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Utilization of fruit processing by-products for industrial applications: A review

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Abstract
The waste utilization of fruit processing industries has become one of the main challengeable aspects in the world due to the generation of large quantities of by-products including peels, seeds, unused flesh in different steps of processing chain. However these plant by-products are rich in valuable compounds which can be utilized in various industries as novel, low-cost, economical and natural sources of dietary fiber, antioxidants, pectin, enzymes, organic acids, food additives, essential oils etc. through different methods of extractions, purifications and fermentations. The aim of this review is to highlight the possibilities of utilization of by-products from pineapple, apple, grapes, citrus fruits, mango and banana processing in industries and to promote the integral exploitation of the by-products rich in bio-active compounds.

Keywords: fruit processing, by-products, waste utilization

1. Introduction
Due to the increase in the world population and the consumer's awareness on the health benefits of consumption of fruits and vegetables, the demand for the fruits and vegetables has increased considerably. In many cases the raw fruit and vegetables is not consumed directly by humans, but first undergoes processing to separate the desired value product from other constituents of the plant [1]. During the processing of fruits and vegetables, large quantities of solid and liquid wastes are generated. The waste obtained from fruits and processing industry is extremely diverse due to the use of wide variety of fruits and vegetables, the broad range of processes and the multiplicity of the product [2]. As an example, tropical and subtropical fruits processing have considerably higher ratios of by-products than the temperate fruits [3]. Due to increasing production and processing of fruits and vegetables, disposal represents a growing problem since the plant material is usually prone to microbial spoilage, thus limiting further exploitation. On the other hand, costs of drying, storage and shipment of by-products are economically limiting factors. Therefore, agro-industrial waste is often utilized as feed or as fertilizer [4].

There is a trend to find new sources of functional ingredients such as plant food by-products that have traditionally been undervalued [5]. The term "by-product" suggests that plant food wastes might be usable and have their own market [6]. These by-products might reach around 60% of harvested plants. These residues are very perishable products that are difficult to manage because of environmental problems in the industries [7].

The processing of plant foods results in the production of by-products that are rich sources of bioactive compounds, including phenolic compounds [3]. The antioxidant compounds from waste product of food industry could be used for increasing the stability of foods by preventing lipid peroxidation and also for protecting oxidative damage in living systems by scavenging oxygen free radicals [8]. Studies have shown that the residues of certain fruits can present a higher antioxidant activity than the pulp [9]. Antioxidants are the substances that are able to prevent or inhibit oxidation processes inhuman body and food products [10] as ascorbic acid, phenolics and flavonoids. Thus, although these residues are usually discarded, it could be used as an alternative source of nutrients to increase the nutritive value of poor people's diets and to help reduce dietary deficiencies [11] as functional food market is one of the top trends in the food industry [12]. Apart from these bio-active compounds, many researchers have identified that food processing by-products have different potential applications in various industries. The objective of this review is to highlight the potential applications of some selected fruit by-products which are generated in fruit processing.

2. By-products of fruit processing
2.1 Pineapple
The pineapple (*Ananas comosus*) is one of the most important fruits in the world and is the leading edible member of the family *Bromeliaceae*. This fruit juice is the third most preferred worldwide after orange and apple juices [13]. Pineapple by-products are mainly the residual pulp, peels, stem and leaves [14]. Processing residuals ranges between 45 to 65%, an indication of serious organic-side streams disposal challenges, which causes environmental pollution if not successfully utilized [15].

Peel is the major bio-waste generated during pineapple processing [16]. Sugars are present in large quantities in pineapple peel that can be used as nutrients in fermentation processes. The peel can be used as a potential substrate for methane, ethanol and hydrogen generation [17, 18, s19]. The second major bio-waste is the core and can be used for the

production of pineapple juice concentrates, alcoholic, non-alcoholic beverages or vinegar [16, 19].
Bromelain (EC 3.4.22.32) is already commercially available enzyme, which is often derived from the pineapple stem. Due to its strong proteolytic activity, this enzyme has been used in numerous industrial applications such as a meat tenderizer, a bread dough improver, a fruit anti-browning agent, a beer clarifier, a tooth whitening agent, animal feed, and cosmetic substance and in textile industry [20]. Bromelin can be extracted from different wastes of pineapple including stem, core and peel [16, 21, 22] using different extraction and purification techniques.
The pineapple by-products contain significant amounts of dietary fiber especially insoluble dietary fiber [23, 24]. Fibers from pineapple by-products are considered high quality due to the physiological effects associated with both soluble and insoluble fibers, and may be used in the development of food reduced in calories and dietary fiber enriched food products [23].
Pineapple waste has been used for the production of lactic and citric acids through submerged and solid state fermentation [25]. Lactic acid was produced from pineapple waste in a mini-fermenter having three litre capacity under anaerobic conditions with a stirring speed of 50 rpm, temperature of 40°C and pH of 6.0 [26]. Solid pineapple wastes also can be utilized as sole substrate for the production of citric acid using *Yarrowia lipolytica* (NCIM 3589) through solid state fermentation [27]. Vinegar can also be produced from the pineapple wastes using a two-stage fermentation process [28]. Pineapple peels have been found to be promising feed for biogas generation, since they are rich in carbohydrates and proteins [29].
The increase in demand for the natural flavours has triggered the research in production of natural vanillin from natural raw material through microbial biotransformation [30]. Vanillin (4-hydroxy-3-methoxybenzaldehyde) which is the main component in vanilla produced from the vanillic acid. Pineapple peel waste contains ferulic acid, a precursor for vanillic acid [31]. Therefore vanillin can be synthesized from pineapple peels from a series of bio chemical reactions [32].
According to a study conducted by Mohammed, Ibrahim and Shitu [33], pineapple peel wastes can also be used as a potential low-cost alternative adsorbent for Safranin-O removal from waste water.

