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Antioxidant potential and bioactive compounds in banana peel: A review

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Abstract
Fruits play a crucial role in the human diet, holding significant importance for nutrition and well-being. They can be ingested as part of religious practises and as nutritional treatment in various human cultures all over the world. Bananas (*Musa*) are non-grass, monocotyledonous, perennial plants famous for their delicious fruits. Their production provides food security and job possibilities in a variety of nations. Banana fruits are rich in phytochemicals, such as flavonoids, that offer positive effects on human nutrition. Following mango, the banana is India's second most important fruit crop. Its consistent presence throughout the year, low cost, broad variety of varietals, pleasant flavour, nutritional advantages, and therapeutic potential all contribute to its popularity among people of all backgrounds. Substantial waste is difficult to avoid following the harvest and during the processing stages of banana. Other plant or fruit pieces may be included in the trash, but the peel is crucial since it accounts for 35–50% of the total fruit mass. Banana peels find application as a culinary component, a facilitator of water purification, a precursor in the creation of numerous biochemical commodities, and a contributor to the generation of inorganic waste. Intriguingly, banana peels have been discovered to encompass a spectrum of bioactive constituents, most notably comprising flavonoids, tannins, alkaloids, glycosides, anthocyanins, and terpenoids. These bioactive compounds imbue banana peels with a diverse array of beneficial attributes, encompassing antibacterial, antihypertensive, antidiabetic, and anti-inflammatory properties, rendering them a subject of growing interest and exploration. Continued investigation into the nutritional potential and bioactive compound reservoirs within banana peels remains an indispensable pursuit in the ongoing quest to unlock their multifaceted benefits.

Keywords: Banana peel, phytochemical, flavonoids, bioactive constituents, tannins, anti-inflammatory

Introduction
Banana plants, hailing from Southeast Asia and belonging to the *Musa* genus, are immense, enduring herbaceous plants. From a botanical standpoint, the *Musa* genus can be divided into two categories: those deemed suitable for consumption and those recognized as wild species. It is widely acknowledged that there exist more than 1,000 banana varieties worldwide, further organized into 50 distinct classifications. The three most common scientific names for cultivated bananas are *Musa balbisiana*, *Musa acuminata*, and *Musa paradisiaca*, indicating the hybrid *Musa acuminata x M. balbisiana*, based on their genomic composition (Prashanthi & Chaitanya, 2020). A diverse range of banana plant species can be observed worldwide. Within the *Musaceae* family, there are two genera, *Musa* and *Ensete*, encompassing a total of 42 distinct species. Among these 42 species, 32 are categorized under the *Musa* genus. To date, a total of 1,200 banana varieties have been recognized (Chakraborty *et al*., 2017) [12]. In recent times, the utilization of banana peels has expanded into diverse sectors, including but not limited to biofuel manufacturing, biosorbents, paper and pulp production, cosmetics, initiatives related to energy, environmental remediation, organic fertilizer development and processes within the field of biotechnology. (Rana *et al.*, 2018) [31]. The agricultural sector and the agro-food industry generate substantial amounts of by-products, and there is a growing interest in exploiting them for the production of value-added goods. The substantial amount of discarded banana peels generated daily by juice factories and fruit markets points to a significant ecological opportunity.

The banana plant is versatile and can be utilized in pharmaceuticals, food, animal feed, packaging, and industrial sectors. In ancient Egypt, banana leaves, fruits, and the sheaths of its flowers were employed as wound dressings. They would often mash the fruit and apply it as a poultice to treat rashes, infected scratches, grazes, and burns. This application was covered with either the fruit's skin or a leaf, which had been warmed in hot water. Banana flowers find application as a vegetable in Southeast Asian and South Asian culinary traditions, whether enjoyed in their raw state, steamed with accompanying dips, or incorporated into a variety of dishes such as soups, curries, and fried preparations. (Lal *et al.*, 2017) [20].

Bananas have a limited window of viability, succumbing to deterioration shortly after the point of harvest. On an annual basis, a substantial volume of bananas is cultivated, yielding a copious harvest wherein the peel constitutes nearly a third of the complete fruit mass; this component is frequently disposed of as refuse. Despite its lucrative nature, the act of consuming bananas contributes to an annual residue exceeding 26 million tonnes of dry matter, largely stemming from the disposal of its peels (Martins *et al.*, 2019) [21-22].

Although the inner part of the banana is widely used, the outer peel is typically only used as animal feed or for producing organic fertilizers. The peel constitutes approximately 40% of the total fruit weight and is highly nutritious, providing carbohydrates, proteins, vitamins, and minerals. (Barman *et al.*, 2015) [9]. A fast rate of increase in global banana production and consumption results in a massive volume of banana peel trash, producing ecological and environmental challenges. Banana peel's antifungal and antibacterial capabilities can be put to good use. Additionally, it contains a high concentration of natural bioactive compounds, such as phenolic compounds, flavonoids, carotenoids, or quercetin. It also has high antioxidant capacity and antimicrobial/antibiotic properties that promote health and prevent illness. (Vu *et al.*, 2019) [41]. The peel of a banana contains more phytochemicals than the pulp. It is considered nutrient-dense due to its high levels of crude protein, ash, and crude fiber, which may contribute to health benefits (Kraithong & Issara *et al.*, 2011) [18]. The presence of phenolic compounds in banana peels endows them with high antioxidant capacity, thereby serving as a protective measure against the incidence of heart disease and cancer (Someya *et al.*, 2002) [37].

