Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2023-s1-073

Review Article

Open Access

Banana Peels as Bioactive Ingredients: A Systematic Review of Nutritional and Pharmacological Attributes

Fathima Ashka, Praveen Kumar Dubey* and Sourabh Kumar*

Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab, India

***Correspondence to:**
Praveen Kumar Dubey
Department of Food Technology and Nutrition,
Lovely Professional University,
Phagwara, Punjab, India.
Email: praveenfpe@gmail.com

Sourabh Kumar
Department of Food Technology and Nutrition,
Lovely Professional University,
Phagwara, Punjab, India.
Email: sourabhkumarkec@rediffmail.com

Received: October 12, 2023
Accepted: November 10, 2023
Published: November 15, 2023

Citation: Ashka F, Dubey PK, Kumar S. 2023. Banana Peels as Bioactive Ingredients: A Systematic Review of Nutritional and Pharmacological Attributes. *J Food Chem Nanotechnol* 9(S1): S577-S587.

Published by United Scientific Group

Abstract

Banana (*Musa* sp.) is a globally prevalent food crop, yielding a substantial quantity annually. The peel, which makes up about one-third of the fruit's weight, is a wasted byproduct. This waste, which is often ignored, has drawn attention due to the increasing focus on using agricultural byproducts as functional ingredients. Despite this, banana peels exhibit strong antibacterial, antioxidant, and phenolic qualities, containing flavanols, rutin, quercetin, and catechin. Historically, these versatile peels have served various purposes as both food and medicine across different regions. Beyond this historical context lies unrealized potential to transform banana peels into nutritious meals. This in-depth analysis examines the inherent bioactive substances in banana peels and offers insights into the nutritional profiles of different banana varieties. A systematic examination reveals pharmacological activities linked to these compounds, uncovering anti-inflammatory, antioxidant, antimicrobial, and anticancer properties. The exploration extends to potential applications in various industries, including food, agriculture, and medicine. Within the food industry, banana peels emerge as a versatile ingredient for crafting nutrient-rich functional foods, enhancing flavors, and fortifying nutritional supplements. Their use is not limited to food; it also enters the pharmaceutical, cosmetic, and value-added food industries. These future applications not only promise sustainability but also economically feasible environmentally conscious practices. This analysis views banana peels as economically valuable commodities, focusing attention on their commercial application. Investigating strategies for utilizing banana peels to generate revenue while adhering to sustainable practices is essential. The synthesis of nutritional value, bioactivity, and commercial feasibility underscores the need for thorough exploration of banana peels' potential.

Keywords

Banana peel, Antimicrobial, Antioxidants, Bioactive compounds, Waste utilization, Value-added products

Introduction

Banana cultivation stands out as one of the initial instances of widespread crop production by humans across the globe [1]. They include several hybrids of the genus Musa and are members of the Musaceae family. The genus Musa is divided into four categories: Eumusa, Rhodochlamys, Australimusa, and Callimusa. Eumusa has the widest geographic distribution, followed by Australimusa [2]. The other two parts don't produce any eatable fruit [3]. It is a large herbaceous plant belonging to the Musa genus that yields a lengthy, consumable fruit referred to as a berry [4].

All over the world cultivates bananas, which are believed to have their origins in the tropical regions of southern Asia [5]. This plant family is also found

in India, and papua new guinea [6]. About 15% of all fruit produced worldwide is bananas, second only to citrus [7]. This fruit is widely favored and makes up 16.8% of the total global fruit production, with apples and oranges closely followed at 11.4% each. Asia produces the most bananas, followed by Africa and the Americas. Oceania and Europe have the lowest production, accounting for just 0.3% of global production [5]. India is the top producer of bananas globally, with a 27% share of production [8]. India is the world's largest banana producer, with 722,000 hectares of planted area and an annual production of 26.51 million tons. The country produces 102 million tons of fresh bananas every year [5]. Over the years, the global production of bananas has grown. Figure 1 shows the production of bananas in the world from 2010 to 2022 [9].

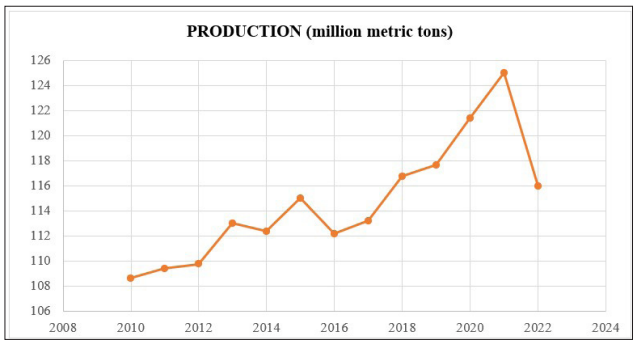

Figure 1: Banana global production in years.

Bananas are unique in that the fruit, pulp, peel, seed, leaves, blooms, and bark are all edible [8]. The banana fruit can be divided into two primary parts: the peel and the pulp. The peel, which is considered a byproduct of bananas, makes up about 40% of the fruit's weight. The banana peel exemplifies a prevalent form of fruit waste that is thrown away rather than consumed or repurposed caused by its unpleasant flavor [4]. About 35% - 40% of the weight of the entire fruit is comprised of the peel [5]. It is a protective outer layer (a peel or skin) with several long strings between the skin and the edible inner part of the fruit. The fruit's husk or skin is referred to as "banana peel" in British English. It makes up around 40% of the fruit's weight. Peels are used as food for animals, to manufacture a range of biochemical products, and to filter water. The usage of banana peels can also introduce new products to a variety of residential and industrial applications. Research shows that banana peel powder has the potential as a functional food source. According to Vu et al. [10], roughly 36 million tons of banana peel are produced each year, and this is a material with high nutrition and potential for future use.

The banana peel contains a high number of phenols, which are important secondary metabolites compared to other fruits. Besides it provides significant amounts of dietary fiber and antioxidants. Banana peel is the best source of both soluble and insoluble dietary fiber. The powerhouse of minerals, bioactive substances, and dietary fiber is banana peel. Protein, dietary fiber, potassium, essential fatty acids, polyunsaturated fatty acids, amino acids, and antioxidants such as polyphenols, catecholamines, and carotenoids are among the nutrients and chemicals found in the banana peel [5].

Due to high dietary fiber and phenolic compounds, peels provide numerous health benefits [5]. Fruit fiber has a higher quality than other fiber sources due to its high total and soluble fiber content, ability to retain water and oil, fermentability in the intestine, low phytic acid level, and caloric value [4]. Dietary fiber is a protective agent against some diseases like cardiovascular diseases, diverticulosis, constipation, colon cancer, other types of cancer and diabetes. Peel is a rich source of dietary fiber, containing approximately 50 g/100 g. The banana peel has been traditionally used in medicine to treat burns, anemia, ulcers, inflammation, diabetes, coughs, snakebites, and heavy menstruation due to its nutrient-rich properties. It promotes strong, healthy bones and aids digestion and depression [5]. However, most of the banana peel is disposed of alongside other debris or in landfills, contributing to the already present environmental issues [2].

