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Lipid Accumulation Staining

Unleashing the Potential of Fruit Byproducts in Value-Added Foods for Sustainable Nutrition: A Review

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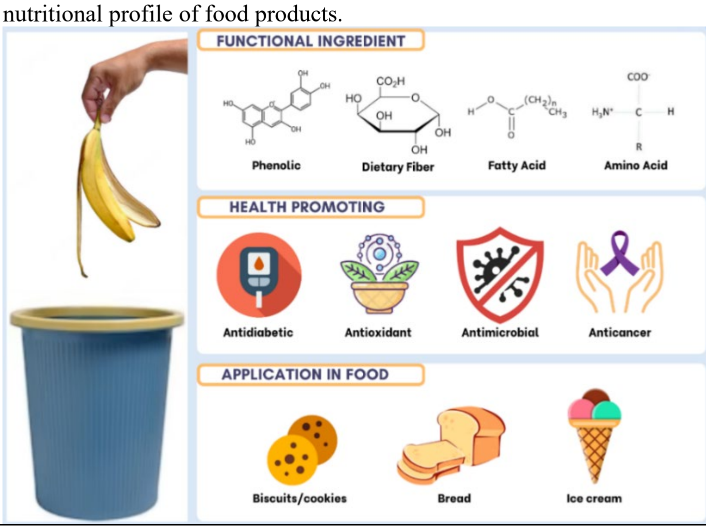
ABSTRACT

The global demand for food continues to increase annually due to the persistent growth of the human population. This rising demand ignites a range of challenges, including resource shortage and the substantial waste generated by the agricultural sector. One significant issue is the incomplete consumption of fruits, where various edible components, such as peels, seeds, and cores, are often discarded, leading to considerable food waste on a global scale. Additionally, agricultural byproducts, including seed coats, husks, pomace, and other plant residues, frequently become underutilized, contributing to environmental degradation. To address these concerns, the efficient valorization of food byproducts, particularly fruit residues, represents a promising strategy for enhancing food system sustainability. Many agricultural byproducts, especially those derived from fruits, are rich in bioactive compounds, including dietary fibres, antioxidants, and micronutrients, which could serve as valuable functional ingredients in the food industry. This review provides an overview of recent advancements in the development of functional foods utilizing various agricultural byproducts, with a particular focus on fruit residues. Furthermore, the review highlights the potential nutritional and functional benefits of incorporating these byproducts into food products, offering a pathway to both reduce waste and improve the nutritional profile of food products.



INTRODUCTION

Post-harvest, processing, distribution, and consumption sectors of the agricultural industry may produce agricultural byproducts that are wasted in significant quantities and may exacerbate food waste issues [1]. Food waste can be accumulated through intentional and unintentional loss. Inadequate farming techniques and poor transportation are examples of unintentional losses, whilst intentional losses are those caused by human eating habits [1]. Not only that, but food waste also comes from the following: a) fresh products that are taken out of the supply chain during sorting procedures because they do not match the base product's ideal size, color, or other criteria; b) food that consumers and stores throw out because it is almost expired, and c) all food produce in home kitchen and restaurants [2,3].

Due to the recent years of the ongoing COVID-19 pandemic and the escalating effects of the climate crisis, food security and nutrition worldwide have declined [2]. According to the Food and Agriculture Organization of the United Nations (FAO) report, approximately 14 percent of the world's food worth $400 billion annually continues to be lost after it is harvested and prior to reaching grocery stores. At the same time, the United Nations Environment Programme's (UNEP) Food Waste Index Report reveals that an additional 17 percent of our food is lost to waste in storage and by consumers [2]. Food loss and waste (FLW) contribute to climate instability and extreme weather events like droughts and floods. Greenhouse gas emissions (GHGs) are also an effect of FLW, which accounts for 8–10% of gas emissions [2].

Agro-industrial byproducts can play important roles even though they are typically used as animal feed, compost, or thrown away. Over the past ten years, numerous studies have demonstrated that these agro-industrial byproducts are sources of bioactive compounds like phenolic compounds, antioxidants, dietary fibre, carotenoids, natural pigments, and protein, among others. Combining these functional ingredients can be used to create novel, nutritious, sustainable and reuseable food [4,5]. Natural bioactive compounds are important because they have the potential to improve health through variety of mechanisms of action including the capacity to interact with proteins, DNA, and other biological molecules, the ability to prevent free-radical-induced oxidation, capacity to change makeup and metabolic activity of intestinal microbiota, and to control serum lipid and glucose levels, among others [6].

