applied sciences

MDPI

Review

Banana Peels: A Genuine Waste or a Wonderful Opportunity?

Mursleen Yasin , Shreya Gangan and Sunil K. Panchal *

School of Science, Western Sydney University, Hawkesbury Campus, Richmond, NSW 2753, Australia; 20485678@student.westernsydney.edu.au (M.Y.); sagangan21@gmail.com (S.G.)
* Correspondence: s.panchal@westernsydney.edu.au; Tel.: +61-7-4570-1932

Abstract: Banana is the second-highest fruit produced in the world and is a staple food for over 400 million people. Only 40% of the crop is utilised, leading to 114 million tonnes of banana waste annually. Banana peel constitutes about ~40% of the whole fruit, and it is considered a domestic and food industry waste. It is enriched with macronutrients, micronutrients and bioactive compounds, which can provide antioxidant, anti-microbial, antibiotic, pharmaceutical and nutraceutical properties. Banana peels also have higher nutrient value than banana pulp, and they are used in traditional medicines to treat diabetes, diarrhoea, inflammation, ulcers, burns and cough. Given its diverse bioactive properties, banana peel waste is now being explored within the framework of a circular economy to promote waste recycling and reduce environmental impact. This review highlights the nutritional and health properties of banana peel while providing opportunities for waste reduction. Potential applications of banana peels include anti-cancer and anti-fungal agents, biosorbents, natural emulsifiers, reducing agents, biofertilisers, food industry ingredients for bakery products, natural preservatives and food fortification. Exploring banana peel waste potential not only contributes to sustainable waste management but also enhances environmentally friendly innovation for the benefit of human health and the environment.

Keywords: banana waste; banana peel; bioactive compounds; phytochemicals; circular economy; waste recycle; food fortification

Academic Editors: Silvia Tabasso and Emanuela Calcio Gaudino

Received: 20 January 2025
Revised: 8 March 2025
Accepted: 11 March 2025
Published: 14 March 2025

Citation: Yasin, M.; Gangan, S.; Panchal, S.K. Banana Peels: A Genuine Waste or a Wonderful Opportunity? *Appl. Sci.* **2025**, *15*, 3195. https://doi.org/10.3390/app15063195

1. Introduction

Fruit and vegetables are essential parts of the human diet. The recommended daily intake of vegetables is five servings, and for fruit, it is two servings. The Banana (genus *Musa*) is one of the most important fruits and belongs to the Musaceae family. The genus *Musa* has over 50 species, and its varieties are differentiated based on the way of consumption (cooking, dessert or fresh) [1]. After citrus, banana is the highest-produced fruit globally [2] and ranked fourth in agricultural commodity production after rice, wheat and milk [3,4]. It is usually grown in 150 countries of tropical and sub-tropical regions of the world [5]. India is the highest banana-producing country, with ~34.5 million tonnes of bananas in 2022, which is one-third of the total global production [6,7]. The production in India was almost three times that in China (~11.8 million tonnes), which is the second largest producer of banana, followed by Indonesia (~9.2 million tonnes) (Figure 1) [7]. Overall, Asia contributes 51% towards banana production, followed by the Americas (24%). Oceania only covers 1.2% of the total banana production in the world. According to the Australian Banana Growers Council, Australia produced 362,000 tonnes of bananas in 2020/2021. The most common varieties grown in India, the Philippines and Ecuador belong to the sub-groups Cavendish or Gros Michel [8,9].

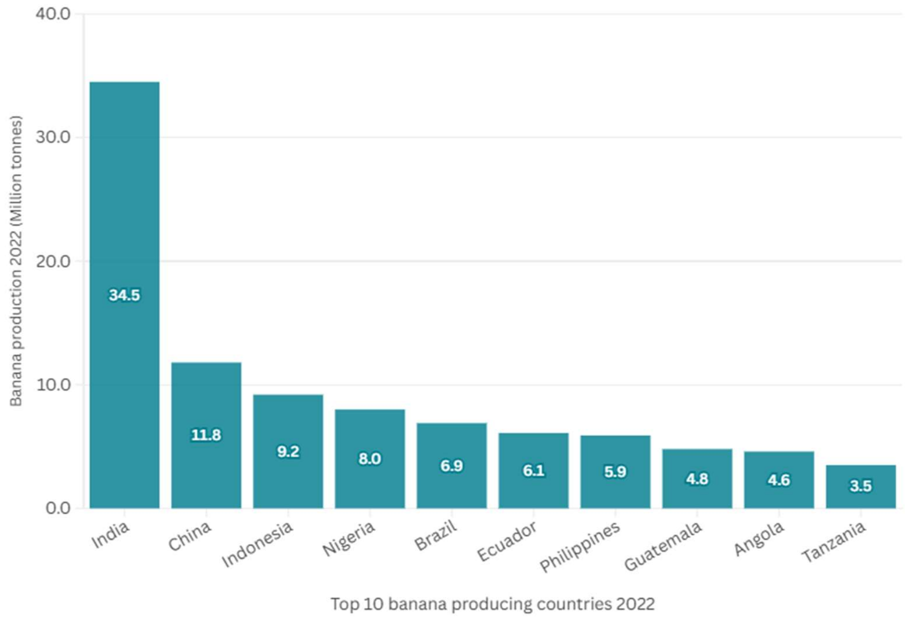

Figure 1. The top ten banana-producing countries in 2022 [7].

In tropical and subtropical regions, banana cultivation is a source of nutrition and a major contributor to the national and local economy in the producing countries. Globally, 15% of the bananas are exported to non-producing countries to provide nutritional diversity in those areas [10,11]. For instance, in Ecuador and Costa Rica, banana and banana products are the second largest agricultural commodities [10]. Banana is evaluated on different external and internal factors for export. The outer appearance is based on the peel colour, fruit shape and size, as well as the defects on the peel. The fruit quality parameters are taste, sweetness, texture, aroma, shelf-life and nutritional values of the fruit [12]. Therefore, banana export is difficult and is limited. Moreover, removal of debris or dust from the fruit, blowing of adjacent leaves and rubbing of petioles also lead to high surface scarring and physical damage to the fruit [12]. This ultimately leads to a reduced export of banana.

The utilisation of banana peel waste is becoming popular to progress toward sustainable development goals. Recently, banana fibre has been used by the textile industry to promote natural fibre used in fabric production [13]. Moreover, banana fibre is also used in the paper, cardboard and packaging industries, along with novel banana leather. Banana fibre has been used to make paper, which is then used to make wallets and paintings [14]. Some applications of banana peel waste include use in agriculture, food and pharmaceutical industries, such as biodegradable pots, biofertilisers, food preservatives, functional foods, antioxidants and anti-microbial drug ingredients [4,15–21]. Innovative extraction techniques such as microwave-assisted extraction, ultrasound-assisted extraction, and pulse-electric-field extraction using deep eutectic and compressed solvents are now suggested for the isolation of bioactive compounds from peels. These novel techniques provide time- and energy-efficient extraction and a higher yield of bioactive ingredients [22]. For example, pulse-electric-field extraction had a higher phenolic compound concentration extracted from Kepok banana peel than the solvent extraction method [23]. However, more research is needed to test novel technologies to evaluate the yield efficiency of bioactive compounds from banana peel and their impact on the environment. Further studies are required to understand the full potential of banana peel and increase the efficacy of utilising this waste for practical application in the circular economy.

The concept of circular economy has gained popularity with the increased amount of food and agro-waste and its harmful disposal to the land. It is defined as reusing or reducing waste by recycling it into useful products and valuable resources. The eco-innovation strategy aims at a 'zero waste' economy [24]. The horticulture products, including mango, apple, banana, citrus, grapes, watermelon, onion, tomatoes, potatoes, cabbage, broccoli, eggplant and cucumber, are sources of agro-waste as seeds, shells, leaves, pseudo stem, pomace, rind and pulp [25]. The agro-waste is a source of many valuable biochemicals and natural resources such as polyphenols, carbohydrates, fibre, prebiotics, protein, pigments, vitamins and lipids. Innovative strategies are now being explored to valorise waste. For example, polyphenols, flavonoids and vitamin C from citrus peels are used as antioxidants, anti-bacterial agents, food packaging and food fortification. Apple pomace is used in the food industry to make ice cream, biscuits, muffins, mayonnaise and crackers and in the pharmaceutical industry as a stabilising agent and nanoparticles [26]. Banana peel is also used for waste valorisation in a similar way to promote the circular economy strategy. This review highlights the potential of banana peel waste as a valuable resource, emphasising its diverse applications across industries while contributing to sustainability, waste reduction and innovative product development.

2. Dessert Bananas and Cooking Bananas

Banana is a perennial crop that is produced around the year. On average, a fruit weighs 125 g, which constitutes ~75% water and the rest is dry matter [27]. The colour of the fruits varies from red to purple and yellow depending on the ripening stages [27].

