the sensory analysis showed that adding less than 3% of the pomace could improve the smell, texture and overall acceptability of the bread, which is also different from the conclusion of Masoodi and Chauhan (1998) [27]. Therefore, the application of apple pomace as a functional ingredient in bread making is feasible. Future studies are required to verify the appropriate proportion of apple pomace in different types of bread.

According to Sudha et al. (2016), buns containing 15% dehydrated apple pomace and dough conditioners increased in volume by 30% compared with no conditioner counterparts [31]. These additives included glycerol monostearate (0.25%), sodium stearoyl lactylate (0.25%), gluten (2%) and α -amylase (1 mg). Besides volume, the firmness together with overall sensory score of the buns with conditioners and pomace were also improved.

3.1.2. Sweet Bakery Products (Cakes, Including Scones and Muffins)

Currently, a number of research studies have been done on the use of apple pomace in cakes and other sweet bakery products in order to enhance their flavor and nutritional values [17,21,30,33]. Masoodi et al. (2002) reported the application of apple pomace with different proportions (5%, 10% and 15%) in cake making [33]. They concluded that with the increase of pomace level, the cake volume reduced dramatically, while the particle size showed an opposite trend. Moreover, remarkable increases were observed in shrinkage and uniformity index after the addition of apple pomace, but there were no significant differences between 10% and 15% treatments. Similar results were reported by Sudha et al. (2007), who increased the addition level of apple pomace up to 30% in cakes [30]. The data revealed that the volume of cake with 30% pomace decreased by 37% compared with the control. As the added pomace level increased from 10% to 30%, the density increased accordingly from 0.49 to 0.67 g/cc, which indicated a harder texture. However, in the organoleptic test, cakes with pomace obtained high scores in eating quality and overall acceptability, with the exception of 30% treatment which had a lower evaluation. Owing to the pleasant fruity odor, Sudha et al. (2007) also regarded apple pomace as a potential flavoring ingredient in cake products, which needs more experiments to implement at the commercial scale [30].

Moreover, apple pomace has also been reported to be used as a wheat flour substitute in muffins [28,29]. A more recent study by Sudha et al. (2016) showed that muffins with less than 20% apple pomace were not only normally symmetrical in shape but also scored highly on sensory tests for color, taste and texture [31]. However, once the replacement level exceeded 20%, the evaluation of crust and crumb color showed a significant decrease because it changed from creamier yellow to brown. These results were in agreement with the findings claimed by Jung et al. (2015) [29]. However, a preference test carried by Wang and Thomas (1989) demonstrated a superior satisfaction for muffins with 50% pomace [28]. The overall preference was 79.2% while the nonfortified muffins were only 20.8%. In addition to flavor improvement, the utilization of apple pomace was proven to increase the total dietary fiber (TDF), total phenolics content (TPC) and antioxidant activity [28,31]. Furthermore, Reis et al. (2014) explored the application of apple pomace in scones [34]. They found that incorporation of 20% apple pomace significantly increased the total flavonoid content (TFC), TPC and proanthocyanidins content (PAC) of scones by 4-, 3.3- and 3.1-fold, respectively. Therefore,

apple pomace can be considered as a great functional ingredient for improving the health-promoting properties of these types of bakery foods.

3.1.3. Brittle Bakery Products (Cookies and Crackers)

Similar to cake doughs, cookie doughs are rich in sugars and lipids that may mask bitter taste caused by the application of apple pomace in the final products [17]. In this case, cookies have a high tolerance for the addition of apple pomace, with some studies even reporting substitution level as high as 30% [31]. In a recent study, Lauková et al. (2016) applied hydrated apple pomace powder to partially replace wheat flour during cookie making [35]. Results showed that with the replacement level increasing from 0% to 15%, the physical properties of cookies such as volume, diameter and porosity declined sharply by 23%, 11% and 25%, respectively. Meanwhile, the fruity flavor of the cookies increased while the grain taste was reduced after the substitution. The overall satisfaction of fortified cookies was found to decrease in sensory evaluation, but the acceptance of all the treatments was above 90%. Additionally, according to Kohajdová et al. (2014), adding 5% of the apple pomace had no significant change in the sensory properties of cookies, which was consistent with the findings of Toledo et al. (2017) [36,37]. Jung et al. (2015) prepared cookies with apple pomace flour of 15% and 20% substitution level. With the incorporation of pomace, cookies were observed to be considerably darker and redder [29]. This finding is concurrent with other bakery products as well. Furthermore, all of these studies mentioned a falling tendency in firmness, which became more marked with the increase of apple pomace replacement level. However, an opposite change in the firmness of apple-pomace-fortified cookies was observed by Sudha et al. (2016), who applied up to 30% of dehydrated apple pomace in cookies [31]. In addition, a mixture of glycerol monostearate (0.25%) and sodium stearoyl lactylate (0.25%) was developed as an additive to alleviate the quality deterioration in cookie caused by the addition of apple pomace [31].

