Review



# Fruit By-Products and Their Industrial Applications for Nutritional Benefits and Health Promotion: A Comprehensive Review

Ejigayehu Teshome , Tilahun Abera Teka * , Ruchira Nandasiri , Jyoti Ranjan Rout , Difo Voukang Harouna , Tessema Astatkie , Markos Makiso Urugo

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*Review*

# Fruit By-Products and Their Industrial Applications for Nutritional Benefits and Health Promotion: A Comprehensive Review

**Ejigayehu Teshome [1,2], Tilahun A. Teka [2,*], Ruchira Nandasiri [3], Jyoti Ranjan Rout [4], Difo Voukang Harouna [5], Tessema Astatkie [6] and Markos Makiso Urugo [1,2]**

[1] Department of Food Science and Postharvest Technology, College of Agricultural Science, Wachemo University, Hosanna, Ethiopia
[2] Department of Postharvest Management, College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia
[3] Department of Food and Human Nutritional Sciences, Faculty of Agriculture and Food Science, University of Manitoba, Winnipeg, Manitoba, Canada
[4] School of Biological Sciences, AIPH University, Bhubaneswar, Odisha 752101, India
[5] Department of Biological Sciences, Faculty of Sciences, the University of Maroua, Maroua- Cameroon
[6] Faculty of Agriculture, Dalhousie University, Truro, NS, Canada
* Correspondence: tilaeta@gmail.com or tilahun.abera@yahoo.com

**Abstract:** Fruits are commonly used, fresh or processed, to prepare different industrial products with superior nutritional and health-promoting properties. Currently, the demand for processed fruit products has motivated the rapid growth of the fruit processing industries, persuading them to produce an enormous amount of by-products with less utilization. Furthermore, people's shifting dietary habits and lack of awareness of nutritional properties result in an avoidable load of fruit by-products. The knowledge of the value of by-products urges exploration with proper documentation, emphasizing the health benefits of some such products. Hence, this review is prepared by carefully analyzing the recent literature on industrial applications of fruit by-products and their nutritional and health-promoting properties. The use of fruit by-products in food industries for various purposes has been reported in the past and has been reviewed and described here. Fruit by-products are a good source of nutrients and bioactive components, including polyphenols, dietary fibers, and vitamins, implying that they could have an important role for novel, value-added functional food properties. Furthermore, fruit by-products are used as the substrate for the production of organic acids, essential oils, enzymes, fuel, biodegradable packaging materials, and preservatives.

**Keywords:** Biomass valorization; Biotechnological techniques; Food waste; Fruit processing; Waste-utilization

## 1. Introduction

According to the Food and Agriculture Organization (FAO), there is a shift in consumers' demand from processed foods to natural foods of superior quality that meet their nutritional requirements while promoting health [1]. Fruits and vegetables are rich in nutritional value and often promote human health. Fruits and vegetables are packed with vitamins, antioxidants, minerals, and dietary fiber. Citrus, watermelon, banana, apple, grape, and mango are the most popular fruits produced in the world [2]. The global production statistics include 124.8 million metric tons (MMT) of citrus, 114.1 MMT of bananas, 84.6 MMT of apples, 74.5 MMT of grapes, 45.2 MMT of mangoes, and 25.4 MMT of pineapples [2].

Even though fruit production statistics show an annual increase, it is still insufficient to meet consumption demand. Increasing global population, as well as a lack of production and supply chain obstacles, frequently necessitates the development of new innovative technologies to meet demand in the near future [3]. According to FAO, over 821 million people are currently malnourished due to a scarcity of staple foods such as starchy cereals, roots, and tuber crops [2]. This created a shift from

conventional plant-based diets to other substitute food products, including the by-products of fruits and vegetables.

Furthermore, a recent report [4] revealed that over 1.3 billion tons of foods are wasted each year [5]. Despite the reduction in fruit and vegetable waste globally (from 60% in 2011 to 45% in 2015), there is still a need for an improvement in bio-waste utilization [5,6]. Fruit waste and scrapped value are affected by the type of fruit, processing methods, and post-harvest technologies. For example, the discarded portion for bananas is 35% [7], pineapples are 33–46% [8], papaya is 15–20% [9], mango is 25–40% [10], citrus is 25–35%, apple is 9–13%, and watermelon is 43–48% [11,12].

Fruits are commonly used fresh and processed into juice, frozen fruit pulps, jam, syrup, and concentrated or dehydrated forms [13]. An enormous amount of waste is generated during fruit processing, and proper disposal is associated with higher operational and transportation costs. Thus, imprudent disposal has negative impacts on both the economy and the environment. Likewise, the wastes generated from fruit processing have environmental risks but also represent an enormous loss of nutrients with high bioactive properties [14]. Fruit by-products including skins, cores, stems, shells, stones, and seeds, account for 50–60% of fresh fruit. In most cases, nutritional comparison shows that the by-products, including peel and seeds, have higher nutritional values as compared to the pulp [15]. Additionally, fruit by-products such as skins are natural sources of soluble and insoluble dietary fiber, pectin, and phenolic antioxidants [16,17]. The therapeutic properties of these by-products offer a high potential for further value while assisting in the prevention of non-communicable diseases such as diabetes, cardiovascular disease, obesity, and cancer [18–20]. Through the process of valorization, promising potentials of by-product utilizations in the food, pharmaceutical, biotechnology, and related industries may inspire the food, pharmaceutical, biotechnology, and related industries in the near future.

## 2. Materials and Methods

A mixed-method approach involving the collection of quantitative and qualitative research findings was used to optimistically analyze the potentials of fruit by-products from existing literature. This approach included identification of published literature indexed in Google Scholar®, Scopus®, Web of Science®, Springer Link, Science Direct, PubMed, and MDPI databases using the following keywords: bio-active components, biotechnological techniques, fruit processing, waste utilization, fruit wastes and by-products, and industrial waste. As some keywords gave a very large number of published articles with a scope far different from the scope of this review, more restricted terms like "bioactive compounds from fruit by-products," "biotechnological techniques of fruit by-product valorizations," "banana by-product," "avocado by-product," "apple by-product," "citrus by-product," and "watermelon by-product" were used. Articles published between 2000 and June 2020 were selected for this review.

## 3. Description of some common fruit by-products: Overview

### *3.1. Banana (Musa spp.) by-products*

Banana, grown in tropical and subtropical biospheres, is a prominent fruit crop consumed throughout the world. The banana fruit is available year-round at a fair price [21]. Banana processing generates lots of industrial by-products such as peels, rhizomes, stems, leaves, sheaths, and inflorescence [22]. These by-products are useful resources for various industrial applications, including in the food and medicine manufacturing industries, due to the rich phenolic composition of the peel [23].

### *3.2. Apple (Malus domestica Borkh.) by-products*

Apple is among the widely cultivated temperate fruits with pleasing taste, aroma, and health-enhancing substances [24]. Nearly 68% of apples are consumed raw, and the remaining is industrially processed for juice, cider, and powder, generating various by-products such as seed, peel, core, and stem using microwave-assisted phosphoric acid activation [25]. The apple by-products, including

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seeds and peels, represent roughly 25–30% of the load of the first fresh fruit [26] and are used as ingredients in food formulation [27].

### *3.3. Mango (Mangifera indica L.) by-products*

Mango is a popular tropical fruit with very extensive production. It is called "the king of fruits" because of its luscious flavor, pleasing aroma, and nutritional value [28]. Mango fruits have bio-functional properties and are commonly consumed as fresh, frozen, juice, jam, or nectar [29]. Processing mango fruit into different value-added products has immense waste products that range from 40 to 60% of by-products based on variety and size, of which peels represent 12–16%, seeds 10–25%, and kernels 15–20% [30].

Mango peels are the main by-products generated from industrial processing and fresh consumption and account for 10–20% of the total weight of the mango fruit [31]. Recently, mango peels have gained attention from the scientific community because of their high content of bioactive compounds such as polyphenols, catechins, kaempferol, gallic acid, mangiferin, quercetin, and benzoic acid with functional and health properties [32,33]. Mango seeds and kernels are also additional by-products obtained during the industrial processing of mango.

### *3.4. Citrus (Citrus rutaceae L.) by-products*

Citrus fruit belongs to the Rutaceae families, which include fruits like oranges, tangerines, mandarins, lemons, limes, sour oranges, and grapefruits. Citrus is among the most widely consumed fruits around the world [34]. Citrus fruits are so-called "fleshy" fruits with lofty amounts of citric acid, which gives them an acidic taste. Industrially, citrus fruits are processed into juice, jam, marmalade, fruit cocktail, and flavoring agents [35,36].

