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HEALTHY AND FUNCTIONAL INGREDIENTS FROM FRUIT PROCESSING BY-PRODUCTS: A REVIEW FOCUSING ON FRUIT PEELS

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ABSTRACT

Fresh and processed fruits represent a large segment in the nutritional and functional food sector and are highly popular among the health-conscious consumers. And the food processing operations are striving to meet that increasing demand for nutritious food products. Consequently, the fast-growing fruit processing businesses across the world have been generating great quantities of waste by-products including peels, pomace, husk, pods, stems and seeds which are usually discarded as waste. Although such fruit waste by-products are rich in nutrients and some functional ingredients, the inappropriate utilization and disposal is creating huge environmental problems. Hence, effective utilization of these by-products is essential. At present small amounts of certain fruit wastes are used as fertilizer or animal feed. However, a better economical and scientific approach to benefit from such waste by-products is to use them as sources of functional and nutritional ingredients. Moreover, the notion of resource optimization from the processing wastes could be a practical step towards achieving sustainable food production systems. This review focuses on the various scientific aspects and potential approaches for the utilization of fruit processing waste by-products, with special reference to fruit peels, in the food and nutraceutical applications.

Keywords: Agro-food waste, processing by-products, bioactive compounds, fruit peels.

1. INTRODUCTION

Domestic and international markets have seen a massive rise in the production, processing and merchandising of fruits due to the mounting acknowledgement of their therapeutic and nutritional potential (Ayala-Zavala et al., 2011). However, such continuous and significant increase in fruit production has been accompanied by rapid generation of huge amounts of waste by-products. For example, tropical fruits like mango, banana, papaya and pineapples are cherished solely for the fleshy tissues (mesocarp), whereas, the skin, seeds and pomes are removed during processing, thus contributing to large amounts of food wastes (Vega-Vega et al., 2013). The traditional disposal of these biodegradable wastes requires high biochemical oxygen demand, and badly affects the ecological, social and economic values. From an environmental perspective, these fruit residues are rich in moisture content together with higher levels of decomposable organic components which make them prone to microbial spoilage, resulting in an unacceptable stink during biodegradation (Wang et al., 2014). Therefore, the continuing removal of these wastes to the atmosphere not only marks the emission of greenhouse gases (GHG), but it also provides a breeding platform for pathogenic bacteria and various pests including mice and

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flies which causes the spread of disease and instigating problems to the society. Additionally, the costs of drying, storage, and shipment of such waste by-products are economically limiting aspects (Dhillon et al., 2013). Moreover, the economic effects can be viewed in terms of costs associated with food wastage, as the amount of the obtained wastes can even surpass the corresponding value produce. To overcome the costs involved and to improve the economics of food processing, further scientific handling of such by-products should be a viable alternative. The productive handling could be employed to isolate and extract some functional and health enhancing ingredients from these waste by-products for utilization by the food and nutraceutical industries (Sun-Waterhouse et al., 2009; Gorinstein et al., 2011).

Therefore, the call for possible recycling of agri-food by-products via novel technologies is continuously increasing (Yusuf, 2017). The common conventional strategies for waste management and minimization include landfilling, incineration, composting and fertilization and in animal feeding. However, the new waste management systems and treatments have attracted greater interest, that are focusing on reutilization and recovery of functional and nutritional constituents such as pectin, polyphenols, carotenoids, flavonoids and fibres (Arvanitoyannis,2008). Therefore, considering the global statutory requirements for waste removal, the European Union introduced a directive named as “Community Strategy for Waste Management”. This concept emphasized a waste hierarchy of reuse, recycle and energy recovery for the prevention and mitigation of food residual waste (Directive, 1999). Since, food wastes in general are produced in various compositions and forms based on their seasonal and regional characteristics, the prospects of recovering sub-products for feed and food requirements differs largely from process to process. For example, the residues coming from fruits are phytochemicals, dietary fibres, food supplements and enzymes which are more likely to be exploited in the manufacture of innovative foodstuffs and for value-addition (Roselló-Soto et al., 2015). On the contrary, the potential wastes of the dairy sector include active proteins, peptides, lactose and fatty substances. Whereas, the resources contributed by meat industry constitute a considerable proportion of functional hydrolysates (Galanakis and Schieber, 2014; Otles et al., 2015). Consequently, a holistic recovery approach was presented by (Galanakis, 2012) which is called as “Universal Recovery Strategy”. This concept involves the identification of waste compositions from a certain source followed by the collection of information regarding its availability, quantity and distribution. Afterwards, the characterization of collected samples at various levels is developed in a coherent manner. These identification and characterization processes allow the recapturing of beneficial compounds from the food waste and pave way towards the expansion of new and innovative products with increased market rate (Rahman et al., 2014). Nevertheless, a better understanding of successful utilization of agri-food waste is essential and latest information in these fields should be effectively disseminated both for scientific and non-scientific communities. Generally, agri-food wastes are rich in nutrients and extra nutritional complexes that are contributing to the gut health, weight management, reducing the blood cholesterol levels and refining the regulation of glycaemic and insulin responses (Bajerska et al., 2016). Some other exciting compounds which can be obtained from herbal wastes are mono-, di- and oligosaccharides, besides nondigestible oligosaccharide. These types of carbohydrates are currently considered as prebiotics. The nondigestible oligosaccharides can reach the colon undigested and undergo fermentation mainly by lactic acid bacteria, thus producing a healthy positive effect for the host (Diaz-Vela et al., 2013). Fruit peels are the major

