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Fruit by-product, significance and their utilization: A review

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Abstract
Fruit by-product is a component of the fruit that can't be eaten because of its unpleasant taste. As a result, researchers and food manufacturers face a significant problem in transforming fruit by-product, which includes a wealth of important bioactive components, into an alternative food source. Recovery of health-beneficial bioactive compounds from fruit wastes is currently a study topic, not only to assist reduce waste, but also to meet the high demand from the public for phenolic compounds, which are thought to have anti-cancer properties. Although the nutritional and techno-functional characteristics of valuable compounds isolated from tropical fruits have been assessed, marketability and customer acceptance are also being investigated, because biorefining is based not only on the process itself, but also on the economic benefits of the final product. This review article provides a brief idea on the importance of fruit byproducts and their utilization with a detailed analysis and utilization of the by-products of some selected fruits.

Keywords: Byproducts, tropical fruits, antioxidant, antiinflammatory, anticancer, dietary fibre

Introduction

Food waste is delivered worldwide for a huge scope at various phases of food creation, handling, promoting and utilization (Bellemare *et al*., 2017) [16]. The measure of food waste age on a worldwide scale lies between 33% to close to half of the complete food delivered around the world (UNFAO, 2016). Notwithstanding, the pace of food misfortune may shift contingent upon the phase of the food waste age. For instance, in the main world nations, food loss of around 220 lb happens per individual every year at the phase of utilization. Subsequently, the absolute food waste delivered overall is practically 1.3 billion tons each year (Bellemare *et al*., 2017) [16] which clarifies that 30%–half of the food delivered internationally gets disposed of. As indicated by the New York Times, United States alone delivers around 60 million metric huge loads of food waste per year worth of nearly $162 billion including organic product waste, vegetable wastes and food wastes (Food waste, 2017). Food wastage not just has an immediate relationship with the monetary crunch yet in addition includes misuse of assets, similar to land, water, and composts utilized for its creation. The food waste delivered end up in the landfills where it disintegrates delivering toxic ozone harming substances like methane. It has been accounted for that 7% of the worldwide ozone harming substance creation happens from such waste (Food waste, 2017). Distinctive food waste medicines like, landfill, treating the soil, burning and feed producing are utilized to debase and decrease the waste. Among the absolute food waste, half is created from natural products, vegetables, and root crops. A large portion of these waste contain bright strips which have a rich substance of various normal colors, high iron/mineral content just as a few associative particles. These properties will work with their utilization in concurrent normal color extraction just as bio adsorbents (Khaskheli *et al.,* 2011; Ahmad and Danish, 2018) [59, 66]. These normal colors have a few advantages over at present utilized artificially incorporated colors, including, biocompatibility, low harmfulness, financial alongside eco-accommodating creation and removal (Kantifedaki *et al.,* 2018; Kaur *et al.,* 2018). A few reports propose the utilization of removed shades from various organic product waste for medical advantages, for model, carotenoids removed from pomegranate strips and tomato skin are utilized as food colorants and have various medical advantages in the type of nutrient A forerunner, skin wellbeing enhancer and helping our safe framework (Goula *et al.,* 2017). Anthocyanin, one more food added substance with medical advantages is utilized in drugs and beauty care products, has been separated from grapes and normal fig (Favre *et al*., 2019).

Strips of Opuntia Stricta (usually known as erect thorny pear) has been viewed as a rich wellspring of betacyanins including betanin and isobetanin (Koubaa *et al*., 2016) [15]. Fruits are consumed primarily for the health benefits associated with their consumption, as well as for their taste and personal preferences. A phytochemical-rich diet has been demonstrated to contain a high concentration of antioxidant molecules, which has various health benefits (Amessis Ouchemoukh *et al*., 2017) [9]. As a result of this information, there has been a huge increase in fruit commerce and acquisition in recent years. Tropical fruit consumption is on the rise on both local and international markets, thanks to growing acknowledgment of its nutritional and medicinal potential (Bhat & Paliyath, 2016) [17]. Fruits are a particularly fascinating possibility for local growers to obtain access to special markets because of their exotic character, high nutrient, and nutraceutical content (R. Alves, de Brito, Rufino, & Sampaio, 2008).

