Bioactive Compounds from Fruit Crop Wastes

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The food industry as a whole is one of the main contributors for food losses and waste generation. To deal with such wastes, research and efforts have been made for the development and valorization of bioactive compounds present in food wastes such as leaves, peels, seeds, and pulp.

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1. Introduction

Food wastes are one of the main sources of bioactive compounds in the world since through intensive research it has become clear that production waste such as peels, seeds, and pomace, contain high-value bioactive compounds [1]. This approach represents the main principles of a circular economy in any agri-food industry since it reduces pollution levels and increases the competitiveness of agri-food industries, where a wide variety of products can be obtained using waste as a raw material. Hence, in addition to the direct ecological benefits, there is also an economic gain for companies, linking integration of recovered ingredients into human food supply chains [1].

Since the fruit and vegetable industry is one of the main contributors for food losses and waste generation [2], the following sections give an in-depth review of innovative techniques used to extract bioactive compounds from different food wastes generated in the consumption and processing of the most consumed and produced fruit crops in the world.

2. Bioactive Compounds from Apples

Produced in large quantities each year, apples (*Malus domestica*) are considered an important source of bioactive compounds [3]. Apples are usually processed for juice recovery leading to large quantities of by-products (30% of raw material) known as apple pomace (fruit pulp, peels, and seeds) [4].

As per Carson et al. [5], apple pomace usually consists of 2.2–3.3% seeds, 0.4–0.9% stems, 70.0–75.7% apple flesh and 20.1–26.4% rice hull (added before pressing juice as a processing aid). Although considered a by-product, apple pomace still contains different functional components such as polyphenols (or phenolic compounds), polysaccharides, vitamins (i.e., vitamin E), fibers, and triterpenes [4]. These compounds have been researched over the last decades for their great health-promoting roles such as antioxidant, anti-histaminic, anti-tumor, and anti-cancer properties [3]. Therefore, the extraction of rich compounds from apple pomace is a crucial process for its valorization, and should be an environmentally friendly process that not only creates value through the extraction of marketable high-value compounds but also prevents environmental hazards [6][7].

In obtaining extracts and bioactive compounds from apple wastes, the extraction method is a relevant factor since this process insures the adequate separation of the bioactive compounds from the cellular matrix. The efficiency and the selectivity of the extraction process depends largely on the technique, the solvent, the energy input, and the agitation that can improve the chemical solubility and efficiency of mass transfer [4]. The traditional techniques (maceration or Soxhlet extraction) are widely used because they are relatively cheap and easy to operate, but they usually require long extraction times, high energy consumption, intensive manual procedures, and may also have low efficiency [4]. Thus, it is necessary to develop innovative and scalable methods leading to implementation in various industries. Methods such as pressurized liquid extraction (PLE), UAE or MAE have been introduced and studied in the extraction of bio compounds from food wastes, particularly from apple pomace.

Cristina-Gabriela et al. [4], evaluated different extraction techniques such as PLE, UAE, and MAE in the pomace of four apple varieties (i.e., Gala, Golden, Granny Smith, and Pink Lady) and the extracts obtained were characterized by liquid chromatography. The results obtained showed that MAE had the highest extraction yield. Moreover, in a different study conducted by Rezaei et al. [3], MAE was faster than the conventional methods (maceration and Soxhlet) when used in the extraction of polyphenolic compounds from apple pomace.

Although the MAE method has its advantages, there have been some reported drawbacks [8], such as the handling and processing of limited sample volumes, that can possibly make difficult the viable scale-up and implementation of this process for processing bulk quantities [8]. Furthermore, it has been reported that uniform heating is rarely achievable in conventional microwave systems, often giving rise to both unprocessed and severely overheated spots [7]. Moreover, different parameters such as the extractant nature, microwave irradiation power, extraction temperature and time, and the solvent-to-feed ratio, must be optimized and considered for an efficient MAE extraction of bioactive compounds from different cellular matrices [8].