On a culinary basis, banana production is divided into two categories: dessert bananas and cooked bananas (plantains). The pulp of dessert bananas is firm when unripe and soft during maturation [28]. Therefore, these fruits are eaten raw after ripening or cooked, baked, dried and ground for flour. Moreover, they are also processed to make vinegar, starch and chips. This group belongs to *M. acuminata* or hybrid *Musa* × *paradisiaca* or *M. sapientum* (*M. acuminata* × *M. balbisiana*) Morton. Almost 56% of global banana production is for the dessert category, and ~97% of the banana export is for this variety [29]. Cavendish is the most popular cultivar of this group [30]. Cooking bananas are harvested at the green stage and can be used in different dishes and to make starch. The consumption and popularity of banana sub-groups are differentiated by region, cultivar and sugar concentration. Dessert banana has higher demand worldwide whereas cooking banana is mostly consumed in developing countries such as Africa and Southeast Asia [31]. In Asia, cooking varieties are usually from sub-groups of the cultivar "pisang awak" [31]. Cooking bananas are usually larger and angular, with more starch than dessert bananas.

On the basis of ploidy and genome, bananas are grouped as diploid, triploid or tetraploid. Triploid bananas are cultivated the most in the world. The culinary groups are developed by intra- or inter-hybridisation between two ancestors, i.e., *M. acuminata* Colla (A genome) and *M. balbisiana* Colla (B genome) [32]. The genomic groups of dessert, plantains and cooking bananas are AAA, AAB and ABB, respectively [31,33].

3. Banana Composition and Waste

Banana fruit is important economically and nutritionally for food security and it is a staple food for 400 million people around the world [34]. Banana ranks second highest in the fruit category after citrus and fourth most important crop after rice, wheat and corn [3,4]. The consumption of banana has increased with the changes in dietary patterns, especially for increasing fibre intake, which is an essential nutrient. Uganda was the country with the highest per capita banana consumption in 2023. The average intake per person was ~300 kg per year in Uganda, followed by Papua New Guinea, with ~120 kg per person consumption every year. Other higher consumers of the banana per capita are Samoa, Rwanda, Laos, Burundi, Dominica and Peru [7]. The vast popularity of the banana is due to their high nutritional value and soft texture. Banana is enriched with fibre, sugars, vitamin B_6, vitamin

C, manganese, amino acids, and phenolics such as gallic acid, catechin, epicatechin, tannins and anthocyanins [35]. It is a low-fat food with a high energy content [35].

The waste produced from banana includes deformed, small size and rotten fruit, peel, leaves, pseudo stem parts such as flowers and underground stem (rhizome). Banana peel constitutes ~40% of the fruit and pseudo stem parts make up 60% of the total plant biomass. Harvesting of each tonne of banana fruit generates about 3 tonnes of pseudo stem, 150 kg of rachis, 480 kg of leaves and 100 kg of rejected fruit waste [36]. Some on-farm ways to reuse the waste include putting waste fruit in feedstock with rice bran, molasses, legumes and grasses. The stalk can be chopped or fed directly to the animals [37]. Banana peel is also used as animal food and added to the feedstock of monkeys, poultry, goats, livestock, poultry, etc. [27]. Pseudo stem, leaves and fruit stalks are also used as mulch or composted for manure [37]. However, the conventional ways of banana waste management are now discouraged because of increased environmental concerns and the spread of plant diseases. One of the main reasons for banana wilt spread is the application of manure or mulch from infected banana plants into the banana field [38]. Over the last decade, increased consumer demand for banana has also increased waste production to ~114 million tonnes every year. Only about 40% of the total banana crop is used and the rest is treated as waste biomass [2]. The percentage of losses and waste in the supply chain can reach up to 35% [39]. The banana supply chain is affected by several challenges at each stage that ultimately contribute to waste and loss. Different challenges in each stage are outlined in Figure 2 [40].

Apart from losses at plantation and harvest stages, the banana is prone to many postharvest losses because of its climacteric nature. The metabolic processes, such as respiration and transpiration, continue after harvesting, making it more perishable [41]. Therefore, temperature plays a key role during the storage of banana which is suggested to be kept at 13 °C at both green and ripen stages. Banana is prone to chilling injury at lower temperatures (below 10 °C) and rapid ripening above 14 °C [41,42]. It is physiologically sensitive and gets easily damaged due to mishandling during harvesting and postharvest stages. Moreover, mechanical damage can cause bruises and injuries on the peel, which appear as brownish-black spots on the skin [43]. The fruit might be unacceptable for the market due to the discolouration of the skin. The mechanical damage to the fruit can further cause changes in chemical composition, sugar content, weight loss, colour change, softening and browning of fruit, weight loss, and ultimately, economic loss.

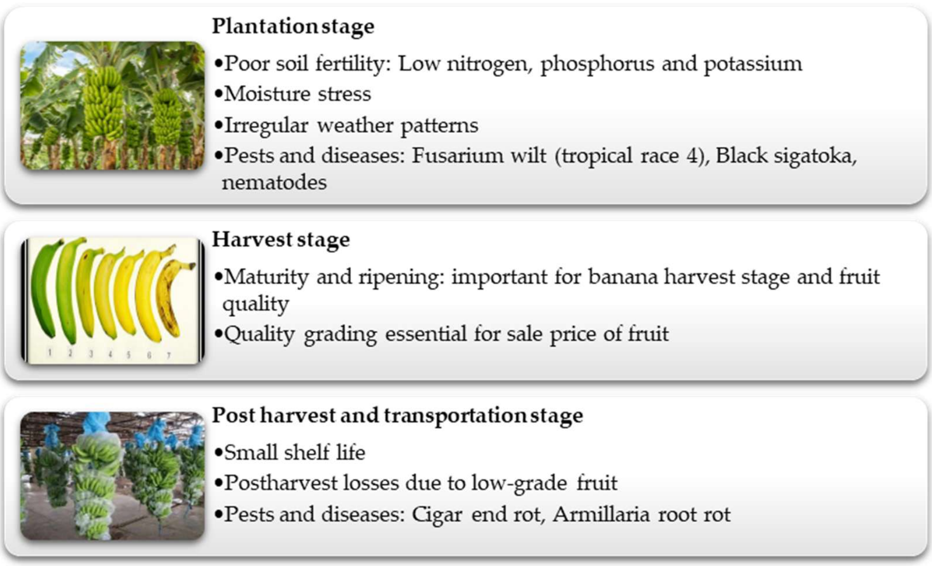

Figure 2. Challenges at each stage of banana production lead to waste production [44].

3.1. Carbon Footprint and Environmental Impacts of Banana Waste

With the increased awareness of climate change and global warming, consumers are now demanding products with the least carbon footprint or global impact. Environmental indicators such as life cycle assessment and carbon footprint are used to evaluate the overall environmental impact of the products. Life cycle assessment helps to understand the overall strategies of the product development to keep it environmentally friendly by analysing the whole product cycle from production to consumption [45]. According to a study, the Ecuadorian banana had a carbon footprint of 1.28 tonnes of CO_2 per tonne of banana [46]. The life cycle assessment of Ecuadorian banana from different stages of the supply chain indicated that the growing stage is the major contributor towards the carbon emission (193.94–220.37 kg CO_2 equivalent/tonnes banana) [47]. In Turkey, the highest impact is at the plantation stage, followed by the transportation stage. The waste disposal of the stems is also one of the major contributors to global warming by banana production [5]. On average, ~114 million tonnes of banana waste is produced globally every year [2]. Natural decomposition of this banana waste releases greenhouse gases when it is dumped in landfills [48].

3.2. Banana Peel

Banana peel is a by-product of the food processing industry and household consumption. Peel is the outer layer or covering that protects the soft, edible part or pulp of the fruit. It consists of ~40% of the total fruit weight, thus banana consumption or use leads to the production of large quantities of banana peel waste every year [49]. It is estimated that around 36 million tonnes of banana peels are produced every year [49]. Traditionally, it has been used for cooking and medicinal purposes, as well as in animal feed. However, a large portion is treated as general waste and discarded in landfills [50]. A study revealed that in Costa Rica, the disposal of rejected bananas in the rivers has caused an imbalance in the aquatic ecosystem. The oxygen demand in the rivers increased because of the higher carbohydrate content in banana biomass, leading to the reduction of aquatic animals [51].

Due to the environmental impact, banana peel waste is now being explored for its potential antioxidant, anti-microbial, antibiotic, pharmaceutical and nutraceutical properties [52]. Previously, it has been used to treat ulcers, burns, diarrhoea, inflammation, cough and diabetes [53].

3.2.1. Nutritional Composition of Banana Peel

Cultivar, variety and ripening stage of the fruit define the nutrient composition of banana peel. Banana peel composition is variable based on these above factors and contains crude protein (2–8%), crude fat (3–11%), carbohydrate (3%) and polyunsaturated fatty acids such as linoleic acid [54]. Table 1 represents the comparison of the proximate composition of peels between the two categories (dessert and cooking) and different cultivars. Banana peels from various cultivars and groups were analysed to compare their nutrient composition. As shown in Table 1, the ripening stage and banana type significantly influence carbohydrate content, including starch and sugar. In the unripe stage, carbohydrates primarily exist as starch. However, as ripening progresses, starch molecules undergo hydrolysis, converting into soluble sugars and leading to an increased total soluble sugar content in ripe banana peels [55]. Moreover, plantain peel has an amylose percentage of starch ranging from 22% to 38%, which makes it less sweet and more resistant to starch hydrolysis [56].

Table 1. Differences between the proximate composition of banana peel from dessert banana and cooked banana.