Banana peels are often thrown away without treatment, but they can be used as organic fertilizer or animal feed due to their high fiber content and low tannin levels. The production of banana peels annually exceeds 36 million tons, causing bad environmental impact and incurring expenses [2]. Every day, fruit markets and households produce several tons of banana peel waste, which is subjected to anaerobic digestion and results in an unpleasant smell. The biomass emits gases that upset the air's delicate balance naturally. Although ripe bananas are eaten whole, considerable amounts of bananas are industrially processed into products like banana flour, chips, bakery items, and other processed foods, creating a significant amount of banana peel waste. In the past, firms involved in food manufacturing disposed of banana peels in landfills. By utilizing its high-added-value elements, such as dietary fiber, the issue can be resolved. If banana peels could be turned into a useful product, the agricultural sector would profit financially. The rapid growth of the global population and the increasing preference for utilizing valuable and environmentally sustainable agricultural remnants provide a solid foundation for ongoing innovation in the utilization of leftover bananas and waste materials. Peels contain bioactive components that can provide health and are commonly used in bakery, gourmet, and meat dishes [2].

Interestingly, this exploration reveals a new way of looking at banana peels, which have usually been seen as leftover material in agriculture. Recent research shows that banana peels, making up about 40% of the fruit's weight, are not just thrown away; they have a lot of nutritional value. This opens new possibilities for sustainable farming and better use of resources. Focusing on environmental sustainability, this review explores innovative ways to use banana peels, moving away from the old idea that they are just waste. The inclusion of recent research, like the potential use of banana peel powder as a functional food source, shows how our understanding of leftover agricultural materials is changing. This simpler perspective not only sees banana peels as valuable for making money but also encourages thinking about the environment. As this review goes on, it aims to show not just the nutrition and medical possibilities of banana peels but also to encourage researchers and industries to find new, sustainable ways to use this resource that is often ignored.

There is multiple literature that focuses on the phys-

iochemical characteristics, traditional uses, and applications of banana peel or powder as food and medicine. This review describes the current uses for this byproduct while proposing direction for future research on banana peel. This review is intended to increase our knowledge of the potential uses for banana peel and to disseminate information on the nutritional importance and pharmacological activity of peel. The focus was made on the active components, driving their biological effects and investigates their potential applications in the food, pharmaceutical, and other sectors. By highlighting the chemical composition and versatile nature of banana peels, this review aims to influence researchers and industries to explore sustainable and economically viable applications for banana peels.

Nutritional composition of banana peels

Bananas are a type of fruit that is known for their high nutritional value [5]. The four main varieties of bananas are *Musa sapientum*, *Musa paradisiaca* L., *Musa cavendishii*, and *Musa acuminata* [8]. The organic composition of banana peels, such as lipids, carbohydrates, protein, and fiber, contains several bioactive substances with diverse functions [2, 11]. Peel contains a higher concentration of micronutrients than pulp [8]. According to Pyar and Peh [12], peels are very perishable due to the high proportion of water in their composition. A peel's freshness and shelf life are determined by its moisture level. High moisture content can cause microbial decomposition, degradation, and a short shelf life. Banana peels are a rich source of essential amino acids, micronutrients, dietary fiber, lipids, pectin, and fat [2]. Peel contains a high amount of protein. Animals and humans both depend on banana peel in their diets to survive by supplying enough of the essential amino acids. As it is rich in nutrients peel can be used for various purposes. The nutritional compositions of banana peel varieties are summarized in table 1 and their composition percentages are shown in figure 2.

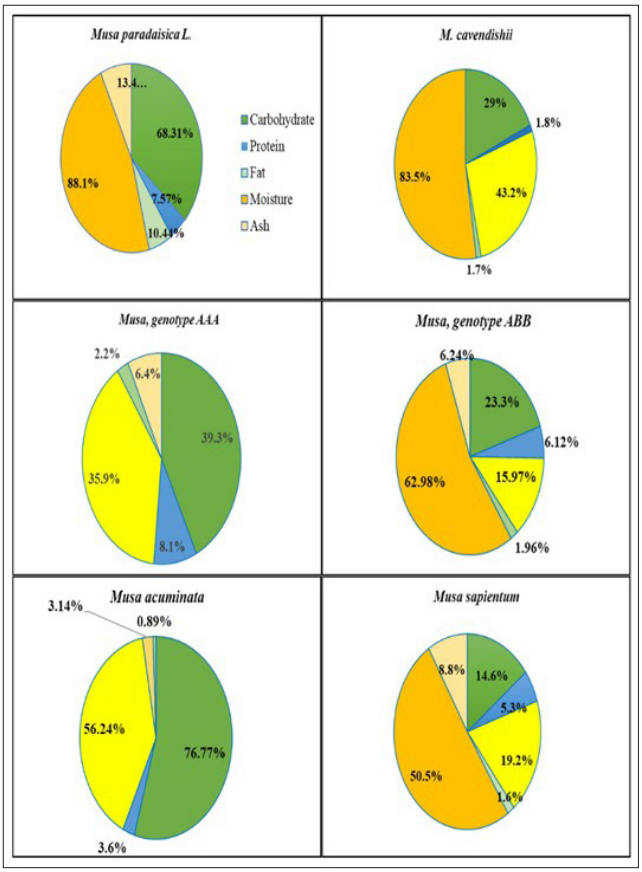

Figure 2: Nutritional composition of different varieties of banana peel in percentage.

Utilization of banana peel in food products

The peel of banana is crucial raw material used in several applications as it is rich in fiber and includes a variety of nutritious components [4]. The banana peels organic composition contains lipids, fiber, carbohydrates, and protein. It's a major source of bioactive substances with various functions [2]. Generally, the major components of proximate analysis for sampling food, including fruit, are protein, carbohydrate, fat, moisture content, and ash content. There are many varieties of food products using banana peel due to its nutritional quality. Pasha et al. [17] investigated whether wheat flour can be replaced with banana peel powder (BPP) for salty noodle production. Supplementation rates of 5%, 10%, and 15% were tested. According to the findings, the flour blend containing 15% BPP had higher levels of protein, ash, and crude fiber compared to the control. Dom et al. [18] prepared yoghurt enriched with phenolic compounds extracted from banana peels. Lee et al. [19] created an antioxidant-packed jam using the banana peel, a common leftover product and then assessed its physicochemical and antioxidant characteristics to confirm the preservation of its antioxidant properties during the jelly-making process. Ahmed et al. [20] prepared cake using peel to increase the nutritive quality. The goal of this research was to emphasize the antibacterial and antioxidant content of peel powder to show its nutritional benefits. Furthermore, it can be used as a cost-effective alternative to wheat flour when making a cake. Kurhade et al. [21] prepared chapatti with high quality. The study assessed the effect of banana peel powder

Table 1: Nutrient composition of different varieties of banana peel.

Banana peel variety	Carbohydrate (%)	Protein (%)	Fibre (%)	Fat (%)	Moisture (%)	Ash (%)	Ref.
M. sapientum	14.6	5.3	19.2	1.6	50.5	8.8	[12]
M. paradaisica L.	68.31	7.57	-	10.44	88.1	13.42	[13]
M. cavendishii	29	1.8	43.2	1.7	83.5	-	[8]
M. acuminata	76.77	3.6	56.24	0.89	-	3.14	[14]
Musa, genotype ABB	23.3	6.12	15.97	1.96	62.98	6.24	[15]
Musa, genotype AAA	39.3	8.1	35.9	2.2	-	6.4	[16]

(BPP) on chapatti's nutritional components, texture, and quality. The stickiness, rollability, strength, and kneading ability of the dough of chapatti dough made from 5, 10, 15, and 20% BPP were tested in the research. Banana peel waste is turned into banana peel flour and used in bread and pasta for human consumption to provide nutrients that may help reduce the amount of this kind of waste and boost nutritional levels [22]. Products using banana peel flour and their physiochemical properties are listed in table 2 given below and products are illustrated in figure 3.