During processing of citrus fruits, 1–10% of the seed, 60–65% of the peel (flavedo and albedo), and 30–35% of internal tissues (juice sac residues and rag), representing 50–70% of the processed fruit depending upon the variety, processing methods, and growth conditions, were discarded from the total generated by-products [37]. Citrus peel is also dried and mixed with pulp to produce molasses for cattle feed.

### *3.5. Grape (Vitis vinifera) by-products*

Grape is a common fruit that is consumed almost everywhere in the world [2]. Approximately 50% of the world's production of grapes goes into winemaking or vinification, and the remaining 50% is consumed fresh or dried to make grape raisins [38]. The main byproducts of wine processing are pomace (skins, stems, and residual pulp) and grape seed, which accounts for nearly 20% of the original grape weight [39]. The grape seeds account for about 5% of the total weight of the whole grape; they account for almost 40%–50%, and the pomace accounts for 10–15% of the discarded solid residues from the wine processing industries [40].

### *3.6. Avocado (Persea americana) by-products*

Avocado is the most important fruit cultivated in tropical and subtropical regions of the world, where one-third of the production is handled by Mexico [41]. Avocado is considered a butter pear due to its shape and the soft texture of its pulp. Avocado fruit contains vitamins (B-vitamins, vitamin K, vitamin E, and vitamin C), minerals (potassium, copper), proteins, fibers, phenolic acids, hydroxycinnamic acids, and essential fatty acids (UFA), all of which have substantial health benefits [42]. During industrial processing of avocados into oils, the remaining residues, such as seeds and peels, representing 21–30% of the fruit are discarded [43].

### *3.7. Pineapple (Ananas comosus L.) by-products*

Pineapple is a tropical fruit grown in several parts of the globe, with Thailand, Brazil, the Philippines, Costa Rica, and India being the main producers. Asia is the main continent producing pineapples (48.2%), followed by America (34.5%), and Africa (16.4%) [2]. Pineapple is commonly

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consumed fresh and used in salads and is commercially available in juice forms, jams, dehydrated products, and canned foods. Pineapple is added to various types of fruit concentrates because of its neutral color, pleasant flavor, and good acidity/sweetness ratios [44].

Processing of pineapple into value-added products generates different by-products, such as residual pulp, peels, stems, and a core, which represent 35–46% of discarded residues [8]. Peels have the highest percentages of by-products, ranging from 30% to 42% w/w, followed by a core at around 10% w/w. Core and stem share 5% by weight of the total waste. Almost half of the total pineapples produced are discarded, along with plenty of bioactive compounds [44].

## 4. Nutritional potentials of fruit by-products

Fruit by-products, including peel, skin, seeds, pomace, and stones, contain a high amount of bioactive compounds and are good sources of nutrients, including pectin, proteins, fat, fiber, minerals, and vitamins. This section briefly explains the nutritional composition as well as the bioactive compounds found in fruit by-products. Proximate composition, mineral content, vitamin composition, and bioactive compounds extracted from fruit by-products are summarized in Tables 1–4, respectively. Tables 5–7 summarize industrial applications of fruit by-products.

**Table 1.** Proximate composition (%) of some common fruit byproducts.

| By-product | Moisture | Ash | Protein | Fat | Carbohydrate | Fiber (%) | References |
|---|---|---|---|---|---|---|---|
| Apple pomace | 8–10.6 | 1–6.1 | 3–5.67 | 1.2–3.9 | 48–62 | 4.7–51.1 | [51] |
| Mango seed kernel | 45.2 | 3.2 | 6.36 | 13.3 | 32.2 | 2.02 | [53,63] |
| Ripe mango peel flour | 7.86 | 4.5 | 4.1 | 4 | 29.4-32 | 51.1-54.2 | [64] |
| Banana peel | 13.6 | 9.83 | 5.53 | 23.93 | 32.39 | 14.83 | |
| Avocado peel | - | 3 | 4.5 | 4.6 | 72 | 3.8 | [59] |
| Avocado seed | 67.2 | 2.3 | 9.6 | 3.9 | - | 10.7 | |
| Pineapple raw peel | 82.7 | 5.0 | 8.9-9.2 | 1.3 | - | 16.3 | |
| Papaya raw peel | 86.8 | 11.6 | 20.27 | 2.3 | - | 18.5 | [65] |
| Papaya seed | 5.8 | 6 | 23.6 | 23.5 | - | 47.2 | |
| Grape pomace | 3.37 | 4.68 | 8.49 | 8.16 | 29.20 | 46.17 | [66] |
| Citrus peel | 2.49 | 13.20 | 0.42 | 9.74 | 71.57 | 2.58 | [67] |

### *4.1. Banana fruit*

Banana peels represent 30–40% of the edible part of the fruit and are a rich source of phytochemicals such as phenolic compounds, dietary fibers, and carotenoids that are known to have high antioxidant capacity [45]. Banana pulp and peel flour also contain many other phytochemicals, such as catecholamines, flavonoids, phenols, steroids, phytosterols, glycosides, and terpenoids [46]. Additionally, banana peel has macro-minerals (potassium, calcium, phosphorus, and magnesium), trace minerals (iron and zinc), and vitamins (vitamins C and A) [47]. The fiber content of the peel is approximately 50%, and it is a rich source of pectin, which forms gels used as an emulsifier [48]. The nutrient components, including proximate (Table 1), mineral (Table 2), and vitamin (Table 3) contents, are presented and discussed. Bioactive compounds of banana by-products are presented in Table 4 and Table 5 and have applications in different industries.

### *4.2. Apple fruit*

Apple pomace is a rich source of beneficial bioactive compounds, including phenolic acids, flavonoids, and dihydrochalcones [49]. Apart from the minor components, apple pomace is also a good source of carbohydrates, proteins, vitamins, and minerals (Table 4). The pomace consists mainly

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of insoluble sugars, including cellulose, hemicellulose, and lignin (a non-starch polysaccharide), with simple sugars such as glucose, fructose, and galactose [50]. It also contains minerals such as phosphorus, calcium, magnesium, and iron. Additionally, apple pomace contains fatty acids, including linoleic acid (18:2 n-6) and oleic acid (18:1 n-9) [51]. The proximate, mineral, and vitamin contents are presented in Tables 1–3, respectively. Bioactive compounds of banana by-products are presented in Tables 4 and 5 and have applications in different industries.

**Table 2.** Mineral content (mg/100 g) of some common fruit by-products.

| By-product | Phosphorus | Potassium | Calcium | Sodium | Magnesium | Iron | Zinc | Copper | Manganese | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Apple pomace | 64.9–70.4 | 398.4–880.2 | 55.6–92.7 | 185.3 | 18.5–333.5 | 2.9–3.5 | 1.4 | 0.1 | 0.4–0.8 | [51] |
| Mango seed kernel | 20 | 158 | 10.21 | 2.7 | 22.4 | 1-12 | 1.1-5.6 | 8.6 | 0.04 | [63] |
| Banana peel | - | 4599.7 | 2011.5 | 32.5 | 95.1 | 2.5 | 2.3 | 12.4 | 5.7 | |
| Avocado peel | - | 899.8 | 679.3 | 21.1 | 46.9 | 2.3 | 1.6 | 14.5 | 1.4 | |
| Avocado seed | - | 1202.6 | 434.9 | 39.4 | 55.8 | 3.7 | 1.8 | 16.7 | 1.5 | [65] |
| Citrus peel | 366.84 | 8.75 | 515.78 | 274.77 | 5.39 | 9.06 | - | - | - | [67] |
| Pineapple peel | | 1349.5 | 4236.2 | 9.8 | 107.6 | 1.6 | 0.8 | 4.7c | 8.2 | [65] |
| Grape pomace | 193 | 4334 | 182 | 131 | - | - | - | - | - | [68] |

*4.3. Mango fruit*

Mango by-products are important sources of bioactive compounds, including vitamin C, beta-carotene, polyphenols, and dietary fiber [52]. Mango seed kernels are used for making multi-purpose nutraceuticals owing to their high composition of phytochemicals like phenolic acids, flavonoids, catechins, hydrolyzable tannins, and xanthanoids [29,30]. Mango seed kernel powder contains a good amount of fat, protein, and carbohydrate, which implies a possibility to produce energy-rich functional foods from this resource [53]. Besides, mango peel is an excellent source of dietary fiber (45 to 78%) and other components such as phenolic acids, flavonoids, xanthones, carotenoids, ascorbic acid, and tocopherols [54]. The proximate, mineral, and vitamin contents are presented in Tables 1–3. Bioactive compounds of mango by-products are presented in Table 4, and Tables 5–7 have their applications in different industries.