Today, food security is an expanding issue due to the exhaustion of natural resources and increasing population, which has prompted a gap among production and utilization. It is subsequently of most extreme significance that the created raw materials are maximally utilized. From starting farming creation down to definite family utilization, around 1.3 billion tons of food is lost or wasted (around 35%), which produces a carbon impression of 3.3 billion tons of CO2Eq. In modern food waste management, the valorization of side-effects is a method of recovering their important mixtures or potentially growing new items with a market value. (European Comission, 2014; Otles *et al*., 2015) [80]. Thus this review is focused on fruit by-product, significance and their utilization potential.

Significance of fruit by-products

Tropical fruits are described as fruits grown in warm, humid climates between the Tropics of Cancer and Capricorn, with an average temperature of roughly 27 °C. They can be categorised into major, minor, and under used groupings based on the fresh volume requested in marketplaces throughout the world. Tropical fruit production, commerce, and consumption have all increased dramatically, according to FAO (2016a) data (Kathy Elst *et al.*, 2020).

Tropical fruits include a large amount of rind or skin, as well as seed, which are discarded as waste. The durian, mangosteen, and jackfruit all have rinds and seeds that are more than 50% each. Because these fruit wastes have a high moisture content and are high in biodegradable organic elements, they emit an awful stink as they decompose (Wang *et al*., 2014) [108]. Long-term disposal of these wastes into the environment produces greenhouse gas emissions during decomposition (Dhillon *et al*., 2013) [29], as well as providing a breeding ground for bacteria, pests, and mice, all of which contribute to the spread of plague. In recent decades, researchers have focused on recovering health-beneficial molecules and converting them to other usable biomass in order to reduce a waste's environmental impact.

Fruit processing companies create a wide range of natural consumer items, including juice, jams, salads, and snacks, among other things. Despite this, considerable volumes of fruit by-products such as peel, seeds, pomace, bagasse, and other by-products are produced as a result of these processes (Débora *et al.,* 2020). However, these natural matrices still include a significant number of bioactive compounds (BCs) with chemical and nutritional value, primarily pectin, proteins, antioxidants, and phenolic compounds, all of which have health-promoting properties. Furthermore, complex polysaccharides, carbs, fibre, and vitamins are abundant in these by-products. The recovery of these BCs is a difficult and vital work for their reintegration into industrial chains (commercialization); hence, they can be used to meet emerging human demand patterns (Débora *et al*., 2020). Thus, a description of the main fruit by-products generated is required to understand the path that must be followed to reuse such products.

Jackfruit (*Artocarpus heterophyllus*)

Jackfruit is one of the most common non seasonal fruit in South India and it made a significant contribution to the people's and livestock's food supply when there was a shortage of basic food grains (Sim *et al*., 2003) [66]. It's a monoecious tree, meaning it has both male and female inflorescences on the same branch (Bose, 1985). Cross-pollination is used to fertilise the plants, and seeds are used to propagate them. The entire fruit growth process takes three to seven months from the time of pollination, depending on the country (Baliga *et al*., 2011) [65]. Very intense off flavours might emerge as the fruits reach maturity, they must be used as soon as possible. As a result, before the fruit ripens on the tree, it is customary to pick it while it is firm and semi-ripe, and then store it until it softens and is ready for processing (Tiwari and Vidyarthi, 2015) [2].

The mineral content of jackfruit is high (Gunasena *et al*., 1996) [47]. It is high in magnesium, which is necessary for calcium absorption and helps to strengthen bones and prevent bone diseases like osteoporosis. Copper is crucial in thyroid gland metabolism, and iron in jackfruit helps to prevent anaemia and aids in normal blood circulation (Singh *et al*., 1991) [3]. According to Prakash *et al*., (2009) [76] and Rama Rao *et al*., (1973) [4], jackfruit contains compounds such as morin, dihydromorin, cynomacurin, artocarpin, isoartocarpin, cyloartocarpin, artocarpesin, oxydihydroartocarpesin, artocarpetin, norartocarpetin, cycloartinone.