Currently, there is a widespread utilization of natural compounds derived from herbs and plants as growth-stimulating agents, antimicrobial substances, and nutrients. These compounds are enriched with bioactive constituents, such as fiber and phenolic compounds, which have been associated with antioxidant capacity. In comparison to synthetic antibiotics, these natural compounds have demonstrated superior efficacy in the treatment of infectious diseases, while limiting the occurrence of adverse effects. Furthermore, plant extracts are employed as additives in animal feed, serving as a cost-effective agent in aquaculture, promoting survival rate, stimulating immunity, and providing greater reliability than chemotherapeutic agents (Naksing *et al.*, 2021) [24]. Bioactive compounds are typically found in limited amounts within foods, primarily in fruits, vegetables, and whole grains. These compounds offer health advantages that go beyond their fundamental nutritional content. Bioactive compounds are specific molecules that hold promise for therapeutic purposes by affecting energy intake while concurrently mitigating pro-inflammatory conditions, oxidative stress, and metabolic irregularities (Santos *et al*., 2019) [33]. The primary constituents of both the peel and pulp of a banana consist largely of carotenoids, phenolic compounds, and biogenic amines. The biological capabilities of these materials are closely linked to their specific chemical makeup.

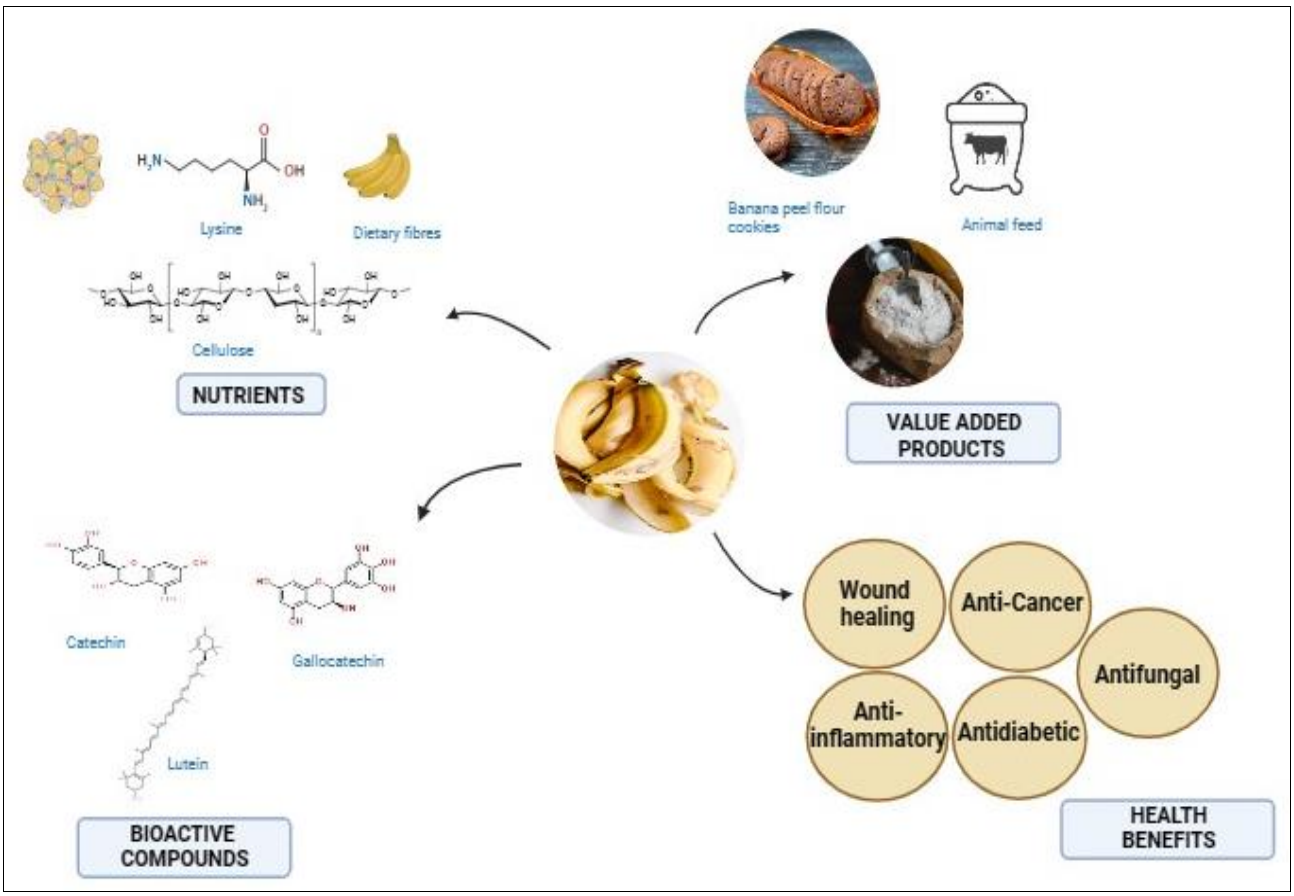


Fig 1: Potential of banana peels

Nutrient composition of banana peel

Banana peels have been utilized as a feedstock due to their nutritional value, specifically on small farms. However, concerns have arisen regarding the impact of tannins found within the peels on animals that consume them. The nutritional composition of the peels varies depending on the cultivar and stage of maturity; for instance, plantain peels have less fiber than dessert banana peels, and the lignin content increases during ripening (7 to 15% dry matter) (table 1). Typically, banana peels contain approximately 6-9% protein and 20-30% fiber (expressed as NDF) in terms of dry matter. The peels of green plantains consist of 40% starch, which undergoes conversion into sugars during ripening. In contrast, green banana peels contain around 15% starch, and when ripe, banana peels can contain up to 30% free sugars. (Hassan *et al.*, 2018) [16].