Extraction of bioactive compounds in banana peel

Bananas have a higher antioxidant capacity due to their bioactive components than many berries, herbs, and vegetables [27]. Banana peels are rich in a variety of beneficial substances, including phenolic and carotenoids. They have a significant direct and indirect impact on human health as well as a wide range of therapeutic properties. The therapeutic properties of bioactive components, such as their anti-inflammatory, antibacterial, antioxidant, and anticancer properties, as well as their capacity to fend off numerous chronic diseases, make them significant [5]. The primary phytochemicals found in fruits and vegetable peels that are associated with human health are phenolics and carotenoids [23]. The phenolics, carotenoids, flavonoids, and biogenic amines are all present in the banana peel as shown in figure 4.

Phenolic compound

The dispersion of phenolic, the most noticeable secondary metabolite in plants, can be seen throughout the metabolic process [28]. These phenolic chemicals, or polyphenols, include simple flavonoids, phenolic acids, complex flavonoids, and vivid anthocyanin. It has been established that flavonoids, one of the most studied families of phenolic compounds, ex-

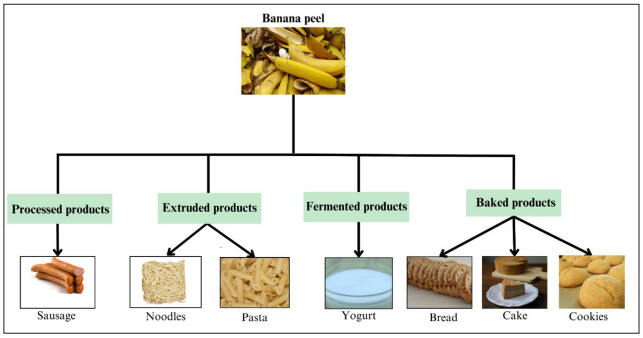

Figure 3: Food products using banana peel flour.

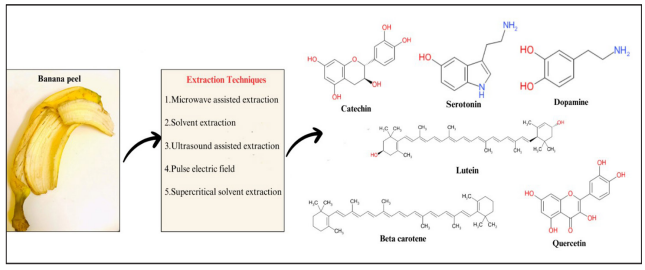

Figure 4: Bioactive compounds from banana peel.

Table 2: Food products using banana peel flour.

Type of banana peel flour	Product	Proximate analysis of banana peel or flour								Ref.
		Protein (%)	Carbohydrate (%)	Fat (%)	Moisture (%)	Ash (%)	Fibre (%)	Antioxidants (%)	Phenolic compound (mg GAE/100 g)	
Ripened bananas *(M. acuminata)*	Noodles	8.82	-	4.52	6.36	22.1	11.2	39.77	581.44 (mg GAE/100 g)	[17]
Banana (*M. paradisaica*)	Muffins	7.76	9.8	-	4.5	8.86	10.93	-	-	[23]
Saba banana	Functional food	6.48	-	1.81	9.04	3.04	-	3649.25 (mg/100 g)	4592.00 (mg GAE/100 g)	[18]
Fully ripe banana (*M. acuminata*)	Yoghurt	7.57	-	1.2	13.37	11.84	19.45	79.07	53.80 (mg GAE/gDM)	[24]
Bananas in the yellow-green stage from the Philippines	Jam	5.5	76.58	2.24	3.31	13.22	55.46	-	-	[19]
Fully ripe bananas (*M. cavendish*)	Cake	9.86	76.63	1.58	10.94	0.89	-	846.58 (mg/100 g)	-	[20]
	Chapathi	7.58	77.4	2.09	1.77	11.1	53.8	-	-	[21]
Green bananas (*M. cavendishii*)	Gluten-free cake	11.16	81.44	-	2.83	1.22	-	-	-	[25]
M. acuminata - Berangan banana	Chicken sausage	8.6	59.41	4.08	8.81	8.54	39.04	-	-	[51]
M. balbisiana - Saba banana	Chicken sausage	4.85	56.68	7.06	11.11	9	44.03	-	-	[51]
M. cavendish	Bread and pasta	6.41	57.13	10.22	3.56	11.86	14.38	-	-	[22]
M. balbisiana	Pasta	7.52	70	9.04	2.21	2.33	8.89	-	40.3 (mg GAE /100 g)	[26]

hibit significant biological features such as antioxidant, antibacterial, antimutagenic, cytotoxic, and anticancer activities [5]. According to Vu et al. [5], banana peels contain more than 40 distinct phenolic substances. Numerous phenolic substances, including catecholamines, flavanones, flavanols, and tocopherols, have been found in banana peels. Catecholamines, flavan-3-ols, flavanols, and hydroxycinnamic acids are the four main groups. The dominant flavanols found in banana peels are rutin and its conjugate. The prominent phenolic compounds in peels are flavan-3-ols, such as monomers, dimers, and polymers (tannin) [4].

Carotnoids

Carotenoids are pigments with antioxidant properties that benefit the human body. Plants use carotenoids like lycopene, alpha-carotene, and beta-carotene to absorb light. Most carotenoids are accumulated in the liver and released into the bloodstream as lipoproteins. The banana peel contains important carotenoids, including lutein, alpha and beta-carotene. Lutein is a yellow pigment belonging to the xanthophyll family. By preventing cellular dysfunction and oxidative stress through the mechanism of reactive oxygen species production, which is typically associated with a compound's antioxidant potential, dietary carotenoids can reduce ageing-related diseases [4]. Some of the bioactive compounds from the banana peel are listed in table 3.

Pharmacological activity of banana peel

As an antioxidant

Antioxidants are substances that remove free radicals from the body. One of the best sources of antioxidants is banana peel. Utilizing a variety of antioxidant tests, banana peel extracts were discovered to have a significant antioxidant capacity [10]. Extracts from banana peels can be utilized in food products as a natural preservative to enhance the quality and shelf life of the food due to their powerful antioxidant and antibacterial properties Various types of dishes have been effectively enhanced with the use of banana peel extracts [36]. Antioxidants in our diet can reduce oxidative stress and scavenge free radicals, potentially preventing certain diseases and aiding existing treatments. Dietary antioxidants are therefore a potential substitute for synthetic antioxidants, whose usage is closely controlled due to the potential health hazards they provide. They can also prevent food from oxidation. Compared to other fruits, phenolic compounds are significant secondary metabolites that are abundant in banana peels. The banana peel is rich in a range of phenolic compounds, such as gallic acid, catechin, epicatechin, tannins, and anthocyanins [2]. Banana peel has five times more gallocatechin than pulp, indicating that peel is a main source of the antioxidant molecule. Dopamine, ferulic acid, and caffeic acid are only a few examples of the individual phenolic chemicals in banana peel that have powerful antioxidant properties. Dopamine in

Table 3: Bioactive compounds from banana peel and its extraction method.