In **Table 1**, a summary of different studies conducted for the extraction of bioactive compounds from wastes of different apple varieties is presented.

Table 1. Summary of studies found in literature on the extraction of bioactive compounds from apple wastes.

Waste	Extraction Method	Bioactive Compounds Detected	Ref.
Pomace	Maceration, 60 min, Water	Polyphenols: gallic acid, catechin, chlorogenic acid, and rutin	[4]
	UAE, 30 min, Water		
	MAE, 1.5 min, Water		
	PLE, 5 min		
	Conventional extraction with temperature, 20 min, 80 °C,	Polyphenols: hydroxycinnamic acids, flavanols, and chalcone (phoretin and phloridzin)	[9]

Waste	Extraction Method	Bioactive Compounds Detected	Ref.
	Ethanol/Water (50:50)		
	UAE, 5 min, 20 °C, Acetone/Water (70:30)	Polyphenols: flavanols, dihydrochalcones (phloridzin and phloretin-20-xyloglucoside), flavonols and cinnamic acids (chlorogenic and caffeic acids)	[10]
	UAE, 15 min, 40 Hz, Hexane/Ethanol/Acetone	Tocopherols (Vitamin E)	[11]
Seed	Maceration, 2 h, 25 °C, Acetone/Water (60:40)	Polyphenols: phloridzin, quercetin, and epicatechin	[12]
	UAE, 5 min, 35 °C, n-hexane	Tocopherols (Vitamin E)	[13]
Peel	Maceration, Acetone, 5 min	Phenolic compounds: gallic acid, catechin	[14]
	Turbo-extraction, 30 min, 40 °C, Ethanol	Phenolic compounds: phenolic acids	[15]

From **Table 1**, it can be seen that the conventional techniques usually require longer extraction times, which usually lead to higher energy consumption, and use conventional solvents [16]. Some of these drawbacks can be overcome by non-conventional techniques such as UAE and MAE methods which use lower solvent quantities and require lower extraction times. Despite their advantages, these extraction methods are mostly done at a laboratory scale, and in several studies the use of organic solvents is still employed [1][5].

Despite the interesting studies conducted on the use of these green and innovative extraction methods in several food wastes (including apple wastes), few studies have used non-organic solvents (ILs, DES and NADES) in these extraction methods, and even fewer scale-up studies have been reported [16]. This is an important factor to keep in mind since it increases the interest of industries in the hidden potential of food wastes. Furthermore, in developing or under-developed countries, where malnutrition is at all-time high, such reasonable and viable nutrition sources are important and should be given proper attention [17]. Moreover, the valorization of food residues in general could solve several issues that these countries face with respect to the proper treatment of organic food wastes [18].

As shown in **Table 1**, several bioactive compounds extracted from apple wastes are reported in the literature such as phenolic compounds (or polyphenols) and tocopherols (or vitamin E). The phenolic compounds can be sectioned into five major classes, namely, hydroxycinnamic acids (primarily chlorogenic acid), flavanols (catechin, epicatechin, and anthocyanidins), flavonols (mainly different quercetin glycosides), dihydrochalcones (mainly phloridzin), and anthocyanins (a reddish bioactive pigment present in the skin of some red-flesh apple varieties [19]) [3].

Phenolic compounds (such as those present in apple pomace) are hydrophilic bioactive compounds [20] that have the capacity to inhibit Reactive Oxygen Species (ROS) (for instance interrupting the cascade of free radical reactions in lipid peroxidation), in addition to other antioxidant effects, depending on their structure [21]. Such capacity represents a great advantage for the inclusion of phenolic compounds in dermal products, since using antioxidants in this type of product is required to maintain their quality throughout their shelf-life [21]. Moreover, phenolic compounds found in apple pomace have also been reported for anti-inflammatory, anti-proliferative, anti-tumor, and cardioprotective properties.