Table 1: Nutritional composition of banana peel

Nutritional Composition	Average Content, %DM
Ash	9-11
Carbohydrate	59.51-76.58
Crude Fat	2.24-11.6
Crude Protein	5.5-7.86
Dietary Fibre	47-53
Resistant Starch	2.3-2.5
Starch	3.5-6.5

% DM stands for dry matter
Source - (Zaini *et al.*, 2022) [43]

Banana peels are rich in phytochemical compounds, predominantly antioxidants. The overall phenolic compound content within banana peels ranges from 0.90 to 3.0 grams per 100 grams of dry weight. Additionally, banana peels contain antioxidants like polyphenols, catecholamines, and carotenoids. Dietary polyphenols, owing to their remarkable antioxidant properties that extend beyond merely combating oxidative stress, play a pivotal role in preventing degenerative diseases, particularly cardiovascular diseases and cancer. Nevertheless, it's essential to highlight that banana peels contain certain anti-nutritional elements, including oxalate, tannins, phytate, and others. These components have the potential to cause negative effects such as impaired growth, decreased food consumption, and organ damage in the body. (Abou-Arab & Abu-Salem, 2017) [1].

Amino acids in banana peel

Banana peels boast a notable protein content. The protein concentration in banana peels was determined through several methods, including the miso-kjeldahl method, Soxhlet extraction, and ICP analysis (Hassan *et al.*, 2018) [16]. Plantain peel is rich in crucial amino acids like leucine and lysine. The intake of leucine in one's diet has been proposed to yield long-term health advantages, such as mitigating diet-induced weight gain, hyperglycemia, and hypercholesterolemia. This discovery suggests that specific lysine compounds hold promise for use in cancer therapy, as they can induce self-destruction in cancer cells when combined with phototherapy, while sparing non-cancerous cells from harm (Zaini *et al.*, 2022) [43]. Amino acid analysis of banana peel (*Musa Paradisiaca*) indicates the presence of tryptophan, phenylalanine, tyrosine, arginine, and cysteine. Tryptophan is a fundamental amino acid present in banana peel and acts as a precursor for serotonin, a vital neurotransmitter in the central nervous system. Phenylalanine and tyrosine are aromatic amino acids with significant roles in both protein synthesis and various physiological processes within the body. Arginine, a semi-essential amino acid, contributes to functions like protein synthesis, wound healing, and immune response (Velumani, 2016) [39]. Table 2 showcases the different amino acids present in varying quantities in banana peel.

Table 2: Different amino acids present in banana peel

AMINO ACID	Plantain PEEL (g / 100 g protein)	Banana Peel (g / 100 g protein)	Source
Alanine	6.22±0.05	0.85±0.04	Zaini *et al.*, 2022 [43]
Arginine	4.99±0.03	3.25±0.05	Zaini *et al.*, 2022 [43]
Aspartic acid	8.68±0.02	9.06±0.05	Zaini *et al.*, 2022 [43]
Cystine	0.85±0.02	2.24±0.03	Zaini *et al.*, 2022 [43]
Glutamic acid	12.72±0.02	5.31±0.01	Zaini *et al.*, 2022 [43]
Glycine	3.94±0.01	13.02±0.82	Zaini *et al.*, 2022 [43]
Histidine	2.11±0.04	3.96±0.01	Zaini *et al.*, 2022 [43]
Isoleucine	5.24±0.05	8.06±0.04	Zaini *et al.*, 2022 [43]
Leucine	7.76±0.05	0.01±0.00	Zaini *et al.*, 2022 [43]
Lysine	7.90±0.03	6.71±0.06	Zaini *et al.*, 2022 [43]
Methionine	1.60±0.03	5.79±0.03	Zaini *et al.*, 2022 [43]
Norleucine	0.02±0.00	7.76±0.05	Zaini *et al.*, 2022 [43]
Phenylalanine	4.79±0.06	4.98±0.07	Zaini *et al.*, 2022 [43]
Proline	3.25±0.02	1.71±0.02	Zaini *et al.*, 2022 [43]
Serine	4.05±0.04	4.59±0.04	Zaini *et al.*, 2022 [43]
Threonine	5.38±0.06	6.10±0.03	Zaini *et al.*, 2022 [43]
Trytophan	0.58±0.03	0.01±0.00	Zaini *et al.*, 2022 [43]
Tyrosine	3.96±0.06	5.50±0.03	Zaini *et al.*, 2022 [43]
Valine	5.67±0.01	0.52±0.02	Zaini *et al.*, 2022 [43]
Total	89.71±5.45	86.71±3.02	Zaini *et al.*, 2022 [43]