*4.4. Citrus fruit*

Among the generated wastes, 60–65% comes from the peel, 30–35% from interior tissues, and 0–10% from seeds [55], which provide a valuable source of phytochemicals with high antioxidant activity, anti-inflammatory properties, and anti-cancer properties compared with the edible portion [56]. The proximate, mineral, and vitamin contents are presented in Tables 1–3. Table 4 lists the major bioactive compounds found in citrus byproducts.

*4.5. Grapes*

Wine processing by-products have various types of biomolecules (dietary fibers, lipids, proteins, and natural antioxidants and phenolic compounds) and are a cheap source for the development of dietary supplements [57]. Grape seed is one of the major by-products with dense bioactive components, including stilbene, resveratrol, gallic acid, rutin, and catechinalate. These bioactive compounds exhibit cardiovascular-protective, anti-microbial, antioxidant, and anti-cancer properties [58].

*4.6. Avocado fruits*

Fresh avocado peel is a potential source of carbohydrates (60–73%), proteins (3–8%), lipids (4–9%), fiber (about 50%), and ash (3–6%). Similar to the peel, the avocado seed also consists of 72% carbohydrates, 4.5% proteins, 4.6% lipids, 3.8% fiber, and 3% ash [59]. Avocado peel and seed are also

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high in phytochemicals such as phenolic acids, condensed tannins, and flavonoids [60]. These bioactive compounds have been shown to exhibit antioxidant and anti-inflammatory properties. Furthermore, avocado byproducts have numerous applications in different industries, as shown in Tables 5–7.

*4.7. Pineapple*

Pineapple by-products are cheap sources of dietary fiber, which may be applied for the production of fiber-rich foods [61]. Pineapple by-products are also used as a substrate for the production of organic acids, with great commercial demand for acidification and flavor-enhancing of low-acid foods, including most fresh vegetables and fruits [62]. The proximate, mineral, and vitamin content are presented in Tables 1–3. Table 4 shows the bioactive compounds of pineapple by-products, and their utilization in different industries is summarized in Tables 5–7.

**Table 3.** Vitamin content of some common fruit by-products in (mg/100 g).

| **Vitamin (mg/100g)** | **Fruit by-products** | | | | | |
|---|---|---|---|---|---|---|
| | **Citrus peel** | **Mango seed** | **Avocado seed** | **Pineapple stem** | **Grape pomace** | **Pineapple peel** |
| Vitamin B1 | 11.9 | 0.08 | 0.33 | - | - | - |
| Vitamin B2 | - | 0.03 | 0.29 | - | - | - |
| Vitamin B3 | 234.16 | - | 0.06 | - | - | - |
| Vitamin B6 | 286.63 | 0.19 | - | - | - | |
| Vitamin B9 | 1.36 | - | - | - | - | - |
| Vitamin B12 | - | 0.12 | - | - | - | - |
| Vitamin C | 21.34 | 0.56 | 97.8 | 121.2 | 26.25 | 212.9 |
| Vitamin A | - | 15.27(IU) | 10.11(IU) | - | - | - |
| Vitamin E | 4.45 | 1.3 | 0.12 | - | - | - |
| Vitamin K | - | 0.59 | - | - | - | - |
| References | [67] | [69] | [70] | [71] | [66] | [71] |

**5. Current knowledge on the utilization of fruit by-products**

*5.1. Banana fruit*

Banana peel is used to produce livestock feed, fertilizer, biogas, and oil [22]. In addition, it is used as a means of heavy metal removal in water purification [79]. Uses of banana by-products in various industries are presented in Tables 5–7.

*5.2. Apple fruit*

About 20% of apple pomace is used traditionally for compost and animal feed, while an oversized proportion of almost 80% remains underutilized and discarded with a great negative impact on the environmental [50].

*5.3. Mango fruit*

Mango seed kernels are used for making multipurpose nutraceuticals owing to their high composition of phytochemicals like phenolic acids, flavonoids, catechins, hydrolyzable tannins, and xanthanoids [29,30]. Mango peel is an excellent source of pectin, enzymes, and fiber for functional food development, while only a few studies show utilization of mango by-products for non-food applications as biosorbents [80]. Bio-sorbents are biological materials containing a variety of functional sites that have the ability to remove heavy metals such as cadmium (Cd) and lead (Pb)

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from aqueous solutions [81]. In addition, mango seeds are used as bio-sorbents to remove heavy metals such as chromium (Cr) [82] and the dye malachite green, which is widely used for food coloring, textile, paper, and acrylic industries [83].

**Table 4.** The main bio-active compounds found in some common fruit by-product.

| Bioactives | Sources | Bioactivity/preservative | References |
|---|---|---|---|
| Flavonols | Pomegranate peels, orange peels, tamarind seeds, mango peels | Antioxidants | [72] |
| Pectins | kiwifruit, pomegranate, apple and orange peels | Food additive, thickening agent | [73] |
| Amino acids and proteins | Mandarin by-products, pineapple peels, papaya peels | Good source of protein | [74] |
| Polyphenols | Avocado seed | Antioxidant activity | [41] |
| Phenolic compounds | Banana peel | Antioxidant activity | [23] |
| Triterpenoids | Apple pomace | Anti-inflammatory, anti-microbial, | [26,75] |
| Limonoids | Citrus seed | Anti-inflammatory, anti-cancer, anti-bacteria, antioxidant activities | [76] |
| Phenolic acids, flavones, flavanones | Citrus peel and pulp | Antioxidant, anti-inflammatory, anti-cancer properties | [77] |
| Carbohydrates (pectin and pectin oligosaccharides) | Apple pomace | Dietary fibre, prebiotic, hypo cholesterolemic | [78] |

*5.4. Citrus fruit*

Citrus peels are dried and mixed with pulp to produce molasses for cattle feed. Pectin extracted from citrus peels has immuno-modulatory effects on the levels of cytokine secretion in the spleen of mice with a pro-inflammatory potential, as previously reported [84]. Recently, citrus by-products are gaining attention and being valorized by using anaerobic digestion for the production of biogas and fermentation to produce high value-added chemicals and biofuels [85].

*5.5. Grapes*

Most often, grape by-products are used for distillate preparation, animal feed, and compost [38]. Grape seed is one of the major by-products with dense bioactive components. Different uses of grape by-products in various industries are listed in Tables 5–7.

*5.6. Avocado fruit*

Avocado by-products have many interesting properties that widen their application prospects. Avocado by-products can be utilized for energy production; its pulp oil is used for biodiesel, and its seed oil is used for biodiesel, charcoal, liquid fuels, and fuel additives [59]. Additional utilization of avocado by-products in some industries is listed in Tables 5–7.

*5.7. Pineapple fruit*

Pineapple processing generates a huge amount of by-products like residual pulp, peels, stems, cores, and leaves [86], which represent 45–65% of the residuals, which, in most cases, are discarded as waste with significant environmental pollution potential if not properly and efficiently utilized [87]. Pineapple peel is used as a source for the extraction of antioxidant compounds (phenolic compounds such as ferulic acid and vitamins A and C). Successful extraction and recovery of these

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antioxidant compounds could have implications for the production of antioxidant-rich functional foods [88]. Pineapple by-products can also be used for bioethanol production and bromelain extraction [89].

**Table 5.** Utilization of some common fruit by-products in food industries.

| Fruit by-product | Uses in food industries | Reference |
|---|---|---|
| Apple pomace | Apple pomace used as a dietary fiber source in some baked foods, chicken meat-based sausages and yoghurt products | [94,95] |
| Apple pomace | Used as stabilizers for oil-water emulsions and have an antimicrobial activity | [96] |
| Apple seed | Addition of defatted apple seed powder into chewing gum enhanced phloridzin uptake | [97] |
| Avocado by-product | Avocado by-products can be used as antioxidants, antimicrobials, and food additives such as colorants, flavorings, and thickening agents | [15] |
| Avocado peel | Dried peels used in a functional beverage formulation (tea rich in antioxidants) | [98] |
| Avocado peel | Peel extract's used to inhibit lipid peroxidation and to avoid oxidation of meat proteins | [99] |
| Avocado seed | Seed starch used for biodegradable polymers for drug delivery or food pack by-product | [100] |
| | Seeds can act as functional ingredients in foods, considering their composition in total fiber (lignin, cellulose and hemicelluloses) | [101] |
| Banana peel | The flour obtained from unripe banana peels used for colon health effects due to its high resistant starch content and ripe peels is digestible due to the high content of starch and proteins | [46] |
| Banana peel | Banana peel jelly has antioxidant properties | [102] |
| Citrus peel | Citrus peels used as a source of molasses, pectin, oil and limone | |
| Citrus (pectin) | Citrus pectin is used as thickener, emulsifier and stabilizer in many foods (jams, jellies, and marmalades and other products) | [103] |
| Citrus (pectin) | Pectin is a suitable polymeric matrix for edible films for active food pack by-product | [104] |
| Citrus essential oils | Citrus essential oils are GRAS; and are used as antimicrobials, antifungal and flavoring agents | [105] |
| Grape pomace | Meat and fish derivatives containing grape pomace powders shows improved sensory and physical properties | [106] |
| Grape (stems, seeds and skins) | Fiber from grape pomace used as functional ingredient in bakery products | [107] |
| Grape seed | Oil obtained from grape seed is rich in linoleic acid (60–70%), as well as in tocopherols, which hinder their oxidation | [108] |
| Mango peel | Mango peel powder used as source of antioxidant and dietary fiber in macaroni | [109] |
| Mango peel seed kernel | mango peels and seed kernels powders used as sources of phytochemicals in biscuit | [110] |
| Mango peel extract | Peel extracts used into gelatin-based films for active food pack by-product due to its free radical scavenging activity and improvements in film strength | [111] |
| Mango peel | Edible films made of mango peel showed good permeability and hydrophobicity properties | [112] |