Notably, Alongi et al. (2019) indicated that the addition of apple pomace can reduce the glycemic index of cookies [38]. As the replacement level increased from 0% to 20%, cookie glycemic index reduced from 70 to 60. As a result, this apple-pomace-enriched product can be ranked as an intermediate glycemic index food. Moreover, a gluten-free cracker made from brown rice flour and 3%, 6% or 9% of apple pomace was developed by Mir et al. (2017). It was noted that the incorporation of pomace significantly increased the content of minerals such as chlorine and potassium, as well as the antioxidant activity; TDF and TPC were also increased [39]. Therefore, apple pomace can be regarded as a nutritional and functional ingredient in bakery products. Future studies are recommended to develop various types of functional baked foods with apple pomace as an ingredient.

3.2. Extruded Food Products

The addition of apple pomace in extruded snack products has been proven to enhance their nutritional value without causing significant negative effects on the physical properties of the snacks [40]. The current research mainly focuses on the development of optimal processing conditions, considering that in addition to the amount of apple pomace, there are a number of parameters that can affect the quality of extruded food [41,42]. Singha and Muthukumarappan (2018) developed an extruded snack based on apple pomace, defatted soy flour and corn grits by single screw extrusion [9]. With the pomace level increasing from 0% to 20%, the bulk density, antioxidant capacity and TPC raised markedly. The expansion ratio was noted to increase under 5% treatment while showing an opposite trend under the addition levels of 10% and 20%. The optimal extrusion condition was determined as 140 °C barrel and die temperature, 200 rpm screw speed and 20% feed moisture content (wet basis). Similarly, O'Shea et al. (2014) applied apple pomace into a corn-flour-based extruded food product [42]. The optimized parameters for this product were reported as 7.7% pomace, 150 °C die head temperature and 69 rpm screw speed. Moreover, the addition of pomace was found to reduce the radical expansion ratio, which in turn negatively affected the texture of the snack. However, contradictory results were reported by Masli et al. (2018), who developed cornstarch-based extrudates with 15% and 30% apple

pomace contents [43]. Higher initial and stable expansion indexes were obtained with the incorporation of 15% pomace while the mechanical energy cost was lower. Furthermore, higher shrinkage was mentioned, which became more marked with the addition level.

Since many of extruded snacks are gluten-free, it is of great significance to evaluate their sensory acceptance. Ačkar et al. (2018) reported the organoleptic test for the corn extruded snacks with added apple pomace [44]. The incorporation of apple pomace to extruded snacks significantly decreased most of the sensory properties including external appearance, chewiness and flavor. These changes became more obvious with the pomace level increasing from 5% to 15%. The same decline was exhibited in overall quality but within the acceptable range. Moreover, extruded products of rice and wheat semolina flour with 10%, 20% and 30% apple pomace incorporation were prepared by Reis et al. (2014), with a particular emphasis on the nutritional aspects [34]. As the pomace level reached 30%, the nitrogen solubility index reduced by 23%, which indicated a low protein denaturation. The increases in TPC, TFC and PAC were observed to be 2.8-, 4- and 1.8-fold, respectively. On the contrary, Lohani and Muthukumarappan (2017) reported that CO₂ extruded food products based on sorghum flour and apple pomace had decreased hardness and increased crispness [45]. These findings via the application of CO₂ extruded food indicate a promising research focus in these areas.