Recovering waste from agro-resources processing companies is regarded as being of significant relevance for economic and environmental sustainability, and it presents new prospects for economic development across a variety of sectors [7]. FAO also agrees that, for the transition to sustainable agri-food systems that increase the effective use of natural resources, minimize their impact on the environment, and maintain food security and nutrition, it is crucial to prioritize the reduction of food loss and waste. Therefore, this review summarizes the importance of valorizing fruit byproducts for their bioactive compounds and health-promoting effects for humans. The utilization and application of fruit byproducts in value-added food is also discussed.

Functional Ingredients from Fruit Byproducts

Consumers frequently receive fruits various products, including jams, juices, concentrated food, and pastes. These formulations' manufacturing procedures do not fully utilize the fruit [8]. Thus, vast amounts of fruit byproducts such as peel, seed, shell, hull, husk, stems/stalks, bran, washings, pulp refuse, and press cakes result from the fruit processing industries [9]. Due to the low economic value of these wastes, these byproducts are treated using a few techniques such as burning, fermenting, composting, burying, and even employing them as farm feed. Although these techniques reduce the quantity of waste, they cannot turn it into commercial products [9].

It has been proven that fruit byproducts have biological activities in the presence of active compounds that have been shown to exist and are known as functional ingredients [10]. Acquiring bioactive substances from refuse has financial worth and is significant due to their potential health advantages [11]. Functional substances have consistently evolved. Initially, fortifiers were limited to minerals such as zinc, calcium, iron, and vitamins like vitamin C, E, and folic acid. Later, more specialized micronutrients, including phytosterols, insoluble fibres, and omega-3 fatty acids, were added [11]. The functional ingredients obtained from fruit byproducts are discussed below.

Phenolic Compound

Findings in the literature portrayed that fruit byproducts are rich in functional ingredients [9]. It has been reported that the peel of fruit is a better source of polyphenols than the seeds for six types of fruits [jackfruit, pineapple, papaya, lychee, banana, and mango] [9]. This may be the cause of the peel's increased susceptibility to abiotic stress caused by external factors, including sunshine, UV irradiation, temperature, gas, and insects, which may encourage the synthesis and accumulation of polyphenols [9,12]. In a report comparing two variations of pitahaya peels (*Selenicereus undatus* and *Hylocereus polyrhizus*), it was noted that both types of peels have high flavonoid contents, which are 356.74 and 352.09 mg RE/g sample, respectively [11]. Pineapple byproducts are also one of the studied subjects, where pineapple peel, core, and pomace were tested for their phenolic and flavonoid content, and the results proved that the peels of pineapple had the highest amount of phenolic (5803.21 mg GAE/g dry extract) and flavonoid compounds (9067.09 mg Quercetin/g dry extract), followed by core and pomace [13].

Dietary Fibre

Dietary fibre comprises of plant cell remnants resistant to being digested by human digestive enzymes [hydrolysis]. These remnants include hemicellulose, cellulose, lignin, oligosaccharides, pectins, gums, and waxes. There are soluble and insoluble fibre components of dietary fibre. The insoluble fibre primarily encourages gastrointestinal motility, which enhances laxation. The bulk of insoluble fibre is fermented in the large intestine and promotes the development of probiotic species among the intestinal microbiotas. Blood cholesterol levels can be lowered, and blood sugar can be controlled with soluble fibre [14].

Sugarcane bagasse is one of the underutilized biomasses after juice extraction. Thus, the proximate composition of sugarcane bagasse was studied, and the results showed that this biomass had a high crude fibre content of 57.55% and was mainly high in insoluble dietary fibre [14]. Proximate composition of banana peel was also studied, and the Indian variety of banana peel was found to have a significantly higher percentage of fibre content than the USA variety of banana peel [15]. Other than that, peels from Himalayan pears, such as *Pyrus pashia,* had the best fibre content compared to watermelon and pomegranate peels [16].

Lipid or Fatty Acids
Building blocks of fat, known as fatty acids, are significant in our food and can also be found in agricultural byproducts. Saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) molecules with varied carbons and diverse chain lengths make up the complex variety of fatty acids. These fatty acids play an important role as a source of energy and modulators of physiological functions [11,17]. Long-chain PUFA, such as eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and arachidonic acid (ARA), are the most important acids that provide health benefits at all life stages, including in decreasing the risks of myocardial infarction, diabetes mellitus, and even some types of cancer [17].

The fatty acids are found in dragon fruit peels, and the tested variety of dragon fruit (*Selenicereus undatus*) had a high hexadecanoic acid methyl ester and methyl linoleate content [11]. Another study conducted on grape byproducts, such as grape stems (25.1%) and grape pomace (70.8%), showed methyl linoleate as the main fatty acid methyl ester (FAME) [17]. Apple byproducts, such as apple skin, are rich in polyunsaturated fatty acids, mainly linoleic acid and palmitic acid, which are in the SFA group [18].

