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Utilization of Fruit Peels as Functional Ingredients in Bakery Products: A Review

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Abstract

Food waste has become an important global issue due to its environmental, economic and social impacts. Among food processing by-products, fruit peels are of particular interest because they contain high levels of dietary fiber and bioactive compounds, such as polyphenols, flavonoids, carotenoids and vitamins. These compounds are associated with numerous health benefits and have considerable potential for the development of functional foods. This paper reviews the composition of selected fruit peels and discusses their potential application in bakery products. Recent studies have shown that peel powders and flours can be successfully incorporated into biscuits, cookies, crackers, muffins and bread, improving their nutritional value and antioxidant properties. Although the addition of peel-derived ingredients may affect certain technological and sensory characteristics, appropriate incorporation levels generally ensure acceptable product quality. The use of fruit peels as functional ingredients represents a promising approach to reducing food waste while enhancing the nutritional value of bakery products. Their valorization contributes to the development of sustainable food systems and supports the principles of circular economy.

Subject Areas

Gastronomy, Food Science, Nutrition

Keywords

Food Waste, Bioactive Compounds, Functional Food

1. Introduction

Food loss encompasses the total quantity of food produced that is not ultimately utilized or is discarded throughout various stages of the production process, whereas food waste refers specifically to the share of this loss consisting of food intended for human consumption that is discarded [1].

According to United Nations Environment Programme (2024), approximately 13.2% of food is lost along the supply chain, while an additional 19% is wasted at the retail, food service, and household levels [2].

Food waste represents a major global challenge with significant environmental, economic, and social implications. Its strong connection to natural resource use, environmental sustainability, and food security highlights the urgent need for more efficient food systems and improved waste management practices [3].

In this context, fruit by-products, particularly peels, represent valuable functional ingredients due to their high content of dietary fiber and bioactive compounds. These compounds, including polyphenols and carotenoids, are associated with health benefits and a reduced risk of chronic diseases, highlighting the potential of peels in functional food development [4] [5].

Therefore, this review focuses on the valorization of fruit peels as functional ingredients in bakery products, including biscuits, muffins, crackers and gluten-free formulations.

2. Food Waste Utilization in Functional Food Development

In many countries around the world, increasing attention is being given to improving the nutritional quality of food and promoting healthier eating habits, which has become an important part of public health policies. This growing focus on health preservation and improvement has led to a noticeable expansion of the market for food products that are promoted as beneficial to health or linked to the concept of overall well-being [6].

In this context, the concept of functional foods has gained increasing attention as scientific research continues to improve our understanding of the link between diet and human health [7].

The Functional Food Center (FFC) describes functional foods as a broad category that includes natural foods, processed products, and foods enriched with bioactive compounds. For a product to be classified as functional, these components must be present in safe and effective amounts, and their beneficial effects on human health should be supported by clinical evidence, often verified using specific biomarkers. The concept of functional foods therefore goes beyond simply satisfying hunger, as such foods are intended to provide essential nutrients and biologically active substances that may support health maintenance and contribute to physiological functions beyond basic nutrition [8].

There has been increasing interest in foods rich in dietary fiber and antioxidants. As a result, the market for products and ingredients containing these compounds has expanded significantly. The intake of dietary fiber and phytochemicals, such as polyphenols, carotenoids, tocopherols and ascorbic acid, has been associated with beneficial health outcomes and a lower risk of certain chronic diseases in observational and experimental studies. Fruit by-products are important sources of these bioactive compounds. They contain phenolic substances such as anthocyanins and flavonoids, as well as carotenoids and other phytochemicals. These compounds exhibit antioxidant and bioactive properties that have been investigated for their potential role in reducing oxidative stress and supporting health. Some studies have suggested possible associations with reduced risk of certain chronic and neurodegenerative diseases. However, direct clinical evidence remains limited [5] [9]. For this reason, fruit by-products have considerable potential for use in the enrichment of existing food products, as well as in the development of new food formulations [10]. Fruit processing by-products represent a valuable source of bioactive compounds and offer significant potential for the development of low-cost functional foods [11]. In the context of this review, fruit peels are considered functional ingredients because they provide dietary fiber, phenolic compounds and other bioactive constituents that can improve the nutritional and technological properties of bakery products. However, the presence of these compounds could not be interpreted as direct evidence of specific health benefits, which require confirmation of well-designed human clinical studies.