Showcasing the different types of amino acids in banana peel.
Source- (Zaini *et al.*, 2022) [43]

Fatty acids in banana peel

The banana peel boasts a substantial content of overall dietary fiber, ranging between 43% to 49%, alongside notable percentages of crude protein, falling within the 6% to 9% range, and crude fat, spanning from 3.8% to 11%. Moreover, it contains starch at a concentration of 3%, as well as polyunsaturated fatty acids, with a particular emphasis on linoleic acid and α linoleic acid. Additionally, it features indispensable amino acids, including leucine, valine, phenylalanine, and threonine, in conjunction with essential micronutrients like calcium, magnesium, potassium, and phosphorous. Malic acid stands out for its heightened antibacterial potency (Azarudeen & Nithya, 2021) [7].

Carbohydrates in banana peel

Banana peels are a notable source of polysaccharides, namely pectin, hemicellulose, and cellulose. Hemicellulose extracted from banana peels exhibits a similar structural composition to that of monocot plants, characterized by the presence of substituting groups like arabinose, galactose, glucuronic acid, and phenolic acids attached to the xylan backbone, giving rise to branched configurations (Pereira *et al.*, 2021) [27].

Dietary Fiber content in banana peel

The consumption of banana peels can serve as a noteworthy means of obtaining dietary fibre due to its considerable total and soluble fibre content, as well as its remarkable water and oil holding capabilities, and noteworthy potential for colonic fermentability. The banana peel can be considered a valuable source of dietary fibre, as evidenced by its high dietary fibre content of approximately 50g per 100g (Hasaan *et al.* 2018) [16]. The inclusion of insoluble dietary fibers sourced from banana

peel in the buns serves to elevate their nutritional profile and fosters the progression of more salubrious food choices (Budhalakoti *et al.* 2019) [11].

Ash content in banana peel

Ash is the residue remaining from an inorganic substance once the water and organic matter have been removed by heating. The ash content also indicates the amount of mineral components present in food. Typically, banana peels have an ash content that falls within the range of 8.50% to 12.45% (Ansari *et al.* 2023) [25].

Mineral content in banana peel

Potassium stands out as the predominant mineral content found in banana peels when compared to other minerals, boasting a concentration of 78.10±6.58 mg/g. It's noteworthy that incorporating the peel when consuming the fruit could contribute significantly to the regulation of bodily fluids and the maintenance of normal blood pressure, owing to its substantial potassium content. (Ansari *et al.*2023) [25].

Turning to trace elements, iron was quantified at 15.15±0.36 mg/100g in the study conducted by Dibanda Romelle *et al.* in 2016. Despite its relatively low concentration in the peel, it serves as a valuable source of iron, as excessive intake has been associated with irregular immune responses, aberrant cell development, and disruptions in cardiovascular system function (Ansari *et al.*2023) [25].

Banana peel contains various minerals that are beneficial for animal feed formulation and waste management. The mineral composition of banana peel includes phosphorus, iron, calcium, magnesium, sodium, zinc, copper, potassium, and manganese. The specific mineral content may vary depending on the stage of maturity and the cultivar of the banana peel. These minerals make banana peel a potential source of nutrients for animal feed production and can contribute to reducing the environmental impact of banana peel waste. The high mineral content in banana peel, such as calcium, phosphorus, magnesium, and iron, makes it a valuable resource for animal feed formulation (Hassan *et al.* 2018) [16].

Bioactive Compounds in Banana Peel

Phenolic content

Phenolic compounds found in plants are regarded as essential elements of the human diet and display powerful antioxidant properties along with various health advantages. Epidemiological research suggests that a diet abundant in antioxidant-rich fruits and vegetables substantially lowers the likelihood of cardiovascular conditions, cancer and diabetes (Kumar & Goel, 2019) [19]. Phenolic compounds are significant secondary metabolites and are notably abundant in banana peels when compared to other fruits. Banana peels contain a variety of phenolic compounds, including gallic acid, catechin, epicatechin, tannins, and anthocyanins (Sidhu & Zafar, 2018) [36] (table 3).

In terms of specific phenolic compounds, over 40 substances have been recognized in banana peels. These can be generally categorized into four subgroups: hydroxycinnamic acids, flavonols, flavan-3-ols, and catecholamines. The predominant class of phenolic compounds discovered in banana peel was the flavan-3-ols, as reported by Rebello *et al.* in 2014. This group includes monomers, dimers, and polymers. Among these, the polymers, known as proanthocyanidins, were found to have the highest combined concentration, measuring 3952 mg/kg in terms of (+)-catechin equivalents. Dimers followed with approximately 126 mg/kg in (+)-catechin equivalents. (Vu *et al.*, 2018) [40].

Among the various extraction techniques at our disposal, microwave-assisted extraction (MAE) has garnered significant attention in research circles due to its capacity to reduce extraction times and solvent consumption. Additionally, microwave irradiation has proven to be effective in releasing bound phenolic compounds from the peel during the drying process. It is a well-established fact that the antioxidant properties of banana peel are primarily linked to its polar constituents. The ripeness of the fruit has been shown to have a significant impact on the phenolic content of the peel. As the fruit ripens, the total phenolic content decreases, with overripe peels having 52% less, and ripe peels having 15-45% less phenolic content compared to green peels. Similar trends were observed for the total flavonoid content and antioxidant properties. The ability of banana peel to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals decreases as the fruit transitions from green to ripe and overripe stages (Vu *et al.*, 2018) [40].