Component (% of Dry Matter)	Dessert Banana Peel			Plantain Peel (Cooking Banana)		
	Cavendish [57]	***M. sinensis* [58]**	**Yangambi Km5 [59]**	**French Clair [57]**	***M. paradisiaca* [58]**	**Big Ebanga [59]**
Total dietary fibre	43.2 (green) 49.7 (ripe)	4.17	49.9 (green) 47.9 (ripe)	32.9 (green) 46.9 (ripe)	4.06	35.9 (green) 37.3 (ripe)
Crude protein	6.3 (green) 8.1 (ripe)	2.48	6.9 (green) 7.9 (ripe)	8.3 (green) 9.1 (ripe)	2.23	8.1 (green) 8.6 (ripe)
Starch	11.1 (green) 3.3 (ripe)	-	14 (green) 2.6 (ripe)	35.4 (green) 3.2 (ripe)	-	39.3(green) 0.1 (ripe)
Other soluble sugars	3.7 (green) 32 (ripe)	67.29 (total sugar)	1.4 (green) 33.2 (ripe)	1.7 (green) 42.2 (ripe)	68.57 (total sugar)	4.3 (green) 38.3 (ripe)
Cellulose	-	-	15.2 (green) 15.6 (ripe)	-	-	6.4 (green) 6.1 (ripe)
Crude fat	3.8 (green) 5.7 (ripe)	1.24	6.3 (green) 10.9 (ripe)	4.6 (green) 5.9 (ripe)	1.10	2.2 (green) 3.6 (ripe)
Lignin	-	-	7.3 (green) 13.3 (ripe)	-	-	7.9 (green) 15 (ripe)
Ash	9.6 (green) 12.8 (ripe)	3.95	10.4 (green) 10.7 (ripe)	8.8 (green) 8.2 (ripe)	2.23	6.4 (green) 7.4 (ripe)
Amino acids	4.3 (green) 4.6 (ripe)	-	-	5.8 (green) 5.6 (ripe)	-	-

Banana peel is enriched with essential macronutrients and micronutrients. It comprises Ca, K, Mg, P, Zn, Fe, Cu, Mn and amino acids such as leucine, valine, phenylalanine and threonine. Banana peel is also enriched with pectin (10–21%), lignin (6–12%), cellulose (~6–15%) and hemicellulose (6.4–20%) [60]. The most abundant mineral is P, followed by Na, Ca, Fe and Mg in the peel of *Musa sapientum* [61]. Their concentrations (mg/100 g) in the peel were found to be 211.3, 115.1, 59.1, 47.0 and 45.5, respectively [30,61]. In another study, K content was highest in the peel of *M. sinensis*, followed by Ca and P (1708.6, 40.9, 28.62 and 27.84 mg/100 g, respectively) [58]. Thus, the abundant minerals found in the peel are P and K. However, the results vary across the studies depending on the type of banana, its maturation stage and the method used for respective analysis [44,58,61]. The major minerals found in banana pulp are K, Mg, P and Na, while peel has higher concentrations of P, Ca, Na, Mg and K, as shown in Table 2.

However, the concentrations of these elements were observed to change in different studies depending on the species, cultivar and maturation stage. A study revealed a lower Fe concentration in three banana varieties: Pachabale (10 mg/100 g), Nendranbale (4 mg/100 g) and Yelakkibale (3.33 mg/100 g). However, they observed a Ca concentration of 44.68 mg/100 g in Yelakkiale banana peels. Vitamin C (17.83 mg/100 g), tannins (1073 mg/100 g), phytic acid and oxalates were also higher in the Yelakkiale variety [62]. Table 2 describes the difference in mineral composition between banana pulp and banana peel.

Table 2. Differences between mineral composition of banana pulp and peel.

Minerals	Banana Pulp (*M. sinensis*) mg/100 g [44]	Banana Peel (*M. sinensis*) mg/100 g [58]	Banana Peel (*M. sapientum*) mg/100 g [61]	Banana Peel (*Musa* ABB) mg/100 g [44]
P	15.47	27.84	211.3	283.1
Fe	0.06	0.07	47	2.72
Mg	29.39	28.62	44.5	138.12
K	350.39	1708.6	4.39	3502.5
Ca	4.64	40.9	59.1	142.9
Na	7.73	9.28	115.1	43.1
Zn	0.15	0.39	0.033	1.64
Cu	0.10	0.06	0.51	0.007
N	273.88	344.79	397.5	-
Mn	0.18	0.35	0.702	0.85

3.2.2. Traditional Uses of Peel and Pulp

Banana pulp, peel and plant are being used as traditional and local medicine in many cultures in Asia, Africa, Oceania and America [63]. The peel of ripened bananas can be used as an antiseptic for wounds to release pain and swelling [64]. It can be wrapped directly on the injury site, with the inner layering touching the skin. In Brazil, banana peels have traditionally been used to treat burn injuries [65]. Peel can also be used to soothe warts and mosquito bites by rubbing it onto the skin [53]. Banana tree is also used for the treatment of anaemia. Psudo-stem is used to treat diarrhoea in children in the form of sweetened juice. The flower of banana is used to treat eye problems and pulmonary diseases [65]. In Asian countries such as India and Pakistan, bananas have been used to treat inflammation, gastrointestinal tract disorders, gastritis, diarrhoea, diabetes and cough. A study reported that a banana diet is used subsequently for children during diarrhoeal episodes [66]. In the Philippines, different parts of the plant are used to treat different ailments. For example, young leaves are used for fever and headache, fruit is used for diarrhoea and juice is used for abdominal pain. Banana is also used for depression, anaemia and blood pressure because of their higher content of omega-3/omega-6 polyunsaturated fatty acids, Fe and K, respectively [53,67,68]. The vitamins B_6 and B_{12}, Mg and K in bananas help the body in nicotine withdrawal and hence can help to quit smoking. Moreover, the high fibre content helps to treat constipation, and high sugar helps to treat hangovers, heartburn and ulcers because of its antacid potential [53].

3.3. Bioactive Compounds in Banana Peel

The composition of banana peel is a complex matrix of many important primary and secondary metabolites, such as phytochemicals, antioxidants, anthocyanins, amines, carotenoids and catecholamines (Figure 3) [69,70].

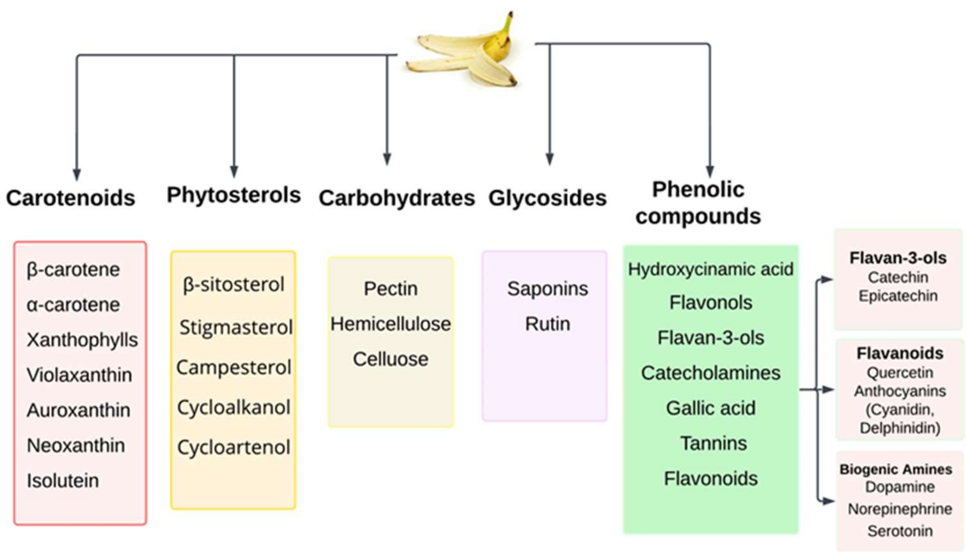

Figure 3. Phytochemicals present in banana peel.

Bioactive compounds in banana peels are secondary metabolites with therapeutic potentials, such as antioxidant effects. Phenolic compounds and carotenoids are the main phytochemicals found in banana peels [71]. Health benefits associated with these compounds are highlighted below. Phenolics, carotenoids, flavonoids and biogenic amines found in ripened and raw bananas are valuable components that can support health benefits [72]. Banana pulp also contains catecholamines (such as serotonin and dopamine), tryptophan and indole compounds [73].

3.3.1. Phenolic Compounds

Phenolic compounds, such as gallic acid, catechin, epicatechin, tannins and anthocyanins, are present in the pulp and peel of banana. Flavonols are the main flavonoids found in the banana, including quercetin, myricetin, kaempferol and cyanidin [74]. These flavonoids have shown many health benefits in several research studies [75–77]. Flavonoids are associated with antioxidant, anti-microbial and anti-inflammatory properties, which are important in preventing cardiovascular diseases, cancer, diabetes and obesity. Flavonoids serve as protective scavengers against the reactive oxygen species and free radicals formed from oxygen that cause ageing and several illnesses [74]. The most abundant flavonoids present in the banana peel are quercetin, myricetin, kaempferol, rutin and cyanidin. Galocatechin was found to be 158 mg/100 g in banana peel, which is the most potent component for antioxidant activity in the peel [78]. A study identified rutin as the most abundant flavonol in the banana peel of the red Yade variety, followed by kaempferol-3-rutinoside and quercetin-deoxyhexose-hexoside (~500 μg/g dry matter, ~175 μg/g dry matter and ~75 μg/g dry matter, respectively) [79].