2.2 Grapes

Grape (*Vitis spp.)* is one of the most valued conventional fruits in the world [34]. It can be consumed raw or can be used in the formulation of products such as wine, jam, juice, jelly, raisins, vinegar and seed oil. According to OIV Statistical Report in 2016, 75.8 million tons of grapes are produced globally and the majority (57%) is used for the production of wine [35]. The wine-making industries produce millions of tons of residues (grape pomace) after fermentation, which represents a waste management issue both ecologically and economically [36]. Grape pomace collectively includes stems, seeds and skins. Grape pomace is considered as a valuable by-product for oil extraction, antioxidant and antibacterial agent preparation [37].
Most grape dietary fibre and phenolics accumulate in the fruit skins, seed and pulp, which after the manufacture of grape juice and in pomace. Grape pomace dietary fibre is a phenolic-rich dietary fibre matrix and is a dietary supplement that combines the benefits of both fibre and antioxidants help to prevent cancer and cardiovascular diseases [37]. The extraction of phenolic rich grape pomace dietary fiber can be optimized from aqueous extraction at 90 °C with solvent/substrate ratio of 4:1 [38]. According to Du *et al.,* [39], extraction of soluble dietary fiber from grape pomace can be optimized by using hydrochloric acid at a concentration of 0.40 moldm^{-3}. Research on utilization of dietary fiber from grape pomace has been conducted as a potential functional ingredient in bakery products [40], seafood [41] to reduce rancidity on ice storage, alternative fining agents for red wines [42], to remove red wine tannins and in dairy products to increase the dietary fiber, total phenolic content and to delaying lipid oxidation in yoghurt and salad dressings [43]. Grape pomace extracts were also successful incorporated into chitosan edible films (hydrophobic and hydrophilic), providing antioxidant properties and promising shelf life extension [44].
Nutraceutical effects of grape seed oil have been reported in several studies due to its fatty acids composition, total phenolics and antioxidant capacity [45]. Phenolic compounds are more concentrated in the seeds than in other parts of the grape and its distribution is about 70% in seeds, 20% in skin and 10% in the pulp [46]. Grape seeds contain 8–15% (w/w) of oils with high levels of unsaturated fatty acids namely oleic and linoleic acids [47], which represents more than 89% of the total oil composition with high level of essential fatty acids [48]. Due to chemical composition of grape seed oil, it can be used as a functional ingredient in the meat industry to modify and formulate healthier food products [49, 50]. According to the studies of Ismail *et al.,* [51, 52], grape seed oil has the hepatoprotective, neuroprotective and liver cholesterol reduction ability.

2.3 Apples

Apple (*Malus domestica Borkh.)* is a climacteric fruit cultivated in temperate regions [53], and one of the most widely cultivated and consumed fruits worldwide [54]. Apples processing generates skin, stems, and residual flesh which are considered as a potential value added food ingredient [55]. Apple pomace is the main by-product of apple cider and juice processing industries and accounts for about 25% of the original fruit mass at 85% (wet basis) moisture content [56]. It is considered a rich source of dietary fiber, especially pectin, with a content in the range of 10-15% (w/w dry basis), depending on the source [57].
According to Younis and Ahmad [58], apple pomace has versatile functional properties like glucose diffusion retardation index, emulsifying activity, water-/oil-holding capacity, and antimicrobial activity.
Apple pomace consists of approximately 10–15% pectin on dry weight basis [59, 60]. However, the production of pectin is considered the most reasonable utilization for apple pomace, according to previous studies [61, 62]. Various extraction methods have been developed over the past decade for the purpose of optimum pectin extraction from apple pomace as the demand for the fruit pectin are increasing due to their non-toxicity and biocompatibility.
Apple pomace also contains a significant amount of non-

starch polysaccharides (35–60% dietary fibre), with a high amount of insoluble fibre (36.5%) as well as soluble fibre (14.6%) [63-66]. A number of fibre enriched bakery products were prepared by adding dried apple pomace powder on a wheat flour replacement basis [63, 66, 67].

Another important application is the recovery of natural antioxidants in the form of polyphenols [61]. McCann *et al.*, [68] have also shown that crude extracts from apple pomace can prevent colon cancer in vitro. Apple pomace is a good source of chlorogenic acid, phloretin glycosides and quercetin glycosides [69, 70]. Other compounds such as catechins and procyanidins are also present [71].