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wastes by-products belong to the canned fruit and fruit juice processing industries. It is estimated that 20-40% weight of the total fruit is denoted by the peels of fruit (Wanlapa et al., 2015). Hence, there is a huge potential for utilization of fruit peels in recovering valuable and health promoting compounds. This review aims to, (1) describe the major agro-food waste by-products and their possible recycling strategies, (3) overview most significant bioactive compounds in fruit processing wastes, and (3) review the applications of fruit processing waste by-products in food and pharmaceutical industries. As most previous reviews have focused on fruit processing by-products in general, in this review, a special emphasis was given to fruit peels.

2. AGRO-FOOD INDUSTRIAL WASTE AND THEIR ENVIRONMENTAL IMPLICATIONS

Food waste is of a significant concern in the manufacturing industries worldwide. Mirabella et al. (2014) stated that food manufacturing industries in the developed countries are producing 39% of food waste and it is becoming an issue in the developing countries as well. The food waste by-products are generated throughout the food supply chain: initiating from the agriculture phase, up to manufacturing and processing, retailing and household. It has been reported that specific and accurate statistics on food waste quantity are difficult to find or to collect (Monier et al., 2010). However, the best presented estimates constitute a total food loss of around 89Mt, or 179 kg per capita, in 2006. Food wastes can be produced along numerous phases of food supply chain, such as up to 42% losses occur in households, 39% of food waste is produced by the food manufacturing industry, 14% relates to food sector (ready to eat food and restaurants), and 5% is misplaced along the supply chain. The same authors predicted that the amounts of food waste will grow to approximately 126 Mt by 2020 if additional prevention strategies and policies are not commenced (Mirabella et al., 2014). Since ancient times, bio-waste products (e.g., peels, fruits, seeds, slurry, manure etc.) had been added to the soil as fertilizers. Such traditional methods of waste disposal are a universal concern to call for the development of alternate cleaning techniques that can utilize such wastes as renewable bioenergy reservoirs (Okonko et al., 2009). This traditional disposal of food processing waste involves a disbursement of millions of dollars (Okino et al., 2015). For example, the disposal cost of 1 ton of compact waste in Europe is $28-60, including a landfill levy of $10. Even though, landfill is a typical dumping technique, still it is the less efficient means to cope with the inevitable problem of environmental issue. It is also linked with the increased levels of greenhouse gas (GHG) emissions (Roggeveen, 2014). For example, GHG emissions associated with food processing by-products were suggested as third main promoters of environmental pollution behind the total emissions from USA and China (FAO, 2013). The GHG emissions related to food waste in Australia amounts to a total of 57,507 Gg- CO_2 per year, which is about 6% of the total GHG emissions (Reutter et al., 2017). Many current literature reports suggested the use of pyrolysis assembly, which is specifically engineered to allow biomass heating at nominated temperatures, resulting in a product named as Biochar. In contrast to composting and landfilling, Biochar can cause a significant reduction in GHG emanations and can provide potential benefits to soil in terms of nutrient support (Aziz et al.,2015; Azni et al., 2019). Another more efficient way of waste by-products management and recycling is altering these wastes into a favourable source of functional components that could be used because of their promising nutritional and functional attributes. The major target compounds n fruit wastes and by-products are listed in Table 1. They include proteins, polysaccharides, fats, fibres, phytochemicals, flavour compounds, and other bioactive compounds which can benefit the human health and the food industry (Helkar et al., 2016).