3.3.2. Carotenoids

Due to their distinctive physiological properties, such as their role as pro-vitamins and as antioxidants, particularly in the scavenging of singlet oxygen, carotenoids have positive effects on health [80]. These are important for performing activities such as pro-vitamin A, antioxidants, cell communication, improved immunity, UV skin protection and macula protection [80]. Carotenoids have been extensively researched for their potential to reduce the risk of illnesses, notably several cancers and eye conditions that were becoming increasingly prevalent across the world. Carotenoids are helpful in preventing cancer, cardiovascular diseases, cataracts and macular degeneration [81]. These are one of the most significant groups of plant pigments, which are categorised as oxygenated hydrocarbon derivatives and pure hydrocarbons (carotenes, xanthophylls). These are by-products of the isoprenoid biosynthesis pathway, and their primary functions in plants are as antioxidants and auxiliary pigments for photosynthesis [80]. Major carotenoids identified in banana peel were lutein, α-carotene, β-carotene, β-cryptoxanthin and lycopene, ranging between 159.66 to 2553.51 μg/100 g among 14 different banana cultivars. Lutein concentration was highest in the unripe peel [82]. A study observed that banana peel is enriched with pro-vitamin A carotenoids such as *trans*-β-carotene, *trans*-α-carotene and *cis*-β-carotene with ~175, 165 and ~92 μg/g dry weight, respectively [83].

3.3.3. Biogenic Amines

Biogenic amines are nitrogenous substances created by the amination of aldehydes and ketones or the decarboxylation of amino acids. It has been demonstrated that banana peel and pulp contain biogenic amines such as serotonin, dopamine and norepinephrine [70]. Biogenic amines are essential for cell survival and the proper functioning of metabolic pathways, such as the synthesis of proteins and hormones and cell replication [84]. However, the excessive accumulation of biogenic amines can lead to cell toxicity and cause food poisoning, diarrhoea, vomiting, headaches, hypertension and carcinogenesis [85].

Banana peel is also enriched with tyrosinase, which is a biocatalyst that produces 3,4-dihydroxyphenyl-l-alanine (L-DOPA). L-DOPA is important as it is the precursor of dopamine and helps in the treatment of Parkinson's disease, a neurodegenerative disorder with reduced dopamine in brain cells. The use of L-DOPA alleviates dopamine by taking the precursor tyrosine across the blood-brain barrier and helps to manage the symptoms of Parkinson's disease [86]. Other bioactive amines present are spermidine, serotonin and putrescine. The biogenic amines make banana peel a useful source for maintaining cholesterol metabolism and cardiovascular diseases [15].

3.3.4. Phytosterol

In functional foods, phytosterols are naturally occurring plant sterols that have a number of favourable health-promoting benefits, including decreasing blood cholesterol and reducing intestinal absorption of dietary cholesterol. They also have anti-cancer effects and modulate the immune system [87].

Other bioactive compounds found in the banana peel are sterols and triterpenes, such as β-sitosterol, stigmasterol, campesterol, cycloalkanol, cycloartenol and 24-methylenecy cloartanol [88]. Some studies observed the total phenolic content in banana peels of 15 varieties at different ripening stages. It ranged from 29.02 to 61.00 mg gallic acid equivalent/100 g for unripe banana peels and 60.39 to 115.70 mg gallic acid equivalent/100 g for ripe banana peels [89]. Another study identified total phenols and total flavonoids to be highest with 80% methanol extraction with concentration at 17.89 mg/g dry weight and 21.04 mg/g dry weight of banana, respectively [90]. The total tannin concentration was found to be 24.2 mg/g. Tannins are important for many medicinal traits such as anti-cancer, antioxidant, anti-inflammatory and anti-bacterial properties.

4. Potentials of Banana Peels

4.1. Antioxidant Activity

Antioxidants are substances that remove free radicals from the body. One of the finest sources of antioxidants is banana peel. It has high concentrations of bioactive substances such as phenols, carotenoids, flavonoids, saponins and tannins [91]. The presence of antioxidant enzymes, including ascorbate peroxidase, catalase, peroxidase and superoxide dismutase, as well as estragole, hexadecenoic acid, ethyl ester, epicatechin and gallocatechin were detected using gas chromatography and mass spectroscopy in banana peels [92]. The banana peel's high concentrations of dopamine, L-DOPA and catecholamines promote antioxidant action [93]. Using the peels from *Musa acuminata*, a semisolid jelly was created to investigate and assess the antioxidant activity of the banana peel. Because the peel itself serves as the gelling component, commercial pectin was omitted from the jelly's formulation. The commercial jelly only has a 65% free radical scavenging activity, but the jelly with a 7% concentration of banana peel has an 84% free radical scavenging activity [94].

4.2. Anti-Bacterial Activity

Because germs are becoming more resistant to the present anti-bacterial treatments, new anti-bacterial agents are now needed. To create novel anti-bacterial agents, researchers are looking at plant materials [95]. The banana peel has anti-microbial effects against both Gram-positive and Gram-negative bacteria such as *Escherichia coli*, *Salmonella enteritidis* and *Pseudomonas aeruginosa* [91]. Gram-positive species such as *Staphylococcus aureus*, *Bacillus subtilis* and *Bacillus cereus* are impacted by banana peels. Peels are also active against *Salmonella typhi*, *Micrococcus luteus* and *Klebsiella pneumonia* [90,96]. *Aggregatibacter actinomycetemcomitans* and *Porphyromonas gingivalis* are two periodontal infections that the banana peel effectively inhibits. Compared to dried peels, fresh banana peels exhibit the largest zone of inhibition against these microorganisms [97]. Moreover, unripe bananas were observed to have higher anti-bacterial activity due to the content of bioactive compounds such as polyphenols, flavonoids, tannins, alkaloids, terpenoids and glycosides [97]. These anti-bacterial metabolites impact the cell membrane of bacteria, which leads to irregular cell shapes and, ultimately, cell death [98]. A study observed the constricted nature of banana peel tannins, which are effective on bacterial peptidoglycan and proteins, thus causing reduced bacterial activity [99].

4.3. Anti-Fungal Activity

Even the synthetic antibiotic agent falls short over the entire spectrum of anti-microbial action. Therefore, the creation of natural antibiotics with broad-spectrum action is necessary [100]. Banana peels can provide a suitable solution as they can inhibit the growth of a large variety of bacteria and fungi. Tannins, alkaloids, saponins and flavonoids from banana peels can provide these anti-microbial actions [101]. Some of the fungi impacted by banana peels are *Aspergillus niger*, *Aspergillus flavus*, *Penicillium digitatum*, *Fusarium oxysporum*, *Candida albicans*, *Saccharomyces cerevisiae* and *Penicillium citrinum*. Due to their effects against *Aspergillus oryzae* and *Rhizopus stolonifer*, banana peels can also be used as a preservative to prevent food spoilage [91].

4.4. Anti-Cancer Activity

Cancer is the leading cause of death worldwide. The efficacy of commercially available anti-cancer medications is declining as a result of rising resistance and excessive cytotoxicity. To treat and prevent cancer, new medicines are investigated [102]. The development of new treatment strategies will benefit from the examination of plant secondary metabolites for their anti-cancer capabilities [102]. Plant-based anti-cancer interventions have been investigated with positive impacts in reducing cancer-related pathologies. Flavonoids and phenols from plant sources are beneficial for the treatment of cancer, as shown in in vitro studies [102]. Due to the abundance of phytochemicals in banana peels, it has shown positive responses as an anti-cancer agent [102].

Tannins are also an important bioactive group of compounds that are enriched with anti-cancer properties. Banana peel contains tannins and studies have identified up to ~24 mg/g concentration in the peel [90]. Banana peel extracts have been used to study anti-cancer properties in vitro. Some of the cell cultures used include breast cancer cell line (MCF-7), human colorectal carcinoma (HCT-116) tumour cell lines and the human umbilical vein endothelial cells (HUVEC cell) [103]. The hexane extract of banana peel and pulp showed the highest efficacy while showing the greatest toxicity against HCT-116 (62%) and MCF-7 (61%) cell lines. In contrast, aqueous and ethanolic extracts exhibited minimal anti-proliferative activities against these cell lines. Notably, all extracts showed negligible cytotoxicity toward normal cell lines, indicating selective action against cancerous cells [103].

The banana is a rich source of carotenoids, and some members of this group, such as lycopene, have anti-cancer activity against prostate cancer in men [83]. It is suggested that higher carotenoid concentration in the diet is effective in preventing cancer, diabetes and cardiovascular diseases [104]. Phytosterols are also effective anti-cancer agents against colon, prostate and breast cancer [105]. The *n*-hexane extract of banana peel effectively inhibited the growth of colon cancer cells due to its potent anti-angiogenic properties [103].

4.5. Other Properties

Banana peel has been identified to have anti-diabetic properties. In a study, rats were orally treated with banana peel extracts from *M. sapientum*, *M. paradisiaca*, *M. cavendish* and *M. acuminata* to test glucose tolerance [106]. The results showed that peels have the capacity to lower blood glucose concentrations. Moreover, it has been suggested that banana peel has enhanced α-amylase inhibitory activity (~81% at 1000 µg/mL) when compared with lemon and pomegranate peels [107].