Bioactive compounds	Extraction	Variety of banana	Findings	Ref.
Phenolic compound and antioxidant	Microwave-assisted extraction	*M. cavendish*	At 30 °C, time 5 min and power 150 W, phenolic compounds yield increased by 23.49 mg, 39.46 mg of flavonoids, and 13.11 mg of proanthocyanidins in 1 g of banana (M. cavendish) peel.	[10]
Phenolic compound	Capillary zone electrophoresis	Yellow banana and red banana peel	Red banana peel extract had greater biological value than yellow banana peel extract in terms of antioxidant activity, antibacterial action, and cytotoxic activity on tumour cells.	[29]
Antioxidant	Solvent extraction method	Xiem banana	At 60% solvent concentration, 68 °C temperature and 48 min time, TPC and TFC were identified as 62.41 mg GAE/g and 6.98 mg QE/g respectively.	[30]
Phenolic compound	Solid-phase extraction	(Musa AAA) Cavendish	The total phenolic compound identified is 29.2 mg GAE/g.	[31]
Antioxidant	Solid-phase extraction	(Musa AAA) Cavendish	The antioxidant activity was identified as 14 M/g (FRAP); 242 M/g (ABTS) and in ORAC assay about 436 M/g. Banana peel flour is probably responsible for the extremely high antioxidant activity.	[31]
Flavanols: Rutin	Solvent extraction	Red yade (AAB)	The value of rutin was identified as 482 ± 206 µg/g DM.	[32]
Flavanols: Laricitrin-3-rutinoside	Solvent extraction	Cavendish (AAA)	The quantity of flavanol in cavendish-type banana peel is identified as 2.22 µg/g DM.	[32]
Carotenoid	Solvent extraction and HPLC	Dwarf cavendish variety	Three solvents (ethanol, ethyl acetate, and methanol) were employed to extract the banana peel. The best solvent was ethyl acetate. The best reading in this solvent for light absorption was 2.204 for ethyl acetate.	[33]
Phenolic compound and antioxidant	Pulse electric field	Kepok banana (*M. paradisiaca*. L)	The Kepok banana peel's best antioxidant activity was identified as 13.086 mg/ml at 4 kv/cm for 4 min.	[34]
Dopamine	Solvent extraction	*M. acuminata* Colla AAA	Methanol-produced extracts contain the most dopamine. The amount of dopamine dramatically increased when the extraction period was extended from 1 to 120 min (at 25 °C).	[35]
Catechin	Liquid-solid extraction	(*M. paradisiaca* L.)	The amounts of total phenolic, flavonoid, and tannin were found in the methanolic extract (80%) as 17.89, 21.04, and 24.21 mg/g DW, respectively. 30.21 µg/g amount of catechin present in banana peel.	[13]
Quercetin	Liquid-solid extraction	(*M. paradisiaca* L.)	Amount of quercetin identified as 78.62 µg/g.	[13]

peel was discovered to have a greater ability to scavenge free radicals than glutathione, BHT, luteolin, or quercetin. And it has similar efficacy to gallocatechin gallate and ascorbic acid and outperforms catechin in terms of radical scavenging [5]. According to a study by Vu et al. [5], the antioxidant capacity of banana peel increased as the fruit ripened and decreased as it grew overripe. Instead of chlorophyll and carotenoids, phenolic components relate to characteristics. For that reason, the maturity stage must be considered based on its intended application. The antioxidant capacity of banana peel extracts and fractions is assessed through a series of multi-mechanistic antioxidant tests. These tests are crucial in determining the effectiveness of the chemical components present in banana peel extracts in neutralizing harmful free radicals [2, 37]. Vu et al. [5] reported banana peel's physicochemical and antioxidant qualities alter dramatically as it ripens through the various stages. The effects of ethylene treatment on the peel's physicochemical and antioxidant alterations are thought to affect how quickly fruit ripens. Chlorophyll was destroyed by almost 90% as the fruit's color changed from green to yellow. Carotenoids and flavonoids experienced an approximate increase of 50% and 27%, respectively. As the fruit ripened, phenolic and proanthocyanin levels as well as antioxidant capability likewise rise [38].

As an antimicrobial agent

Herbal remedies have frequently been employed to treat a wide range of infectious diseases. These remedies primarily originate from various parts of plants, including leaves, flowers, fruits, and stems. To develop innovative antimicrobial compounds that can effectively combat multidrug-resistant microorganisms, banana peel extracts may be employed to create new chemical structures and mechanisms of action [2]. Banana peels, both the yellow and green varieties, have been the subject of numerous research. These peels showed strong antibacterial properties against several microorganisms, including *Staphylococcus aureus* (19.75 mm), *Bacillus subtilis* (20.60%), *Pseudomonas aeruginosa* (19.57 mm) and *Escherichia coli* (18.15 mm). Inhibition zones against alcoholic extract of peels of the bananas were 15 mm for *Porphyromonas gingivalis* and 12 mm for *Aggregatibacter actinomycetemcomitans*, respectively. As a negative control, 70% isopropyl alcohol caused *P. gingivalis* and *A. actinomycetemcomitans* to exhibit inhibitory zones of 8 and 10 mm, respectively. As a result, this finding indicated that *P. gingivalis* and *A. actinomycetemcomitans* were resistant to the antibacterial effects of the alcoholic extract of banana peel [39].

At a dosage of 300 mg/mL, the methanolic extract from *M. acuminata* peel displayed varying levels of inhibition against *E. coli* (ATCC 25922), *Lactobacillus casei*, *Bacillus* sp., *S. aureus* (ATCC 25923), *P. aeruginosa*, and *Saccharomyces cerevisiae* [40]. The ethanol extracts of the plant varieties *M. acuminata* cv. Grand nain showed a variety of antibacterial activity against the investigated microbes, with *Salmonella paratyphi* and *Proteus vulgaris* [2]. The three examined bacteria (*E. coli, S. aureus*, and *P. aeruginosa*) have shown some antibiotic activity in the presence of tannins [13]. Chabuck et al. [41] reported that the banana peel's aqueous extract has varied antibacterial activity. These findings demonstrated that this extract provides good gram-positive bacteria, such as *Streptococcus pyogenes* and *S. aureus*, are inhibited with inhibition zones of 30 and 18 mm, respectively, however, *Candida albicans* is not affected. Banana peel extract has an inhibitory impact on gram-negative bacteria, with an inhibition zone extending from 10 to 30 mm. *Moraxella catarrhalis* is most susceptible, followed by *Klebsiella pneumoniae* and *Enterobacter aerogenes*, apart from *E. coli*, which showed no susceptibility to the extract.

Anticancer agent

Despite significant advances in cancer treatment and research over the past few decades, the disease continues to rank second in the world in terms of morbidity and mortality. Recent data indicates that 23% of all deaths in the USA occur from cancer. Even though there are several therapeutic methods for treating cancer, they all depend on hazardous substances. The cytotoxicity is quite high. Most chemotherapy drugs lack specificity, making it impossible to distinguish between healthy cells and tumor cells. This has resulted in inappropriate and toxic therapeutic agents with a variety of side effects, lowering the maximum tolerated doses and the lowest effective doses of chemotherapy. Some fruit peels can act as anticancer agents, especially banana peels. The most dangerous substance against human colon cancer cells was a banana peel extract made from hexane solvent, which showed a 64.02% reduction in cell multiplication [42].

Ruangtong et al. [43] produced green synthetic ZnO nanorods and nanosheets by using zinc acetate and banana peel (*M. sapientum*) crude extract. ZnO nanosheets made by green synthesis have reportedly been used to develop antibacterial and anticancer medications. Durgadevi et al. [44] identified the antioxidant and anti-tumor properties of the aqueous methanol extract obtained from nendran banana peel, which is a promising source of bioactive substances for combatting cancer. The research revealed that this extract possesses substantial cytotoxic effects on MCF-7 breast cancer cells, which is valuable information in the fight against cancer. According to a study by Phacharapiyangkul et al. [45], Ferulic acid in sucrier banana peel may facilitate melanogenesis by regulating vascular endothelium growth factor expression, starting nitric oxide synthase, and acting as a tumor suppressor gene.