For instance, phloridzin is a polyphenol that has been proven as a competitive inhibitor of intestinal glucose and also as an anti-diabetic compound [22]. In addition, phloridzin has antioxidant capabilities that could play an interesting role in pharmaceutical and food applications [23]. Moreover, phenolic acids (e.g., gallic acid and caffeic acid) present in apple pomace, have also shown potential as antioxidants mainly through radical scavenging via hydrogen atom donation [24].

On the other hand, tocopherols (vitamin E), which are lipophilic bioactive compounds [20], are also among the most important natural antioxidants found in apple, and more specifically in apple seeds. From a study conducted by Akšic et al. [11], several apple varieties were studied in order to determine their tocopherol and fatty acid content. Results showed that the maximum value for vitamin E found in one apple variety was 1.811 µg/g of dry weight. This compound could play a major role in human health since it can impact the human neurological system and also prevent heart disease and prostate cancer.

3. Bioactive Compounds from Citrus

Citrus fruits are among the most extensively cultivated fruits in the world. Orange (*Citrus sinensis*), mandarin (*Citrus reticulate*), lemon (*Citrus limon*), lime (*Citrus aurantiifolia*), and grapefruit (*Citrus paradisi*) are some of the important commercially grown citrus fruits, mostly due to their numerous phytochemicals and bioactive components, which have been studied for their health-promoting properties [25].

Citrus fruits have acquired great interest because of their high content of bioactive compounds such as AsA (ascorbic acid or vitamin C) and polyphenols, mainly flavonoids. Flavanones (phenolic compounds) such as naringin and hesperidin are usually found in tissues and peels of citrus fruits, displaying numerous therapeutic advantages due to their antioxidant, anti-inflammatory, and anti-carcinogenic properties [25].

Orange (*Citrus sinensis*) is one of the most cultivated citrus fruits in the world with an estimated production of 72 million tons in 2014 [26]. Like most of the fruits covered herein, a large quantity of oranges (almost 50%) is used for juice processing [26]. The disposal of orange fruit segments without proper treatment is dangerous to the surroundings because of their undesirable and unhygienic nature. Since citrus juice (including orange juice) production leads to the generation of waste—including peels (50–55% of the total fruit mass), seeds (20–40% of total fruit mass), pomace, and wastewater (portions of spoiled fruit, seeds, pulp, and peels)—which is practically 50% of the fresh fruit mass, the development of innovative ways to treat these wastes is ever more relevant [26].

In **Table 2**, studies focused on the extraction of valuable bioactive compounds from orange wastes (i.e., phenolic compounds, polyphenols, and tocopherols) found in the literature are summarized.

Table 2. Summary of different studies that have been conducted for the extraction of bioactive compounds from wastes of orange (*Citrus sinensis*).

Waste	Extraction Method	Bioactive Compounds Detected	Ref.
Peel	UAE and PEF, Ethanol, 15–180 min, 20–80 °C	Hesperidin, polyphenols and vitamin C	[27]
	UAE, 400 W, 30 min, 50% Ethanol	Vitamin C and phenolics (mainly hesperidin)	[28]
Seed	Soxhlet, 40–60 °C, 6 h, Petroleum ether	Tocopherols	[29]
	Maceration, Methanol	Limonoids and phenolic compounds: flavanones, phenolic acids	[30]

Athanasiadis et al. [27], studied the parameters that affect the extraction of bioactive compounds such as polyphenols, AsA, and hesperidin from orange peel. In this study, antioxidant properties were optimized using a response surface methodology (RSM), the main variables being the extraction temperature, time, and composition of the extraction solvent. In addition, the effects of two more techniques (UAE and PEF) were examined separately and combined to determine whether they can enhance the extraction of the desired compounds. Results showed that orange peels are an excellent source of many bioactive compounds, since the extracts contained hesperidin (1.626% of dry weight) for 180 min of PEF extraction at 65 °C, polyphenols (3.471% of dry weight) for 30 min of PEF combined with UAE extraction at 35 °C, and AsA (1.229% of dry weight) for 180 min of UAE extraction for 80 min.