The anti-ulcer impacts of banana peels have also been observed. The extract of tepal and peel was tested against ulcer index, gastric wall mucus, and pH and volume of gastric juice in ulcer-induced animals. Banana tepal and peel were subjected to a cold extraction technique using methanol and concentration of phytochemicals, along with the determination of anti-ulcer activity on Swiss albino mice. The extracts of banana tepal were found to be enriched with glycosides, phenols and saponins, while the peel had higher flavonoids. Therefore, preventive effects against indomethacin- and pylorus ligation-induced ulcers by ~69 and ~43% were observed, respectively [108]. Moreover, the extract reduces the gastric juice volume, strengthens the gastric wall mucous and decreases the acidity of gastric juice [108]. Leucocyanidin, a compound present in banana peel, was found to be preventive against ulcers [74].

4.6. Pectin Extraction from Banana Peel

Components sourced from natural sources are preferred over synthetic ones for various formulations due to their non-toxic, non-irritating and inexpensive nature [109]. Pectin is a polymer that occurs in nature and includes α-(1,4)-linked D-galacturonic acid units. Pectin interacts with other cell constituents to give plants their mechanical strength [110]. Pectin is most frequently used as an emulsifier, stabiliser and gelling agent. It is seen as a very important component due to its outstanding stabilising and emulsifying abilities [111].

4.7. Banana Peel Extract as a Reducing Agent in the Formulation of Silver Nanoparticles

Silver has a crucial function in metallic nanoparticles as an inorganic anti-bacterial component. Silver nanoparticles may be made for various purposes. The preparation techniques include electrochemical, green chemistry, simple procedure and sono-chemical breakdown of silver complexes [112]. The most common and simple method for producing silver nanoparticles is the reduction of metal salts. Several chemical reducing agents are used, such as hydrazine, sodium citrate, sodium borohydride, ascorbic acid, ammonium formate and dimethylformamide, to produce stable and variably structured silver nanoparticles in an aqueous solution [113,114].

Silver nanoparticles are produced using expensive, time-consuming, energy-intensive and hazardous physical and chemical procedures. Therefore, there is an unmet need for a practical alternative to the plant extract-based method of manufacturing silver nanoparticles [115]. Because it tends to change silver ions (Ag^+ to Ag^0), banana peel extract can be utilised as a reducing agent to produce silver nanoparticles. Silver nitrate ($AgNO_3$) was reduced using banana peel extract to create silver nanoparticles [116]. Surface plasmon resonance (SPR) bands, a unique visual property of noble metals, are present. Banana peel extract is reportedly utilised to biosynthesise silver nanoparticles, which have a clearly discernible SPR band. These biosynthesised nanoparticles have high anti-bacterial activity and successfully help against clinically isolated multidrug-resistant human infections [117]. Compared to Gram-positive bacteria, Gram-negative bacteria are more resistant to them. These nanoparticles also possess powerful anti-fungal and anti-bacterial capabilities [118].

5. Other Uses of Banana Waste

5.1. Lignocellulosic Biomass for Ethanol Production

Agricultural waste from crops such as wheat straw, rice husk and corn stover is used for ethanol production from lignocellulosic waste. The banana is among the top-produced fruit [119] and researchers are now investigating the bioconversion of their waste into ethanol. Almost 2.13 tonnes of fresh lignocellulosic waste is generated with every tonne of banana production [120]. The waste parts include pseudo stem, leaves and rachis. The ethanol production from waste depends on different factors such as time, temperature, pH, particle size and fermentation process [121]. The optimum conditions for enzymatic conversion of banana waste into ethanol were identified in a study [122].

5.2. A Biosorbent of Water Pollutants

With the industrial revolution, water pollution has also increased and many harmful pollutants are released into water without proper treatment [123]. Industries release heavy metals, dyes, pesticides, chiral chemicals, pharmaceuticals and oil particles into the aquatic environment [124]. These pollutants are causing severe threats to human and aquatic life because of their carcinogenic properties. The reproductivity of fish is affected by some elements, even at very low concentrations (1.0 ng/L) [125]. There are several treatment methods being used to decontaminate the water, such as reverse osmosis, filtration, solvent extraction, chelation, ozonation, skimming, adsorption and electrophoresis. Adsorption by activated carbon is one of the most effective methods, but its application is limited due to its high cost [126]. Natural and synthetic adsorbents can be used as alternatives, such as biochar, clay, inorganic materials, chitosan and carbon nanotubes [127,128]. Although efficient, these materials mostly have complicated and expensive procedures for preparation, enhancements and regeneration. Moreover, these processes release secondary pollutants and are non-biodegradable [128]. Hence, biomass materials are now being explored for use in the adsorption of water contaminants as they are easily available, eco-friendly, biodegradable and less expensive [129,130]. The biosorbents effectively being tested are rice husk, banana peel, corn cob, potato peel, coconut husk, cocoa pod, orange peel and sugarcane bagasse [131,132].

Banana peel waste is getting attention to be explored as a biosorbent because it is available all over the world. The overall efficiency of banana peel as an adsorbent depends on factors such as water pH, temperature, contamination level, time of treatment and dosage, reusability, regeneration, thermodynamics and kinetics [133–135]. It has been observed that lower pH values are suitable for decontaminating anionic pollutants and high pH solutions for cationic compounds. The optimum time was 1 h of treatment, and banana peel is an effective biosorbent over a range of temperatures. It can undergo both exothermic and endothermic reactions, making it suitable for use in both tropical and temperate regions [136]. Biosorbent made from banana peel was tested for oil spill removal. The peel biosorbent can be reused up to 10 times after treating it with mechanical action and *n*-hexane to remove the absorbed oil [137]. Banana peel has been used to decontaminate many metals such as Cd, Cu, Pb, Fe, Sr, Zn, Ni, Mn and many dyes such as methylene blue, amido black, Congo red, etc. [128]. Further studies are required to make banana peel a more efficient biosorbent, focusing on the reusability of biomass, effectiveness on more pollutants such as Hg and As, and commercialising it on higher industrial scales [128].

5.3. Use of Banana Peel in Food Sector

The utilisation of agricultural by-products in functional food production has gained significant attention. Banana peel, rich in fibre, essential nutrients, minerals and bioactive compounds, holds promising potential for use as a value-added ingredient in functional foods [138]. Banana peel from ripe and unripe fruits are used to improve the nutritional value of food products such as noodles, jelly, meat and bakery products. Banana peel flour is used as a food fortification ingredient as it is enriched with antioxidants and dietary fibre [139].

Steamed bread was prepared by using 30% green banana pulp flour as a wheat flour substitution. The mineral comparison showed higher Mg, K, Na and Ca content than normal wheat bread, along with higher total dietary fibre and resistant starch. However, the elasticity and chewiness were negatively impacted because of the inconsistency of gluten in the pulp flour [140]. Moreover, the study also used 10% yellow banana pseudo-stem flour and observed an increase in the crust lightness, crumb, total phenolic content, ash and dietary fibre of the banana bread [140]. In another study, 10% yellow banana peel flour was used as a substitute for wheat flour to make chapati bread. The peel chapati bread was softer because of the reduced tear force and high water absorption. The total phenols and flavonoids were also enhanced in peel flour bread compared to the control. The sensory evaluation did not show a significant difference between the acceptance of 10% banana peel flour bread and wheat bread [140]. Another study observed the physiochemical and sensory properties of Egyptian Baladi flatbread made with 5% and 10% banana peel flour as a substitute for wheat flour. It reported higher protein, ash and fat content in banana peel flour bread than in normal wheat flour bread [141]. Moreover, the carbohydrate content decreased from 75% to 50.5% and 44.34%, respectively [141]. The acceptance of banana peel bread was also found to be similar to wheat bread. So, bread with low carbohydrate and enhanced fibre and phenolic content is also proposed as a better alternative for blood glucose control, insulin resistance and obesity [142]. Functional biscuits prepared with 5%, 10% and 15% banana peel flour had improved dietary fibre (~16–37%), ash, moisture content and phenolic composition. The biscuits with 10% peel flour were more accepted by the sensory panelists because of the better colour, taste and texture [143].

Banana peel is a good source of xylitol, which is a naturally produced 5C sugar in plants and is used as a sweetening agent in food products. It has 40% less calories and 75% less carbohydrate than sucrose [4]. Xylitol obtained from banana peel was used in rusk preparation, and it decreased the water activity of the rusk, thus prolonging its shelf life. It also had a good acceptance score [144]. A study used banana peel powder at 3, 6, 9, 12 and 15% in cakes and compared the nutritional, organoleptic, anti-microbial and antioxidant properties. The results indicated that cake was fortified with enhanced nutrients and fat, ash, protein and amino acids. The texture and taste analysis also showed no significant difference, which means the banana peel cake was accepted as much as the regular cake [145]. Further, the addition of 10% peel powder to the cake mix increased the foam stability and acceptance [146]. Another study proposed adding 15% peel flour for the best organoleptic qualities and 30% for fortification purposes in the cake [147]. Banana peels can also be a good ingredient in gluten-free products.

Banana peel powder was used to enhance the fibre content of the chicken sausage. The results showed positive improvement in the fibre and mineral composition of the sausage, with a decrease in total fat from 9.18% (control chicken sausage) to 7.6% in banana peel sausage [148]. Banana peel water extract (2%) was used to produce ground chicken patties and it improved the free radical scavenging activity in the patties [149].

Banana peel is also used as an edible packaging material. It was observed to have similar tensile strength as polyethylene because of its higher fibre content with inorganic nutrients, which improved its mechanical properties. Moreover, these films are degradable and can be composted, offering an environmentally friendly solution [150].