Antidiabetic

Chronic hyperglycemia and changes in the metabolism of carbohydrates, proteins, and lipids are features of the metabolic condition diabetes mellitus, which is brought on by deficiencies in insulin production, insulin action, or both. Type 1 (insulin-dependent diabetes mellitus) and Type 2 (noninsulin-dependent diabetes mellitus) are the main types of diabetes [46]. Banana flowers, leaves, pseudostems, roots, stalks, and peels were discovered to have an anti-diabetic effect. The peel of the banana can be used as a natural source of diabetic-friendly food, medicine, or other substances. The diabetic drug lupenone was initially extracted from banana peel [47]. It is a potential complementary treatment for type 2 diabetes. Since herbal remedies have long been the best form of medicine, they are now a growing component of modern, high-tech medicine. Banana peels were shown to have significant quantities of catecholamines, dopamine and L-dopa which have

strong antioxidant properties to prevent diabetes. Flavonoid is an antioxidant found in peel. Flavonoids have a crucial function in managing blood sugar levels and preventing diabetic complications [48]. The pharmacological activity of the peel of the banana is summarized in figure 5.

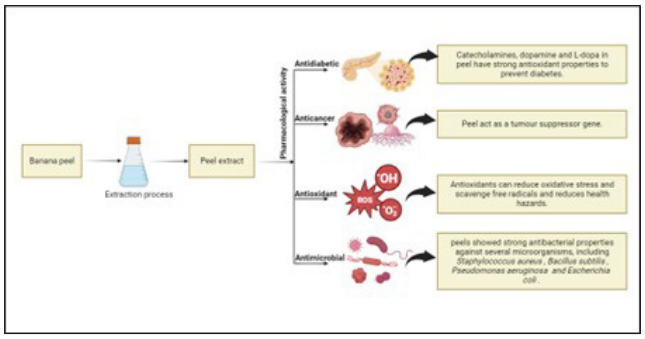

Figure 5: Pharmacological activity of banana peel.

Uses of banana peel

In the food industry

Banana peels, whether ripe or unripe, enhance the nutritional and physicochemical properties of various food items (such as baked goods, noodles, jellies, and meat products). As banana peel contains more nutrients like protein, ash, fat, crude fiber, and other nutrients than pulp, it can be used to make foods with outstanding functions. The high concentration of peel in food formulations may enhance its phytochemical and antioxidant activity. It can also produce foods having inferior physicochemical qualities and sensory unacceptability [2].

In the food processing business, banana peel powder was even employed as a flavoring ingredient [49]. Pasha et al. [17] Studied the suitability of developing salty noodles by replacing wheat flour with banana peel powder (BPP) at supplementation rates of 5%, 10%, and 15%. Dom et al. [18] prepared yoghurts were fortified with peel extract, a source of bioactive chemicals. Lee et al. [19] created jam by using banana peel, a common banana by-product, that has antioxidant activity and contains dietary fiber. Ahmed et al. [20] prepared cake using peel to increase the nutritive quality. Kurhade et al. [21] prepared chapatti with high quality. The banana peel was used to make ready-to-cook curry mix, sauce, and instant soup mix (ISM). The nendran healthy ISM was placed in a laminated bag with a three-month shelf life [50]. Food products prepared using banana peel powder are listed in table 4.

Pharmaceutical industry

Natural bioactive substances in banana peels, like polyphenols, carotenoids, and dietary fiber, have positive effects on our health, including the prevention of cancer, heart disease, and other degenerative diseases. It contains bioactive sub-

Table 4: Uses of banana peel in the food industry.

Products	Varieties of banana peel	Properties	Ref.
Salty noodles	Ripened bananas (*M. acuminata*)	High amount of ash, crude fibre, fat, micro-minerals, and antioxidant capacity of the supplemented noodles.	[17]
		Increased absorption capacity and high viscosity.	
Noodle	Saba banana	High water holding capacity.	[18]
		Low tensile strength.	
Yoghurt	Musa acuminata	Reduced lipid oxidation.	[24]
		Increased the viscosity.	
		Increased total phenolic content and high antioxidant.	
Jam	Bananas in the yellow-green stage of ripening, which were imported from the Philippines by the Dole Co.	High hardness, chewiness, and springiness.	[19]
		High content of dietary fibre, phenolics, flavonoids and antioxidant activities.	
Cake	Fully ripe bananas (Musa cavendish), a variety of (Williams)	Increased amount of protein and fat.	[20]
		Caloric value increased.	
		High amount of potassium, phosphorus, and sodium.	
Chapatti	-	Softer chapatti and better pliability.	[21]
		High phenolic and flavonoid content.	
Sauce	Nendran	Long shelf life, high viscosity.	[50]
Instant soup mix	Nendran	Long shelf life.	[50]
		High antioxidant.	
Chicken sausage	Saba variety	High water-holding capacity and reduced cooking loss.	[51]
		Less protein and fat content.	
		High vitamin and mineral content.	

stances that are utilized to prevent cancer [44]. For centuries, people have used banana peel as a natural remedy to treat a variety of conditions, including burns, coughs, ulcers, and diarrhea. The banana peel has been used to treat burn wounds, dysentery, and excessive menstruation [3]. The peel is the therapy of heel fissures or heel cracks produced, particularly in females, by a lack of moisture and thickening of the skin. This leads to a worsening of the cracks, as they provide an opportunity for bacteria to enter, potentially causing foot infections and leading to an increase in swelling. So, banana peel extract and carboxyl methyl cellulose are combined to create a gel. Compared to other chemical ointments, this gel is much more potent and environmentally friendly. Banana peels are rich in fructooligosaccharides, a prebiotic that nourishes good bacteria in the colon. These bacteria are helpful as they create vitamins and digestive enzymes that improve the body's ability to absorb nutrition [51].

It has high phenolic content. Phenolic compounds, which are abundant in banana peels function as antioxidants to prevent cancer and heart disease. A natural and effective way to whiten teeth is by using banana peel, which also provides valuable nutrients for dental health. Brushing your teeth with banana peel enhances the potassium level, ultimately contributing to the strengthening of the teeth. Also, the bioactive compounds present in banana peel may have cancer-preventive properties. Mosquitoes and bug bites cause scratching; thus, banana peel endocarp should be applied right away before using an ointment; it works well and concurrently reduces inflammation and itching [49].The banana peel also has been utilized for treating and preventing a range of health problems such as anemia due to its high iron content, high blood pressure (owing to its high levels of potassium and low levels of salt) and depression due to the banana's tryptophan content [51]. Bioactive substances discovered in banana peels include flavonoids, tannins, alkaloids, glycosides, anthocyanins, and terpenoids that have a range of biological and pharmacological effects, including antimicrobial, antihypertensive, antidiabetic, and anti-inflammatory effects [36].

Food packaging

The substantial waste generated in banana processing is banana peel. It has a great role in preparing biodegradable packages [52]. They are environmentally acceptable alternatives to plastic packaging since they are organic materials that naturally disintegrate. They can be composted, minimizing waste and harm to the environment [5]. They are composed of insoluble dietary fibers, including cellulose (18.7%), hemicellulose (20.3%), and lignin (16.8%). These peels are nutrient-rich but are often discarded in landfills or on roadsides. Therefore, there is potential for more efficient utilization of these resources in the production of 3D-printed food packaging [52]. Ahmad et al. [53] created composite packaging films at the nanoscale using starch molecules that were reinforced with cellulose nanofibers extracted from unripe banana peels. The addition of nanoparticles led to a substantial enhancement in the mechanical characteristics of the films, particularly in terms of elongation at break. Peels of tanduk banana (*Musa corniculata* Rumph) were used to make an edible film for food packaging [54]. Tensile characteristics resembled those of polyethene. A bioplastic film with high tensile strength was created from corn starch and banana peel biopolymers. Due to their antibacterial qualities, banana peels can help keep and prolong the shelf life of some foods. The chemicals naturally present in the peel help prevent food spoilage by inhibiting the growth of bacteria, fungi, and other microbes [5].