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| | | |
|---|---|---|
| Pineapple peel | Pineapple peel is rich source of sugar that can be used as nutrients in fermentation processes | [113] |
| Pineapple core | Core can be used in pineapple juice concentrates, vinegar and wine production | [113] |
| Pineapple stem | Bromelain enzyme, extracted from the pineapple stem used as a meat tenderizer, a bread dough improver, a fruit anti-browning agent, a beer clarifier | [114] |

## 6. Prospective impact of fruit by-products on food and nutrition security

According to FAO, more than 820 million people in the world are still suffering from hunger in 2018, which underscores the immense challenge of achieving the Zero Hunger target by 2030 [90]. Therefore, the search for alternative food sources for human consumption with high nutritive value is needed. These alternative and innovative food sources would fulfill the need to feed the exponentially growing human population as 70% more food is needed to cover the gap, which becomes an imperative. On one hand, exploring the unexplored, refining the unrefined traits, cultivating the uncultivated, and popularizing the unpopular remain the most appropriate steps proposed by some researchers to achieve food and nutrition security with consideration of the current global food challenges [91–93]. On the contrary, a significant amount of by-products from the fruit processing industry are discarded due to ineffective management and disposal systems. Such fruit by-products have been proven to be rich sources of nutritious and bioactive components and have a considerable effect on the economy and environmental safety. As a result, a careful investigation of the adequate supply of nutritious components from by-products may be of interest and appear to have a positive impact on global food and nutrition security.

**Table 6.** Utilization of common fruit by-products in medicinal and Pharmaceutical industries.

| Fruit by-product | Uses in Pharmaceutical industries | Reference |
|---|---|---|
| Guava leaf | Guava leaves contain a high level of antioxidants, phenolic compounds and immune-stimulatory agents | [115] |
| Apple phloridzin | It can inhibit lipid peroxidation and prevent bone loss, enhance memory and even inhibit cancer cell growth | [116–118] |
| Apple peel | Apple peel consumption improves metabolic alterations associated with a fat-rich diet and also slowed the atherogenesis development | [119] |
| Avocado peel extracts | Avocado peel extract has been proved to be used as inhibitors for the inflammation mediator nitric oxide by a possible reduction of free radicals during inflammation | [60] |
| Avocado peel and seed | Polyphenols from avocado peel and seed possess anti-cancer, anti-diabetic and anti-hypertensive effects | [41] |
| Banana peel | The bioactive compounds extracted from peel Antioxidant, anti-bacterial, anti-fungal activity, reducing blood sugar, lowering cholesterol, anti-angiogenic activity, neuro-protective effect | [23,110] |
| Banana Peel | Banana peels are used to synthesize bio-inspired silver nano-particles which used as antimicrobials to pathogenic fungi and some bacterial species | [79] |
| Citrus pulp and seed | D-limonene was shown to exhibit a therapeutic effect on lung cancer mice and breast cancer in mice and rat | [120,121] |
| Grape byproduct | Grape by-products used in pharmaceuticals due to their antibacterial, anti-viral, and anti-fungal properties. they also showed anti-inflammatory actions | [58,122] |
| Grapes-seed oil | Grapes seed oil evaluated in various in vitro and *in vivo* tests showed anti-microbial, anti-inflammatory, cardio-protective and anticancer properties | [123] |

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|---|---|---|
| Mango seed and peel | Seed and peel extracts were shown to have anti-inflammatory and anti-oxidative properties on vivo studies related to obesity, diabetes, CVD and skin cancer | [124] |
| Mango pectin | Pectin extracted from mango by-products used for prevention and reduction of carcinogenesis | [125] |
| Mango seed/peel | Mangiferin extracted and isolated from the seed/peel shows strong anti-oxidant, anti-tumor, anti-bacterial, and immuno-modulatory effects | [126] |
| Peach kernel | Peach kernels phenols, carotenoids and cyanogenic glycosides, have Antidiabetic, antioxidative, and anti-aging properties | [127] |

Proper management of these by-products is believed to be the key opportunity to increase their utilization. This includes cost-effective extraction techniques that give optimum yields of the by-products for their reuse in a wide array of industrial applications. Therefore, it is important to carry out such studies within the realm of the fruit regarding the by-products' extraction and wider utilization. This can significantly help to reduce food loss and waste, which can improve food security and environmental sustainability. It has been reported that fruit by-products such as skins, cores, stems, shells, stones, and seeds account for 50–60% of fresh fruit. In most cases, by-products appear to have higher nutritional values than the pulp [15]. Paradoxically, human feeding habits have given preference and priority to a smaller portion of the fruit, resulting in food and nutritional insecurity.

**Table 7.** Utilization of some common fruit by-products in biotechnology.

| **Fruit by-products** | **Uses in biotechnology** | **Reference** |
|---|---|---|
| Apple pomace | Apple pomace used as a substrate for value-added products, such as enzymes, aroma compounds and organic acids | [128] |
| Avocado peel | Carbonaceous material produced from avocado peel is used as alternative adsorbent for dyes removal | [129] |
| Banana peel | Banana peels can be used as a substrates by solid state fermentation (SSF) to produce enzymes and organic acids | [130] |
| Banana peel | Organic acids (citric, lactic and acetic acid) were successfully produced from banana peels with *Aspergillus niger* or *Yarrowia lipolytica* | [131] |
| Orange peel | Orange peels as a substrate to produce pectinolytic, cellulolytic and xylanolytic enzymes by (SSF) using fungi from the genera Aspergillus, Fusarium, and Penicillium | [55] |
| Grape by-products | Grape by-products have been used as a substrates for the production of hydrolytic enzymes such as cellulase and pectinase | [132] |
| Mango peel | Mango peels were used to produce lactic acid (up to 17.5g/L) and pectinase enzyme | [133] |
| Mango seed-kernel | Mango seed kernels were used to produce $\alpha$-amylase with *Fusarium soloni* | [134] |
| Pineapple peel | Pineapple peel can be used as a substrate for methane, ethanol and hydrogen generation by *S. cerevisiae* and *Enterobacter aerogenes* | [8] |
| Pineapple peel | Pineapple peels have been anaerobically digested to yield biogas in the form of methane | [135] |
| Pineapple & orange peel | Bioethanol is produced from fruit peels of pineapple, orange and sweet lime using *S. cerevisiae* | [136] |
| Papaya seed | Papaya seeds are used as biosorbents to remove heavy metals such as lead and cadmium | [137] |

## 7. Summary and research need

This review presents important information on fruit processing and by-product utilization. Several previous studies have confirmed that depending on the type of fruit, variety, and cultivation conditions, up to 60% loss occurs. Such a huge loss of fruit by-products has a significant negative implication for the economy, environment, and social well-being worldwide. Fruit by-products are good sources of nutrients and bioactive components, implying that they could have an important role in functional food development. These bioactive compounds have anti-cancer, anti-diabetic, anti-microbial, anti-oxidative, and immune-modulatory effects, confirming their role in nutraceuticals. Furthermore, fruit processing and by-products are also used as a substrate for the production of organic acids, essential oils, enzymes, fuel, biodegradable packaging, and preservatives. Given the significant importance of fruit processing by-products in food insecurity alleviation, health promotion, and environmental sustainability, further studies aiming at addressing this knowledge gap are greatly important.