Montero-Calderon et al. [28], studied the use of UAE to extract bioactive compounds from orange peel. The results demonstrated that the optimal conditions for the UAE of bioactive orange peel compounds were 400 W, a time of 30 min, and 50% ethanol in water. In these conditions, it was possible to obtain a vitamin C concentration of 53.78 mg/100 g, and a phenolic concentration of 105.96 mg/100 g, which were lower than the results reported by Athanasiadis et al. [27].

In summary, orange peels contain a plentitude of bioactive constituents, such as polyphenols (hesperidin, naringin, nobiletin, and tangeretin) and flavoring compounds, that have been shown to have great antioxidant properties. However, as shown in **Table 2**, studies employing other non-organic solvent options are still an untapped research theme.

On the other hand, orange seeds, which are a rich source of protein, are another by-product of orange processing and constitute of approximately 4.8% of dried citrus pulp [31]. Citrus seeds contain bioactive phytochemicals such as polyphenols, flavonoids, antioxidants, limonoids [30], and tocopherols [29]. Owing to the presence of these functional compounds, citrus seeds have many applications in food, pharmaceuticals, and cosmetics [16].

4. Bioactive Compounds from Cherries

Prunus avium L., known as sweet cherry, is a native from the area between the Black and Caspian seas of Asia. According to the FAO, Turkey is the world's biggest producer of cherries (480,748 tons), followed by the United States of America (384,646 tons), Iran (200,000 tons), and Italy (104,766 tons), while the global sweet cherry production is around 4.0 million tons per year [1].

Sweet cherries are composed of an edible and thin protective red, maroon, or purplish-black skin (exocarp), an edible red and sometimes white succulent flesh (mesocarp) and an inedible seed (endocarp) [26][27]. Most of sweet cherries are produced to be consumed as fresh fruits, but since they are seasonal fruits, they are not available year-round in the supermarket, and are usually frozen, brined, canned, dried, and processed into jams or juices [32].

For instance, cherry seeds that result from processing sweet cherry into sweets, juices, and jams, are one of the major cherry processing by-products [1]. In fact, cherry seeds constitute more than 60% of the fruit weight [33]. Generally, seeds are considered production waste, and have gained strong interest due to the environmental aspects related to disposal.

On the other hand, the main by-product in cherry processing is cherry pomace, which consists of skin and flesh obtained after juice pressing, and makes up to 15–28% of the initial fruit [34].

In **Table 3**, a summary of different studies found in the literature focusing on the extraction and valorization of cherry wastes is presented.

Table 3. Summary of different studies that have been conducted for the extraction of bioactive compounds from wastes of different cherry varieties.

Waste	Extraction Method	Bioactive Compounds Detected	Ref.
Seeds	Maceration, Ethanol/Water, 80 °C	Phenolic compounds, flavonoids and flavonols	[1]
	Soxhlet, 6 h, Diethyl ether	Tocochromanols and polyphenols	[35]
	UAE, 5 min, 35 °C, n-hexane	Tocochromanols (tocopherol and sitosterol)	[36]
Pomace	Maceration, 2 h, Ethanol/Water (80:20)	Phenolic compounds	[31]
	Maceration, 2 h, Ethanol/Water (50/50)	Polyphenols	[37]
	MAE, 90 s, 900 W, 60 °C	Phenolic compounds	[38]
	Maceration, 30 min, 50 °C, Methanol/water (80/20)		
	UAE, 5, 10, 15 min, 24 kHz, 400 W, Room temperature,		

Waste	Extraction Method	Bioactive Compounds Detected [1]	Ref.
	Methanol/Water (80/20)		

...action of polyphenol... ...gated by employing different conditions to optimize extraction parameters, such as solvent and temperature, for the maximum yield of extracted bioactive compounds. The results showed that the best extraction technique for phenolic compounds was an aqueous ethanol solution at 80 °C. In addition, it was reported that temperatures above 80 °C were not beneficial, since they can degrade some families of phenolic compounds, reduce the extraction of total phenolic compounds, and consequently the potential of the overall extraction. On the other hand, it was concluded that temperatures of 80 °C also favor the recovery of flavonoids.