Used in wastewater treatment

Banana peels have shown potential for use in wastewater treatment due to their ability to remove certain pollutants and contaminants. Numerous forms of agricultural waste are currently being investigated for the treatment of wastewater. For instance, if banana peels are properly prepared with surface-active chemicals, they can be used to absorb different metals and other contaminants found in industrial wastewater. Banana peels were examined by analyzing their sorbent qualities using fourier's transform infrared spectroscopy (FT-IR). The qualities of banana peels were improved through chemical treatment. Chemicals like sodium hydroxide, sulfuric acid, and oxalic acid have the power to improve the sorption capabilities of banana peels [55].

Ahmad and Danish [56] used parts of banana plants including peels, stems, trunks, and leaves to create an adsorbent to remove environmental pollutants such as heavy metals, dyes, organic pollutants, and pesticides. Before the waste contaminates our water surface and groundwater, dyes from industrial and domestic wastewater must be remedied. Adsorbents made from banana waste have recently been tested for their ability to bind to several types of synthetic colors. Synthetic pesticides were increasingly used in residential and agricultural areas, which gradually seeped into surface and groundwater [57].

As animal feed

The nutritional value of banana peel is significant, especially in terms of lipids, proteins, and carbohydrates. In addition, the substance has significant quantities of minerals and indigestible fiber. Animal feed has been produced using banana peel. When ingredients like soybean and cassava were replaced with the peel in the diet of developing pigs, the peel was comparable quality. The peels are utilized in part place of other forage sources. To make a balanced and nourishing diet for cattle, they can be blended with other feed components like hay, silage, or concentrates. They are rough and fibrous; livestock normally don't eat them directly. Hence, to improve digestibility and ease feeding, processing techniques like chopping, shredding, or drying might be used [5].

As fertilizer

Numerous farmers employ chemical fertilizers to enhance soil quality and increase yields. The extensive use of these chemical fertilizers disrupts the ecological balance by causing eutrophication and contaminating the air, surface water, groundwater, and soil with heavy metals. In addition to this, it poses potential hazards to human health. Also, bioorganic fertilizers represent the optimal solution for safeguarding the environment and human well-being [58]. To restore soil nutrients, peels of the bananas have traditionally been used as fertilizer by decomposing them. Biotechnological advancements and high demand for organic fertilizers have led to the

use of peel in the production of a variety of organic fertilizers. They are produced through composting in both oxygen-rich and oxygen-deprived settings using cow manure, avian excreta, or earthworms. They have high nitrogen and potassium content [5]. Hussein et al. [59] extracted a nano bio-stimulant fertilizer from peels of bananas under alkaline conditions. These peels contain minerals like potassium, magnesium, iron, copper, sodium, calcium etc. The resulting nano bio-stimulant significantly enhances the germination and growth of tomato and fenugreek seeds, making it a highly recommended natural promoter (Figure 6).

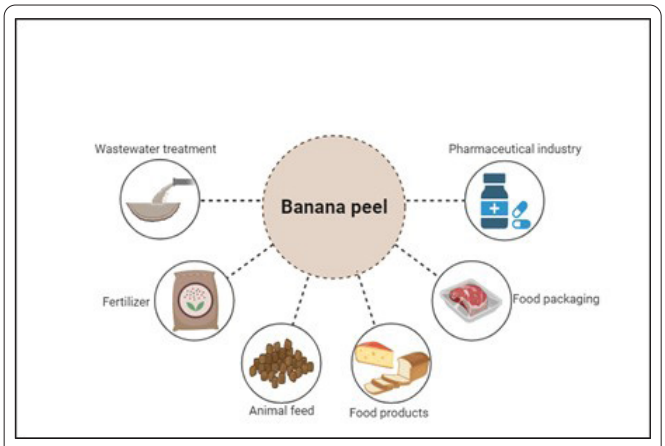

Figure 6: Application of banana peel.

Conclusion

Banana peels, often discarded for their unpalatable flavor, represent a substantial global agricultural by-product. Despite being discarded universally; the total volume of banana cultivation contributes to an escalating annual accumulation of these peels. As this waste continues to rise, there is a critical need for more comprehensive research to uncover the active ingredients responsible for the various biological activities of banana peels. To limit the disposal of banana peels and unlock their potential, further exploration is required to understand and harness their bioactive components. These include phenolic substances and carotenoids, known for their therapeutic benefits. Given the widespread cultivation and consumption of bananas globally, investigating innovative applications for banana peels in the food, pharmaceutical, and cosmetic industries become important. The intrinsic nutritional and therapeutic value of banana peels, rich in dietary fiber, can significantly contribute to promoting healthy digestion and enhancing the nutritional profile of food products. The literature underscores the presence of a diverse array of highly valuable bioactive chemicals in banana peels. Focusing research efforts on sustainable ways to incorporate banana peel derivatives into diverse food formulations, including baked products, snacks, beverages, and functional foods, should be a primary objective.

While the merits of banana peels are evident, challenges arise in the food industry. High-temperature drying methods can result in a decline in antioxidant content, necessitating further investigation into optimal processing parameters. Additionally, inadequate post-harvest handling and storage practices may render banana peels microbiologically unsuitable for certain applications. The potential of banana peels extends beyond the food industry, with opportunities in environmental sustainability. Further research should explore the use of banana peel extracts and compost as biopesticides, organic fertilizers, and soil conditioners. Investigating pharmacological effects, such as anti-inflammatory, antibacterial, anticancer, and antioxidant properties, can cover the way for the development of pharmaceutical or nutraceutical products derived from banana peels.

Future Perspective

Beyond agriculture, banana peels exhibit important characteristics for water and soil remediation, acting as effective adsorbents for contaminants. The development of durable techniques for environmental remediation, including wastewater treatment and heavy metal removal, holds significant promise for reducing pollution and restoring ecosystems. In conclusion, the multifaceted potential of banana peels demands sustained research efforts. From their applications in creating value-added food products to their role in environmental sustainability, banana peels offer a wealth of possibilities. Future research and innovation should investigate their antioxidant and antibacterial qualities, exploring applications in water filtration, bioplastics, agriculture, and animal feed.

Acknowledgements

The authors thankfully acknowledge to the Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Punjab, for providing the necessary facilities to conduct this review.

Conflict of Interest

None.