3.3. Meat Products

Most of current studies emphasize the application of apple pomace in meat products in order to improve the deficiency in the dietary fiber of meat. Efforts have been made in mutton products, including mutton nuggets [46] and mutton goshtaba (a traditional Kashmiri meatball) [47], as well as chicken products, such as chicken sausages [48] and chicken nuggets [49]. In addition, Younis and Ahmad (2018) prepared buffalo meat patties in which the meat level was substituted by 2% to 8% of apple pomace [50]. The contents of fat, moisture and crude fiber were observed to have a significantly positive correlation with the replacement level. Similar trends were detected in cooking yield and thickness of the patties, as well as the texture properties such as firmness and toughness. A decline in cohesiveness and springiness was found as the substitution level exceeded 6%. Younis and Ahmad (2015) used the same level of pomace substitution for buffalo sausages and obtained similar results [51]. However, decreased hardness was reported in fortified chicken products by Jung et al. (2015), who applied 10% and 20% of apple pomace as a meat replacement in chicken patties [29]. According to Verma et al. (2010), a similar decline in hardness was exhibited in low-fat chicken nuggets with 8% to 12% (w/w) of pomace [49]. All these tested meat products showed darker and redder color changes and an improved amount of TDF in the final product. When considering different meat types, there was relatively less research on the application of apple pomace in pork products, so this can be regarded as the orientation of future research.

3.4. Confectionery Products

Apple pomace is considered as a suitable ingredient to include in the preparation of confectionery due to its high content of pectin and flavor compounds [5]. A jelly product using a puree of apple pomace and quince fruit was developed by Royer et al. (2006) [52]. Another study by Hussein et al. (2015) reported an apple-pomace-based jam made by fruit by-products such as apple pomace, carrot peels, banana peels and mandarin peels [53]. The mixture of each by-product and sugars was stirred and adjusted to pH 3.2 using citric acid until the total soluble solids reached 67° Brix. It was found that the phosphorus content, TPC and TFC of apple pomace jam were relatively high, with the concentrations of 220 mg/100 g, 82.5 mg/100 g and 30.1 mg CAT/100 g, respectively. Among all the jams, apple pomace jam gained the highest score in overall acceptability owing to the fruity flavor and satisfying appearance.

3.5. Dairy Products

Wang et al. (2019) conducted a study using apple pomace as a natural stabilizer and texturizer in set-type yoghurt [19]. Various concentrations of apple pomace (0.1%, 0.5% and 1% w/w) were combined

with skim milk and fermented by a mixture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* at 42 °C. Results showed that the addition of 1% pomace led to a dramatically higher onset pH and shorter time of gelation. Moreover, all fortified yoghurts exhibited improved consistency and cohesiveness during 28 days of storage. The potential of freeze-dried apple pomace powder as a dairy ingredient has recently been evaluated by Wang (2018). This study reported that addition of 1% apple pomace powder increased the gelation pH and shortened the fermentation time in yogurt manufacturing, eventually developing a more viscoelastic, consistent, and firmer yogurt gel [54]. The same study revealed that adding apple pomace into stirred yogurt allowed even a higher level of pomace to be incorporated (3%) and resulted in a significant decrease of syneresis along with increase in viscosity, firmness, and cohesiveness of the matrix during 28 days of cold storage. Wang (2018) highlighted the potential of apple pomace as a natural stabilizer, texturizer and source of dietary fiber and polyphenols in dairy products such as yogurt [54]. Owing to the lack of research on the direct application of apple pomace in dairy products, subsequent studies are needed to explore the feasibility and acceptability of such products.

4. Apple Pomace as a Substrate for Food and Beverage Manufacturing

4.1. Using Apple Pomace in Alcoholic Beverages Production

The fermentation of apple pomace to produce ethanol has been developed for decades due to its minimum land requirement and low cost [55,56]. The common method of ethanol production is reported as solid-state fermentation on apple pomace alone [57,58] or on a mixture substrate of pomace and molasses [59]. Simultaneous saccharification and fermentation (SSF) have also been mentioned in recent research [60]. In the food industry, apple pomace is applied to develop mild alcoholic beverages, which is expected to improve their flavor [61].