3. Food Peels as Sources of Bioactive Compounds

Although rich in valuable compounds, banana peels and other plant residues are traditionally discarded or composted in most parts of the world, except in some producing regions in Asia and Latin America. However, banana peel is a valuable source of bioactive compounds, including anthocyanins (delphinidin), cyanidins, β-carotene, gallocatechin, and vitamins A, C, and E [12]. Additionally, it contains high levels of dietary fiber, particularly hemicellulose and pectin polysaccharides [13]. According to Borges *et al.* [14], banana peel contains higher levels of phenolic compounds and minerals than the pulp. Such a composition likely contributes to its reported bioactive properties, supporting its traditional use in wound healing (especially burns) as well as in the prevention or mitigation of certain conditions, including depression [12].

Similarly, citrus peels represent the primary by-product of citrus fruit processing and are rich in dietary fibers (cellulose, hemicellulose, and pectin), as well as bioactive compounds such as phenolics, flavonoids, carotenoids, and vitamin C [12]. In line with this, Yaqoob *et al.* [15] reported that kinnow peel contains a diverse range of bioactive compounds, including anthocyanins, limonoids, phenolic acids, flavones, flavan-3-ols, flavanones. Other studies further highlight citrus peels as promising sources of pectin. β-carotene, naringin, hesperidin, neohesperidin. Overall, citrus peels have attracted considerable attention due to their high content of essential oils, primarily composed of volatile compounds, particularly oxygenated derivatives, including aldehydes (e.g., citral), alcohols, and esters, as well as terpenes (e.g., limonene) [16] [17]. For instance, tangerines grown in Madeira are characterized by a particularly intense and distinctive aroma, mainly attributed to high levels of volatile bioactive compounds in their peels, such as thymol and dimethyl anthranilate [18].

Passion fruit peel accounts for approximately 52% of the total fruit weight and is characterized by a high content of fiber [19], pectin [20], and phenolic compounds, predominantly isoorientin, along with lower levels of other flavonoids such as vicenin, isovitexin, vitexin, orientin, and schaftoside. It has also been identified as an excellent source of essential minerals, particularly potassium (K) and calcium (Ca) [21]. The incorporation of orange passion fruit peel flour into food products (e.g., bread, cakes, biscuits, and cereal bars) has been shown to enhance their nutritional value by increasing the content of dietary fiber, minerals, and bioactive compounds [22].

Mango peel has attracted considerable attention due to its high content of bioactive compounds, including polyphenols, carotenoids, enzymes, and dietary fiber, highlighting its potential for value-added food applications. Nevertheless, it is predominantly produced as by-product of mango processing (e.g., pulp and amchur production) and it remains largely underutilized, often treated as waste, which represents both an environmental burden and a missed opportunity for sustainable use. In addition to its bioactive components, mango peel is rich source of vitamins C and E, as well as minerals such as K, Ca, Mg, Fe, Na Mn, Cu and Zn [23]. It additionally contains pectins and anthocyanins [24] and has been shown to possess higher concentration of polyphenols than mango pulp [23]. Mango peel contains a wide range of phytochemicals, including fatty and phenolic acids, mangiferin, xanthones, benzophenone derivates and procyanidins as well as compounds such as methyl gallate, penta-O-galloyl-glucoside, tetra-O-galloyl-glucoside, maclurin di-O-galloyl glucoside and isoquercitrin [25].

Pineapple is a widely appreciated tropical fruit due to its nutritional and organoleptic properties. However, the rapid growth of the pineapple market in recent years has led to the generation of large amounts of by-products, mainly peel and core, which pose economic and environmental challenges [26]. Pineapple peel contains carbohydrates, proteins, bromelain, pectin and phenolic compounds, including catechin, epicatechin, gallic acid and ferulic acid. acid [27].

The chemical components in pear peel are present at levels approximately 6 - 20 times higher than in the flesh. Among the monomeric compounds, arbutin, oleanolic acid, ursolic acid, chlorogenic acid, epicatechin, and rutin are predominant in both peel and flesh across different cultivars. Overall, these findings indicate that pear peel represents an excellent source of polyphenols and triterpenes [28].