Amino Acids
Amino acids are regarded as necessary biomolecules that play a key part as the building blocks of tissue proteins and human health. They are thought to have positive benefits on ailments like infertility, digestive issues, and neurological abnormalities, and could be used as genetic fingerprints to determine the fruit's varietal origin [18]. Apple skin and pomace have essential amino acids such as valine, isoleucine, and leucine [18] that can increase insulin synthesis, stop or even reverse hepatic encephalopathy, and modulate neurotransmission. Mango kernel has higher contents of essential amino acids [isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine] than in apricot and peach kernel, and the most significant is leucine [19]. Peanut shell powder holds a significant amount of essential amino acids, including L-histidine, L-isoleucine, L-leucine, L-lysine, L-methionine, L-phenylalanine, L-threonine, and L-valine [20].

Health-promoting Effects of Fruit Byproducts

Fruits are significant in supplying essential dietary elements for preserving human health. However, a significant portion of the fruits in the form of peel is wasted owing to a lack of knowledge and information regarding the nutritional content of various fruit peels [16]. More bioactive components are found in fruit byproducts than in fruit pulp, and these compounds contribute to good health and the maintenance of overall well-being by, for example, enhancing immunity and treating certain diseases [21].

Dietary fibre from fruit byproducts, for instance, is made up of a variety of non-starch polysaccharides, including pectin, beta glucans, gums, lignin, cellulose, and hemicellulose, which are essential for the treatment and prevention of chronic diseases like cancer, cardiovascular disease, gastrointestinal disorders, obesity, and diabetes as well as for promoting physiological processes like lowering blood triglycerides [22]. In this part of the review, some health-promoting effects of fruit byproducts are discussed, such as antidiabetic effects, antioxidant capacity, antimicrobial and antifungal effects, and anticancer effects.

Antidiabetic Effect
Fruit byproducts with health-promoting properties, such as antidiabetic actions, are greatly desired, especially in treating of chronic degenerative disorders like diabetes mellitus. Alpha-glucosidase and alpha-amylase inhibition can control this illness. In a study by Jimenez-Garcia *et al*. [11], the peel of *H. polyrhizus* had the highest inhibition for alpha amylase (67.78%) and alpha-glucosidase (69.6%). Another study by Panjaitan and Novitasari [23] focused on the ethanolic extract of *H. polyrhizus* to treat diabetic rats for 14 days.

After 14 days, the group of rats that were administered an ethanolic dragon fruit peel extract dose of 74.88 mg/200 g body weight showed a significant decline in blood glucose level. It was also reported that extracts from peel, seed, and other byproducts of mango, jackfruit, pineapple, papaya, lychee, and banana fruit could inhibit the activity of alpha-glucosidase with a dose-dependent property [9]. Byproducts of a local fruit, *Artocarpus odoratissimus,* also known as *Tarap,* showed that the seeds of this fruit had the highest potential for antidiabetic development against the pulp and peel extracts. The seed extract exhibited comparable anti-alpha-glucosidase activity to the positive control, acarbose [24].

Antioxidant Capacity
Another health-promoting effect that can be obtained from fruit byproducts is antioxidant activity, closely related to the total phenolic and flavonoid content in a byproduct. Many studies have tested the antioxidant activities of fruit byproducts using two repetitive tests, $ABTS^+$ and DPPH, where both tests indicate the sample's capacity to eliminate free radicals [9,11-13]. Both *in vitro* assays are recommended when testing for antioxidant activities due to the complexity of plant extracts [9,11]. For instance, *S. undatus* had higher antioxidant capacity in $ABTS^+$ than DPPH. This was due to the nature of the compound in the dragon fruit peel, which had a high amount of flavonoids and fatty acids that contributed to the ability of $ABTS^+$ to capture lipophilic and hydrophilic compounds involved in free radical scavenging [11]. In a similar assay, the DPPH radical scavenging activity of the pineapple peel extract and core was significantly higher than that of the pomace.

Meanwhile, an $ABTS^+$ assay of peel extract exhibited the highest radical scavenging activity, with the core and pomace extracts having the same value [13]. Another underexploited byproduct, the sugarcane bagasse, showed the potential to have an antioxidant activity by presenting a 67,535± 10,44 mmol of trolox equivalent per 100 grams of dried bagasse in $ABTS^+$ testing.

Antimicrobial and Antifungal Activities
Studies in the literature have found several types of fruit peel with the potential for antimicrobial and antifungal activities. In the study by Shah *et al*. [16], Himalayan pear peel was found to have the highest antimicrobial activity towards Gram-positive bacteria, *Staphylococcus aureus,* and antifungal activity against *Aspergillus niger*, among all the fruit byproducts studied. Another peel that demonstrated an antifungal activity against *A. niger* was reported by Naqvi *et al*. [25], where orange peel showed a remarkably high activity.