The antifungal effects of jackfruit are also well-known. Trindade *et al*., (2006) [62] discovered jackin, a chitin-binding lectin that inhibits the growth of Fusarium moniliforme and Saccharomyces cerevisiae. Hemagglutination activity was also demonstrated against human and rabbit erythrocytes (Trindade *et al*., 2006) [62]. According to Fernando *et al*., (1991) [63], when studied at oral doses comparable to 20 g/kg, the hot water extract of jackfruit leaves significantly improved glucose tolerance in normal people and diabetic patients. Methanolic extracts of jackfruit stem and root, barks, heartwood, leaves, fruits, and seeds have shown antibacterial action across a wide range of bacteria (Khan *et al*., 2003) [64]. The jackfruit branches have also been found to have nematode-killing efficacy against Rotylenchulus reniformis, Tylenchorhynchus brassicae, Tylenchus flifofmis, and Meloidogyne incognita (Sharma and Trivedi, 1995) [106].

Inhibition of melanin production is another property of jackfruit wood extract. Some prenylated flavone-based polyphenols extracted from jackfruit wood were found to inhibit *in vivo* melanin formation in B16 melanoma cells with little or no cytotoxicity (Arung *et al*., 2007) [33]. The use of jackfruit flesh has expanded in recent years due to all of these various health benefits (Montanez *et al*., 2014). Its antibacterial, antifungal, antidiabetic, anti-inflammatory, and antioxidant properties are well established (Shanmugapriya *et al*., 2011) [55]. One of the key risk factors for the development of coronary heart disease is an increase in the LDL: HDL ratio in the blood (Esmaillzadeh and Azadbakht, 2008) [1]. Tissue injury, protein oxidation, DNA damage, and proinfammatory reactions are all caused by free radicals (Xu and Touyz, 2006) [88]. Antioxidants are chemicals that can slow, stop, or stop the oxidation process (Halliwell, 1997) [12]. They shield the body and biomolecules from the harm caused by excessive free radical production. Jackfruit includes a variety of phytonutrients, including carotenoids, which are antioxidants (Baliga *et al*., 2011) [65]. Jackfruit has useful chemicals that can help with high blood pressure, heart disease, strokes, and bone loss, among other things. It can help improve muscular and nerve function while lowering blood homocysteine levels. Jackfruit is also high in potassium, which helps to lower blood pressure and reverse the effects of sodium, which raises blood pressure and harms the heart and blood vessels. As a result, heart disease, strokes, and bone loss are reduced, and muscle and nerve function are improved (Swami *et al*., 2012) [87]. Vitamin B6 in jackfruit helps to lower homocysteine levels in the blood, which reduces the risk of heart disease (Fernando *et al*., 1991) [63].

Jackfruit seed: Although jackfruit seeds are underutilised and underappreciated, they provide significant nutritional benefits and account for 10% to 15% of the fruit's weight (Hossain, 2014). The seeds are harvested from the ripe fruit in various regions of South India, dried in the sun, and stored suitably for use during the rainy season. Massive numbers of seeds are thrown away each year due to challenges faced during processing and storage. The seeds are normally discarded as waste due to their perishable nature, however they have a one-month shelf life when maintained in a cool, moist environment. The roasted seeds can be powdered and used to add value to a variety of items to increase their shelf life. By combining it with wheat flour and other low-cost flours, jackfruit seed powder is used as an alternative flour in bread and confectionary items (Hossain, 2014). The seeds are consumed by boiling or roasting them in certain parts of India, or they are used to augment potato (Banerjee & Datta, 2015). The rising consumer knowledge of the diet-disease association has increased demand for jackfruit seeds. It's thought to be a powerful functional food element since, in addition to basic nutrition, it provides additional physiological benefits. Protein, fibre, and starch are all abundant in jackfruit seeds. Many minerals, including N, P, K, Ca, Mg, S, Zn, Cu, and others, are abundant in jackfruit (Maurya & Mogra, 2016). The phytonutrients found in seeds, such as lignans, saponins, and isoflavones, are helpful to human health (Noor, 2014). When jackfruit seed flour is added to deep-fried foods, fat absorption is reduced to a certain extent (Butool & Butool, 2015).