Apple peel is generated as a by-product during the manufacture of dried apple products and contains higher levels of phenolic compounds, dietary fiber, and minerals compared to other edible parts of the fruit. Apple peel powder (APP) is therefore considered a valuable source of polyphenols and flavonoids, particularly quercetin, with demonstrated antioxidant and antiproliferative properties [29]. Moreover, its high dietary fiber content may contribute to metabolic health by slowing carbohydrate absorption and reducing postprandial blood glucose spikes, thereby offering protective effects against metabolic syndrome and type 2 diabetes

[30] [31].

Peel Powders in Bakery Products

The bakery industry represents a major segment of the global food sector. Among bakery products, biscuits and cookies are particularly popular due to their convenience, ready-to-eat nature, and extended shelf life [32]. Recent studies have explored the use of flour produced from fruit peels in biscuit formulations as partial replacements for wheat flour, aiming to improve nutritional value and promote sustainable resource utilization [33]. However, careful evaluation of the nutritional composition and functional characteristics of fruit peels is required to support their effective incorporation into biscuit formulations while maintaining product quality [34].

Prickly pear peel accounts for approximately half of the fruit weight and is generally discarded, contributing to environmental concerns. However, due to its high content of bioactive compounds, it represents a promising raw material for nutraceutical and functional food applications, particularly in bakery products.

A study by Parafati *et al.* [33] investigated the incorporation of prickly pear peel flour (PPPF) and evaluated its use as functional ingredient in bread formulations. Bread formulations containing up to 20% PPPF showed satisfactory leavening properties, while the 10% substitution level resulted in the highest dough expansion, specific colume and sensory scores. In addition, a considerable proportion of bioactive compounds was retained after baking, demonstrating the potential of PPPF for the development of nutritionally enhanced bakery products.

Banana peels represent a significant source of agro-industrial waste generated during consumption and processing. A study by Pomasa *et al.* [35] investigated the feasibility of incorporating ripe banana peel powder (RBP) into gluten-free corn flour cookies as a functional ingredient. Cookies were formulated with increasing levels of RBP substitution (0 - 12%), with formulations containing up to 9% RBP showing acceptable sensory properties. The selected formulation (9% RBP) exhibited improved nutritional and functional characteristics, including higher dietary fiber and total phenolic content, as well as enhanced antioxidant activity (DPPH and ABTS assays), compared to the control. Structural analysis (SEM) indicated a more compact matrix in RBP-enriched cookies, while storability tests revealed lower peroxide values and maintained hardness. Overall, the incorporation of RBP improved the nutritional profile and shelf stability of gluten-free cookies, highlighting the potential of banana peel as a value-added ingredient. Future research should focus on clinical and epidemiological studies to evaluate the health effects of such products and explore their application in other functional bakery formulations.

A study by Mala *et al.* (2024) [36] highlights the potential of pineapple peel powder (PP) as a functional ingredient in the production of nutritionally enhanced and sensory-acceptable crackers. The incorporation of PP significantly increased dietary fiber, total phenolic (TPC) and flavonoid content (TFC), as well as antioxidant capacity (AOC), while also affecting physical properties such as increased expansion and weight loss, and reduced hardness and lightness compared to the control. Crackers containing up to 10% PP were sensorially acceptable, with this formulation showing marked increases in TPC, TFC, and antioxidant activity (DPPH and FRAP). HPLC analysis identified key phenolic compounds, including ferulic acid, vanillic acid, quercetin and sinapic acid. Overall, these findings demonstrate that PP can be effectively utilized to develop functional bakery products while contributing to the sustainable valorization of pineapple processing waste. However, further in vivo studies are needed to confirm the associated health benefits.

The study by Ramya *et al.* (2020) [37] aimed to develop high-fiber cookies by incorporating jackfruit rind flour (JRF) into wheat flour formulations and to evaluate their physical, chemical, and sensory properties. JRF was added at substitution levels of 5%, 10%, and 15%. The incorporation of JRF significantly affected cookie characteristics, leading to increased fiber content and darker color, along with a reduced spread ratio compared to the control. Sensory evaluation indicated that cookies containing 5% JRF achieved the highest overall acceptability. These findings suggest that JRF can be effectively utilized as a functional ingredient to enhance the nutritional value of bakery products, with potential for commercial application and contribution to improved health and sustainability.