3. DEMAND FOR HEALTHY FOODS

In contemporary times, the alterations in life standards has shifted the focus of health-conscious society towards diet and its associated diseases. Key priority is to prevent the complications, particularly some chronic diseases arising from the poor diet which could be prevented following better lifestyle (Goetzke et al., 2014). Besides, exercising the practice of physical movement, enough nutrition is a vital aspect prompting one's health and wellbeing. Consumers' awareness about well-being and general quality of life has boosted the call for natural produces claimed to have nutritional and health benefits. This has provoked the industry and academia towards dietary guidelines as sources of vitamins, particularly vitamins A and C, minerals, and more lately health enhancing phytochemicals (Slavin and Lloyd, 2012). While the importance of fruits and vegetables being sources of nutrients and non-nutritive food ingredients is largely acknowledged, there are still doubts about their significance in the prevention of diseases. Boeing et al. (2012) comprehensively analysed the available literature and evaluated the results of respective studies regarding the effect of diet on various diseases. They concluded that a high daily consumption of fruits and vegetables promote health by preventing the risk of several chronic diseases including obesity, hypertension, type 2 diabetes mellitus, cancer, coronary heart disease (CHD), stroke, chronic inflammatory bowel disease (IBD), asthma, osteoporosis, eye diseases, and dementia. Many clinical studies support the role of the plant phytochemicals as health-promoting food components. For example, Bondonno et al. (2018) investigated the cardio protective effects of apples. Their findings suggested that apple with skin contains high flavonoid contents in comparison to apple flesh only. Moreover, a lower risk of cardiovascular disease was perceived with higher consumption of unpeeled apple and that effect was attributed to apple flavonoids.

4. MAJOR FRUIT PROCESSING WASTE BY-PRODUCTS

Fruits are the most popular natural food items by the reason of their nutritional worth and rich of valuable anti-oxidants, vitamins, minerals and fibres (Rahman et al., 2014). Examples of the substantial amounts of fruits generated worldwide include 124.73 megatons (Mt) of citrus, 74.49Mt of grapes, 84.63 Mt of apples, 114.08 Mt of bananas, 25.43 Mt of pineapples, and 45.22 Mt of mangoes, mangosteens, and guavas (FAO, 2017). The industrial manufacturing of these fruits generates approximately 50% of the original weight as waste by-product in various forms such as pomace, peels, cores, unripe and/ or damaged fruits (Padayachee et al., 2017). Such industrial waste by-products are less likely to be deteriorated as compared to the household food waste. Therefore, sensible use of these by-products can assist in the alleviation of nutritional problems, generation of revenue for the industry and yielding beneficial health effects (Torres-León et al.,2018). Many recent works have been focused on these aspects of waste by-products nutritional, revenue and health benefits utilization (Table 2). Noor et al. (2014) reported that fruit processing waste by-products could be used not only as a good source of bioactive compounds but also as value-added ingredients to some food products. Recently, fruit processing by-

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products from certain fruits including banana, mango and apple have attracted great attention of the scientific community as a result of their significant potential in recovering health and functional components.

4.1 Mango

Mango (Mangifera indica L.) is majorly cultivated in tropical and subtropical parts around the world. Asia is the leading producer of mango (75.6%), followed by America (13.4%) and finally Africa (11%) (FAOSTAT, 2017). An appreciable volume of by-products, such as peels (13-16%) and seeds (9.5–25%), are generated as a result of mango fruit processing (Torres-León et al.,2017). The same authors indicated that mango seed has a very good profile of carbohydrates (58-8-%), essential amino acids with proteins (6-13%), and lipids (6-16%). The physicochemical characteristics associated with mango seed lipids resembles those of cocoa butter (Jahurul et al.,2015). Whereas, mango peel (MP) is a key element of mango processing which accounts for 15-20% of total weight of mango fruit. Mango peel contains total dietary fibre (TDF) in the ranges of28% to 78%, where the soluble dietary fibre represents 13%-28% and insoluble dietary fibre content is 14-50%. Such increased level of dietary fibres in MP places it in the list of important food additives for functional food formulations (Ajila et al., 2008).