Madrera et al. (2013) prepared spirits from dry apple pomace and yeast strains including *Saccharomyces cerevisiae*, *Hanseniaspora uvarum* and wine dry yeast with β -glucosidase enzyme [62]. Fermentations were carried out under 16 ± 2 °C for 4 weeks. The spirits were distilled twice, with an alcohol strength of 20%–22% (v/v) in the first stage and 60% (v/v) in the second stage. All of the spirits showed high alcohol contents, from 261 g/hL AA for *H. uvarum* to 509 g/hL AA for *S. cerevisiae*. However, the enzymatic treatment was considered to be not advisable because of its excessive methanol concentration. Another noteworthy finding was that spirits under different yeast species had significant differences in aromatic composition, which was of great commercial value. Li et al. (2015) prepared apple homogenate cider with koji and *S. cerevisiae*, individually and in combination [61]. The final products were achieved after 6-day fermentation and 7-day ageing. The greatest fermentation capacity happened in *S. cerevisiae* monoculture group, with the ethanol production of 7.50% (v/v). Cider with koji generated the highest amounts of total sugar, reducing sugar and ester compounds, which were 24.12 g/100 g, 22.93 g/100 g and 37.35%, respectively. Furthermore, volatile compounds such as 2-methyl-1-butanol and alpha-farnesene that are mainly generated by apple pomace were higher in koji monocultures. This result indicated that apple pomace can be considered as a fruity flavoring in cider products.

4.2. Apple Pomace as a Substrate for Edible Mushroom Production

Apple pomace is considered as good support for mushroom cultivation. This is mainly because it is rich in carbohydrate polymers, such as lignin, as well as minerals including nitrogen, both of which are essential nutrients for mushroom growth. Worrall and Yang (1992) cultivated shiitake (*Lentinula edodes*) and oyster mushrooms (*Pleurotus ostreatus* and *P. sajor-caju*) on apple pomace and sawdust, separately and in combination [63]. Higher yield was observed using pomace alone than on sawdust. The combined substrate with 50% (w/w) pomace produced five shiitake isolates and two *Pleurotus* spp. with greater fresh weights than either substrate alone. Park et al. (2012) applied 2.5%, 5% and 10% apple pomace to sawdust and then cultivated *P. ostreatus* [64]. Their results showed that adding 2.5% pomace increased the mycelial growth rates in solid culture, liquid culture and solid-state

fermentation by 34.5%, 20% and 26%, respectively. However, adding more than 5% pomace was found to negatively affect the mycelia growth. Moreover, Park et al. (2014) determined the optimum conditions for *P. ostreatus* to produce laccase as 2.5% apple pomace addition and 9 days of cultivation time [65]. At present, cultivation of mushrooms using apple pomace as a substrate is only in the experimental stage and needs to be commercialized in the future in order to expand its application.

4.3. Miscellaneous Use and other Potential Application of Apple Pomace

Madrera et al. (2015) analyzed volatile compounds generated during the fermentation of apple pomace with *S. cerevisiae*, *H. valbyensis*, *H. uvarum* and a combination of *S. cerevisiae* and an inoculated enzyme [66]. A total of 132 volatile compounds belonging to different chemical families were identified, which were found to be strain dependent. Results indicated that fermented apple pomace can be used as a natural flavoring in beverages by maceration or infusion. Huc-Mathis et al. (2019) investigated the emulsifying properties of apple pomace and oat bran [67]. Rapeseed, jojoba and myrtilol oils were used to obtain 50/50 (w/w) oil in water emulsion. Results indicated that apple pomace can better stabilize emulsions of rapeseed and myrtilol oil. Therefore, apple pomace can be regarded as a potential stabilizing agent, and its interactions with other common ingredients in food products need further investigations. Bartkiene et al. (2017) applied apple pomace to immobilize *Pediococcus acidilactici* LUHS29 and added them to wheat–barley sourdough fermentation [68]. An increase of 15.3% in the lactic acid production was noted during the fermentation of sourdough with immobilized strain. The same trends were found in the TPC and radical scavenging activity, with the increases of 34.6% and 79.7%, respectively. In this case, owing to its bioactivity, the immobilization of apple pomace matrix bacterial cells can be utilized in the processing of other fermented products.

5. Major Functional Ingredients and Bioactives that can be Extracted from Apple Pomace

Major functional bioactive compounds from apple pomace and their bioactivities are listed in Table 3. These functional apple pomace ingredients, including pectin, phenol and fiber can be extracted and applied as functional ingredients in various food products. Due to the high concentration of nutrients, these extracts can play a more obvious role in foods such as cookies [69], ciders [70] and meat products [71]. However, studies related to the extractions of such functional ingredients concentrate mainly on the extraction technologies, and there are relatively few studies on the applications of these extracts in food products.

Table 3. Major bioactive compounds from apple pomace.