Banana (*Musa spp*.)

Bananas are one of the most widely planted crops in practically every tropical country. It is a plentiful and inexpensive agricultural commodity. The major goods made from banana flesh are banana chips and banana figs, which are produced by a variety of small and medium enterprises across the country. Peels are roughly 30-40 g/100 g of fruit weight as industrial by-products (Pangnakorn, 2006) [82].

Banana is a carbohydrate-rich-source, with a content around 12. As a result, many conditions have been attempted to isolate pectin and starch, which are easily isolated under acidic conditions, among other substances. Banana peels are the most common byproduct of the banana industry, accounting for 30 to 38 percent of the biomass. Banana peel has been found to be a promising source of bioactive components for the culinary and pharmaceutical industries. The garbage from banana peels is typically disposed of in municipal landfills, contributing to current environmental issues. However, by exploiting its high-added-value constituents, such as the dietary fibre fraction, which has a lot of potential in the manufacture of functional foods, the problem can be solved (Wanlapa *et al*., 2009). Dietary fibre has been demonstrated to help prevent a variety of ailments, including cardiovascular disease, diverticulosis, constipation, irritable bowel syndrome, colon cancer, and diabetes (Rodriguez *et al*., 2006). Fruit fibre has a higher total and soluble fibre content, water and oil holding capabilities, and colonic fermentability than other fibre sources, as well as a lower phytic acid and caloric value content (Figuerola *et al*., 2005). Banana peel with a high dietary fibre content (approximately 50 g/100 g) is a rich source of dietary fibre (Happi Emaga *et al*., 2007) [35]. Happi Emaga *et al.*, (2008) [35] discovered that banana fruit maturation affects the dietary fibre contents of banana peels.

Furthermore, as various authors have demonstrated, the use of banana peels in bioremediation procedures can be a critical component of the solution for severely polluted wastewater from mines, industries, and municipal landfills. It is highly abundant in Starch (3%), crude protein (6-9%), crude fat (3.8-11%) (Emaga *et al*., 2008) [35], total dietary fibre (43.2-49.7%), polyunsaturated fatty acids, notably linoleic acid and α-linolenic acid, pectin, essential amino acids (leucine, valine, phenylalanine, and threonine), and micronutrients (K, P, Ca, Mg) (Emaga *et al*., 2007) [35]. All essential amino acids, with the exception of lysine, have higher levels than the FAO standard. Fruit maturation is marked by an increase in soluble sugar content (Emaga *et al*., 2008) [35], a decrease in starch and hemicelluloses, and a modest increase in protein and fat content. Increased soluble sugar content could be due to endogenous enzymes degrading starch and hemicelluloses (Mohapatra *et al*., 2010). Banana oil (amyl acetate) can also be extracted from the skins and utilised as a food flavouring (Archibald, 1949) [10]. Lignin (6-12 percent), pectin (10-21 percent), cellulose (7.6-9.6 percent), hemicelluloses (6.4-9.4 percent), and galactouroninc acid are all found in banana peels. Glucose, galactose, arabinose, rhamnose, and xylose are all found in pectin derived from banana peel (Mohapatra *et al*., 2010). Peels contained higher concentrations of micronutrients (Fe and Zn) than pulps (Davey *et al*., 2009) [27]. As a result, peels could be a valuable source of protein for cattle and poultry (Dormond *et al*., 1998) [31]. Banana peel can also be used to make wine ethanol, as a biogas substrate, and as a pectin extraction base material (Faturoti *et al*., 2006) [36] (Gomez *et al*., 1988) [21]. Peel ash can be used as a fertiliser for banana plants and as an alkali source for soap production (Udosen and Enang, 2000) [100]. The ethanol extract of M. *sapientum* peels can be utilised as a mild steel corrosion inhibitor (Eddy and Ebenso, 2008) [34]. Wastewater treatment plants can also benefit from the use of peel (Memon *et al*., 2008) [68].