Moreover, the study also reported that the orange peel had a high antimicrobial activity against *Pseudomonas fluorescens*, moderate antimicrobial activity against *Salmonella choloerasuis*, and the least antimicrobial activity against *Enterobacterogenes*. Another peel that exhibits potential antifungal effects is the jackfruit, where there was a decrease in the mycelial growth of phytopathogens, namely *Penicillium digitatum*, *Geotrichum candidum*, *A. niger*, and *Botrytis cinerea* [26].

Anticancer Effects

Worldwide, cancer is a multifaceted illness that places a financial cost on society. Adults and even fetuses can develop cancer at any age, and the risk for most cancer types rises with age. Toxic substances are used in therapeutic cancer treatment methods. Many chemotherapy drugs have non-specific cytotoxic capabilities that do not distinguish between tumor and normal healthy cells. Therefore, natural sources of anticancer are in demand. Fruit byproducts are one of the potential candidates possessing the ability for anticancer activity [27]. A study by Kamal *et al*. [27] showed that the banana peel extract-treated mice had improvement in hematological parameters by a significant increase in red blood cells (RBCs), white blood cells (WBCs), hemoglobin (Hb), hematocrit (HCT), and mean corpuscular volume (MCV), as it was found that the counts were low when it was cancerous. Carcinoembryonic antigen (CEA) was also found in low amounts in banana peel extract-treated mice. This was attributed to the high amount of antioxidants in banana peel, which minimized the radical damage [27]. The banana peel extract was also studied by Kumar *et al*. [28] against breast cancer cells, where there was a decrease in the cell viability of breast cancer cell line through 3- (4,5-dimethylthiazol-2-yl)-2,5-diphenyl-2H-tetrazolium bromide (MTT) assay and through acridine orange/ethidium bromide (AO/EB) staining. The results showed that the cell lines were in the process of apoptosis after treatment with banana peel extract. Another study by Hendra *et al*. [29] showed that among different extracts of dragon fruit peel, the dichloromethane extract showed potential with weak toxicity towards ovarian cancer cells.

Table 1. Antidiabetic effect of fruit byproducts.

Fruit byproduct	Target	Main findings	Reference
Dragon fruit peel	Alpha-amylase enzyme inhibition Alpha-glucosidase inhibition	Peel of *H. polyrhizus* generated a greater inhibition of the alpha-amylase enzyme (67.78%) compared to *S. undatus* (57.95%). No statistical difference was observed in the inhibition presented for alpha-glucosidase for both *H. polyrhizus* and *S. undatus*, 69.6% and 55.08%, respectively.	Jimenez-Garcia *et al*. [11]
Dragon fruit peel	Rats [*Rattus norvegicus]* induced to a diabetic condition by administration of streptozotocin and nicotinamide	The measurement of blood glucose levels was conducted three times; the initial blood glucose levels or before streptozotocin and nicotinamide (STZ-NA) induction, the 72 hours blood glucose levels after STZ-NA induction, and overall blood glucose levels after 14-days treatments. Initial measurement of blood glucose levels showed that all rats had normal rates; after STZ-NA injection all blood glucose levels spiked; after the treatments for 14 days, the positive and extract-treated group experienced declines.	Panjaitan & Novitasari [23]
Jackfruit, pineapple, papaya, lychee, banana, and mango seeds and peels	Alpha-glucosidase enzyme inhibition	All extracts from peel, seed and other byproducts of mango, jackfruit, pineapple, papaya, lychee, and banana fruits were able to inhibit the activity of alpha-glucosidase, and this activity was dose-dependent, which was promising for antidiabetic benefits. Alpha-glucosidase inhibitory activity of the extracts from different fruit byproducts varied from species to species and cultivar to cultivar.	Islam *et al*. [9]
Marang *[tarap]*	Alpha-glucosidase enzyme inhibition	Extracts from fruit parts of marang contained phenols and flavonoids and were active inhibitors of alpha-glucosidase enzyme. The fruit peel extract of marang was the most potent (IC_{50} = 48.19 µg/mL) compared to the seed extract, pulp extract, and the standard drug acarbose.	Jonatas *et al*. [24]
MD2 pineapple peel, crown, and core	Alpha-glucosidase enzyme inhibition	The percentage of alpha-glucosidase inhibitory activity of MD2 pineapple peel, crown, and core extracted with different ethanol ratios ranged from 23.59% to 73.86%. Detectable IC_{50} values ranged from 92.95 µg/mL to 878.75 µg/mL, with a quercetin standard of 0.99 µg/mL. The 100% ethanol ratio peel extract significantly possessed the highest percentage of alpha-glucosidase inhibitory activity compared to the 50% and 0% ethanol ratio extracts. It possessed the lowest IC_{50} value (92.95 µg/mL), indicating the strongest capability of inhibiting the action of the alpha-glucosidase enzyme. The 100% ethanol was the most capable solvent of extracting the phytochemical constituents responsible for the alpha-glucosidase inhibition of MD2 pineapple peel.	Azizan *et al*. [30]

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Table 3. Antimicrobial and antifungal effects of fruit byproducts.