Carotenoids in banana peel

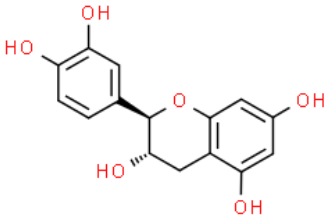
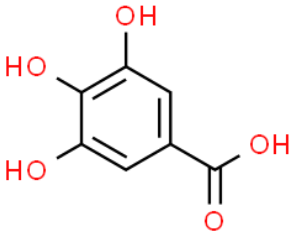
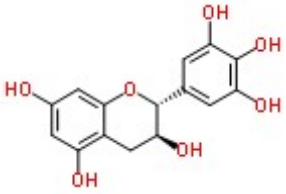
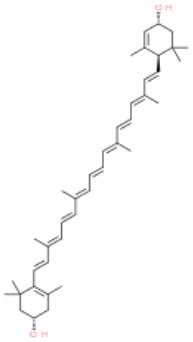
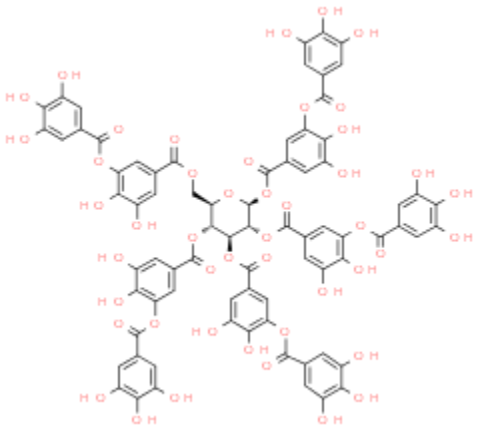
The banana peel is discovered to contain antioxidant compounds that are double in concentration compared to the edible part, which renders it a valuable reservoir for carotenoid extraction. In banana peels, carotenoids include 10.9% alpha-carotene, 14.9% beta-carotene, and 52.3% lutein. To extract carotenoids from banana peels for food-related purposes, it is imperative to employ a food-grade extraction approach (Yan *et al.* 2016) [42].

In the carotenoid analysis of ripe banana flesh and peel from three cultivars of banana (Raja, Ambon Kuning, and Kepok Kuning) the primary carotenoids detected in the research were lutein, α-carotene, and β-carotene. Lutein emerged as the predominant carotenoid in the fresh banana peel, whereas fresh banana flesh contained α-carotene and β-carotene in addition to lutein. Among the three examined banana samples, the Raja banana cultivar exhibited the highest overall carotenoid content (Septiany *et al.* 2019) [35].

Dopamine in banana peel

The existence of bioactive amines has been documented in various consumable fruits. Compounds like dopamine, noradrenaline, octopamine, serotonin, histamine, and 2-phenylethylamine have been identified in bananas and banana-derived products. Amines such as histamine, phenylethylamine, and serotonin can serve as protective agents by discouraging insects and molds (Adao *et al.*, 2004) [4]. Multiple studies have documented the substantial presence of dopamine and L-dopa in banana peels, catecholamines known for their notable antioxidant properties. Dopamine, recognized for its robust antioxidative capabilities, is thought to be a key contributor to the overall antioxidant potential of banana extracts. Additionally, research findings have indicated that the dopamine content within the peel, ranging from 80 to 560 mg per 100 grams, surpasses that found in the pulp by several orders of magnitude (2.5 to 10 mg per 100 grams) (Vu *et al.*, 2018) [40]. The structure and molecular formula for different bioactive compounds is given in table 3.

Table 3: Chemical structures and molecular formulas of some of the bioactive compounds found in banana peel

Bioactive Compound	Structure	Molecular Formula
Catechin		C15H14O6
Gallic acid		C7H6O5
Gallocatechin		C15H14O7
Lutein		C40H56O2
Tannic acid		C76H52O46

Antioxidant property of banana peel

Antioxidants have garnered significant scientific attention because of their numerous advantages, including their anti-aging and anti-inflammatory properties. They continue to find applications in various fields. In the realm of food technology, antioxidants are incorporated into many food products to enhance their nutritional value and address various issues. Consequently, research efforts aimed at assessing the antioxidant capabilities of natural foods and their individual components are progressing swiftly (Zehiroglu & Sarikaya, 2019) [44].