2.4 Mango

The waste generated from the mango processing industry, derived mainly from the epicarp and endocarp has been estimated at 75000 MT [72], and is on the rise due to growth in mango fruit production and processing industry. However, there is virtually no commercial utilization of mango seed kernel which in most cases is discarded as waste in the fruit processing industry. This is despite the fact that mango seed tends to be between 20 and 60% of the whole fruit weight, and the kernel occupies between 45 and 75% of the seed depending on the variety [73].

Carotenoids play a potentially important role in human health by acting as biological antioxidants, protecting cells and tissues from the damaging effects of free radicals and singlet oxygen and are used as natural colorants in the food industry [74]. The carotenoid content was found to be 4–8 times higher in ripe mango peels compared to raw fruit peels [75].

The dietary fiber content in mango peels of different varieties has been estimated. The total dietary fiber content in dry peel varied from 45 to 78% [76]. The soluble dietary fiber content in both raw and ripe mangos peels are more than 35% of total dietary fiber. Insoluble dietary fiber relates to both water absorption and intestinal regulation whereas soluble dietary fiber associates with cholesterol in blood and diminishes its intestinal absorption [76].

Mango seed kernel oil has been reported to be a good source of polyunsaturated fatty acids such as oleic and linoleic acids which have health benefits [77]. The potent antimicrobial activity demonstrated by the mango kernel extracts could be attributed to the presence of specific phytochemicals such as flavonoids, terpenes, tannins, and coumarins [78]. High antimicrobial and antifungal activity against *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Candida albicans* has been reported in kernel powder of South African mango variety [79].

2.5 Citrus

Citrus (*Citrus L. from Rutaceae*) is one of the most important fruit crops around the world. Citrus fruits are highly consumed worldwide as fresh produce, juice and most often the peel is discarded as waste which contains a wide variety of secondary components with substantial antioxidant activity in comparison with other parts of the fruit [80]. Citrus peels are subdivided into the epicarp or flavedo (coloured peripheral surface) and mesocarp or albedo (white soft middle layer) [81].

Food industry uses citrus peel as a source of molasses, pectin [82, 83], oil and limone [84], and has been studied because it contains several bioactive compounds, such as flavanones, polymethoxylated flavones, flavonols and phenolic acids; these compounds have a lot of uses as a natural antioxidants for pharmaceutical, biotechnological and food industries [85].

Orange is the main citrus fruit investigated and commercialized. Orange juice is the most important product of citrus species worldwide [86], and causes a higher amount of by-product that could be used as a good source of bioactive compounds [87]. Gorinstein *et al.*, [88] found that the total phenolics content in peels of lemons, oranges, and grapefruit were 15% higher than those in the peeled fruits.

Lime and lemon peel oils are widely used as aroma flavor enhancers for soft and alcoholic beverages and food. In pharmaceutical industries they are used as flavoring agents to mask unpleasant tastes of drugs. In perfumery, they form the base of many compositions. They have a higher market value per pound than orange, grapefruit, or tangerine oils [89].

Different antimicrobial packaging systems including lemon extracts have been used to preserve Mozzarella cheese. Results showed an increase in the shelf life of all active packaged Mozzarella cheeses, confirming that lemon extract may exert an inhibitory effect on the microorganisms responsible for spoilage phenomena without affecting the functional micro biota of the product [90].

2.6 Banana

Bananas are one of the most popular fruits; peel is the main by-product, which represents approximately 30% of the whole fruit [91], and is rich in phytochemical compounds, with high antioxidant capacity such as phenolic compounds (gallocatechin), anthocyanin (delphinidin and cyanidin), carotenoids (β-carotenoids, α-carotenoid and xanthophylls), catecholamines, sterols and triterpenes [92,93]. An incorporation of banana peels at a ratio of 10 % into biscuits did not show significant differences in the overall colour, aroma, and taste, which make it suitable for the production of low calorie food products with high dietary fiber content [94]. Other notable innovations include the reported heavy metals sorption capacity of banana peels in removing chromium (III) [95] and chromium (IV) [96, 97]. Banana peels also can be used to synthesise silver nanoparticles as it is rich in natural polymers such as lignin, hemicellulose and pectin. These bio-inspired silver nanoparticles displayed antimicrobial activity towards pathogenic fungi and most of the tested bacterial cultures [98].

3. Conclusion

During industrial processing of fruits, large quantities of wastes are generated. This has become a serious problem as they exert an influence on environment and need to be managed and/or utilized. Further exploitation of the fruit processing by-products as sources of functional ingredients and possible applications has become a promising field and global requirement due to the increase in the concern towards the environment. Natural functional compounds from fruit processing wastes can be used to replace synthetic additives adding multifunctional concepts by combining health benefits to technological use. Novel scientific and alternative technologies should be used to extract the optimum levels of bio-active compounds as well as other compounds of economic importance from the fruit wastes. The combined effort of waste minimization and sustainable utilization of the by-products would substantially reduce the large quantities of fruit wastes accumulated globally.

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