Fruit Byproduct	Target strains	Main findings	Reference
Watermelon, pomegranate, and Himalayan peer peels	Antibacterial activity against *Escherichia coli* and *S. aureus*	Antibacterial activity of fruit peel extract [FPE] was determined in terms of zone of inhibition (ZOI) of growth of bacterial strains *E. coli* and *S. aureus.* The ZOI (mm) of growth of *E. coli* and *S. aureus* under the influence of fruit peel extracts and standard antibiotics at 10 mg/100 ml concentration was found to be watermelon (11.60 ± 2.15) and (10.50 ± 2.01], pomegranate (6.50 ± 1.12) and (9.03 ± 2.01), and Himalayan pear (5.6 ± 1.15) and (11.6 ± 1.17) mm, respectively. Watermelon FPE was found to be significantly lower than those of standard antimicrobial drugs Erythromycin (ZOI: 30 mm against *E. coli*) and Azithromycin (ZOI: 28 mm against *S. aureus*).	Puraikalan [15]
	Antifungal activity against *A. niger* and *Fusarium oxysporum*	Antifungal activity of FPE was determined by percent inhibition growth (IOG) of fungal strains. Griseofulvin with concentration of 10 mg/100 mL was taken as a standard antifungal drug.	
Orange peels	Antibacterial activity against *Salmonella choloerasuis, Enterobacterogenes, P. fluorescens, Proteus* spp.	Overall, the extract exhibited positive inhibition against the bacterial growth. A high positive response in terms of bacterial growth inhibition was exhibited by all extracts against *P. fluorescens*.	Naqvi *et al*. [25]
	Antifungal activity against *A. niger* and *Histoplasma capsulatum*	Positive inhibition was observed for all extracts. The pea peel extract exhibited a higher positive response against *H. capsulatum*, while orange peel exhibited a higher positive response against *A. niger*.	
Jackfruit pulp	Antifungal activity against *Penicillium digitatum, A. niger, Geotrichum candidum,* and *Botrytis cinerea*	Mycelial growth of the phytopathogens decreased: *P. digitatum* (20% vs. 14%), *G. candidum* (56% vs. 55%), *A. niger* (72% vs. 67%), and *B. cinerea* (100% vs. 100%) for J1 and J2, respectively.	Chavez-Santiago *et al*. [26]
Lemon, mandarin, and orange peels	Antimicrobial activity against *S. aureus, E. coli, Bacillus cereus, Salmonella typhimurium,* and *Pseudomonas aeruginosa*	The highest antimicrobial activity was obtained with the ethanol extract of orange peel against *P. aeruginosa* and *B. cereus* with inhibition zone diameters of 26 mm and 24 mm, respectively. Effectiveness of ethanol extracts can be summarized as orange peel > mandarin peel > lemon peel.	Zaki & Naeem [31]
	Antifungal activity against *Aspergillus niger*	Orange peels had the highest inhibition activity against *A. niger*; however, the inhibition zones of all three ethanolic extracts were low against *A. niger*.	
Citrus limetta Risso peel	Antimicrobial activity against *Escherichia coli*, *P. aeruginosa*, *S. aureus*, and *Salmonella enterica*	Disc diffusion assay observed significant inhibition of bacterial growth in the *Citrus limetta* essential oil treatment (CLEO). Highest activity was observed against *S. aureus* and showed moderate activities against other bacterial strains.	Narayanankutty *et al*. [32]

Table 4. Anticancer activities for fruit byproducts.