Class	Concentration (mg/kg dry weight basis)	Major Compounds	Bioactivity and Therapeutic Potential
Carbohydrates	Data not available	Pectin and pectin oligosaccharides	Soluble viscous fermentable fiber/dietary fiber, potential prebiotic properties and hypo-cholesterolemic effects
Phenolic acids	523–1542	Chlorogenic acid, caffeic acid, ferulic acid, <i>p</i> -coumaric acid sinapic acid, <i>p</i> -coumaroyl-quinic acid	Antioxidant, antimicrobial, anti-inflammatory, anticancer and cardio-protective effects
Flavonoids	2153–3734	Isorhamnetin, kaempferol, guercetin, rhamnetin, glycoconjugates, procyanidinB2, epicatechin	
Anthocyanins	50–130	Cyanidin-3-O-galactoside	Antidiabetic, potential in treating obesity, promoting bone-forming, blastogenesis
Dihydrochalcones	688–2535	Phlorizin, phloretein	
Triterpenoids	Data not available	Ursolic acid, oleanolic acid	Antimicrobial and anti-inflammatory effects

Adapted and modified from [72,73].

5.1. Pectin

Pectin is a soluble viscous fermentable fiber and common additive in the food industry which functions as a gelling agent, emulsifier and thickener in various food products such as confectionery, bakery jellies, yoghurts and beverages [4]. Apple pomace is one of the main fruit sources of pectin, thus, extracting pectin has been regarded as a reasonable approach of pomace utilization [74,75]. Currently, the common extraction methods include enzymatic [76,77], mechanical [78] and chemical extractions [79]. Notably, novel methods are constantly being proposed. For example, Wang et al. (2014) extracted apple pomace pectin by adding 30× subcritical water. The mixture was heated under 130 °C, 150 °C, and 170 °C for 5 min, the supernatant liquid was filtered, and pectin product was collected by alcohol precipitation, washing and drying. The highest pectin recovery rate (16.68%) was found in the treatment of 150 °C [80]. Additionally, combined extraction techniques using ultrasonic homogenizing and viscozyme (fungal β -glucanase) treatments were reported by Min et al. (2010) to extract pectin, which was applied in cookie formulations to partially replace shortening [69]. Results showed that with the incorporation of extracted pectin, the height of cookies increased while the diameter decreased. The moisture content increased from 6.72% to 11.00% as the replacement level increased from 0% to 30% (w/w), which led to dramatic declines in fracturability and hardness of 21.6% and 40.2%, respectively. A lighter color was also observed after the addition of replacement. Therefore, apple pomace pectin extract can be used not only to modify the textural properties of the food product but also as a functional ingredient to replace fat in bakery products. However, sensory evaluations to test the acceptability of pectin-fortified food product are required.

5.2. Phenol

Phenol extracts from apple pomace mainly consist of phloridzin, epicatechin, chlorogenic acid and quercetin glycosides [81,82]. The application of these polyphenols is supposed to affect the organoleptic properties, such as color, flavor and odor, as well as the antioxidant ability of food products [8,83]. Therefore, phenol concentrations can be used as both functional ingredients and natural antioxidants. Current phenol extraction methods include maceration and Soxhlet extraction [84,85], enzymatic method [86], ultrasound extraction [87] and microwave extraction [88]. Benvenuti et al. (2019) conducted solid–liquid extraction to prepare phenol concentration and applied 77 and 130 mg/L of it into cider production [70]. Results showed that the antioxidant activity of ciders increased by 1.6- and 2.8-fold, respectively. A darker and yellower color, as well as accentuated bitterness and astringency, were detected after phenol addition. All of these changes were within the acceptable range. Notably, quercetin glycosides, which only exists in fruit epicarp, were detected in ciders with added pomace phenol extract. There has been relatively little research on the direct use of apple pomace phenol extract, and given its health benefits, further research is needed to develop a variety of phenol-enriched foods.

5.3. Fiber

Although apple pomace can be directly used as a functional ingredient in food products, the pomace fiber extract is expected to play a more effective role in fiber enrichment. Fiber extract is applied to provide dietary fiber including pectin, cellulose and lignin in various foods and pharmaceutical products. Issar et al. (2017) developed an acidophilus yoghurt containing apple pomace fiber with the starter culture of *Lactobacillus acidophilus* and *Bifidobacterium longum* [89]. The fiber extract was prepared by acid–alkali digestion method and 2.5% to 10% of it was added as a functional ingredient. Increasing the amounts of added fiber extract from 0% to 10% caused decline in acidity and fat content, with the percentages changed from 0.15% to 0.09% and 1.65% to 1.59%, respectively. Yoghurts with 5% fiber concentration were considered ideal in the sensory test, gaining the highest scores in color, flavor and consistency. However, the products were regarded as unacceptable when the fiber level exceeded 5%.