References

1. Hikal WM, Ahl SA, Hussein AH, Bratovcic A, Tkachenko KG, et al. 2022. Banana peels: a waste treasure for human being. *Evid Based Complement Alternat Med* 2022: 1-9. https://doi.org/10.1155/2022/7616452
2. Zaini HM, Roslan J, Saallah S, Munsu E, Sulaiman NS, et al. 2022. Banana peels as a bioactive ingredient and its potential application in the food industry. *J Funct Foods* 92: 105054. https://doi.org/10.1016/j.jff.2022.105054
3. Pereira A, Maraschin M. 2015. Banana (*Musa* spp) from peel to pulp: ethnopharmacology, source of bioactive compounds and its relevance for human health. *J Ethnopharmacol* 160: 149-163. https://doi.org/10.1016/j.jep.2014.11.008
4. Ansari NAIM, Ramly NZ, Faujan NH, Arifin N. 2023. Nutritional content and bioactive compounds of banana peel and its potential utilization: a review. *Malaysian J Sci Health Technol* 9(1): 74-86.
5. Vu HT, Scarlett CJ, Vuong QV. 2018. Phenolic compounds within banana peel and their potential uses: a review. *J Funct Foods* 40: 238-248. https://doi.org/10.1016/j.jff.2017.11.006
6. De Langhe E, Vrydaghs L, De Maret P, Perrier X, Denham T. 2009. Why bananas matter: an introduction to the history of banana domestication. *Ethnobot Res Appl* 7: 165-177.
7. Anjum S, Sundaram S, Rai GK. 2014. Nutraceutical application and value addition of banana (*Musa paradisica* L. variety "bhusawal keli") peel: a review. *Int J Pharm Pharm Sci* 6(10): 81-85.
8. Mohapatra D, Mishra S, Sutar N. 2010. Banana and its by-product util-

isation: an overview. *J Sci Indust Res* 69: 323-329.

9. Food and Agriculture Organization of United Nations. 2020. The Food and Agriculture Organization Statistical Database.
10. Vu HT, Scarlett CJ, Vuong QV. 2017. Optimization of ultrasound-assisted extraction conditions for recovery of phenolic compounds and antioxidant capacity from banana (*Musa cavendish*) peel. *J Food Process Preserv* 41(5): e13148. https://doi.org/10.1111/jfpp.13148
11. Singh R, Deshpande AS, Pallavi A, Kamboj V. 2023. Sustainable use of waste banana peel (*Musa sapientum* L.) powder for enhancement of nutritional properties of dark chocolate. *Agro Environ Sustainability* 1(1): 22-28. https://doi.org/10.59983/s2023010104
12. Pyar H, Peh KK. 2018. Chemical compositions of banana peels (*Musa sapientum*) fruits cultivated in Malaysia using proximate analysis. *Res J Chem Environ* 22(2): 108-111.
13. Aboul-Enein AM, Salama ZA, Gaafar AA, Aly HF, Abou-Elella F, et al. 2016. Identification of phenolic compounds from banana peel (*Musa paradaisica* L.) as antioxidant and antimicrobial agents. *J Chem Pharm Res* 8(4): 46-55.
14. Menezes EW, Tadini CC, Tribess TB, Zuleta A, Binaghi J, et al. 2011. Chemical composition and nutritional value of unripe banana flour (*Musa acuminata*, var. Nanicão). *Plant Foods Human Nutr* 66: 231-237. https://doi.org/10.1007/s11130-011-0238-0
15. Khawas P, Deka SC. 2016. Comparative nutritional, functional, morphological, and diffractogram study on culinary banana (*Musa* ABB) peel at various stages of development. *Int J Food Prop* 19(12): 2832-2853. https://doi.org/10.1080/10942912.2016.1141296
16. Emaga TH, Bindelle J, Agneesens R, Buldgen A, Wathelet B, et al. 2011. Ripening influences banana and plantain peels composition and energy content. *Trop Anim Health Prod* 43: 171-177. https://doi.org/10.1007/s11250-010-9671-6
17. Pasha I, Basit A, Ahsin M, Ahmad F. 2022. Probing nutritional and functional properties of salted noodles supplemented with ripen banana peel powder. *Food Prod Process Nutr* 4(1): 22. https://doi.org/10.1186/s43014-022-00100-5
18. Dom ZM, Mujianto L, Azhar A, Masaudin S, Samsudin R. 2021. Physicochemical properties of banana peel powder in functional food products. *Food Res* 5(1): 209-215.
19. Lee EH, Yeom HJ, Ha MS, Bae DH. 2010. Development of banana peel jelly and its antioxidant and textural properties. *Food Sci Biotechnol* 19: 449-455. https://doi.org/10.1007/s10068-010-0063-5
20. Ahmed Z, El-Sharnouby GA, El-Waseif MA. 2021. Use of banana peel as a by-product to increase the nutritive value of the cake. *J Food Dairy Sci* 12(4): 87-97. https://dx.doi.org/10.21608/jfds.2021.167053
21. Kurhade A, Patil S, Sonawane SK, Waghmare JS, Arya SS. 2016. Effect of banana peel powder on bioactive constituents and microstructural quality of chapatti: unleavened Indian flat bread. *J Food Meas Charact* 10: 32-41. https://doi.org/10.1007/s11694-015-9273-0
22. Segura-Badilla O, Kammar-García A, Mosso-Vázquez J, Sánchez RÁ, Ochoa-Velasco C, et al. 2022. Potential use of banana peel (*Musa cavendish*) as ingredient for pasta and bakery products. *Heliyon* 8(10): e11044. https://doi.org/10.1016/j.heliyon.2022.e11044
23. Singh JP, Kaur A, Shevkani K, Singh N. 2015. Influence of jambolan (*Syzygium cumini*) and xanthan gum incorporation on the physicochemical, antioxidant and sensory properties of gluten-free eggless rice muffins. *Int J Food Sci Technol* 50(5): 1190-1197. https://doi.org/10.1111/ijfs.12764
24. Kabir MR, Hasan MM, Islam MR, Haque AR, Hasan SK. 2021. Formulation of yogurt with banana peel extracts to enhance storability and bioactive properties. *J Food Processing Pres* 45(3): e15191. https://doi.org/10.1111/jfpp.15191
25. Turker B, Savlak N, Kaşıkcı MB. 2016. Effect of green banana peel flour substitution on physical characteristics of gluten-free cakes. *Curr Res Nutr Food Sci J* 4: 197-204. http://dx.doi.org/10.12944/CRNFSJ.4.Special-Issue-October.25
26. Castelo-Branco VN, Guimarães JN, Souza L, Guedes MR, Silva PM, et al. 2017. The use of green banana (*Musa balbisiana*) pulp and peel flour as an ingredient for tagliatelle pasta. *Braz J Food Technol* 20: e2016119. https://doi.org/10.1590/1981-6723.11916
27. Karasawa MM, Mohan C. 2018. Fruits as prospective reserves of bioactive compounds: a review. *Nat Prod Bioprospect* 8: 335-346. https://doi.org/10.1007/s13659-018-0186-6
28. Lin D, Xiao M, Zhao J, Li Z, Xing B, et al. 2016. An overview of plant phenolic compounds and their importance in human nutrition and management of type 2 diabetes. *Molecules* 21(10): 1374. https://doi.org/10.3390%2Fmolecules21101374
29. Avram I, Gatea F, Vamanu E. 2022. Functional compounds from banana peel used to decrease oxidative stress effects. Processes 10(2): 248. https://doi.org/10.3390/pr10020248
30. Tai NV, Linh MN, Thuy NM. 2021. Optimization of extraction conditions of phytochemical compounds in "Xiem" banana peel powder using response surface methodology. *J Appl Biol Biotechnol* 9(6): 56-62. http://dx.doi.org/10.7324/JABB.2021.9607
31. Rebello LP, Ramos AM, Pertuzatti PB, Barcia MT, Castillo-Muñoz N, et al. 2014. Flour of banana (*Musa AAA*) peel as a source of antioxidant phenolic compounds. *Food Res Int* 55: 397-403. https://doi.org/10.1016/j.foodres.2013.11.039
32. Tsamo CV, Herent MF, Tomekpe K, Emaga TH, Quetin-Leclercq J, et al. 2015. Effect of boiling on phenolic profiles determined using HPLC/ESI-LTQ-Orbitrap-MS, physico-chemical parameters of six plantain banana cultivars (*Musa sp*). *J Food Compos Anal* 44: 158-169. https://doi.org/10.1016/j.jfca.2015.08.012
33. Sheikhzadeh M, Hakimzadeh V, Abedi MR. 2015. Carotenoids extraction optimization of lutein-based banana peel. *J Appl Environ Biol Sci* 4(11S): 213-217.
34. Hendrawan Y, Larasati R, Wibisono Y, Umam C, Sutan SM, et al. 2019. Extraction of phenol and antioxidant compounds from kepok banana skin with PEF pre-treatment. *IOP Conf Ser Earth Environ Sci* 305: 012065. https://doi.org/10.1088/1755-1315/305/1/012065
35. González-Montelongo R, Lobo MG, González M. 2010. Antioxidant activity in banana peel extracts: testing extraction conditions and related bioactive compounds. *Food Chem* 119(3): 1030-1039. https://doi.org/10.1016/j.foodchem.2009.08.012
36. Kumari P, Gaur SS, Tiwari RK. 2023. Banana and its by-products: a comprehensive review on its nutritional composition and pharmacological benefits. *eFood* 4(5): e110. https://doi.org/10.1002/efd2.110
37. Zou F, Tan C, Zhang B, Wu W, Shang N. 2022. The valorization of banana by-products: nutritional composition, bioactivities, applications, and future development. *Foods* 11(20): 3170. https://doi.org/10.3390%2Ffoods11203170
38. Hong YH, Kao C, Chang CC, Chang FK, Song TY, et al. 2023. Anti-Inflammatory and T-cell immunomodulatory effects of banana peel extracts and selected bioactive components in LPS-challenged *in vitro* and *in vivo* models. *Agriculture* 13(2): 451. https://doi.org/10.3390/agriculture13020451
39. Kapadia SP, Pudakalkatti PS, Shivanaikar S. 2015. Detection of antimicrobial activity of banana peel (*Musa paradisiaca* L.) on *Porphyromonas gingivalis* and Aggregatibacter actinomycetemcomitans: an *in vitro* study. *Contemp Clin Dent* 6(4): 496-499. https://doi.org/10.4103%2F0976-237X.169864
40. Niamah AK. 2014. Determination, identification of bioactive compounds extracts from yellow banana peels and used *in vitro* as antimicrobial. *Int J Phytomed* 6(4): 625-632.
41. Chabuck ZA, Al-Charrakh AH, Hindi NK, Hindi SK. 2013. Antimicrobial effect of aqueous banana peel extract, Iraq. *Res Gate Pharm Sci* 2013; 1: 73-75.
42. Dahham SS, Mohamad TA, Tabana YM, Majid AM. 2015. Antioxidant activities and anticancer screening of extracts from banana fruit (*Musa sapientum*). *Ac J Cancer Res* 8(2): 28-34.