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## References

1. FAO. Food and agriculture organization Data. 2016. Influencing food environments for healthy diets. In influencing food environments for healthy diets.
2. FAO. Food and agriculture organization Data. 2017. The state of food and agriculture. Retrieved January 10, 2020, from http://www.fao.org/faostat/en/#home.
3. Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. Food Security: the challenge of feeding 9 billion people. *Food Secur*. **2010**, 327, 1-8.
4. Agro Press and Tomra Sorting Solutions Food. 2019. It is Time to End Food Waste. Retrivedfrom:https://www.tomra.com/en/sorting/food/why/food-waste/, Accessed on 16 January, 2021.
5. FAO. Food and agriculture organization Data. 2015. Global initiative on food loss and food waste reduction. *United Nations*, 1–8.
6. FAO. Food and agriculture organization Data. 2011. Global food losses and food waste – Extent, causes and prevention. In Food and Agriculture Organization of the United Nations.
7. Gupta, K., and Joshi, V. K. Fermentative utilization of waste from food processing industry In: Postharvest Technology of Fruits and Vegetables: Handling Processing Fermentation and Waste Mangement. **2000**, Vol. 2 Verma L R and Joshi VK (Eds). Indus Pub Co, New Delhi.
8. Choonut, A., Saejong, M., & Sangkharak, K. The production of ethanol and hydrogen from pineapple peel by *Saccharomyces cerevisiae* and *Enterobacter aerogenes*. *Energy Procedia*. **2014**, 52, 242–249.
9. Parni, B., & Verma, Y. Biochemical properties in peel, pulp and seeds of Carica papaya. *Plant Arch*. **2014**, 14(1), 565–568.
10. Mitra, S. K., Pathak, P. K., Lembisana, H. D., & Chakraborty, I. Utilization of seed and peel of mango fruit. *Acta Hortic*. **2013**, 992, 593–596.
11. De Laurentiis, V., Corrado, S., & Sala, S. Quantifying household waste of fresh fruit and vegetables in the EU. *Waste Manage*. **2018**, 77, 238–251.
12. Gupta, K., and Joshi, V. K. Fermentative utilization of waste from food processing industry In: Postharvest Technology of Fruits and Vegetables: Handling Processing Fermentation and Waste Mangement. **2000**, Vol. 2 Verma L R and Joshi VK (Eds). Indus Pub Co, New Delhi.
13. Sharma, K., Mahato, N., HwanCho, M., & Lee, Y. R. Converting citrus wastes into value-added products: Economic and environmently friendly approaches. *Nutr*. **2017**, 34, 29–46.
14. Narayan P., S. M. S., Lata, K., Singh, U., Kumar, V., Rajender, S. S., & P.Singh, S., Improved operational stability of d-psicose 3-epimerase by a novel protein engineering strategy, and d-psicose production from fruit and vegetable residues. *Bioresour. Technol*. **2016**, 216, 121–127.

15. Ayala-Zavala, J. F., Vega-Vega, V., Rosas-Domínguez, C., Palafox-Carlos, H., Villa-Rodriguez, J. A., Siddiqui, M. W., Dávila-Aviña, J. E., & González-Aguilar, G. A. Agro-industrial potential of exotic fruit byproducts as a source of food additives. *Food Res. Int.* **2011**,44(7), 1866–1874.
16. Fierascu, R. C., Sieniawska, E., Ortan, A., Fierascu, I., & Xiao, J. Fruits By-Products – A Source of Valuable Active Principles. A Short Review. *Front. bioeng. biotechnol.* **2020**, 8, 319.
17. Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G., Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Compr. Rev. Food Sci. Food Saf.* **2018**, 17(3), 512–531.
18. Wang, L., Wang, J., Fang, L., Zheng, Z., Zhi, D., Wang, S., Zhao, H. Anticancer Activities of Citrus Peel Polymethoxy flavones Related to Angiogenesis and Others. *Biomed Res. Int.* **2014**, 1–10.
19. Aruna, S., & Suneetha, V. Studies on biochemical analysis and antioxidant property in culinary fruit peels collected from Kannamagalam town of Vellore districts. *Der Pharm. Lett.* **2016**, 8(4), 381–388.
20. Nguyen, N. M. P., Le, T. T., Vissenaekens, H., Gonzales, G. B., Van Camp, J., Smagghe, G., & Raes, K. *In vitro* antioxidant activity and phenolic profiles of tropical fruit by-products. *Int. J. Food Sci. Technol.* **2019**, 54(4), 1169-1178.
21. MINAGRIC,. Post Harvest Profile of Banana : 2015. Government of India Ministry of Agriculture (Department Of Agriculture & Cooperation), Directorate of Marketing & Inspection, Branch Head Office.
22. Mohapatra, D., Mishra, S., & Sutar, N. Banana and its by-product utilization: An overview. *J. Scient. Ind. Res.* **2010**, 69(5), 323–329.
23. Vu, H. T., Scarlett, C. J., & Vuong, Q. V. Phenolic compounds within banana peel and their potential uses: *A review. J. Funct. Foods*. **2018**, 40(July2017), 238–248.
24. Sinha, & Nirmal, K. Apples and pears: production, physicochemical and nutritional quality, and major products. In Handbook of fruits and fruit processing. **2012**, (pp. 365–383).
25. Hesas, R. H., Arami-Niya, A., Daud, W. M. A. W., & J. N. Sahu A. Preparation and characterization of activated carbon for separation of $CO_2$. *J. China Univ. Min. Technol*. **2014**, 43(5), 910–914.
26. Barreira, J. C. M., Arraibi, A. A., & Ferreira, I. C. F. R. Bioactive and functional compounds in apple pomace from juice and cider manufacturing: Potential use in dermal formulations. *Trends Food Sci. Technol*. **2019**, 90(May), 76–87.
27. VasanthaRupasinghe, H. P., Wang, L., Pitts, N. L., & Astatkie, T. Baking and sensory characteristics of muffins incorporated with apple skin powder. *J. Food Qual.* **2009**, 32(6), 685–694.
28. Tharanathan, R. N., Yashoda, H. M., & Prabha, T. N. Mango (*Mangifera indica* L.), "The King of Fruits"—An Overview. *Food Rev. Int*. **2006**, 22(2), 95–123.
29. Torres-León, C., Rojas, R., Contreras-Esquivel, J. C., Serna-Cock, L., Belmares-Cerda, R. E., & Aguilar, C. N. Mango seed: Functional and nutritional properties. *Trends Food Sci. Technol.* **2016**, 55, 109–117.
30. Ballesteros-Vivas, D., Alvarez-Rivera, G., Medina, S. J. M., delPilar Sánchez Camargo, A., Ibánez, E., Parada-Alfonso, F., & Cifuentes, A. An integrated approach for the valorization of mango seed kernel: Efficient extraction solvent selection, photochemical profiling and anti-proliferative activity assessment. *Food Res. Int*. **2019**, 126 (May), 108616.
31. Kim, H., Kim, H., Mosaddik, A., Gyawali, R., Ahn, K. S., & Cho, S. K. Induction of apoptosis by ethanolic extract of mango peel and comparative analysis of the chemical constitutes of mango peel and flesh. *Food Chem*. **2012**, 133(2), 416–422.
32. Ajila, C., Naidu, K., Bhat, S., & Rao, U. Bioactive compounds and antioxidant potential of mango peel extract. *Food Chem*. **2007**, 105(3), 982–988.
33. Solís-Fuentes, J. A., & Durán-de-Bazúa, M. C. Mango (*Mangifera indica* L.) seed and its fats. In V. Preedy, R. R. Watson, & V. B. Patel (Eds.), Nuts and Seeds in health and disease prevention. **2011**, (pp. 741–748). San Diego: Academic Press. Chapter 88.
34. Ledesma-Escobar, C. A., & Luque de Castro, M. D. Towards a comprehensive exploitation of citrus. *Trends Food Sci. Technol*. **2014**, 39(1), 63–75.
35. Ferguson, U. Citrus fruits processing. *In Horticultural Science*. **1990**, (pp. 117–118).
36. Sharma, K., Mahato, N., Hwan Cho, M., & Lee, Y. R. Converting citrus wastes into value-added products: Economic and environmently friendly approaches. *Nutr*. **2017**, 34, 29–46.
37. Zema, D. A., Calabrò, P. S., Folino, A., Tamburino, V., Zappia, G., & Zimbone, S. M., Valorisation of citrus processing waste: A review. *Waste Manage.* **2018**, 80, 252–273.
38. Bordiga, M., Travaglia, F., & Locatelli, M. Valorisation of grape pomace: an approach that is increasingly reaching its maturity – a review. *Int. J. Food Sci. Technol*. **2019**, 54(4), 933–942.
39. Beres, C., Costa, G. N. S., Cabezudo, I., da Silva-James, N. K., Teles, A. S. C., Cruz, A. P. G., Mellinger-Silva, C., Tonon, R. V., Cabral, L. M. C., & Freitas, S. P. Towards integral utilization of grape pomace from winemaking process: A review. *Waste Manage.* **2017**, 68, 581–594.
40. Brenes, A., Viveros, A., Chamorro, S., & Arija, I. Use of polyphenol-rich grape by-products in monogastric nutrition. A review. *Anim. Feed Sci. Technol*. **2016**, 211, 1–17.
41. Araújo, R. G., Rodriguez-Jasso, R. M., Ruiz, H. A., Pintado, M. M. E., & Aguilar, C. N., Avocado by-products: Nutritional and functional properties. *Trends Food Sci. Technol.* **2018**, 80, 51–60.