4.2 Banana

Mostly, banana (Musa acuminate) is consumed in tropical and subtropical areas of the world. its contribution to the global food import market is 13.1% with a generation of US$ 14,595.1 million per annum (SEICA, 2016). The major by-product comes from banana processing business is the peel, that constitutes approximately 30-40% of the fruit (Babbar et al., 2011). As the fruits of banana are eaten at green and ripe stages, the massive accumulation of these wastes urges the need for the formulation of appropriate strategies for recycling and utilization of these residues. The possible applications of banana peels are determined by the chemical composition of their chemical compounds (Pelissari et al., 2013). Banana peel (BP) comprises high content of dietary fibre principally insoluble dietary fibre (11.04%) and saturated fatty acids which constitutes 40-50% of the fatty acids. In addition, BP is rich in phytochemicals with potential antioxidant properties, essential amino acids and vitamins (Venkateshwaran and Elayaperumal, 2010; Pelissari et al., 2013). The extraction and utilization of these compounds from food wastes contributes to the reduction of environmental pollution and the development of functional and value-added food ingredients (Venkateshwaran and Elayaperumal, 2010).

4.3 Apple

Apple (Malus domestica) is the 4th most commonly cultivated fruit globally (Konarska, 2013). Apple fruit flesh as well as pulp, seeds and peel possess therapeutic properties (Thilakarathna et al., 2013). Studies revealed that apple peel contains more phenolic compounds than the flesh (Bondonno et al., 2018). Moreover, it has high antioxidant and antiproliferative activity (Kalinowska et al., 2014). These phenolic compounds in apple peels play an imperative part as a shield for the indigenous material from insects and pathogenic and spoilage microorganisms. They contribute to the colour and appearance of the fruits as well. Similar to what has been discussed under mango and banana peels, the proper recycling of apple peel can yield excellent functional and healthy phenolic compounds.

5. BIOACTIVE COMPOUNDS IN FRUIT WASTE BY-PRODUCTS

Fruit wastes are excellent reserves of phytochemicals and are studied for the possible extraction of polyphenols, fibres, and other bioactive ingredients (Galanakis, 2012). Effective utilization and recovery of these components leads towards the notion of zero waste. This concept (zero waste) is an efficient approach which allows the valorisation of agro waste materials to valuable products and the detection of newer components with precise roles in human metabolism (Saini et al.,2019). The major bioactive compounds that can be obtained from fruits processing wastes and their characteristics health benefits are discussed in the following sections.

5.1 Phenolic compounds and their health benefits

Phenolics are the phytochemicals which are known to be the principal bioactive compounds in fruits for their health benefits. Phenolic compounds have attracted an appreciable amount of attention because of the public awareness about the direct association between ingested food with high phytochemical content and health (Varzakas et al., 2016). The incorporation of these compounds in diet is a resourceful tool to deter the adverse effects instigated by reactive oxygen species (ROS) in human body. This oxidative pressure, triggered by the ROS, is measured as one of the core causes of some serious illnesses, including cancer, diabetes, cardiovascular and neurodegenerative diseases (Socaci et al., 2017). Fruit peel wastes could be excellent reservoirs of bioactive phenolic compounds that can be utilized to protect against such diseases. Apples are known for their high contents of phenolic compounds with excellent health benefits. There are four most prominent polyphenolic groups in apples such as, flavanols, flavan-3-ols, phenolic acids and dihydrochalcones (Ceymann et al., 2012). The in vitro testing of apple polyphenols showed significant development of glutathione S-transferases, reduction in the generation of H2O2, inhibition against oxidative-induced DNA damage and obstruction of intestinal glucose absorption (Schulze et al., 2014). McCann et al. (2007) revealed the potential of phenolic extracts from apple waste (by-products of juice extraction) to affect numerous colon cancer biomarkers, i.e. colonocyte barrier function, DNA damage and cell cycle progression. Studies on apple peel revealed the scope of this waste in ameliorating and antagonizing the lethal complications of diabetes mellitus (Fathy and Drees, 2015) and acute liver damage (Nie et al.,2015). Similarly, mango peel contains many bioactive compounds, such as phenolics, vitamins, carotenoids and terpenoids. Moreover, syringic, gallic, protocatechuic and ferulic acids are phenolic acids recognized in the bound phenolic segment of mango peel dietary fibre. Among the identified bound flavonoids were kaempferol, quercetin and rutin (Ajila and Rao, 2013). Formerly, it has been found that phenolics from mango peels exhibit antagonistic effects against various degenerative diseases related to oxidative stress (Torres-León et al., 2017). Inhibition of adipogenesis and the anti-cancer properties are some of the health benefits associated with mango polyphenols (Pierson et al., 2015). Mangiferin is the highly documented phenolic compound from mango waste owing to its pharmacological traits such as antiviral and antiproliferative effects (Gold-Smith et al., 2016). It can significantly avert the development of cardiovascular problems that are corelated to nephritis and hyperlipidaemia in diabetes (Pal et al.,2014). Mangiferin has been reported as an efficient neuro protector in relation to its capability to reverse amnesia, probably because of its capacity to obstruct leukotrien and prostaglandins, which are produced by lipoxygenases and cyclooxygenases respectively (Bhatia et al., 2008). Apart from its medicinal properties, there are revelations about its chemotherapeutic and chemo preventive outcomes. Keeping in view the diverse therapeutic applications of mangiferin, both the peel and its extracts could find their use as a potential drug in future (Saha et al., 2016).