43. Ruangtong J, Jiraroj T, T-Thienprasert NP. 2020. Green synthesized ZnO nanosheets from banana peel extract possess anti-bacterial activity and anti-cancer activity. *Mater Today Commun* 24: 101224. https://doi.org/10.1016/j.mtcomm.2020.101224

44. Durgadevi PK, Saravanan A, Uma S. 2019. Antioxidant potential and antitumour activities of Nendran banana peels in breast cancer cell line. *Indian J Pharm Sci* 81(3): 464-473. https://doi.org/10.36468/pharmaceutical-sciences.531

45. Phacharapiyangkul N, Thirapanmethee K, Sa-Ngiamsuntorn K, Panich U, Lee CH, et al. 2019. Effect of sucrier banana peel extracts on inhibition of melanogenesis through the ERK signaling pathway. *Int J Med Sci* 16(4): 602. https://doi.org/10.7150%2Fijms.32137

46. Ishak NA, Rashid MY,A Zabidi NA. 2019. Antidiabetic and antioxidant capacities of local banana peels extract by using subcritical water extraction technique. *Ulum Islamiyyah* 26: 19-30. https://doi.org/10.33102/uij.vol26no.90

47. Thomas A, Krishnakumar K. 2017. Banana peel: pharmacological activities: a review. Int *J Innov Res Adv Studies* 4(5): 62-64.

48. Genatrika E, Laksari VN, Tjiptasurasa T. 2018. Antidiabetic activity of *Musa acuminata* colla fruit peel (MACFP) ethanol extract in glucose-induced diabetic rats. In The 3rd Annual Applied Science and Engineering Conference (AASEC 2018). MATEC Web of Conferences.

49. Bhavani M, Morya S, Saxena D, Awuchi CG. 2023. Bioactive, antioxidant, industrial, and nutraceutical applications of banana peel. *Int J Food Prop* 26(1): 1277-1289. https://doi.org/10.1080/10942912.2023.2209701

50. Dhake K, Jain SK, Lakhawat SS. 2019. Value addition in green banana for rural employment generation. *Food Eng* 59(1): 1.

51. Zaini HB, Sintang MD, Pindi W. 2020. The roles of banana peel powders to alter technological functionality, sensory and nutritional quality of chicken sausage. *Food Sci Nutr* 8(10): 5497-5507. https://doi.org/10.1002/fsn3.1847

52. Nida S, Moses JA, Anandharamakrishnan C. 2022. 3D extrusion printability of sugarcane bagasse blended with Banana Peel for prospective food packaging applications. *Sugar Tech* 24(3): 764-768. https://doi.org/10.1007/s12355-021-01095-y

53. Ahmad K, Din ZU, Ullah H, Ouyang Q, Rani S, et al. 2022. Preparation and characterization of bio-based nanocomposites packaging films reinforced with cellulose nanofibers from unripe banana peels. *Starch-Stärke* 74(5-6): 2100283. https://doi.org/10.1002/star.202100283

54. Ningtyas R, Nugroho H, Sabrina A. 2021. Mechanical properties of edible film from tanduk banana (*Musa corniculata* Rumph) peels for food packaging. *IOP Conf Ser Mater Sci Eng* 1011(1): 012060. https://doi.org/10.1088/1757-899X/1011/1/012060

55. Khan A, Naqvi HJ, Afzal S, Jabeen S, Iqbal M, et al. 2017. Efficiency enhancement of banana peel for wastewater treatment through chemical adsorption: efficiency of banana peel for waste water treatment. *Proc Pak Acad Sci* 54(3): 329-335.

56. Ahmad T, Danish M. 2018. Prospects of banana waste utilization in wastewater treatment: a review. *J Environ Manag* 206: 330-348. https://doi.org/10.1016/j.jenvman.2017.10.061

57. Ahmad T, Rafatullah M, Ghazali A, Sulaiman O, Hashim R, et al. 2010. Removal of pesticides from water and wastewater by different adsorbents: a review. *J Environ Sci Health C* 28(4): 231-271. https://doi.org/10.1080/10590501.2010.525782

58. El Barnossi A, Moussaid FZ, Saghrouchni H, Zoubi B, Housseini AI. 2022. Tangerine, pomegranate, and banana peels: a promising environmentally friendly bioorganic fertilizers for seed germination and cultivation of *Pisum sativum* L.. *Waste Biomass Valori* 13(8): 3611-3627. https://doi.org/10.1007/s12649-022-01743-8

59. Hussein HS, Shaarawy HH, Hussien NH, Hawash SI. 2019. Preparation of nano-fertilizer blend from banana peels. *Bull Natl Res Cent* 43: 1-9. https://doi.org/10.1186/s42269-019-0058-1