Fruit Byproduct	Type of cancer cell	Main findings	Reference
Banana peel	Ehrlich tumor Gamma Radiation induced	Significant increase in hematological parameters of mice as seen by a significant increase in RBCs, WBCs, Hb, HCT and MCV for tumor and irradiation induce mice. Decreased level of CEA for tumor and radiation mice treated with banana peel extract (BPE) Decrease in the level of malondialdehyde (MDA) for tumor and irradiated mice treated with banana peel extract.	Kamal *et al*. [27]
Banana peel	Breast cancer cell line	MTT assays exhibited that, as the concentration of banana peel increased, the absorbance which was related to the cell viability [%] of breast cancer cell line decreased. AO/EG staining showed that the breast cancer cell lines treated with banana peel extract appeared to be in the process of disintegrating with early apoptotic cells (28%) and late apoptotic cells (65%).	Kumar *et al*. [28]
Dragon fruit peel	Ovarian cancer cell line Cervical cancer line [HeLa]	Dichloromethane extract of dragon fruit peel showed a weak toxicity towards ovarian cancer cells.	Hendra *et al*. [29]
Sugarcane bagasse	Human colon cancer line Mouse colon cancer line Human lung cancer line Murine melanoma Human ovarian cancer line Breast cancer line Human pro-monocytic leukemia cell line	Antiproliferative effects in a dose-dependent manner in human colon cancer cell line and mouse colon cancer line. Weak antiproliferative effect noted on human lung cancer cell line. Dose-dependent effect in murine melanoma. Dose-dependent effect in human ovarian cancer cell line. No antiproliferative effect on human breast cancer. Dose-dependent antiproliferative effect in human pro-monocytic leukemia cell line.	Prakash *et al*. [33]
Mango peel	Colon cancer cell line Normal human dermal fibroblasts	Mango peel extract reduced cell viability of all the analyzed colon cancer cells in a dose-dependent manner. No significant cytotoxicity was observed when the mango peel extract was assayed on normal human dermal fibroblasts.	Lauricella *et al*. [34]

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Application of Fruit Byproduct in Food

Food businesses have recently focused heavily on encouraging consumers to maintain a balanced and nutritious diet, as evidenced by the sharp rise in demand for "lightly processed" or "minimally processed" meals [35]. Food waste generated in various industrial processes is being reused or minimized, as well as new food sources, as the food industry works to meet consumer demands for healthier goods [35]. According to estimates, plant-based raw materials like fruits and vegetables account for over 20% of supply chain losses and biowaste [36]. As a result, several scientists are using the fruit peel waste produced by the agricultural industry to create value-added food items that offer supplemental calories and key elements, including protein, lipids, fibre, vitamins, and minerals [36]. Therefore, this part of the review discusses some selected food enriched with fruit byproducts.

Biscuit/ Cookies

Children, adults, and seniors all adore biscuits, a common baked confectionery eaten as a snack in between meals or at any time of the day [37,38]. As functional food and nutraceuticals become more common, new standards are being put on many ready-to-eat meals, including biscuits, mandating that they be both nutrient-dense and healthy [37]. In accordance with this, a study by Weng *et al*. [37] focused on substituting wheat flour with passion fruit peel flour in rates of 0%, 5%, 10%, and 15%. The result showed that incorporating passion fruit peel flour can significantly improve the texture of prepared biscuits but has an adverse effect on the color. In the study by Thliza *et al*. [38], which evaluated the storage properties of biscuits from orange peels and pomace, the biscuit samples containing 10% orange pomace had a higher fibre content than the biscuits containing 10% peel flour. In a similar study by Sangeetha and Kavya [39] on cookies incorporated with orange peel, lemon peel, and pomegranate peel, it was concluded that at certain percent levels, the amount of peel powder can be incorporated into biscuits without adversely affecting the quality attributes.

Breads

The primary sources of carbs in a person's diet are bakery goods. Among these goods, bread is a well-known, essential staple item that is eaten across the world. Most of the breads sold are manufactured with refined wheat flour, which customers find more appealing due to their soft crumbs, crispy crusts, light color, and ease of digestion. However, the loaves' nutritional content leaves much to be desired [40,41]. In a study by Raczyk and Michalowska [40], coconut flour from leftovers of coconut oil or juice production was used as a substitution at 5, 10, 15, 30, and 50% w/w for wheat in bread production. Meanwhile, in a study by Ibrahim *et al*. [41], mango peels and seed kernels were used as a substitute for wheat flour. They showed that the replacement level of 2.5% of mango peel powder and mango seed kernel powder up to 5.0% was the best level accepted by consumers, taking advantage of the active compounds found in both. Honey dew peel powder was incorporated with the bread production in the study by Amiza *et al*. [42], and it was shown that adding this byproduct to bread formulation in a low amount of 3% was acceptable.

Ice Cream

One of the most popular dairy products is ice cream. It is a complex colloidal frozen system that is beneficial to the typical diet for all age groups, especially for kids. This sweet treat is rich in macronutrients like fats and carbs as well as micronutrients like calcium and vitamins [A, D, and E]. However, it lacks natural nutrients and dietary fibre [43,44]. In the study by Hafids *et al*. [43], red dragon fruit peel was studied as a carbohydrate-based fat replacer in low-fat ice cream. Their study showed that the best formulation of low-fat ice cream with the substitution of red dragon fruit peel was found at a treatment of 8%, and there was no significant difference in paired comparison evaluation with the score of 0.20 [similar]. In a similar study, pomegranate peel and doum fruit syrup were used as an enrichment for ice cream [44], where pomegranate peels showed a higher potential than doum fruit syrup. In addition, apple peel was also studied to be incorporated in ice cream to develop low-calorie ice cream by Lazari *et al*. [45].