Banana peels are packed with phytochemical substances, primarily antioxidants. The quantity of phenolic compounds in the peel of ripe bananas (*Musa acuminata Colla* AAA) varies between 0.90 and 3.0 grams per 100 grams of dry weight. Ripe banana peels also have additional compounds like anthocyanins such as delphinidin and cyanidin, as well as catecholamines (González-Montelongo *et al.*, 2009) [30]. The consumption of antioxidants has the potential to prevent the occurrence of oxidative stress, which has been linked to numerous diseases. Certain plants, such as guava, tea, coffee, banana, and papaya, contain compounds such as phenolics and flavonoids that possess antioxidant properties. The peel of bananas, specifically, contains flavanone glycoside naringin and flavonol glycoside

rutin, as well as lutein, betacarotene, alpha-carotene, violaxanthin, auroxanthin, neoxanthin, isolutein, alphacryptoxanthin and beta-cryptoxanthin (Fidrianny *et al.*, 2018) [13]. The presence of these phytochemicals in banana peel contributes to its ability to scavenge free radicals and protect against oxidative stress. Alkaloids, flavonoids, and tannins are known to exhibit antioxidant activity by neutralizing reactive oxygen species and preventing cellular damage. The antioxidant properties of banana peel can help reduce the risk of degenerative diseases like cardiovascular disease and cancer. Including banana peel in food products can provide a natural source of antioxidants, which can synergistically act to promote health and reduce the risk of various diseases (Velumani, 2016) [39].

The source of antioxidant capabilities in banana peel extract can be attributed to the secondary metabolites it harbors, specifically alkaloids, flavonoids, tannins, and saponins. Among these, flavonoids stand out as potent antioxidants that have the capacity to diminish free radicals and generate various flavonoid compounds (Hikal *et al.* 2021) [17].

Gallocatechin, recognized as an antioxidative compound, has been detected in the banana peel extract. Notably, the concentration of gallocatechin in the banana peel is significantly greater at 158 mg per 100 grams of dry weight, in contrast to the pulp's content at 29.6 mg per 100 grams of dry weight. The antioxidant capacity of the banana peel extract in combatting lipid autoxidation exceeded that of the banana pulp extract, and this aligns with the elevated presence of gallocatechin in the peel. The enhanced gallocatechin levels in the banana peel are likely responsible for its superior antioxidative effects (Someya *et al.* 2002) [37].

Value added products from banana peel

The considerable concentration of organic components such as lipids, proteins, and carbohydrates in banana peels signifies their capacity to serve as an excellent source of fibers and carbohydrates. The presence of high fiber content further underscores the potential of banana peels in addressing constipation and promoting general health and well-being. The limited shelf life and amplified production demands necessitate the creation of non-traditional banana-derived products that do not require any gel additives. The incorporation of this property can facilitate the development of diverse unconventional commodities derived from banana peels. The standardization and production of jellies using banana peels have been found to be nutritive, health-enhancing, and more desirable compared to pills or tablets. Given its digestibility and delightful texture, jelly remains a popular dessert for individuals of all ages (Anjum *et al.* 2014) [6].

Study has been done to cultivate cookies that are enriched with fiber and minerals through the incorporation of banana and banana peel flour, which are typically disregarded in Bangladesh despite their substantial nutrient content, including dietary fiber, essential vitamins, and minerals. The research endeavors to evaluate the effects of varying the amount of wheat flour in cookies with banana and banana peel flour, exploring the impact on texture, sensory attributes, and nutritional composition. The energy levels of the cookies exhibit a range that spans from 480 Kcal to 513 Kcal per 100 g. Notably, the cookies that are composed of 15% banana and banana peel flour exhibit the lowest value. Furthermore, the incorporation of 10% banana and banana peel flour in cookies has been observed to be more satisfactory, as indicated by all quality factors (Alam *et al.* 2020) [5].

Green Banana Peel Flour (GBPF) represents a promising functional ingredient for snack formulations, given its considerable dietary fiber, carbohydrate, and nutrient content. Through utilization of a fluidized bed dryer, the GBPF obtained from banana peels offers good microbiological quality that renders it appropriate for integration into nutritional recipes. Within the context of the target population, namely university students who exhibit insufficient dietary fiber intake, the designed nutritional recipe incorporating GBPF satisfies both energy and dietary fiber demands (Acosta- coello *et al.*, 2021) [3].

Three distinct blends containing varied concentrations of banana peel were formulated and proceeded to evaluate their morphological parameters. This assessment allowed to uncover the inherent properties of the powders in question. The blends containing banana peel displayed significantly higher antioxidant properties. This finding suggests that banana peel may serve as a highly desirable option for the production of powders with exceptional antioxidant capabilities (Martins *et al.*, 2019) [21-22].

The reduction of industrial waste can be achieved through the conversion of banana peels into flour, which may serve as an economical food ingredient with improved nutritional value and elevated dietary fiber content for other food products. The utilization of unripe banana peel flour (UBPF) as a partial substitute in biscuit formulations considerably elevates the total dietary fiber content of the biscuits while simultaneously reducing the starch digestion rate, leading to a lower estimated glycemic index (eGI) of the biscuits. This indicates that UBPF has the potential to enhance the nutritional quality of food and decrease the glycemic index of food products (Bakar *et al.*, 2020) [8].

For muffin production wheat flour can be substituted with banana peels. In one study the muffin dough was supplemented with varying proportions of banana peels (10%, 20%, and 30%) and to determine the polyphenol contents of fortified and control muffins, distinct extraction mediums were employed. The most noteworthy quantity of polyphenol was detected in the methanol-treated microwave processed 30% banana peel muffins (7.92 gm GAE/100 gm) and baking oven processed 30% banana peel muffins (7.77 gm GAE/100 gm). The sensory evaluations, on the other hand, revealed that the microwave processed 30% banana peel muffins and baking oven processed 20% banana peel muffins had the greatest overall acceptance (Chakraborty *et al.*, 2017) [12]. In table 4 some of the value-added products have been discussed.