The study by Oladunjoye *et al.* (2025) [38] investigated the quality attributes of cookies produced from sorghum flour incorporated with hog plum (*Spondias mombin* L.) peel (HPP) at levels of 0 - 20%. The inclusion of HPP significantly improved functional properties, including bulk density, water and oil absorption capacity, and solubility index, while increasing fat and dietary fiber content and reducing protein levels. Additionally, HPP incorporation enhanced total phenolic content and antioxidant capacity, while affecting physical characteristics such as increased weight, thickness, and hardness, alongside reduced diameter and spread ratio. Microstructural analysis (SEM) revealed a denser and more irregular structure with HPP addition. Cookies containing 10% HPP showed the highest sensory acceptability, and microbial analysis indicated improved shelf stability. Overall, the results suggest that hog plum peel can be effectively utilized as a functional ingredient in gluten-free bakery products, contributing to improved nutritional quality and potential benefits for individuals with coeliac and other autoimmune conditions.

The peel powder can alter the biscuits' surface, texture, and rheological characteristics [39]. Furthermore, Topkaya and Işık (2019) [40] examined the effects of incorporating pomegranate peel into muffin formulations on their physical, nutritional, and chemical characteristics. The inclusion of pomegranate peel powder at levels of 5%, 10%, and 15% led to an increase in batter viscosity and significantly enhanced total phenolic content, mineral composition (Ca, Mg, and K) as well as both insoluble and total dietary fiber. In a related study, Hasnaoui (2022) [41] identified 10% pomegranate peel powder as the optimal inclusion level for improving the sensory quality of muffins. This level contributed positively to overall acceptability and taste while having no adverse effect on color. Additionally, the use of pomegranate peel extract improved the aroma profile of the muffins by masking the undesirable egg odor observed in the control samples.

Overall, the reviewed studies showed similar effects of peel incorporation across different bakery products. Peel-derived ingredients generally increased dietary fiber, phenolic compounds and antioxidant activity. Peel addition affected several technological properties. Changes were observed in texture, color, hardness and dough behavior. The extent of these changes depended on the type of peel and the level incorporation. Despite these modifications, most formulations maintained acceptable sensory quality. The best results were generally obtained at moderate incorporation levels.

4. Limitations

Despite their promising nutritional and functional properties, several limitations should be considered when evaluating the use of fruit peels in bakery products. The bioavailability of many bioactive compounds after consumption remains insufficiently understood and requires further investigation.

In addition, the composition of peels may vary depending on factors such as cultivar, maturity stage, growing conditions and processing methods.

Technological treatments, including drying, milling and baking may also affect the stability and retention of bioactive compounds.

Furthermore, safety aspects such as pesticide residues, environmental contaminants and microbial quality should be carefully assessed before the large-scale use of peel-derived ingredients.

Future studies should address these limitations to support the safe and effective application of fruit peels in functional food development.

5. Conclusions

Fruit peels represent an abundant and underutilized source of dietary fiber, phenolic compounds, flavonoids, and other bioactive substances with significant potential for application in functional bakery products. Their incorporation has shown significant potential for improving nutritional value and antioxidant capacity. Studies have demonstrated successful applications of peel-derived flours and powders from prickly pear [33], banana [35], jackfruit [37], hog plum [38], and pomegranate [40] in biscuits, cookies, crackers, muffins, and bread products.

Peel incorporation can affect texture, color, hardness, and other technological properties. However, appropriate substitution levels generally preserve sensory quality and consumer acceptability. While many studies reported favorable nutritional, technological, and sensory acceptance at incorporation levels of approximately 5% - 10%, the optimal substitution level remains dependent on the characteristics of the peel and the specific bakery product formulations.

The use of fruit peels supports food waste valorization and contributes to a circular economy. Therefore, peel-derived ingredients represent a promising sustainable approach for the development of functional bakery products.

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Conflicts of Interest

The authors declare no conflicts of interest.

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