Likewise, observations and the identification of health promoting bioactive chemicals such as, dietary fibres, carbohydrates, certain vitamins have been reported in banana peel (Pelissari et al.,2013). The polyphenols and carotenoids from banana peel are considered as of prime importance because of their manifold benefits and certain medicinal attributes such as ant carcinogens and antimutagenic effects. The peel extracts from banana fruit have shown numerous protective effects against several ailments such as oxidation induced haemolysis (Sundaram et al., 2011), hepatic injury (Wang et al., 2016) liver dysfunction (Mosa and Khalil, 2015), and ulceration (Onasanwo et al., 2013). Moreover, some of the recent works on banana peels have find the usage of these by-products in aquaculture, as a feed additive and as a safeguard to certain infections (Rattanavichai and Cheng, 2014; Giri et al., 2016).

5.2 Dietary fibres and their health benefits

Typically, fibres in wheat, rice and corn have been widely used in food processing and in nutraceuticals both for the purpose of their health characteristics and technological functions (Liand Komarek, 2017). Since many years, dietary fibre (DF) has received positive consideration due to its therapeutic properties (Anderson et al., 2009). It has also been used as a food ingredient with specific functions, such as gelling ability, water binding and structure building and as a fat replacer in some food systems (Telrandhe et al., 2012). It is a broad group of indigestible food constituents that includes oligosaccharides, non-starch polysaccharides, alike polysaccharides and lignin with allied health benefits (Raninen et al., 2011). In general, DF is categorized based on its solubility in water, viscosity and bacterial fermentation in the gut. Soluble DFs include polysaccharides, pectin and gums, while insoluble DFs include cellulose, hemicellulose and lignin (Dai and Chau, 2017). The chemical assembly of DF is the determinant of its biological functions. Soluble dietary fibre undertakes microbial degradation in the gastrointestinal tract and influence carbohydrates and fat metabolism, whereas insoluble dietary fibres curtail the gastrointestinal transit time, thus improve gut health. Dietary fibre sourced from fruits shows a higher quality as compared to other sources because of its increased total and soluble fibre contents, good hydration capacities, excellent colonic fermentability, poor phytic acid values and lower caloric contents. Wanlapa et al. (2015) evaluated the chemical composition, functional aspects and virulence of dietary fibres obtained from the skins of seven tropical fruits. All fruit peels presented high content of total dietary fibre (52–84g/100 g dry matter) and showed significant differences in the quality of dietary fibre. The authors suggested that peels of tropical fruits exposed abundant potential to be employed as low-calorie but useful ingredients for the enrichment of dietary fibre. For example, mango peel powder when incorporated into some cereal based products such as, macroni preparation, it exhibited a rise in the total dietary fibre and antioxidant properties of the product. Ajila et al. (2010) suggested that mango peel powder could augment the nutritional and nutraceutical properties of macronies.