In addition, pomace fiber extract can be used as a fat replacer in meat products, which is reported to improve their rheological properties as well as emulsion stability [90]. Choi et al. (2016) made

uncured, reduced-fat chicken sausages with partially replacing 5% and 10% of pork fat by 1% and 2% of apple pomace fiber concentration [71]. According to the results, both fat content and caloric energy decreased significantly with the increased substitution level. The same tendencies were found in emulsion stability, such as cooking loss and fat separation. Therefore, fiber extract from apple pomace has been successfully applied to food products to control fat consumption.

6. Health Hazards Related to Apple Pomace Consumption

At present, the research on the health hazards of apple pomace is still insufficient and needs further investigations. Existing studies indicated two potential risks of apple pomace consumption, which are natural plant toxins and pesticide residue intake [91]. Apple seed amygdalin, which may induce acute cyanide poisoning, has always been the focus of plant toxin research. However, recent studies have reported that the level of amygdalin in apple seeds is generally safe for human consumption [92]. Approximately 800 g of apple pomace consumption, which is highly unlikely to occur, is required to cause acute cyanide poisoning in humans [91].

Another potential hazard of apple pomace is pesticide residue, in which neonicotinoids gain great attention because they are not considered sufficient to be removed by commonly available methods [93]. Chen et al. (2014) tested neonicotinoid residues in eight apple varieties and reported that the majority of neonicotinoids had negligible contents [93]. Although acetamiprid was detected in two apple varieties, its levels are considered to have a low risk of toxicity [91]. Additionally, in order to improve the quality and yield of apple fruit, fungicides are increasingly used, which raises great concern regarding safety. According to Liu et al. (2016), the detectable fungicides in apple fruits mainly included thiophanate, carbendazim and pyrimethanil [94]. The United States Environmental Protection Agency (EPA) reported that thiophanate and carbendazim had low acute toxicity [95]. Although the assessment of pyrimethanil remains to be completed, a similar fungicide, cyprodinil, has been regarded as low-risk by the EPA. Moreover, the residue of plant growth regulators such as naphthaleneacetic acid [96] and diphenylamine [97] was also mentioned by several studies, and they are regarded as having no risk and low risk of toxicity by the EPA, respectively [98,99]. At present, there is no strong evidence showing health hazards related to apple pomace consumption. However, with the update of pesticides and other chemical agents, future studies are required to continuously explore this problem.

7. Conclusions

Apple pomace is a fruit by-product generated from apple juice processing. The common disposal methods of apple pomace can cause environmental pollution and even public health hazards. Apple pomace is rich in nutrients such as carbohydrates, phenolic compounds, dietary fiber and minerals. Therefore, apple pomace can be applied directly or after minimal processing as functional ingredients in various types of food products. For example, apple pomace can improve the dietary fiber content and health-promoting properties of bakery products, such as bread, sweet bakery products and brittle bakery food. Apple pomace can also be incorporated with extruded food and meat products to enhance their nutritional value. Additionally, the utilization of apple pomace in confectionery products and dairy food was found to have contributions to the product quality characteristics. Moreover, it can also be used as a part of the substrate for alcoholic beverage development and edible mushroom cultivation. Further potential applications as flavoring and stabilizing agents were also apparent. In addition, many functional bioactive compounds that are extracted from apple pomace, including pectin, phenol and fiber, can also be utilized in food products to improve the product quality and nutritional properties. Although natural plant toxins and pesticide residues in apple pomace are considered to pose potential health hazards, current studies suggest that apple pomace consumption does not possess serious health risks for human health. The variety of food products that can be incorporated with apple pomace is relatively small. Therefore, more applications need to be explored in the future to solve the problem of excess apple pomace disposal in an environmentally friendly manner and to improve the quality and health aspects of a variety of food products by incorporation of this valuable functional ingredient.

Author Contributions: Conceptualization, C.S.R. and F.L.; writing—original draft preparation, F.L.; writing—review and editing, C.S.R., S.A., A.G.C., S.F.L. and D.R.P.A. All authors have read and agreed to the published version of the manuscript.

Funding: Research Initiatives Fund, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Australia.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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