Avocado (*Persea americana*)

Avocado, one of the most widely traded tropical fruits, is well-known not only for its distinct flavour and texture, but also as a source of health-promoting oils and bioactives. Avocados are also high in vitamins (particularly vitamins E and C), pigments (such as anthocyanins, chlorophylls, and carotenoids), sterols, phenolic compounds, and seven-carbon sugars and their related alcohols. Hurtado-Fernandez, Fernandez-Gutierrez, and Carrasco Pancorbo (2018) [50] (D-mannoheptulose and perseitol). Nonetheless, following industrial processing, 21% to 30% of the fruit is thrown as byproducts. Different beneficial chemicals have been discovered in these leftovers.

In extracts of avocado peels obtained with a mixture of EtOH: Water (1:1, v:v) in an accelerated solvent extraction system, Figueroa, Borrás-Linares, Lozano-Sánchez, and Segura Carretero (2018b) [37] identified 61 compounds belonging to 11 families using liquid chromatography coupled to ultra-high-definition accurate-mass spectrometry. The most commonly discovered compounds were procyanidins, flavonols, hydroxybenzoic, and hydroxycinnamic acids. In a comparable work, the phenolic profile and other polar compounds of avocado pulp, peel, and seed extracted with a mixture of MeOH: Water (80:20, v:v) in a de-fatted sample were compared in extracts obtained with a mixture of MeOH: Water (80:20, v:v). Figueroa, Borrás-Linares, Lozano-Sánchez, and Segura-Carretero studied the phenolic composition of avocado seed and seed coat (2018a) [38]. In total, 84 chemicals from eight different classes were discovered in extracts using rapid solvent extraction with EtOH: water (1:1, v:v) and liquid chromatography with accurate mass detection. Avocado seed and seed coat extracts had substantial antioxidant activity, with the seed coat having much higher antioxidant activity than the seed in all three experiments. After hot-air drying, the phenolic component of avocado seed and peels was reduced by less than 50% on average. Chlorogenic acid was the most abundant phenolic ingredient in the peel, while catechin was the most abundant phenolic compound in the seed (Saavedra *et al*., 2017) [89].

Avocado extracts have been linked to a number of health benefits. According to Athaydes *et al*., (2019) [11], the presence of phenolics in seed extracts is linked to the mitigation of oxidative stress via a decrease in oxidised product levels and an increase in superoxide dismutase enzyme activity, as well as preventing ulcer and indomethacin-induced gastric lesions and histological changes. Similarly, anti-inflammatory and anticancer actions in a cell line for colon cancer (HCT116) and liver cancer (HePG2) were caused by the presence of oleic acid and sterol components in a chloroform/methanol extract of seeds, and this was dose-dependent. Using the DPPH and ABTS techniques, it also demonstrated effective scavenging of free radicals (Alkhalf *et al*., 2018) [8].

Several studies have found that including avocado byproducts in the diet of living organisms has a favourable health effect, which could be due to the presence of bioactive chemicals. As a result, Uchenna, Shori, and Baba (2017a) [99] found that including avocado seeds in rats' diets could affect their feeding and growth performance. It reduced blood cholesterol levels, regulated excessive blood glucose, and increased the rats' ability to store glycogen in their livers. After de-oiling the seeds, the leftovers were used to make edible protein. Avocado protein includes all of the required amino acids in terms of nutrition. Furthermore, as compared to soy protein, the protein had higher water and oil absorption capacities, as well as stronger radical scavenging capacity and poorer *in vitro* digestibility. Furthermore, using avocado protein as an emulsifier resulted in a more stable oil-in-water emulsion system than using soy protein, resulting in improved emulsifying stability (Wang *et al*., 2019) [107].

Avocado residues have demonstrated to have promise in the food and pharmaceutical industries, thanks to their bioactivity, which is linked to a high concentration of phenolic compounds, and nutritional value, which is linked to health-improving fatty acids and sensory features. Furthermore, bioactive chemicals extracted from avocado have been proven to have a beneficial effect against several cancer lines (Kathy Elst *et al.,* 2020).