Apple peel is a waste product from apple juice industry. The phenolic compounds, dietary fibre, and mineral contents in apple peel are higher than in other edible parts of apple fruits (Henríquez et al., 2010). A study by Leontowicz et al. (2003) examined the dietary fibre content of a whole apple, its peel and its pulp. Interestingly, they found that most of the total fibre was in the peel (0.91% fresh weight). Further, the proportion of insoluble (0.46% FW) to soluble fibre (0.43% FW) was found to be well maintained in the sense of receiving a health benefit. Analysis of mango peel dietary fibre revealed higher percent in the range of 40.6% to 72.5%, where the major sugars in both soluble and insoluble fibres were glucose, galactose and arabinose (Ajila and Rao, 2013). Orange peel has also been known as an excellent source of fibre in addition to antioxidants, sugars, essential oils and a few minerals. Chau and Huang (2003) reported that orange peel contained 57% dry weight (DW) total dietary fibre (47.6% insoluble and 9.41% soluble). Pectic polysaccharides and cellulose were determined as the major constituents of orange peel fibre. The fruit waste by-products, being rich sources of dietary fibres and bioactive elements could be an additional source of income for food processors if utilized properly. Customers expect a natural supplement, free from cytotoxic and synthetic ingredients, which can be sourced from the fruit waste by-products. DF possess several advantageous nutritious and protective effects (Li & Komarek, 2017). The literature from the past two decades has documented several health benefits of DF. Numerous diseases such as obesity, cardiovascular diseases, colon cancer and diabetes could be prevented as a result of beneficial effects of DF. It has been demonstrated that enough intake of DF has lowered the risk of developing stroke, type-2 diabetes and cardiovascular diseases (Ye et al., 2012; Threapleton et al., 2013; Ning et al., 2014). Additionally, adequate intake of fibre is recommended to aid in weight management, mainly through satiety or fullness regulation (Li et al., 2014), and seems to expand immune functions in terms of gut health and fibre-microbiota interactions (Dong et al., 2016). Moreover, the occurrence of civilization-induced diseases has been associated to the inappropriate intake of DF by some epidemiological findings (Nawirska and Kwaśniewska, 2005).

6. PREBIOTIC EFFECTS OF FRUIT PEELS

It is well documented that fruit peels possess appreciable biological activities due to their prebiotic effects in comparison with other fractions of fruits (Ashoush and Gadallah, 2011). Prebiotic is defined as a non-digestible compound that, through its metabolization by microorganisms in the gut, modulates composition and/or activity of the gut microbiota, thus conferring a beneficial physiologic effect on the host (Bindels et al., 2015). Prebiotic dietary fibres are specific, microbiota-shaping compounds that function as a carbon source for the growth of beneficial bacteria, thus delivering a specific change that confers the host health related to its metabolism (Carlson et al., 2018). Over the past 15 years, heaps of information have been collected on prebiotics to understand their active mechanisms and to explicate their advantageous health effects on humans (Anandharaj et al., 2014). Several studies suggested the utilization of fruit peels as prebiotics. Akhtar et al. (2015) explored the potential of pomegranate peel and peel extracts as food preservatives, prebiotics and as food quality enhancers. Similarly, pineapple peel powder and cactus pear peels were assessed as alternate carbon sources throughout bacterial fermentation (Diaz-Vela et al., 2013). Kinetic parameters indicated that both pear and pineapple peel flours were equally suitable carbon sources as they allowed the lactic acid bacteria to grow and to acidify the culture media due to their prebiotic potential. Sayago-

Ayerdi et al. (2019) examined the prebiotic properties of pre-digested mango peel in an authenticated in vitro model. The production of beneficial branched chain fatty acids (BCFA), short chain fatty acids (SCFA)and ammonia profiles were detected in both lumen and dialysates. Manuel (2014) studied the effect of pectin derived from discarded fruits on the growth of health promoting probiotic microorganisms. The results suggested that extracted pectin enhanced the number of Lactobacillus acidophilus and Bifidobacterium bifidum, and the presence of pectin with prebiotic properties supported the endurance of the probiotics in the digestive tract at exciting acidic to alkaline conditions. In another study by Gómez et al. (2014) pectic oligosaccharides (POS) from orange peel wastes were assessed for their prebiotic potential by in vitro colonic fermentation using human faecal inoculum. Microbial populations were assessed by fluorescent in sit hybridization (FISH). Additionally, gas generation, pH, and SCFA production were also measured. Results showed an increase in the number of lactic acid bacteria population, particularly the numbers of bifid bacteria and lactobacilli. The amount of generated SCFA were similar to those observed using fructo-oligosaccharides (FOS). Prebiotic ingredients from fruit peel and by-products clearly have a significant positive effect not only on both probiotic growth and survival in food products but also gut microbiota upon consumption.

The colon is the most highly colonized and metabolically active region of the human GI tract, with up to 1012 cfu/g of gut microbiota (Gibson et al., 2010). The major functions of gut microbiota include, prevention of colonization of potentially pathogenic microorganisms, fermentation of non-digestible carbohydrates to organic acids, and modulation of the immune system. The major nutrient substrates reach the colon for fermentation are non-digestible carbohydrates, (including resistant starch, cellulose, pectin, inulin and oligosaccharides) and residual proteins (Scott et al.,2013). Human alimentary enzymes are unable to degrade complex carbohydrates, these are digested by microbes which generate short-chain fatty acids (SCFAs), such as butyrate, acetate and propionate, which are beneficial to host health (Holscher, 2017). Therefore, inclusion of prebiotics in diet is important for establishing a healthy gut microbiota, and fruit processing by-products including peels with prebiotic potential could contribute to host health.