42. Yahia, E. M. The Contribution of Fruit and Vegetable Consumption to Human Health. In Fruit and Vegetable Phytochemicals: Chemistry, Nutritional Value, and Stability. **2009,** (pp. 3–51).
43. López-Cobo, A., Gómez-Caravaca, A. M., Pasini, F., Caboni, M. F., Segura-Carretero, A., & Fernández-Gutiérrez, A. HPLC-DAD-ESI-QTOF-MS and HPLC-FLD-MS as valuable tools for the determination of phenolic and other polar compounds in the edible part and by-products of avocado. *LWT-Food Sci. Technol*. **2016**, 73, 505–513.
44. Hemalatha, R., & Anbuselvi, S. Physicohemical constituents of pineapple pulp and waste. *J. Chem. Pharm. Res.* **2013**, 5(2), 240–242.
45. Babbar, N., Oberoi, H. S., Uppal, D. S., & Patil, R. T. Total phenolic content and antioxidant capacity of extracts obtained from six important fruit residues. *Food Res. Int*. **2011**, 44(1), 391–396.
46. Amini Khoozani, A., Birch, J., & Bekhit, A. E. D. A. Production, application and health effects of banana pulp and peel flour in the food industry. *J. Food Sci. Technol.* **2019**, 56(2), 548–559.
47. Happi Emaga, T., Andrianaivo, R. H., Wathelet, B., Tchango, J. T., & Paquot, M. Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chem*. **2007**, 103(2), 590–600.
48. Pelissari, F. M., Sobral, P. J. D. A., & Menegalli, F. C. Isolation and characterization of cellulose nano-fibers from banana peels. *Cellulose.* **2014**, 21(1), 417–432.
49. Lavelli, V., & Corti, S. Phloridzin and other phytochemicals in apple pomace: Stability evaluation upon dehydration and storage of dried product. *Food Chem*. **2011**, 129(4), 1578–1583.
50. Dhillon, G. S., Kaur, S., & Brar, S. K. Perspective of apple processing wastes as low-cost substrates for bio-production of high value products: A review. *Renew. Sustain. Energy Rev.* **2013**, 27, 789–805.
51. Bhushan, S., Kalia, K., Sharma, M., Singh, B., & Ahuja, P. S. Processing of Apple Pomace for Bioactive Molecules. *Crit. Rev. Biotechnol*. **2008** 28(4), 285–296.
52. Jahurul, M. H. A., Zaidul, I. S. M., Ghafoor, K., Al-Juhaimi, F. Y., Nyam, K. L., Norulaini, N. A. N., Sahena, F., & Mohd Omar, A. K. Mango (*Mangifera indica* L.) by-products and their valuable components: A review. *Food Chem*. **2015**, 183, 173–180.
53. Sagar, A., & Singh, R. Biochemical estimation of nutritive parameters in waste seed kernel of Mango (*Mangifera indica* L.). *Int. J. Agric. Res. Innov. Technol*. **2016**, 1(1), 113-115.
54. Asif, A., Farooq, U., Akram, K., Hayat, Z., Shafi, A., Sarfraz, F., Aftab, S. Therapeutic potentials of bioactive compounds from mango fruit wastes. *Trends Food Sci. Technol*. **2016**, 53, 102–112.
55. Mamma, D., Kourtoglou, E., & Christakopoulos, P. Fungal multienzyme production on industrial by-products of the citrus-processing industry. *Bioresour. Technol*. **2008**, 99(7), 2373–2383.
56. Ben-Othman, S., Jõudu, I., & Bhat, R. Bioactives from agri-food wastes:Present insights and future challenges. *Molecules*. **2020**, 25, 1–34.
57. Yu, J., & Ahmedna, M. Functional components of grape pomace: Their composition, biological properties and potential applications. *Int. J. Food Sci. Technol*. **2013**, 48(2), 221–237.
58. Friedman, M. Antibacterial, antiviral, and antifungal properties of wines and winery byproducts in relation to their flavonoid content. *J. Agric. Food Chem*. **2014**, 62(26), 6025–6042.
59. Domínguez, M. P., Araus, K., Bonert, P., Sánchez, F., San Miguel, G., & Toledo, M. The Avocado and Its Waste: An Approach of Fuel Potential/Application. *Environment, Energy and Climate Change* II. **2014**, 199–223.
60. Tremocoldi, M. A., Rosalen, P. L., Franchin, M., Massarioli, A. P., Denny, C., Daiuto, É. R., and Alencar, S. M. Exploration of avocado by-products as natural sources of bioactive compounds. *PLoS ONE*. **2018**, 13(2), e0192577.
61. Huang, Y. L., Chow, C. J., & Fang, Y. J. Preparation and physicochemical properties of fiber-rich fraction from pineapple peels as a potential ingredient. *J. Food Drug Anal*. **2011**, 19(3), 318–323.
62. Roda, A., & Lambri, M. Food uses of pineapple waste and by-products: a review. *Int. J. Food Sci. Technol*. **2019**, 54(4), 1009–1017.
63. Nzikou, J. M., Kimbonguila, A., Matos, L., Loumouamou, B., Pambou-Tobi, N. P. G., Ndangui, C. B., Abena, A. A., Silou, Th., Scher, J., and Desobry, S. Extraction and characteristics of seed kernel oil from mango (*Mangifera indica L.*). *Research J. of Environ Earth Sci*. **2010**, 2(1), 31-35.
64. Noor, S. A. A., Siti, N. M., & Mahmad, N. J. Chemical Composition, Antioxidant Activity and Functional Properties of Mango (*Mangifera indica* L. var Perlis Sunshine) Peel Flour (MPF). *Int. J. Appl. Mech*. **2015**, 754, 1065–1070.
65. Morais, D. R., Rotta, E. M., Sargi, S. C., Bonafe, E. G., Suzuki, R. M., Souza, N. E., and Visentainer, J. V. Proximate Composition, Mineral Contents and Fatty Acid Composition of the Different Parts and Dried Peels of Tropical Fruits Cultivated in Brazil. *J. Braz. Chem. Soc*. **2017**, 28(2), 308-318.
66. Sousa, E. C., Uchôa-Thomaz, A. M. A., Carioca, J. O. B., Morais, S. M. de, Lima, A. de, Martins, C. G., Rodrigues, L. L. Chemical composition and bioactive compounds of grape pomace (*Vitis vinifera* L.), Benitaka variety, grown in the semiarid region of Northeast Brazil. *Food Sci. Technol.* **2014**, 34(1), 135–142.