Mango (*Mangifera indica*)

Mango is one of the most extensively researched tropical fruits. Mango has important and useful nutrients that can be employed in a variety of products, according to Irondi *et al.*, 2014. Overall, mango processing produces a large amount of byproducts, mostly peels and seeds, which account for 7 percent to 24 percent and 45 percent to 85 percent of the total fruit, respectively. The existence of dietary fibre, crude protein, carotenoids, and total soluble phenol content, as well as a high concentration of important chemicals that can create unique nutritional properties, have all been found in these byproducts (Sánchez-Camargo *et al*., 2019) [91].

Mango byproducts, primarily peels, have been studied in attempt to isolate phenolics. After doing an ethanolic extraction, Agatonovic *et al*., 2018 discovered a higher concentration of phenolic chemicals in peel (463 to 2692 mg GAE per 100 g) than in pulp (275 to 1267 mg GAE per 100 g). Furthermore, using high performance thin layer chromatography, the major components were identified as chlorogenic, gallic, and caffeic acids. After utilising acidified methanol as an extraction medium, da Silva Sauthier *et al*., (2019) [26] found and measured other components such as ellagic and gallic acids, rutin, and catechin.

Peel extracts had stronger antioxidant activity than pulp, which was consistent with prior investigations. Parniakov *et al*., 2016 [84] discovered that using a pulsed electric field followed by a supplemental aqueous extraction considerably improves the extraction of phenolics from mango peel (+400%). Pectin, in addition to bioactives, has been a goal in the valorization of mango peels. Guandalini *et al*., 2019 found that a mixture of EtOH: water (50:50; v:v) removed 67 percent of the phenolics present in the mango peel in the first instance, and the remainder was used to extract pectins with ultrasonic assisted extraction. When compared to a reference extraction performed without ultrasound, this approach boosted pectin extraction yield by more than 50% while having no effect on quality, as evaluated by galacturonic acid content and degree of esterification. Mugwagwa and Chimphango (2019) [73] used a stepwise fractionation of mango peels for pectin and anthocyanins in a similar investigation. Anthocyanins were extracted with acidified ethanol, and the residue yielded pectin with a 5.5 percent higher antioxidant activity, a 23 percent higher polygalacturonic acid content, and a 31 percent higher yield (w: w) than conventionally extracted samples. Chen *et al*., (2019) [22] investigated the effects of mango peel powder on starch digesting qualities and bread quality attributes, based on the nutritional value of mango peels. The scientists discovered that adding less than 5% mango peel to the bread did not affect its quality, but it did dramatically reduce starch digestibility.

On the other hand, Mango seed has attracted scientific attention due to its high protein content and presence of bioactive compounds with high antioxidant activity, lipids with acceptable physical and chemical characteristics, and bioactive compounds with high antioxidant activity (Torres-León *et al*., 2016) [98]. The most common method for extracting the oils inherent in the seed is pressure liquid extraction.

The physical and chemical characteristics of the seed oil, which are similar to those of cocoa fat, and the peel's high content of bioactive compounds, which confer the potential to be incorporated as a food ingredient or in the pharmaceutical industry, have led to the conclusion that mango byproducts are a potential source of nutritional food ingredients. The importance of mango as a source of useful chemicals can be deduced from the rising body of scientific evidence on bioactive compound extraction and evaluation (Kathy Elst *et al.*, 2020).