Table 5. Some applications of fruit byproducts in food.

Product developed	Fruit byproduct	Main findings	Reference
Biscuit	Passion fruit peel	Both types of PFPF showed a higher fat absorption capacity (2.44 g/g (yellow) and 2.38 g/g (purple)). PFPF could significantly improve the texture of the prepared biscuits but showed an adverse effect on the color. Incorporation of PFPF (5%) can produce fibre-rich (TDF, 2.05% and 2.08%) biscuits with a low water content (2.20% and 2.28%), excellent texture characteristics (Firmness, 13.18 N and 15.68 N), and good sensory quality.	Weng *et al*. [37]
	Orange peel and pomace	Orange peel pomace flour was significantly higher in ash and moisture content but lower in fat and carbohydrate contents than the orange peel flour. The biscuit samples containing 10% orange pomace had a higher fibre content than the biscuit containing 10% peel flour. Moisture content of biscuits fluctuated during storage; values ranged between 5.56% and 8.85%. The peroxide values of the biscuits increased slightly after some days of storage.	Thliza *et al*. [38]
	Orange peel Lemon peel Pomegranate peel	Organoleptic evaluation showed 2% level of incorporation of lemon and orange peel powder and 5% level of pomegranate peel powder were acceptable in cookies. Fruit peels improved the nutritional properties of cookies.	Sangeetha & Kavya [39]
	Dragon fruit peel	In sensory evaluation, dragon fruit biscuit 50% (DFB_{50}) showed increased fibre content by about five-fold (7.81 g %), minerals (0.91 g %), and improved spread ratio (8.76) when compared with wheat flour biscuits. Biscuit was enriched with 0.0092 mg % gallic acid with no significant change noticed in protein, fat, calcium, and iron content as from wheat biscuit.	Pawde *et al*. [46]
	Dragon fruit peel	Consumer acceptability of the biscuits showed that those formulated from composite flours of wheat and dragon fruit peel favourably compared to those of wheat flour alone in the sensory attributes tested. DFDF contributed to the production of smaller diameter, lesser thickness, reduced spread ratio, and lower percent spread than the control treatment containing 100 percent wheat flour. Supplementing the preparation of biscuits with DFDF decreased the expenditure of production. WF-DFDF blends could be used as raw materials to produce biscuits.	Cacatian & Guittap [47]