6. Limitations and Future Opportunities

Banana peel has been studied extensively for its potential antioxidant and anti-microbial properties because it has high concentrations of bioactive compounds. However, most of the studies are conducted in vitro, and hence, there is a lack of practical application. The storage, handling, transportation and processing of banana peels also present challenges due to their high moisture content and organic molecules. These factors cause degradation and instability of the peel [151]. Hence, research is required to address a modern and sustainable technology for enhancing the efficiency of banana peel processing and its use in food, pharmaceuticals, agriculture, bioprocessing, paper and textile industries. Utilising banana peel waste as a natural resource contributes to environmental sustainability and human health while supporting the principles of a circular economy.

The addition of waste value also plays an integral role in the Sustainable Development Goals (SDG), especially SDG 2 Zero Hunger, SDG 9 Industry, innovation and Infrastructure, SDG 12 Responsible Consumption and Production, and SDG 13 Climate Action. The use of banana peel as a functional food ingredient for preservation and fortification contributes towards the zero hunger, good health and well-being goals. Technological advancements in processing and using peels for biorefinery, bioprocess, bioethanol production and bioplastics promote sustainability and environmentally friendly innovations. The value addition to waste and the utilisation of its bioactive potential to maximum capacity supports SDG 12 and, ultimately, SDG 13, as these actions will reduce greenhouse gas emissions from waste in landfills. Therefore, integrating banana peels into various industries promotes economic growth, environmental sustainability and public health (Figure 4).

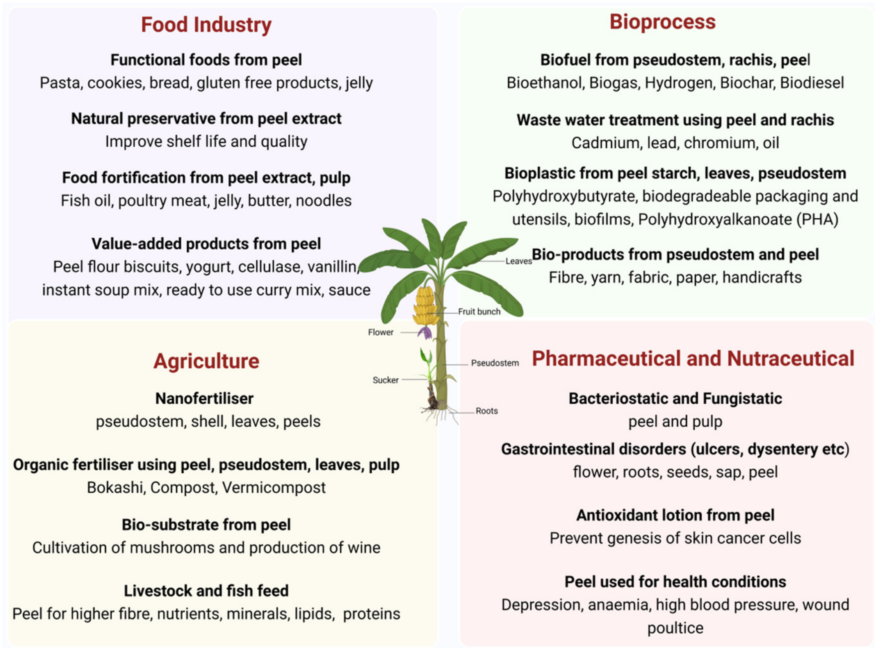

Figure 4. Use of banana waste for the circular economy.

7. Conclusions

Food waste and by-products have been recognised as sustainable sources of nutrients. Banana, as one of the important fruits consumed globally, provides banana peel as a source of many bioactive nutrients, such as carotenoids, phytosterols, carbohydrates and biogenic amines, along with many micronutrients and macronutrients. These components can serve as functional and nutritional ingredients in various industries, including food, pharmaceuticals, nutraceuticals, agriculture and bioprocessing. Food fortification with banana peels to provide nutrients can help with improving food security and improving health outcomes. Further, banana peels can also serve as the ingredients for biofuels and bioproducts that can help recycle waste from banana production, thus contributing to the circular economy. Overall, banana peel can serve as a raw material for value-added products in food, agriculture, bioprocess and nutraceutical industries, thus providing sustainable and environmentally friendly solutions for this waste.

Author Contributions: Conceptualisation, S.K.P.; methodology, M.Y., S.G. and S.K.P.; writing—original draft preparation, M.Y. and S.G.; writing—review and editing, S.K.P.; supervision, S.K.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Lucas Aguirre, J.C.; Quintero Castaño, V.D. Rheological characterization of starch and morphological evaluation of 20 varieties of musaceae (*Musa* sp.), from the Fedeplátano germplasm bank, Chinchiná—Caldas, Colombia. *Acta Agron.* **2016**, *65*, 218–225. [CrossRef]
2. Alzate Acevedo, S.; Díaz Carrillo, Á.J.; Flórez-López, E.; Grande-Tovar, C.D. Recovery of banana waste-loss from production and processing: A contribution to a circular economy. *Molecules* **2021**, *26*, 5282. [CrossRef]
3. Ploetz, R.C.; Kema, G.H.J.; Ma, L.-J. Impact of diseases on export and smallholder production of banana. *Annu. Rev. Phytopathol.* **2015**, *53*, 269–288. [CrossRef] [PubMed]
4. Mohd Zaini, H.; Roslan, J.; Saallah, S.; Munsu, E.; Sulaiman, N.S.; Pindi, W. Banana peels as a bioactive ingredient and its potential application in the food industry. *J. Funct. Foods* **2022**, *92*, 105054. [CrossRef]
5. Rattanapan, C.; Ounsaneha, W. The potential for value-added banana production waste under circular economy concept. *Int. J. Environ. Sci. Dev.* **2022**, *13*, 92–96. [CrossRef]
6. Panigrahi, N.; Thompson, A.J.; Zubelzu, S.; Knox, J.W. Identifying opportunities to improve management of water stress in banana production. *Sci. Hortic.* **2021**, *276*, 109735. [CrossRef]
7. World Population Review. Banana Consumption by Country 2024. 2024. Available online: https://worldpopulationreview.com/country-rankings/banana-consumption-by-country (accessed on 10 January 2025).
8. Amarasinghe, N.K.; Wickramasinghe, I.; Wijesekara, I.; Thilakarathna, G.; Deyalage, S.T. Functional, physicochemical, and antioxidant properties of flour and cookies from two different banana varieties (*Musa acuminata* cv. Pisang awak and Musa acuminata cv. Red dacca). *Int. J. Food Sci.* **2021**, *2021*, 6681687. [CrossRef]
9. Torres, L.C.; Zamora, L.C. Benefits in Latin America and the Caribbean about production of Cavendish AAA banana resistant to black Sigatoka. *Rev. Bionatura* **2018**, *3*, 740–744. [CrossRef]
10. Varma, V.; Bebber, D.P. Climate change impacts on banana yields around the world. *Nat. Clim. Chang.* **2019**, *9*, 752–757. [CrossRef]
11. Heslop-Harrison, J.S.; Schwarzacher, T. Domestication, genomics and the future for banana. *Ann. Bot.* **2007**, *100*, 1073–1084. [CrossRef]
12. Santosh, D.T.; Tiwari, K.N.; Reddy, R.G. Banana bunch covers for quality banana production—A review. *Int. J. Curr. Microbiol. Appl. Sci.* **2017**, *6*, 1275–1291. [CrossRef]
13. Provin, A.P.; Medeiros d'Alva, A.; de Aguiar Dutra, A.R.; Salgueirinho Osório de Andrade Guerra, J.B.; Leal Vieira Cubas, A. Closing the cycle: Circular economy strategies for the textile industry using banana farming waste. *J. Clean. Prod.* **2024**, *470*, 143352. [CrossRef]
14. Tewari, S.; Reshamwala, S.M.S.; Bhatt, L.; Kale, R.D. Vegan leather: A sustainable reality or a marketing gimmick? *Environ. Sci. Pollut. Res.* **2024**, *31*, 3361–3375. [CrossRef]
15. Afzal, M.F.; Khalid, W.; Akram, S.; Khalid, M.A.; Zubair, M.; Kauser, S.; Mohamedahmed, K.A.; Aziz, A.; Siddiqui, S.A. Bioactive profile and functional food applications of banana in food sectors and health: A review. *Int. J. Food Prop.* **2022**, *25*, 2286–2300. [CrossRef]
16. Anirudh, M.K.; Nandhu Lal, A.M.; Harikrishnan, M.P.; Jose, J.; Thasim, J.; Warrier, A.S.; Venkatesh, R.; Vaddevolu, U.B.P.; Kothakota, A. Sustainable seedling pots: Development and characterisation of banana waste and natural fibre-reinforced composites for horticultural applications. *Int. J. Biol. Macromol.* **2024**, *270*, 132070. [CrossRef] [PubMed]
17. Bishnoi, S.; Sharma, S.; Agrawal, H. Exploration of the potential application of banana peel for its effective valorization: A review. *Indian J. Microbiol.* **2023**, *63*, 398–409. [CrossRef]
18. Mohd Dom, Z.; Azhar, A.Z.; Masaudin, S.N.A. Utilization of banana peel as functional ingredient in product development. *Adv. Agric. Food Res. J.* **2023**, *4*, a0000209. [CrossRef]
19. Shaukat, N.; Farooq, U.; Akram, K.; Shafi, A.; Hayat, Z.; Naz, A.; Hakim, A.; Hayat, K.; Naseem, S.; Khan, M.Z. Antimicrobial potential of banana peel: A natural preservative to improve food safety. *Asian J. Agric. Biol.* **2023**, *3*, 1–6. [CrossRef]
20. Manzoor, A.; Ahmad, S. Banana peel: Characteristics and consideration of its extract for use in meat products preservation: A review. *ACS Food Sci. Technol.* **2021**, *1*, 1492–1506. [CrossRef]
21. Narwal, P.; Kapoor, B.; Negi, N.P. Decoding the chemical repertoire, antimicrobial synergy, and antioxidant mastery of banana pulp and peel extracts. *J. Plant Biochem. Biotechnol.* **2024**, *33*, 436–446. [CrossRef]
22. Roselli, V.; Pugliese, G.; Leuci, R.; Brunetti, L.; Gambacorta, L.; Tufarelli, V.; Piemontese, L. Green methods to recover bioactive compounds from food industry waste: A sustainable practice from the perspective of the circular economy. *Molecules* **2024**, *29*, 2682. [CrossRef]