Besides phenolic compounds, studies [35][36] have been done focusing on the extraction of tocochromanols from cherry seeds, which have shed light on two different extraction methods (Soxhlet and UAE). Both studies were able to extract bioactive compounds with antioxidant capabilities. While both studies employed organic solvents, they were able to introduce valorization of the seeds of different cherry cultivars. In the study done by Górnas et al. [36], the influence of the cherry specie in the results obtained for the extraction of bioactive compounds was evaluated. It was found that the cherry species appeared to be directly associated with tocopherol profile.

Concerning another by-product of cherry processing, cherry pomace, multiple studies have been done. For instance, in a study conducted by Gonçalves [31], data revealed that sweet cherry extracts obtained from Hedelfinger, Saco and Maring cherry varieties, were more effective in the inhibition of α-glucosidase activity than acarbose, one of the most well-known drugs commercialized as an enzyme inhibitor for type two diabetes. Furthermore, from the results obtained, it was concluded that sweet cherry extracts have great biological potential, mainly due to their antioxidant activity against free radical species and protecting cells against oxidative damages, and may even be used as a therapeutic in the treatment of inflammatory diseases (such as diabetes, gout, and arthritis), hemolytic anemia, cancer, neurological and cardiovascular pathologies [31].

Šaponjac et al. [37], conducted a study in which bioactive compounds extracted from cherry pomace were encapsulated in whey (WE) and soy (SE) proteins and incorporated in cookies, replacing 10% (WE10 and SE10), and 15% (WE15 and SE15) of flour. Total polyphenols, antioxidant activity and color characteristics of enriched cookies were followed during 4 months of storage, and it was concluded that total polyphenols of WE10, SE10, WE15 and SE15 showed a slight increase, and antioxidant activity decreased. Overall, encapsulated sour cherry pomace positively influences the functional characteristics of fortified cookies and their preservation [37].

Nowadays, there are more attempts to use environmentally friendly extraction methods, using more sustainable approaches, resulting in the maximum recovery of bioactive compounds, using ecological solvents, and reducing processing costs. From the studies found, hydrophilic and lipophilic bioactive compounds such as phenolic compounds and tocochromanols, were present in several cherry by-products. While the extraction of bioactive compounds from cherry wastes using green solvents is still very much undeveloped, this fruit shows great potential for bioactive compound extraction and application in cosmetics and pharmaceuticals offering health benefits [35].

5. Bioactive Compounds from Almond

Almonds (*Prunus dulcis (Mill.), D.A. Webb or Amygdalus communis L.*) are largely used in the preparation of several traditional bakery and confectionery products, including almond cookies, marzipan, and almond milk [39]. The almond fruit is the most produced nut worldwide, due to its exceptional nutritional value (low sugar content, high levels of proteins, unsaturated fatty acids, vitamins, and minerals, as well as health-enhancing phytochemicals).

Besides the fruit, almond production involves the generation of several by-products that are normally discarded, accounting for 0.8–1.7 million tons of shells and more than 6 million tons of almond hulls [40]. Recent studies show that *Prunus* species may protect against metabolic syndrome, which includes sensitivity to insulin, visceral obesity, dysregulated metabolism of glucose and lipid, and hypertension. They can also be used to treat stress, immune problems, and anemia, as well as improve brain function.

The first processing step of the almond fruit is the removal of the brown skin by means of blanching in hot water and subsequent mechanical peeling. The almond skin accounts for 6–8% of the seed, and its main use is for cattle feed. The blanching water represents a processing waste, and the producers must incur costs for its disposal [39]. Consequently, the accumulation of almond by-products is causing an increasing concern about their processing, and novel solutions are required to add value to these residues, with the aim of improving the economic profit and environmental sustainability of the process [40].