Table 5. Some applications of fruit byproducts in food.-continue

Dietary cookies	Passion fruit peel	Formulations tested had significantly higher mean contents of ash and crude fibre and showed adjusted microbiological standards. Acceptance of the appearance, aroma, and flavour attributes were similar in all formulations. Results showed that the viability of optimized production of alternative flour (30% of passion fruit peel flour) from agro-industrial waste and the potential of the flour as an ingredient for the nutritional enrichment of dietary food.	Garcia *et al*. [48]
	Coconut pomace	Insoluble dietary fibre fraction content on breads was significantly increased by replacing wheat with coconut flour or chestnut flour. Sensory evaluation showed that breads with 30% and 50% coconut flour and chestnut flour did not have a positive effect on the tested parameters. Breads with substitution 5%, 10%, and 15% coconut flour or chestnut flour had improved taste, flavour, and overall acceptability.	Raczyk *et al*. [40]
	Honey dew peel	Honeydew contained 12.13% moisture, 5.89% ash, 2.17% crude fat, 6.86% crude protein, 36.76% crude fibre, and 36.18% carbohydrate. Incorporation of honeydew peel in bread formulation increased crude fibre and moisture content while decreasing the crude protein and carbohydrate content. Yellowness for both the crust and the crumb color increased with increasing honeydew peel powder substitution. Sensory analysis showed that the most acceptable bread was control bread, followed by bread with substitution of 3% honeydew peel powder.	Amiza *et al.* [42]
Bread	Pomegranate peel	A study group of 11 people who consumed bread containing 500 mg of pomegranate peel daily for 8 weeks and control group of 11 people who consumed standard bread. Decreases were detected in the waist circumference, waist/hip and waist/height ratios, body fat percentages, blood pressure, and serum insulin, triglyceride, and total cholesterol levels in individuals in the treatment group, compared to those in the control group.	Akkus *et al*. [49]
	Prickly pear fruit peel	Prickly pear peel was characterized to be high in fibre and carbohydrate contents and an elevated number of polyphenols and betalain compounds. All concentrations, except 50% PPPF, evidenced good leavening dough properties. By the addition of PPPF, the amount of betalains, representing bioactive compounds, remained high even after the baking process, suggesting a protective matrix effect. Breads containing PPPF at 10% showed the highest values in terms of leavening dough capacity and bread specific volume and received the best sensory evaluation score.	Parafati *et al*. [50]
	Orange peel	Orange peel powder significantly altered the wheat dough characteristics and bread quality by adding fibre, pectin, and polyphenol contents. Orange peel improved dough water absorption and increased the development time and decreased the retrogradation degree. Alveograph and rheofermentographic parameters confirmed that OPP improved the total volume of carbon dioxide production but reduced the gas retention coefficient during fermentation accordingly. No remarkable deterioration of the bread staling was observed.	Han *et al*. [51]
Pan bread and cake	Mango peel Mango seed kernel	Chemical composition of MPP revealed that it had higher contents of ash, crude fibres, dietary fibre, and minerals (K, Na, Ca, Mg, and Zn). MKSP showed that it had higher fat, protein, dietary fibres, and minerals contents (K, Ca, Mn, and Zn). Increasing the substitute percent from 0% to 10% increased the dough water absorption and degree of softening. However, the dough stability, resistance to extension, and dough energy gradually decreased. Weight values increased, while volume and specific volume of bread and cake gradually decreased by increasing the substitution level. No significant difference in sensory characteristics between control samples, pan bread samples with substitution levels up to 5.0% of MPP, and 7.5% of MSKP, as well as cake with replacement level of 2.5 and 7.5%, respectively. Pan bread and cake could be enhanced without changing in their physical, staling, and sensory properties with 2.5% of MPP or with MSKP up to 5.0% to take advantage of the active compound found in both.	Ibrahim *et al*. [41]
Low-fat ice cream	Red dragon fruit peel	Best formulation of low-fat ice cream with substitution of super red dragon fruit peel was found at the treatment of 8% with the value of overrun 38,40%, melting time of 16,11 minutes, viscosity of 551,03 cP, color lightness (L^*) of 63,80, red-green chromatic (a^*) of 12,78 and yellow-blue chromatic (b^*) of 19,25, hedonic quality of color of 3,10 (pink), hedonic quality of texture of 4,15 (smooth, non-snowy), and overall acceptance of 4,45. The best formulation of low-fat ice cream with substitution of 8% super red dragon fruit peel was not significantly different on the paired comparison evaluation against commercial ice cream with the score of 0,20 (similar).	Hafids *et al*. [43]
Ice cream enriched with pomegranate peel	Pomegranate peel	Ice cream enriched with pomegranate peel had lower pH value than that in the samples enriched with doum fruit syrup only. The acidity value of ice cream with pomegranate peel was higher than control and with doum fruit syrup. Adding PPP to ice cream led to an increase in the consequently weight per gallon (kg) Pomegranate peel ice cream showed the lowest freezing points among all treatments. Increasing ratio of PPP and DFS decreased the overrun values. The melting rate of PPP enriched ice cream was lower. PPP enriched ice cream decreased the melting resistance. PPP enriched ice cream had higher viscosity. Increasing the levels of PPP and DFS negatively influenced the sensory scores of ice cream.	Ismail *et al*. [44]
Low-calorie ice cream	Apple peel	Three (3) different formulations of ice cream enriched with apple peel were studied. F2 with composition (% w/w): 62.3% apple [peel and pulp), 12.5% of condensed milk, 12.5% of cream, 12.5% of skimmed milk and 0.2% of emulsifier had high sensory acceptance, which were 92.0% for sweetness, 92.2% for flavour, and 84.7% for texture. There was a reduction of 50% in the concentration of condensed milk used, which rendered a product with a reduced caloric content in comparison to other ice creams.	Lazari *et al*. [45]
Ice cream added with essential oil from fruit peels	Lemon peel Tangerine peel Orange peel	Essential oils from these fruit peels had high antibacterial and antifungal properties. Addition of essential oils from fruit peels to ice cream did not impair the sensorial properties; they, instead, improved them.	Tomar & Akarca [52]
Probiotic ice cream	Apple peel Banana peel Mango peel	Using fibres had no significant effects on overrun values; however, viscosity and melting resistance of ice cream samples increased with increasing fibre amounts. Apple, banana, and mango peel powder would act as prebiotics that can improve growth and viability of *Lactobacillus casei* in ice cream during freezing and freeze storage.	Mahdian & Karazhian [53]

CONCLUSION

Fruit byproducts are wastes from the agricultural industry that can be accumulated through intentional and unintentional loss, from post-harvest, processing, distribution, and consumption stages. Some byproducts have been used as animal feed, compost, or thrown away. Many types of fruit byproducts from the food industry have been shown to have high nutritional qualities. Findings in the literature point out that the fruit byproducts are rich sources of bioactive compounds that can be used to create novel, nutritious, and reuseable food. This review illustrates the potential of fruit byproducts as value-added ingredients for food interventions. It can be concluded that fruit byproducts have a high potential for valorization for human consumption.

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