Table 1: Utilization of Fruit By-product

Fruits	References
Jackfruit (Artocarpus heterophyllus)	
▪ Jackfruit seeds flour is used in preparation of bakery products such as bread, biscuits, pasta, cake, instant powder etc. ▪ Perianth of jackfruit is used in preparation of fermented beverage.	Chowdhury *et al*., 2012; Airani, 2007; Tulyathan *et al*., 2002 F. Akter and M. A. Haque
Banana (Musa acuminata)	
▪ Banana peels is used in wine and ethanol production, as substrate for biogas production and as base material for pectin extraction. ▪ Banana peels used for making biscuits. Peels mix biscuits have a pleasant colour, scent, and flavour, making them ideal for making low-calorie foods with a high dietary fibre content.	Wadhwa and Bakshi, 2013; Mohapatra *et al*., 2010; someya et al. Pranav *et al*., 2017; Joshi, 2007 [90] Memon *et al*., 2008 [68] Memon *et al*., 2009 [59]; Bankar *et al*., 2010 Faturoti *et al*., 2006 [36]
Avocado (Persea americana Mill.)	
▪ Avocado peels and seeds can be used in a variety of ways (food, cosmetic, energy and chemical industries). ▪ They are good sources of bioactive substances that can be utilised to make activated carbon, which is effective for adsorption of various pollutants in the environment. ▪ Seeds, which are high in polysaccharides and lipids, are becoming an increasingly important source of energy and biofuel.	Colombo & Pappetti, 2019
Mango (Mangifera indica)	
▪ Mango seed kernel oil is said to be high in polyunsaturated fatty acids like oleic and linoleic acids, both of which have health benefits. ▪ Mango peel powder is also high in antioxidants and is used in a variety of value-added goods. Mango ready-to-eat breakfast cereals and mango dry chutney are examples of mango byproducts that can be used with various technologies. ▪ Soluble dietary fibre binds to cholesterol in the blood and reduces its intestinal absorption, whereas insoluble dietary fibre binds to cholesterol in the blood and reduces its intestinal absorption. Antimicrobial action was found in mango kernels, which are high in flavonoids and tannins.	Dorta *et al*., 2012 Maisuthisakul and Gordon, 2009 Oreopoulou and Tzia, 2007 [78]; Ajila *et al*., 2011 [6] Orijajogun *et al*., 2014 [79] Kittiphoom and Sutasinee, 2013 Ahmed *et al*., 2005
Citrus (Citrus spp.)	
▪ Citrus peel is used in the pharmaceutical, biotechnological, and food industries as a source of molasses, pectin, oil, and limone, as well as natural antioxidants. ▪ Citrus peel, which provides roughly 0.5–3 kg oil per tonne of fruit, is a possible source of certain essential oils. ▪ Orange peel is made up of cellulose, hemicellulose, lignin, pectin, chlorophyll pigments, and essential oils and flavouring chemicals, which are separated into volatile and nonvolatile portions. Germicidal, antioxidant, and anti-carcinogenic effects were also discovered in orange peel. ▪ Lime and lemon peel oils are commonly used to provide scent and cover undesirable medication flavours. As a result, it sells for more per pound than orange, grapefruit, or tangerine oils. ▪ Lemon extracts are utilised as antimicrobial packaging and help mozzarella cheese last longer.	Rafiq *et al*., 2016; Mohapatra *et al*., 2010 Seixas *et al*., 2014; Braddock, 1995; Bocco *et al*., 1998 [19] Khaskheli *et al*., 2011 [59]; Feng *et al*., 2009; Foo and Hameed, 2012 [40]; Garcıa-Perez *et al*., 2008 Pranav *et al*., 2017 Gorinstein *et al*., 2001 [44] Lota *et al*., 2002 Conte *et al*., 2007

Citrus Fruits

Citrus fruits are one of the world's most widely grown fruits, and the citrus sector is the world's second-largest fruit processor. Around 30% of citrus fruits are processed to produce a variety of goods, primarily juice (Izquierdo & Sendra, 2003) [52]. Several fruits are grown throughout the three zones of the tropics, according to Ding (2017), and citrus is one of the most exported. In 2017, global citrus fruit output, including lime, lemons, mandarins, and oranges, was predicted to reach over 88 million tonnes (John *et al*.,2017) [54]. Citrus fruits are classified as acidic fruits because they contain a high level of citric acid, a powerful natural antioxidant. Normally, these fruits are bought fresh from the market or used as industrial goods in juices, marmalades, and flavourings. However, such industrialization generates a significant amount of citrus by-products, most notably peel. More than 10 million tonnes of citrus fruits are predicted to be produced in the European Union alone, with a very low economic value. Citrus peels have been proven to preserve a high concentration of polyphenols such phenolic acids and flavonoids in recent years (Taghizadeh *et al*., 2017) [95]. Citrus byproducts, on the other hand, can be used to extract essential oils, particularly D-limonene, a natural antibacterial with potential use in the food and pharmaceutical industries (Negro *et al*., 2016) [75].