Table 4: Value added products from banana peel

Name of product	Variety	Purpose
Banana peel biscuits	Local Banana peels + wheat flour	Provide antioxidant and total phenolic content without affecting physical and nutritional properties.
Banana peel flakes	Kothiya, Alpan, Batisha & G-9	Minimum browning and can be eaten as breakfast (banana flakes + milk), snacks by all age group people.
Chicken sausage	Saba variety (genome BBB)	Increase water holding capacity and dietary fibre content, and decrease fat content in the sausage.
Formulation of yogurt with banana peel		Total phenol content increases.
Instant soup mix (ISM) from banana peel	Nendran	3 months shelf life, cheap, healthy, easy to cook in busy morning
Jelly	*Musa acuminata* × *Musa balbisiana* 'Pisang Awak'	This variety banana peel was a good source of pectin, improves firmness of jelly
Production of amylase, cellulase	Local banana	Used in food processing, textile industry & commercially amylase used as substrate *Bacillus subtilis* and *Bacillus diastaticus*
Ready to cook (RTC) curry mix from banana peel	Nendran	Healthy, easy to cook in busy morning
Sauce from banana peel	Nendran	Healthy, easy to cook in busy morning
Vanillin was used as a flavoring ingredient	Local banana	*Enterobacter hormaechei* was used to extract ferulic acid from banana peels convert into bio-vanillin.
Yellow noodles	(Saba is local name of banana in Philippines)	These noodles balance the nutritional levels in human body

Table showcasing the efficient use of banana peels in the food and beverage manufacturing sector.
Source- (Bhavani *et al.*, 2023) [10]

An antioxidant lotion made from banana peel can tame the menace of free radicals which contribute to the genesis of skin cancer. The formulation of the lotion boasts a pleasingly soft and smooth texture, devoid of stickiness, and operates on a cellular level.

The lotion maintains a pH level falling within the range of 5.0 to 5.5, harmonizing with the pH spectrum of the human skin's acid mantle, which typically spans from 4.5 to 6.5. Consequently, the lotion poses no threat to the integrity of the skin's acid mantle layer. Moreover, the moisturizer, derived from banana peels, exhibits an organic essence, yielding no adverse effects upon human skin (Bhavani *et al.*, 2023) [10].

Health benefits of banana peel

Anti- inflammatory

The peel of a banana is abundant in bioactive elements such as carotenoids polyphenols, phytosterols, biogenic amines and antioxidants.

These components have the potential to lower the susceptibility to diseases such as cancer. The antioxidants found in banana peels are essential for eliminating toxins from the human body. Furthermore, banana peels contain essential minerals like calcium, iron, phosphorus, sodium and magnesium, contributing to overall well-being. The dietary fiber present in banana peels can effectively address issues related to constipation. Moreover, the anti-inflammatory properties of banana peels can be harnessed to manage, decrease, and treat inflammation as well as infections (Bhavani *et al*. 2023) [10].

The antioxidants like ascorbic acid and cyanidin that are found in banana peels counter inflammation by preventing the breakdown of fibroblasts, inhibiting the activities of reactive oxygen species (ROS) and preserving protease inhibitors against oxidative harm. Trigonelline which is an anti-inflammatory agent found in banana peel Inhibits the activity of bacterial enzymes and the synthesis of nucleic acids. Another case in point is isovanillic acid, which is accountable for diminishing the production of inflammatory signaling molecules and cytokines. (Savitri *et al.*, 2022).

Anticancer

The portion of hexane extracted from both the peel and pulp of the banana fruit (*Musa sapientum*). have been found to have anti-cancer properties against a particular type of cancer cell line derived from human colon tissue, known as the cell line associated with colon carcinoma, known as HCT-116. The extract from both the peel and pulp was noted to hinder cell growth by triggering cytotoxic effects. In laboratory investigations, the aqueous methanol extract obtained from Nendran banana peel showed notable ability to induce apoptosis in a concentration-dependent manner, exhibiting anti-tumor effects (Mondal *et al.*, 2021) [23].

Wound healing

The process of wound healing encompasses a range of molecular and cellular mechanisms aimed at repairing damaged tissues. Numerous studies have consistently identified plant-derived compounds that play a role in hemostasis, or stopping bleeding. These include flavonoids, saponins, and tannins, all of which are present in the peels of Kepok bananas (*Musa paradisiaca L.*). Flavonoids impact the function of capillary blood vessels, saponins contribute to hemostasis by reducing blood clotting, and tannins can induce vasoconstriction in capillary blood vessels (Achmad & Putri, 2021) [2].

The Gallocatechin found in banana peel is a prevalent group of natural phenolic compounds known for their antioxidant properties. The gallocatechin-rich extract (GE) from *Musa spp* peel (106.6 µg/mL) reduce the time required for epithelization, allowing the healing of lesions in just 9 days. Additionally, GE treatment lead to an increase in hydroxyproline content throughout the treatment period.