7. APPLICATION OF FRUIT PEEL DERIVED PRODUCTS IN THE FOOD INDUSTRY

It has been well documented that fruit wastes can be a vital source of micronutrients, vitamins and other phytochemicals that can be utilized in food fortification (Varzakas et al., 2016). These valuable constituents can be extracted by appropriate physical and chemical treatments (Wang and Lai, 2016). Access to these techniques offers a prospect to the finest usage of these explicit components. A study of the literature revealed that the most underlying extraction technologies are mainly solvent extraction (SE), enzymatic hydrolysis, supercritical fluid extraction (SFE), microwave and ultrasound assisted extraction (Kumar et al., 2017). Therefore, biotechnological advancement has led the way towards comprehensive utilization of these constituents in the food and pharmaceutical industries. For example, Göksel Saraç and Dogan (2016) examined the effect of adding dietary fibre concentrates (DFC), sourced from various fruits and vegetable wastes, on bio-functional and sensory aspects of butter. They concluded that incorporation of food waste derived ingredients to butter improved its textural and sensory parameters. As a processing by-product, various fruit peels may contain a variety of active compounds that can turn such wastes into functional ingredients. Thus, introducing peel flours in food formulations could offer viable options for the exploitation of waste both on monetary and practical grounds. Coelho et al. (2017) studied the technological properties of passion fruit peel flours and compared them with five commercial additives. They concluded that the skin of passion fruit is good source of fibre with properties similar to some food additives. The passion fruit peel flour samples were evaluated for their thickening, stabilizing and gelling ability. The flour samples exhibited rich attributes, in ice cream toppings, as thickening and gelling agent. The same results demonstrated

that the commercial hydrocolloids can be replaced by the flour produced from passion fruit peel. In another study by Al-Sahlany and Al-musafer (2018) wheat flour in bread dough was substituted with banana peel flour (BPF). They concluded that BPF could be beneficial for improving the rheological properties and yeast numbers in bead dough. A summary of various recent applications of fruit peel derived products and ingredients in the food systems are presented in Table 3.

8. APPLICATION OF FRUIT PEEL POWDER IN THE PHARMACEUTICAL INDUSTRY

In addition to the significant importance of fruit peels in the food industries, they do also contain important chemical composition and good pharmacological properties (Hassan, 2016). Fruits wastes are rich sources of phytochemicals which can be used for prevention and treatment of various diseases including obesity, type 2-diabetes, cardiovascular disease, cancer and respiratory problems. For example, a study by Tow et al. (2011) examined the total polyphenolic contents of industrial apple waste including apple peel for their ant proliferation effects on human cancer cells. Their results revealed that non-extractable polyphenols (NEPPs) from industrial apple waste could be a good source of antioxidants with significant ant proliferation against human cancer cells.

The pharmaceuticals extracted from some fruits waste by-products can help improving human health, delaying the aging process, preventing chronic diseases, increasing life expectancy, and support the structure or function of the human body (Nasri et al., 2014). Additionally, the medically important ingredients obtained from plant source, in general, are considered excellent because they have fewer or no undesirable side effects (Joshi et al., 2012). However, the application of fruit processing by-products including peels remained mostly less investigated and poorly utilized.

9. CONCLUDING REMARKS

Many scientific patents have addressed the nutritional effects of various bioactive components, especially those related to fruits and vegetables compounds. However, the recent trends among the scientific community and food sector are focusing on the exploration of new and affordable ingredient with health benefits and added values. In this regard, the fruit waste by-products represent a likely solution both in terms of availability and possessing significantly higher levels of multi-functional bio components. Extensive research has shown that fruit processing waste by-products are rich in dietary fibres and important phytochemicals that can contribute to the human health. However, procurement of purified dynamic compounds is somewhat challenging for the food industry as well as for the consumers, since it requires some scaled-up procedures.

Implementation of appropriate management tools and scientific extraction principles could result in a better recycling of fruits waste by-products and improve the social, economic and environmental profits.