67. Ani, P. N., & Abel, H. C. Nutrient, phytochemical, and antinutrient composition of *Citrus maxima* fruit juice and peel extract. *Food Sci. Nutr*. **2018**, 6(3), 653–658.
68. García-Lomillo, J., González-SanJosé, M. L., Del Pino-García, R., Rivero-Pérez, M. D., & Muñiz-Rodríguez, P. Antioxidant and Antimicrobial Properties of Wine Byproducts and Their Potential Uses in the Food Industry. *J. Agric. Food Chem*. **2014**, 62(52), 12595–12602.
69. Fowomola, M. A. Some nutrients and antinutrients contents of mango (*Magnifera indica L.*) seed. *Afr. J. Food Sci.* **2010**, 4(8), 472 – 476.
70. Anthony, C.E., Chinazum, O., Okechukwu, C.A., and Uchendu, O.M. Vitamins composition and antioxidant properties in normal and monosodium glutamate-compromised rats' serum of *Persea americana* (Avocado Pear) seed. *Open Chem.* **2017**, 1(1), 19-24.
71. Campos, D.A., Ribeiro, T.B., Teixeira, J.A., Pastrana, L., and Pintado, M.M. Integral Valorization of Pineapple (*Ananas comosus* L.) By-Products through a Green Chemistry Approach towards Added Value Ingredients. *Foods*. **2020**, *9*(1), 60:1-22.
72. Çam, M., İçyer, N. C., & Erdoğan, F., Pomegranate peel phenolics: Microencapsulation, storage stability and potential ingredient for functional food development. *LWT - Food Sci. Technol*. **2014**, 55(1), 117–123.
73. Güzel, M., & Akpınar, Ö. Valorisation of fruit by-products: Production characterization of pectins from fruit peels. *Food Bioprod. Process*. 2**019**, 115, 126–133.
74. El-Safy, F. S., Salem, R. H., & Abd El-Ghany, M. E. Chemical and nutritional evaluation of different seed flours as novel sources of protein. *World J. Dairy Food Sci*. **2012**, 7(1), 59–65.
75. Huang, L., Luo, H., Li, Q., Wang, D., Zhang, J., Hao, X., & Yang, X. Pentacyclictriterpene derivatives possessing polyhydroxyl ring A inhibit Gram-positive bacteria growth by regulating metabolism and virulence genes expression. *Eur. J. Med. Chem*. **2015**, 95, 64–75.
76. Liu, S., Zhang, S.,Lv, X.,Lu, J.,Ren, C.,Zeng, Z.,Zheng, L.,Zhou, X.,Fu, H.,Zhou, D. Limonin ameliorates ulcerative colitis by regulating STAT3/miR-214 signaling pathway. *Int. J. Immunopharmacol*. **2019**, 75, 105768.
77. Mahato, N. Sharma, K. Sinha, M., and Cho, M.H. Citrus waste derived nutra-/pharmaceuticals for health benefits: Current trends and future perspectives. *J. Funct. Foods*. **2018**, 40, 307–316.
78. Wang, Z., Xu, B., Luo, H., Meng, K., Wang, Y., Liu, M., Bai, Y., Yao, B., and Tu, T. Production pectin oligosaccharides using Humicolainsolens Y1-derived unusual pectatelyase. *J. Biosci. Bioeng*. **2019**, 129(1), 16-22.
79. Bankar, A., Joshi, B., Kumar, A. R., & Zinjarde, S. Banana peel extract mediated novel route for the synthesis of silver nanoparticles. *Colloids Surf, A Physicochem Eng Asp*. **2010**, 368(1–3), 58–63.
80. Iqbal, M., Saeed, A., & Zafar, S. I. FTIR spectrophotometry, kinetics and adsorption isotherms modeling, ion exchange, and EDX analysis for understanding the mechanism of $Cd^{2+}$ and $Pb^{2+}$ removal by mango peel waste. *J. Hazard. Mater*. **2009**, 164(1), 161–171.
81. Wang, J., & Chen, C. Biosorbents for heavy metals removal and their future. *Biotechnol. Adv*. **2009**, 27(2), 195–226.
82. Premkumar, M., & Shanthakumar, S. Process optimization for Cr(VI) removal by *Mangifera indica* seed powder: a response surface methodology approach. *Desalin. Water Treat.* **2013**, 53(6), 1653–1663.
83. Franca, A. S., Oliveira, L. S., Saldanha, S. A., Santos, P. I. A., &Salum, S. S. Malachite green adsorption by mango (*Mangifera indica* L.) seed husks: Kinetic, equilibrium and thermodynamic studies. *Desalination and Water Treat*. **2010**, 19(1-3), 241–248.
84. Merheb, R., Abdel-Massih, R. M., & Karam, M. C. Immunomodulatory effect of natural and modified Citrus pectin on cytokine levels in the spleen of BALB/c mice. *Int. J. Biol. Macromol*. **2019**, 121, 1–5.
85. Chavan, P., Singh, A. K., & Kaur, G. Recent progress in the utilization of industrial waste and by-products of citrus fruits: A review. J. Food Process Eng. **2018**, 41(8), e12895.
86. Upadhyay, A., Lama, J. P., & Tawata, S. Utilization of Pineapple Waste: A Review. *J. Food Sci. Technol*. **2013**, 6(0), 10–18.
87. Deliza, R., Rosenthal, A., Abadio, F. B. D., Silva, C. H. O., & Castillo, C. Application of high pressure technology in the fruit juice processing: Benefits perceived by consumers. *J. Food Eng*. **2005**, 67(1–2), 241–246.
88. Saraswaty, V., Risdian, C., Primadona, I., Andriyani, R., Andayani, D. G. S., & Mozef, T. Pineapple peel wastes as a potential source of antioxidant compounds. IOP Conference Series: *Environ. Earth Sci.* **2017**, 60, 012013.
89. Seguí Gil, L., & Fito Maupoey, P. An integrated approach for pineapple waste valorization. Bio-ethanol production and bromelain extraction from pineapple residues. *J. Clean. Prod*. **2018**, 172, 1224–1231.
90. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2019. Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. 2019.
91. Harouna, D. V., Venkataramana, P. B., Matemu, A. O., & Alois Ndakidemi, P. Agro-morphological exploration of some unexplored wild vigna legumes for domestication. *Agronomy*. **2020**, 10(1), 1–26.

92. Singh, A., Dubey, P. K., Chaurasia, R., Dubey, R. K., Pandey, K. K., Singh, G. S., & Abhilash, P. C. Domesticating the Undomesticated for Global Food and Nutritional Security: Four Steps. *Agronomy*. **2019**, 9(9), 1–9.
93. Singh, A., Dubey, R. K., Bundela, A. K., & Abhilash, P. C. The trilogy of wild crops, traditional agronomic practices, and un-sustainable development goals. *Agronomy*. **2020**, 10,1–10.
94. Choi, Y.-S., Kim, Y.-B., Hwang, K.-E., Song, D.-H., Ham, Y.-K., Kim, H.-W., Kim, C.-J. Effect of apple pomace fiber and pork fat levels on quality characteristics of uncured, reduced-fat chicken sausages. *Poult. Sci. J.* **2016**, 95(6), 1465–1471.
95. Huc-Mathis, D., Journet., C., Fayolle, N., and Bose, V. Emulsifying properties of food by-products: Valorizing apple pomace and oat bran. *Colloid Surf. A-Physicochem. Eng. Asp*. **2019**, 568, 84–91.
96. Perussello, C. A., Zhang, Z., Marzocchella, A., & Tiwari, B. K. Valorization of Apple Pomace by Extraction of Valuable Compounds. *Compr. Rev. Food Sci. Food Saf.* **2017**, 16(5), 776–796.
97. Gunes, R., Palabiyik, I., Toker, O. S., Konar, N., & Kurultay, S. Incorporation of Defatted Apple Seeds in Chewing Gum System and Phloridzin Dissolution Kinetics. *J. Food Eng*. **2019**, 255, 9–14.
98. Rotta, E. M., de Morais, D. R., Biondo, P. B. F., dos Santos, V. J., Matsushita, M., and Visentainer, J. V. Use of avocado peel (*Persea americana*) in tea formulation: A functional product containing phenolic compounds with antioxidant activity. *Acta Sci. Technol*. **2016**, 38(1), 23–29.
99. Utrera, M., Rodríguez-Carpena, J.-G., Morcuende, D., & Estévez, M. Formation of Lysine-derived oxidation products and loss of Tryptophan during processing of porcine patties with added avocado by products. *J. Agric. Food Chem*. **2012**, 60(15), 3917–3926.
100. Chel-Guerrero, L., Barbosa-Martín, E., Martínez-Antonio, A., González-Mondragón, E., & Betancur-Ancona, D., Some physicochemical and rheological properties of starch isolated from avocado seeds. *Int. J. Biol. Macromol*. **2016**, 86, 302–308.
101. Barbosa-Martín, E., Chel-Guerrero, L., González-Mondragón, E., & Betancur-Ancona, D. Chemical and technological properties of avocado (*Persea americana* Mill.) seed fibrous residues. *Food Bioprod. Process*. **2016**, 100, 457–463.
102. Lee, E.-H., Yeom, H.-J., Ha, M.-S., & Bae, D.-H. Development of banana peels jelly and its antioxidant and textural properties. *Food Sci. Biotechnol*. **2010**, 19(2), 449–455.
103. Satari, B., & Karimi, K. Citrus processing wastes: Environmental impacts, recent advances, and future perspectives in total valorization. *Resour. Conserv.Recycl*. **2018**, 129, 153–167.
104. Espitia, P. J. P., Du, W.-X., Avena-Bustillos, R. de J., Soares, N. de F. F., & McHugh, T. H. Edible films from pectin: Physical-mechanical and antimicrobial properties - A review. *Food Hydrocoll*. **2014**, 35, 287–296.
105. Lang, G., and Buchbauer, G. A review on recent research results (2008-2010) on essential oils as antimicrobials and anti-fungal. A review. *Flavour Fragr. J*. **2012**, 27(1), 13–39.
106. Mainente, F., Menin, A., Alberton, A., Zoccatelli, G., & Rizzi, C. Evaluation of the sensory and physical properties of meat and fish derivatives containing grape pomace powders. *Int. J. Food Sci. Technol*. **2019**, 54(4), 952–958.
107. Acun, S.; Gül, H. Effects of grape pomace and grape seed flours on cookie quality. *Qual. Assur. Saf. Crops Foods*.**2014**, 6(1), 81-88.
108. Mattos, G. N., Tonon, R. V., Furtado, A. A. L., and Cabral, L. M. C. Grape by-product extracts against microbial proliferation and lipid oxidation: a review. *J. Sci. Food Agric*. **2017**, 97(4), 1055–1064.
109. Ajila, C. M., Aalami, M., Leelavathi, K., & Rao, U. J. S. P. Mango peel powder: A potential source of antioxidant and dietary fiber in macaroni preparations. *Innov. Food Sci. Emerg. Technol.* **2010**, 11(1), 219–224.
110. Ashoush, I. S., and Gadallah, M. G. E. Utilization of mango peels and seed kernels powders as sources of phytochemicals in biscuit. *World J. Dairy Food Sci*. **2011**, 6(1), 35–42.
111. Adilah, A. N., Jamilah, B., Noranizan, M. A., and Hanani, Z. A. N. Utilization of mango peel extracts on the biodegradable films for active pack by-product. *Food Packag. Shelf Life*. **2018**, 16,1–7.
112. Torres-Leon, C., Vicente, A. A., Flores-Lopez, M. L., Rojas, R., Serna-Cock, L., Alvarez- Perez, O. B., et al. Edible films and coatings based on mango (var. Ataulfo) by-products to improve the gas transfer rate of peach. *LWT- Food Sci. Technol*. **2018**, 97, 624–631.
113. Kodagoda, K.H.G.K., Marapana, R.A.U.J. Development of non-alcoholic wines from the wastes of Mauritius pineapple variety and its physicochemical properties. *J. Pharmacogn. Phytochem*. **2017**, 6(3), 492-497.
114. Arshad, Z.M, Amid, A., Yusof, F., Jaswir, I., Ahmad, K., and Loke, S.P. Bromelain: An overview of industrial application and purification strategies. *Appl. Microbiol. Biotechnol*. **2014**, 98(17), 7283-7297.
115. Laily, N., Kusumaningtyas, R.W., Sukarti, I., and Rini, M.R.D.K. The Potency of Guava (*Psidium guajava* L.) Leaves as a Functional Immunostimulatory Ingredient. *Procedia Chem*. **2015**, 14, 301-307.
116. Baldisserotto, A., Malisardi, G., Scalambra, E., Andreotti, E., Romagnoli, C., Vicentini, C., and Vertuani, S. Synthesis, Antioxidant and Antimicrobial activity of a aew Phloridzin derivative for dermo-cosmetic applications. *Molecules*. **2012**, 17(11), 13275–13289.