23. Hendrawan, Y.; Larasati, R.; Wibisono, Y.; Umam, C.; Sutan, S.M.; Hawa, L.C. Extraction of phenol and antioxidant compounds from Kepok banana skin with PEF pre-treatment. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *305*, 012065. [CrossRef]
24. Aguiar Pascoalino, L.; Barros, L.; Barreira, J.C.M.; Oliveira, M.B.P.P.; Reis, F.S. Closing the loop: Exploring apple pomace as a source of bioactive compounds in the framework of circular economy. *Sustain. Food Technol.* **2025**, *3*, 81–95. [CrossRef]
25. García-González, A.G.; Rivas-García, P.; Escamilla-Alvarado, C.; Ramírez-Cabrera, M.A.; Paniagua-Vega, D.; Galván-Arzola, U.; Cano-Gómez, J.J.; Escárcega-González, C.E. Fruit and vegetable waste as a raw material for obtaining functional antioxidants and their applications: A review of a sustainable strategy. *Biofuels Bioprod. Biorefin.* **2025**, *19*, 231–249. [CrossRef]
26. Barreira, J.C.M.; Arraibi, A.A.; Ferreira, I.C.F.R. Bioactive and functional compounds in apple pomace from juice and cider manufacturing: Potential use in dermal formulations. *Trends Food Sci. Technol.* **2019**, *90*, 76–87. [CrossRef]
27. Heuzé, V.; Tran, G. Banana (General). 2016. Available online: https://www.feedipedia.org/node/4670 (accessed on 17 January 2025).
28. Huang, P.-H.; Cheng, Y.-T.; Lu, W.-C.; Chiang, P.-Y.; Yeh, J.-L.; Wang, C.-C.; Liang, Y.-S.; Li, P.-H. Changes in nutrient content and physicochemical properties of cavendish bananas var. Pei Chiao during ripening. *Horticulturae* **2024**, *10*, 384. [CrossRef]
29. Arias, P.; Dankers, C.; Liu, P.; Pilkauskas, P. *The World Banana Economy, 1985–2002*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2003.
30. Hikal, W.M.; Said-Al Ahl, H.A.H.; Bratovcic, A.; Tkachenko, K.G.; Sharifi-Rad, J.; Kačániová, M.; Elhourri, M.; Atanassova, M. Banana peels: A waste treasure for human being. *Evid. Based Complement. Alternat. Med.* **2022**, *2022*, 7616452. [CrossRef]
31. Amah, D.; van Biljon, A.; Brown, A.; Perkins-Veazie, P.; Swennen, R.; Labuschagne, M. Recent advances in banana (*Musa* spp.) biofortification to alleviate vitamin A deficiency. *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 3498–3510. [CrossRef] [PubMed]
32. Häkkinen, M. Reappraisal of sectional taxonomy in *Musa* (Musaceae). *Taxon* **2013**, *62*, 809–813. [CrossRef]
33. Robinson, J.C.; Galán Saúco, V. Taxonomic classification, cultivars and breeding. In *Bananas and Plantains*; Robinson, J.C., Galán Saúco, V., Eds.; CABI: Wallingford, UK, 2010; pp. 21–49. [CrossRef]
34. Thangavelu, R.; Saraswathi, M.S.; Uma, S.; Loganathan, M.; Backiyarani, S.; Durai, P.; Edwin Raj, E.; Marimuthu, N.; Kannan, G.; Swennen, R. Identification of sources resistant to a virulent Fusarium wilt strain (VCG 0124) infecting Cavendish bananas. *Sci. Rep.* **2021**, *11*, 3183. [CrossRef]
35. Sidhu, J.S.; Zafar, T.A. Bioactive compounds in banana fruits and their health benefits. *Food Qual. Saf.* **2018**, *2*, 183–188. [CrossRef]
36. Castillo, M.; de Guzman, M.J.K.; Aberilla, J.M. Environmental sustainability assessment of banana waste utilization into food packaging and liquid fertilizer. *Sustain. Prod. Consum.* **2023**, *37*, 356–368. [CrossRef]
37. Gumisiriza, R.; Hawumba, J.F.; Okure, M.; Hensel, O. Biomass waste-to-energy valorisation technologies: A review case for banana processing in Uganda. *Biotechnol. Biofuels* **2017**, *10*, 11. [CrossRef]
38. Kagezi, G.H.; Kangire, A.; Tushemereirwe, W.; Bagamba, F.; Kikulwe, E.; Muhangi, J.; Gold, C.S.; Ragama, P. Banana bacterial wilt incidence in Uganda. *Afr. Crop Sci. J.* **2006**, *14*, 83–91. [CrossRef]
39. Sagar, N.A.; Pareek, S.; Sharma, S.; Yahia, E.M.; Lobo, M.G. Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. *Compr. Rev. Food Sci. Food Saf.* **2018**, *17*, 512–531. [CrossRef]
40. Almeyda, E.; Ipanaqué, W. Recent developments of artificial intelligence for banana: Application areas, learning algorithms, and future challenges. *Eng. Agríc.* **2022**, *42*, e20210144. [CrossRef]
41. Al-Dairi, M.; Pathare, P.B.; Al-Yahyai, R.; Jayasuriya, H.; Al-Attabi, Z. Evaluation of chemical quality attributes in bruised bananas during storage. *LWT* **2024**, *197*, 115904. [CrossRef]
42. Al-Dairi, M.; Pathare, P.B.; Al-Yahyai, R.; Jayasuriya, H.; Al-Attabi, Z. Postharvest quality, technologies, and strategies to reduce losses along the supply chain of banana: A review. *Trends Food Sci. Technol.* **2023**, *134*, 177–191. [CrossRef]
43. Sugianti, C.; Imaizumi, T.; Thammawong, M.; Nakano, K. Recent postharvest technologies in the banana supply chain. *Rev. Agric. Sci.* **2022**, *10*, 123–137. [CrossRef]
44. Khawas, P.; Deka, S.C. Comparative nutritional, functional, morphological, and diffractogram study on culinary banana (*Musa* ABB) peel at various stages of development. *Int. J. Food Prop.* **2016**, *19*, 2832–2853. [CrossRef]
45. Ounsaneha, W.; Buadit, T.; Rattanapan, C. Assessment of human health impact based on life cycle assessment: A case study of Thai retread tire. *IOP Conf. Ser. Mat. Sci. Eng.* **2019**, *773*, 012038. [CrossRef]
46. Roibás, L.; Elbehri, A.; Hospido, A. Evaluating the sustainability of Ecuadorian bananas: Carbon footprint, water usage and wealth distribution along the supply chain. *Sustain. Prod. Consum.* **2015**, *2*, 3–16. [CrossRef]
47. Veliz, K.; Chico-Santamarta, L.; Ramirez, A.D. The environmental profile of Ecuadorian export banana: A life cycle assessment. *Foods* **2022**, *11*, 3288. [CrossRef] [PubMed]
48. Housagul, S.; Sirisukpoka, U.; Boonyawanich, S.; Pisutpaisal, N. Biomethane production from co-digestion of banana peel and waste glycerol. *Energy Procedia* **2014**, *61*, 2219–2223. [CrossRef]
49. Vu, H.T.; Scarlett, C.J.; Vuong, Q.V. Optimization of ultrasound-assisted extraction conditions for recovery of phenolic compounds and antioxidant capacity from banana (*Musa cavendish*) peel. *J. Food Process. Preserv.* **2017**, *41*, e13148. [CrossRef]