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Table 1. Functional ingredients recovered from fruit waste by-products

Fruits	By-product	Functional ingredient	Reference
Pomegranate	Peel	Ellagitannins	(Akhtar *et al*., 2015)
Mango	Seed Peel	Ellagic acid Quercetin, 1,2,3,4,6-penta-O-galloryl-β- D- glucose	(Dorta *et al*., 2014)
Citrus	Peel	Dietary fiber and phenolic compounds	(Rafiq *et al*., 2018)
Apple	Pomace Skin	Total dietary fiber and phloridzin, quercetin, phloretin Proanthocyanidins, flavan-3-ols, flavonols and anthocynins	(Rana *et al*., 2015) (Huber and Rupasinghe, 2009)
Pineapple	Peel, core, crown, stem	Proteolytic enzyme - bromelain	(Umesh *et al*., 2008)
Blueberry	Peel	gallic acid, Epicatechin, catechin, cyanidin 3-glucoside and Chlorogenic acid	(Deng *et al*., 2012)
Avocado	Stone	Cyanidin 3-glucoside, catechin, homogentisic acid, and chlorogenic acid	(Deng *et al*., 2012)
Blackberry, Raspberry	Seed and pomace	Linoleic acid (omega-6) and α-linoleic acid (omega-3)	(Radočaj *et al*., 2014)
Pineapple	Peel	Dietary fibers	
Kiwi fruit	Peel	Vitamin E, α- and δ- tocopherol	(Fiorentino *et al*., 2009)
Passion fruit	Peel	Pectin	(Liew *et al*., 2014)
Grape	Seeds	Phenolic compounds and Flavonoids	(Shan *et al*., 2011)

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Table 2. Recently published reviews on fruit wastes: Food and non-food applications

Contents	References
Overview of methods for determining antioxidant activity and extraction of polyphenolic compounds from fruit residue	(Babbar *et al*., 2011)
Innovative and green extraction technologies for the extraction of biocomponents and enhancement of extraction yield	(Ferrentino *et al*., 2018)
The nutritional and functional properties of pomegranate peel and their application as food additives	(Akhtar *et al*., 2015)
Recovery and recycling of agro industrial waste and their application as nutraceutical and functional components	(Mirabella *et al*., 2014)
Exploration of the nutraceutical assets of bambangan fruit (*Mangifera pajang*) and its by-products based on their health improving phytochemicals	(Jahurul *et al*., 2019)
Highlights on the valorization approach of different agricultural peels	(Anastopoulos and Kyzas, 2014)
Potential use of agricultural wastes as biosorbents for removal of heavy metals from wastewater	(Nguyen *et al*., 2013)
Incorporation of food waste byproducts in various foodstuffs as multifunctional food additives with antioxidant and antimicrobial properties	(Faustino *et al*., 2019)
Recovery of medicinal components from food waste and the prevention of chronic and protracted diseases	(Kumar *et al*., 2017)
An updated summary of alternative adsorbents developed from fruits and vegetables wastes for carcinogenic pollutants removal from waste water	(Patel, 2012)
Extraction and purification of antioxidants from food wastes and their underlying potential regarding health benefits	(Socaci *et al*., 2017)
Potential utilization of generated wastes of fruits and vegetables, their extraction techniques and bioactive compounds	(Sagar *et al*., 2018)
Various dimensions of managing fruit and vegetable pomace in food industry as enrichment materials	(Majerska *et al*., 2019)

Table 3. Recent applications of fruit peel derived products in the food systems

Fruit peel type	**Food Application**	**Highlights/ Contents**	**References**
Peach palm peel	Cake	Increased total carotenoid contents, natural food dye alternative in bread products	(Martinez-Giron *et al*., 2017)
Orange peel	Marmalade	Analytical parameters (stability, antioxidant effect) were maintained	(Sicari *et al*., 2017)
Pomegranate peel	Idli (popular savoury rice cake type in Indian subcontinent	Highest score was recorded for overall acceptability in sensory evaluation	(Fathima and Puraikalan, 2015)
Mosambi (*Citrus limetta*) peel	Papaya jam	Significant increase in firmness and chewiness values of jam	(Younis *et al*., 2015)
Apple peel	High fiber cake	Resistant starch levels increased and lower glycemic index	(Jun *et al*., 2013)
Mango peel	Mango nectar	Mango peel powder beyond 1g decreased the overall acceptability	(Avhad *et al*., 2017)
Avocado peel	Tea formulation	Exhibited good antioxidant activity and good acceptability	(Rotta *et al*., 2016)
Mango peel	Bread	Peel powder induced reduction in the rate of starch digestion	(Chen *et al*., 2019)