117. Antika, L.D., Lee, E.J., Kim, Y.H., Kang, M.K., Park, S.H., Kim, D.Y.,Oh, H., Choi, Y.J., and Kang, Y.H. Dietary phlorizin enhances osteoblastogenic bone formation through enhancing catenin activity via GSK-3-inhibition in a model of senile osteoporosis. J. *Nutr. Biochem*. **2017**, 49, 42–52.
118. Nair, S. V., Ziaullah, and Rupasinghe, H. P. Fatty acid esters of phloridzin induce apoptosis of human liver cancer cells through altered gene expression. *PLoS One*. **2014**, 9**(**9), 1-16 e107149.
119. Gonzalez, J., Donoso, W., Sandoval, N., Reyes, M., Gonzalez, P., Gajardo, M., Morales, E., Neira, A., Razmilic, I., Yuri, J A., and Carrasco, R. M. Apple Peel Supplemented Diet Reduces Parameters of Metabolic Syndrome and Atherogenic Progression in ApoE−/− Mice. *Evid.-based Complement. Altern. Med*. **2015**, 6, 1-10.
120. Yu, X., Lin, H., Wang, Y., Lv, W., Zhang, S., and Qian, Y. D-limonene exhibits antitumor activity by inducing autophagy and apoptosis in lung cancer. *Onco Targets Ther*. **2018**, 11, 1833–1847.
121. Miller, J. A., Thompson, P. A., Hakim, I. A., Chow, H. H. S., and Thomson, C. A. D-Limonene: A bioactive food component from citrus and evidence for a potential role in breast cancer prevention and treatment. *Oncol. Rev*. **2011**, 5(1), 31–42.
122. Petersen, K. S., & Smith, C. Ageing-Associated Oxidative Stress and Inflammation Are Alleviated by Products from Grapes. *Oxidative Med. Cell. Longev*. **2016**, 1–12.
123. Garavaglia, J., Markoski, M. M., Oliveira, A., and Marcadenti, A. Grapes seed oil compounds: Biological and chemical actions for health. *Nutr. Metab. Insights*. **2016**, 9, 59-64.
124. Burton-Freeman, B. M., Sandhu, A. K., and Edirisinghe, I. Mangos and their bioactive components: Adding variety to the fruit plate for health. *Food Funct*. **2017**, 8(9), 3010–3032.
125. Maxwell, E. G., Belshaw, N. J., Waldron, K. W., and Morris, V. J. Pectin-An emerging new bioactive food polysaccharide. *Trends Food Sci. Technol*. **2012**, 24(2), 64–73.
126. Wang, X., Gao, L., Lin, H., Song, J., Wang, J., Yin, Y,. Zhao, J., Xu, X., Li, Z., and Li, L. Mangiferin prevents diabetic nephropathy progression and protects podocyte function via autophagy in diabetic rat glomeruli. *Eur. J. Pharmacol*. 2018, 824, 170–178.
127. Nowicka, P., and Wojdyło, A. Content of bioactive compounds in the peach kernels and their antioxidants, anti-hyperglycemic, anti-aging properties. *Eur. Food Res. Technol*. **2019**, 245(5), 1123–1136.
128. Vendruscolo, F., Albuquerque, P. M., Streit, F., Esposito, E., and Ninow, J. L. Apple pomace: a versatile a substrate for biotechnological applications. *Crit. Rev. Biotechnol*. **2008**, 28(1), 1–12.
129. Palma, C., Lloret, L., Puen, A., Tobar, M., & Contreras, E. Production of carbonaceous material from avocado peel for its application as alternative adsorbent for dyes removal. *Chin. J. Chem. Eng*. **2016,** 24(4), 521–528.
130. Bharathiraja, S., Suriya, J., Krishnan, M., Manivasagan, P., & Kim, S.-K. Production of enzymes from agricultural wastes and their potential industrial applications. *Adv. Food Nutr. Res*. **2017**, 125–148.
131. Panda, S. K., Mishra, S. S., Kayitesi, E., & Ray, R. C. Microbial-processing of fruit and vegetable wastes for production of vital enzymes and organic acids: Biotechnology and scopes. *Environ. Res*. **2016**, 146, 161–172.
132. Botella, C., Diaz, A., de Ory, I., Webb, C., & Blandino, A. Xylanase and pectinase production by *Aspergillus awamori* on grape pomace in solid state fermentation. *Process Biochem*. **2007**, 42(1), 98–101.
133. Jawad, A. H., Alkarkhi, A. F. M., Jason, O. C., Easa, A. M., & NikNorulaini, N. A. Production of the lactic acid from mango peel waste – Factorial experiment. *J. King Saud Univ. Sci.* **2013**, 25(1), 39–45.
134. Kumar, D., Yadav, K. K., Muthukumar, M., and Garg, N. Production and characterization of α-amylase from mango kernel by *Fusarium solani* NAIMCC-F-02956 using submerged fermentation. *J. Environ. Biol*. **2013**, 34(6), 1053–1058.
135. Rani, D. S., & Nand, K. Ensilage of pineapple processing waste for methane generation. *Waste Manage*. **2004**, 24(5), 523–528.
136. Mishra, J., Kumar, D. Samanta, S., Vishwakarma, M.K. A comparative study of ethanol production from various agro residues by using *Saccharomyces cerevisiae* and Candida albicans. *J. Yeast Fungal Res*. **2012**, 3, 12–17.
137. Adie Gilbert, U., Unuabonah Emmanuel, I., Adeyemo Adebanjo, A., & Adeyemi Olalere, G. Biosorptive removal of $Pb^{2+}$and $Cd^{2+}$ onto novel biosorbent: Defatted Carica papaya seeds. *Biomass Bioenerg*. **2011**, 35(7), 2517–2525.