Various studies have shown that almond by-products (kernel, skin, and shell) contain bioactive compounds such as phenolic compounds (flavonoids and phenolic acids) and terpenoids (sterols and triterpenoids), whose composition and quantity depend on factors such as geographical distribution, origin, environmental conditions, exposure to pests, UV radiation, harvest maturity and the extraction process. These by-products are a source of potent antioxidants for the control of oxidative processes [40].

For instance, reports have shown the total content of phenolic compounds in the kernel (8 ± 1 mg QCE/g ethanolic extract to 8.1 ± 1.75 mg CE/g ethanolic extract), skin (87.8 ± 1.75 mg CE/g ethanolic extract to 88 ± 2 mg QCE/g ethanolic extract), shell (38 ± 3.30 mg GAE/g methanolic extract) and hull (71.1 ± 1.74 mg CE/g ethanolic extract to 78.2 ± 3.41 mg GAE/g methanolic extract) of the almond (*Prunus amygdalus L.*). Furthermore, the almond of *Prunus serotina* has been studied as a source of lipids, raw fiber, and carbohydrates, in addition to containing vitamin E and minerals such as Ca, Fe, Mg, P, K, Zn, and Na. Moreover, the *Capulin* almond stands out for its high level of α-eleostearic acid (27%), which is effective in the suppression of the growth of cancer cells, and possesses antihypertensive properties due to the presence of vasodilator compounds such as ursolic acid and uvol [41].

In **Table 4**, different extraction procedures applied to almond by-products (almond hull, almond kernel, almond shell, and almond skin) for recovery of bioactive compounds are summarized [41].

Table 4. Summary of different extraction procedures applied to almond by-products (almond hull, almond kernel, almond shell, and almond skin) for recovery of bioactive compounds (adapted from [41]).

Waste	Extraction Method	Bioactive Compounds Detected
Hull	Maceration, Ethanol/Acetone, 24 h	Phenolic and flavonoid compounds
	UAE, 51.2% Ethanol, 40 kHz, 300 W, 13 min	Phenolic acids and catechin
Shell	Soxhlet	Phenolic compounds
	SFE, Petroleum ether, 40–60 °C, 90 min, 11 kPa	Lignin
Kernel	MAE, NaOH, 2450 MHz, 800 W, 23–67 °C, 3 min	Phenolic compounds (Lignans)
	SFE, butane, −0.09 MPa	Phenolic, phylosterol, tocopherol and tocotrienol compounds
Skin	UAE, Water, 20 kHz, 100 W, 20 min	Phenolic compounds, lipids, and proteins.
	MAE, 70% Ethanol, 2450 MHz, 100 W, 60 s	Flavonol rutinosides

6. Bioactive Compounds from Mango

Mangifera indica L., commonly known as mango, is one of the most consumed fresh fruits in the world, with production occurring in more than one hundred countries. In fact, mango is the second most produced tropical fruit in the world, and India is its largest producer (accounting for around 45% or 15 million tons), cultivating more than 1000 varieties of the tropical fruit [42].

The year-round availability of mangoes is attributed to several factors, including the diverse climatic conditions in which the fruit can be grown. The demand for mangoes is also on the rise due to the higher percentage of health-conscious consumers [43]. Mango chemical composition varies according to culture, selection, maturation stage conditions, and other factors, but it is generally mostly composed of water, carbohydrates, organic acids, minerals, proteins, vitamins (AsA), carotenoids, and other pigments [42]. In addition, with the increasing interest in the characteristics of mangoes (flavor, health benefits), it is ever more important to study different bioactive compounds present in mangoes and mango food wastes (peel, leaves, and kernel) [43].

In **Table 5**, a summary of studies conducted for mango waste valorization, through several extraction methods, is shown.

Table 5. Summary of different studies that have been conducted for the extraction of bioactive compounds from wastes of different mango varieties.