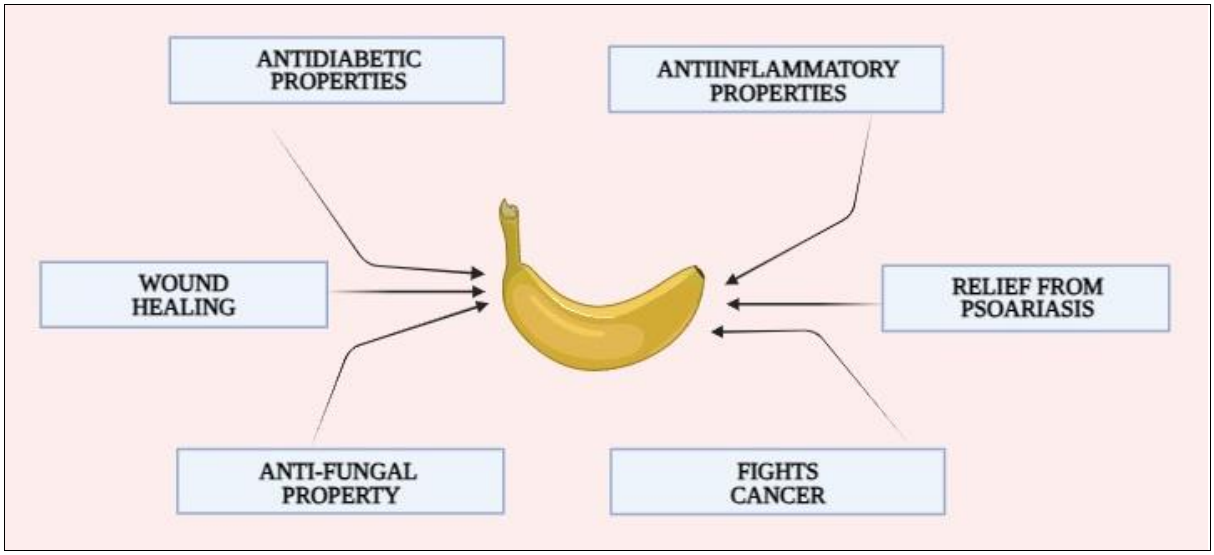


Fig 2: Health benefits of banana peel

Antidiabetic properties

The potential antidiabetic properties of banana peel extract, specifically in relation to its impact on hyperlipidemia, hyperglycemia and oxidative stress in diabetes mellitus has been studied. The presence of lignin, pectin, cellulose and hemicellulose in banana peel is associated with a decline in blood glucose levels and the prevention of hypercholesterolemia. The ability of banana peel extract to act as an antioxidant is attributed to the existence of dopamine and L-dopa, contributing to the mitigation of oxidative stress associated with diabetes. Extract from banana peels can function as an alternative treatment for type 2 diabetes. To elucidate the precise mechanism behind its antidiabetic effects and identify the optimal dosage, additional thorough investigations involving both chemical and pharmacological aspects are essential. (Fitriani *et al.*, 2015) [14].

Antifungal Property for scalp fungi

Extract derived from dried Kadali banana peel powder and its ash exhibits antifungal properties against Aspergillus niger. Therefore, the peel powder can be used to treat scalp fungi. (Prakash *et al.*, 2017) [28].

Provide relief from Psoariasis

Psoriasis is a dermatological condition that is inherited dominantly through autosomal genes. It is characterized by an accelerated life cycle of skin cells, leading to the formation of thick, scaly, and white patches or plaques on the skin. Banana peels contain inherent properties with natural anti-inflammatory, antiseptic, and cooling effects, which can potentially provide relief and mitigate the intensity of the symptoms associated with this condition (Thomas & Krishnakumar, 2017) [38].

Conclusion

Bananas are a globally significant staple crop, with a rich diversity of uses beyond their delicious pulp. Banana peels, often underutilized, are a nutrient-dense source of carbohydrates, protein, vitamins, and minerals. They possess bioactive components, including flavonoids, phenolic compounds, and carotenoids, with high antioxidant and antimicrobial properties. These properties have the potential to promote good health and prevent diseases. The increasing global production and consumption of bananas contribute to environmental challenges, making the proper utilization of banana peels even more crucial. Natural compounds derived from plant sources, including banana peels, have gained recognition for their growth-stimulating and antimicrobial properties, as well as their nutritional value. Banana peels are rich in leucine and lysine. Leucine has potential long-term health benefits, including weight gain that has been induced by dieting and hyperglycemia. Banana peels are a treasure trove of bioactive compounds, offering potential health benefits and applications in various industries. Further research and utilization of these valuable compounds in banana peels have the potential to promote health, reduce waste, and contribute to various industries. banana peels have emerged as a remarkable and versatile resource with significant potential for both the food industry and health-related applications. The concentration of essential organic components in banana peels, including lipids, proteins, carbohydrates, and notably, high dietary fiber, signifies their ability to serve as valuable sources of nutrition and dietary fiber. Furthermore, their incorporation into non-traditional food products, such as jellies, cookies, pasta, and more, has been shown to enhance nutritional value, promote health, and address various dietary needs. Peels of banana possess anticancer, anti-inflammatory, antidiabetic, antifungal, and wound-healing properties making them valuable in healthcare and cosmetics. The extensive research conducted on banana peels has brought to light their significant value, which is often ignored. Not only do they help in reducing food waste, but they also enhance nutrition and promote good health. This demonstrates their potential in numerous practical applications, not only in the kitchen but also beyond it.

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