Citrus fruits (Citrus spp.) are typically processed to make juice, which results in a large amount of waste, primarily peel and seeds. Citrus byproducts can make up 60–65 percent of overall weight, with internal tissues accounting for 30–35 percent and seeds contributing for 0–10 percent (Coman *et al*., 2020) [25]. Citrus byproducts contain antioxidants such as ascorbic acid, natural flavonoids (hesperidin, naringin, and narirutin), flavonols (rutin and quercetin), and flavones (diosmin and tangeretin), as well as flavones (diosmin and tangeretin) (Inan *et al*., 2017) [51]. Furthermore, citrus peel is a possible source of dietary fibre and polysaccharides, with far better water and oil-holding capacity and swelling qualities than cellulose. Citrus peel waste has been reported to be an excellent source of essential oils, with D-limonene accounting for 32–98% of total oils, as well as natural antioxidants, ethanol, organic acids, pectic oligosaccharides, and pectin throughout the previous decade (Pacheco *et al*., 2018) [81].

Numerous studies have demonstrated the importance of researching citrus fruit byproducts, which have the potential to be useful in a variety of applications. Phytochemical research found that limonoids are present in the majority of citrus seeds and peels, which account for 10% and 60% of the biomass, respectively (Zou *et al*., 2016) [52].

After feeding Sandhoff disease mice limonoid aglycones derived from Citrus junos seeds, the proportion of beneficial bacteria and their metabolites in their gut flora rose. As a result, the mice's life expectancy was shown to be increased by 10%. (Minamisawa *et al*., 2017) [71]. Ajikumaran *et al*., 2018 [8] found that hydrodistilled essential oils had bioactive and anticancer activities *in vivo* and *in vitro*, despite the reduced extracted yield compared to oils extracted using organic solvents. In another study, Sah *et al*., 2011 [110] found that using the petroleum ether extract of C. medica Linn, they were able to regenerate β-cells in the pancreas and stimulate insulin secretion in diabetic rats.

Citrus fruit peels, on the other hand, are well-known as a source of pectins, which have traditionally been removed for their technical features (Verkempinck *et al*., 2018) [101]. Pectins have also been shown to have immunomodulatory effects on the amounts of cytokine release in the spleens of mice with pro-inflammatory propensity (Merheb *et al*., 2019) [70]. In this regard, many methods for separating pectins from citrus peels have been tested and optimised. With a pH of 1.6, a boiling aqueous HNO3 extraction time of 100 minutes, and a liquid: solid ratio of 36 mL/g, an extraction yield of 25.6 percent was obtained, with galacturonic acid purity of 84.5 percent (Colodel *et al*., 2018) [24]. Güzel and Akpnar (2019) [46] used citric acid as an acidifier in a similar investigation and attained a yield of 11.46 percent. Su *et al*. (2019) [49] used HCl to get a 28 percent extraction yield, which could be enhanced by 17 percent with the addition of non-ionic surfactants.

Pectins are frequently hydrolyzed by enzymes to produce oligosaccharides with putative prebiotic effects (Babbar *et al*., 2016) [14]. After enzymatic hydrolysis of pectins, oligosacharides were produced, which worked as a prebiotic compound for Bifidobacterium bifidum and Lactobacillus acidophilus growth, fermentation, acid tolerance, and survival (Ho *et al*., 2017) [49]. After chemically altering citrus pectins with alkali and acid hydrolysis, the viscosity of the pectins was lowered, and better water dissolving and less strong gels were observed (Fracasso *et al*., 2018) [41].

Conclusion

The by-products developed as a result of the growing global production and consumption of tropical fruits poses a sanitary and environmental problem. There is still a lack of understanding about how to fully valorize tropical fruit by-products using a whole bio-refinery process. However, it is obvious that significant advances are being done, both in academics and in society, toward the full utilisation of tropical fruit by-products, particularly the most traded in terms of productivity and economic importance: mango, jackfruit, citrus fruits, banana and avocado. Developing creative procedures for converting fruit by-products such as seeds (oils, starch and proteins) and peels (fibres) and antioxidants, into value-added products could be a viable way to address this waste problem while also promoting long-term economic growth from a bio-economy standpoint.

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