Waste	Extraction Method	Bioactive Compounds Detected	Ref.
Leaves	Enhanced solvent extraction using a mixture of CO_2/Methanol (50%) at 120 bar and 100 °C	Polyphenols	[44]
Kernel	Maceration, 1 h, Room temperature, Ethanol/Water	Polyphenols (gallic acid, caffeic acid, rutin and penta-O-galloyl-b-D-glucose)	[45]
Peel	80% Acetone	Polyphenols	[46]
	Alcoholic maceration and maceration with pectinase	Flavanols	[47]

In the study conducted by Sanchez-Sanchez et al. [44], extracts obtained from mango leaves were successfully impregnated into textile polyester using supercritical carbon dioxide. In this study, used leaves of *Mangifera indica L.* were submitted to enhance solvent extraction using a mixture of CO_2/methanol (50%) at 120 bar and 100 °C, obtaining mango leaf extracts (MLE). MLE were then used in conjunction with supercritical CO_2 to impregnate a polyester textile, and results showed that the extracts presented antioxidant, bacteriostatic, and bactericidal activities [44]. Mangiferin is also one of the predominant polyphenols in mango leaves and has multiple pharmaceutical properties, such as antioxidant, antibacterial, antifungal, antidiabetic, immunomodulatory, anti-inflammatory, and analgesic properties, with potential uses in the treatment or prevention of chronic diseases including cancer, neurodegenerative, and cardiovascular diseases [46].

Other valuable phenolic compounds with interesting pharmaceutical properties, such as quercetin, gallic acid, gallotannins, and iriflophenones, have been identified in mango leaves. The high content of potent antioxidant polyphenols is the reason for the great potential of mango leaf extracts in cosmetic, nutraceutical, pharmaceutical or food applications [44].

Mango peel is another major by-product of the mango processing industry, and accounts for approximately 15–20% of the total weight of fresh fruit [46]. This mango by-product has been studied for the presence of bioactive compounds. In a study conducted by Ajila et al. [46], peels from Raspuri and Badami mango varieties were prepared with 80% acetone to obtain mango peel extracts. Results showed that the acetone extracts of mango peel contained polyphenols. Furthermore, the extracts obtained from different peel varieties showed differences in antioxidant activities that may be due to variations in the peel composition; more precisely in the content of antioxidants like polyphenols [46].

In a study conducted by Coelho et al. [47], different methods of maceration were evaluated in the production of mango peel liqueurs from two different mango varieties (Haden and Tommy Atkins). The two maceration techniques used were alcoholic maceration and maceration with pectinase. Results showed that alcoholic maceration in wine ethanol (65% *v*/*v*) produced liqueurs with higher phytochemical and antioxidant content, while maceration with pectinase resulted in liqueurs with higher quercetin-3-O-glucopyranoside content. In relation to mango varieties, Haden liqueurs presented higher bioactive content than Tommy Atkins liqueurs. The main bioactive compounds found were flavanols (epicatechin-gallate and epigallocatechin-gallate), flavonols (quercetin-3-O-glucopyranoside and rutin), and phenolic acids (gallic acid, o-coumaric acid, and syringic acid). Thus, the production of liqueur enabled the recovery of an important part of the bioactive content of mango peels, suggesting an alternative for the recovery of antioxidant substances from this by-product [47].

In an interesting study done by Manhongo et al. [48], an economic assessment of mango process feasibility, economic viability, and environmental impacts of model integrated biorefineries for co-producing bioenergy and bioactive compounds were evaluated using three scenarios for integration with dried mango chips [48]. The study concluded that in both techno-economic and environmental life cycle assessment, mango waste is an attractive bioresource for co-producing pectin and polyphenols, as well as bioenergy, in a self-sufficient manner. Although demonstrating the lowest environmental impacts and the least capital investment, mango processing for production of bioenergy was the least attractive option in terms of profitability. In contrast, the co-production of polyphenols with heat and electricity was shown to be the most capital-intensive option and presented the highest environmental impacts, yet the scenario is the most favorable in terms of profitability, demonstrating the value of bioactive compound production from mango fruit waste [48].

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