50. Schieber, A.; Stintzing, F.C.; Carle, R. By-products of plant food processing as a source of functional compounds—Recent developments. *Trends Food Sci. Technol.* **2001**, *12*, 401–413. [CrossRef]
51. Zhang, P.; Whistler, R.L.; BeMiller, J.N.; Hamaker, B.R. Banana starch: Production, physicochemical properties, and digestibility—A review. *Carbohydr. Polym.* **2005**, *59*, 443–458. [CrossRef]
52. Vu, H.T.; Scarlett, C.J.; Vuong, Q.V. Phenolic compounds within banana peel and their potential uses: A review. *J. Funct. Foods* **2018**, *40*, 238–248. [CrossRef]
53. Sampath Kumar, K.P.; Bhowmik, D.; Duraivel, S.; Umadevi, M. Traditional and medicinal uses of banana. *J. Parmacogn. Phytochem.* **2012**, *1*, 51–63.
54. Youssef, M.A.; Eman, A.A.; Abeir, M.E. Evaluation the bioactive compounds extracted from dried banana (*Musa* sp.) peels which obtained by different drying methods. *Curr. Sci. Int.* **2018**, *7*, 135–148.
55. Sinanoglou, V.J.; Tsiaka, T.; Aouant, K.; Mouka, E.; Ladika, G.; Kritsi, E.; Konteles, S.J.; Ioannou, A.-G.; Zoumpoulakis, P.; Strati, I.F.; et al. Quality assessment of banana ripening stages by combining analytical methods and image analysis. *Appl. Sci.* **2023**, *13*, 3533. [CrossRef]
56. Marta, H.; Cahyana, Y.; Djali, M.; Pramafisi, G. The properties, modification, and application of banana starch. *Polymers* **2022**, *14*, 3092. [CrossRef]
57. Emaga, T.H.; Andrianaivo, R.H.; Wathelet, B.; Tchango, J.T.; Paquot, M. Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chem.* **2007**, *103*, 590–600. [CrossRef]
58. Oyeyinka, B.O.; Afolayan, A.J. Comparative evaluation of the nutritive, mineral, and antinutritive composition of *Musa sinensis* L. (banana) and *Musa paradisiaca* L.(plantain) fruit compartments. *Plants* **2019**, *8*, 598. [CrossRef]
59. Emaga, T.H.; Bindelle, J.; Agneesens, R.; Buldgen, A.; Wathelet, B.; Paquot, M. Ripening influences banana and plantain peels composition and energy content. *Trop. Anim. Health Prod.* **2011**, *43*, 171–177. [CrossRef] [PubMed]
60. Sial, T.A.; Khan, M.N.; Lan, Z.; Kumbhar, F.; Ying, Z.; Zhang, J.; Sun, D.; Li, X. Contrasting effects of banana peels waste and its biochar on greenhouse gas emissions and soil biochemical properties. *Process Saf. Environ. Prot.* **2019**, *122*, 366–377. [CrossRef]
61. Hassan, H.F.; Hassan, U.F.; Usher, O.A.; Ibrahim, A.B.; Tabe, N.N. Exploring the potentials of banana (*Musa sapietum*) peels in feed formulation. *Int. J. Adv. Res. Chem. Sci.* **2018**, *5*, 10–14. [CrossRef]
62. Nagarajaiah, S.B.; Jamuna Prakash, J.P. Chemical composition and antioxidant potential of peels from three varieties of banana. *Asian J. Food Agro-Ind.* **2011**, *4*, 31–46.
63. Tsamo, C.V.P.; Herent, M.-F.; Tomekpe, K.; Emaga, T.H.; Quetin-Leclercq, J.; Rogez, H.; Larondelle, Y.; Andre, C. Phenolic profiling in the pulp and peel of nine plantain cultivars (*Musa* sp.). *Food Chem.* **2015**, *167*, 197–204. [CrossRef]
64. Abiodun-Solanke, A.; Falade, K.O. A review of the uses and methods of processing banana and plantain (*Musa* spp.) into storable food products. *J. Agric. Res. Develop.* **2010**, *9*, 85–166. [CrossRef]
65. Pereira, A.; Maraschin, M. Banana (*Musa* spp.) from peel to pulp: Ethnopharmacology, source of bioactive compounds and its relevance for human health. *J. Ethnopharmacol.* **2015**, *160*, 149–163. [CrossRef]
66. Khaliq, A.; Amreen; Jameel, N.; Krauth, S.J. Knowledge and practices on the prevention and management of diarrhea in children under-2 years among women dwelling in urban slums of Karachi, Pakistan. *Matern. Child Health J.* **2022**, *26*, 1442–1452. [CrossRef] [PubMed]
67. García, O.P.; Martínez, M.; Romano, D.; Camacho, M.; de Moura, F.F.; Abrams, S.A.; Khanna, H.K.; Dale, J.L.; Rosado, J.L. Iron absorption in raw and cooked bananas: A field study using stable isotopes in women. *Food Nutr. Res.* **2015**, *59*, 25976. [CrossRef] [PubMed]
68. Tavakkoli-Kakhki, M.; Motavasselian, M.; Mosaddegh, M.; Esfahani, M.M.; Kamalinejad, M.; Nematy, M.; Eslami, S. Omega-3 and omega-6 content of medicinal foods for depressed patients: Implications from the Iranian Traditional Medicine. *Avicenna J. Phytomed.* **2014**, *4*, 225–230.
69. Laufenberg, G.; Kunz, B.; Nystroem, M. Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementations. *Bioresour. Technol.* **2003**, *87*, 167–198. [CrossRef] [PubMed]
70. Kanazawa, K.; Sakakibara, H. High content of dopamine, a strong antioxidant, in cavendish banana. *J. Agric. Food Chem.* **2000**, *48*, 844–848. [CrossRef]
71. Septembre-Malaterre, A.; Stanislas, G.; Douraguia, E.; Gonthier, M.-P. Evaluation of nutritional and antioxidant properties of the tropical fruits banana, litchi, mango, papaya, passion fruit and pineapple cultivated in Réunion French Island. *Food Chem.* **2016**, *212*, 225–233. [CrossRef]
72. Alexandra Pazmiño-Durán, E.; Giusti, M.M.; Wrolstad, R.E.; Glória, M.B.A. Anthocyanins from banana bracts (*Musa* X *paradisiaca*) as potential food colorants. *Food Chem.* **2001**, *73*, 327–332. [CrossRef]
73. Rao, U.S.M.; Mohd, K.S.; Muhammad, A.; Ahmad, B.A.; Mohamad, M.; Ali, R.M. Taxonomical, phytochemical and pharmacological reviews of *Musa sapientum* var. paradisiaca. *Res. J. Pharm. Technol.* **2014**, *7*, 1356–1361.
74. Lewis, D.A.; Fields, W.N.; Shaw, G.P. A natural flavonoid present in unripe plantain banana pulp (*Musa sapientum* L. var. paradisiaca) protects the gastric mucosa from aspirin-induced erosions. *J. Ethnopharmacol.* **1999**, *65*, 283–288. [CrossRef]

75. Boots, A.W.; Haenen, G.R.M.M.; Bast, A. Health effects of quercetin: From antioxidant to nutraceutical. *Eur. J. Pharmacol.* **2008**, *585*, 325–337. [CrossRef]
76. Ullah, A.; Munir, S.; Badshah, S.L.; Khan, N.; Ghani, L.; Poulson, B.G.; Emwas, A.-H.; Jaremko, M. Important flavonoids and their role as a therapeutic agent. *Molecules* **2020**, *25*, 5243. [CrossRef] [PubMed]
77. Zheng, X.; Zhang, X.; Zeng, F. Biological functions and health benefits of flavonoids in fruits and vegetables: A contemporary review. *Foods* **2025**, *14*, 155. [CrossRef] [PubMed]
78. Someya, S.; Yashiki, Y.; Okubo, K. Antioxidant compounds from bananas (*Musa cavendish*). *Food Chem.* **2002**, *79*, 351–354. [CrossRef]
79. Tsamo, C.V.P.; Herent, M.-F.; Tomekpe, K.; Emaga, T.H.; Quetin-Leclercq, J.; Rogez, H.; Larondelle, Y.; Andre, C.M. 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 Comp. Anal.* **2015**, *44*, 158–169. [CrossRef]
80. Van den Berg, H.; Faulks, R.; Granado, H.F.; Hirschberg, J.; Olmedilla, B.; Sandmann, G.; Southon, S.; Stahl, W. The potential for the improvement of carotenoid levels in foods and the likely systemic effects. *J. Sci. Food Agric.* **2000**, *80*, 880–912. [CrossRef]
81. Bufka, J.; Vaňková, L.; Sýkora, J.; Křížková, V. Exploring carotenoids: Metabolism, antioxidants, and impacts on human health. *J. Funct. Foods* **2024**, *118*, 106284. [CrossRef]
82. Aquino, C.F.; Salomão, L.C.C.; Pinheiro-Sant'Ana, H.M.; Ribeiro, S.M.R.; De Siqueira, D.L.; Cecon, P.R. Carotenoids in the pulp and peel of bananas from 15 cultivars in two ripening stages. *Rev. Ceres* **2018**, *65*, 217–226. [CrossRef]
83. Davey, M.W.; Keulemans, J.; Swennen, R. Methods for the efficient quantification of fruit provitamin A contents. *J. Chromatogr. A* **2006**, *1136*, 176–184. [CrossRef]
84. Wójcik, W.; Łukasiewicz, M.; Puppel, K. Biogenic amines: Formation, action and toxicity—A review. *J. Sci. Food Agric.* **2021**, *101*, 2634–2640. [CrossRef]
85. Shalaby, A.R. Significance of biogenic amines to food safety and human health. *Food Res. Int.* **1996**, *29*, 675–690. [CrossRef]
86. Ademakinwa, A.N.; Agunbiade, M.O. Banana peel wastes as a source of tyrosinase useful in the production of l-DOPA. *Sustain. Chem. Pharm.* **2022**, *30*, 100853. [CrossRef]
87. Marangoni, F.; Poli, A. Phytosterols and cardiovascular health. *Pharmacol. Res.* **2010**, *61*, 193–199. [CrossRef] [PubMed]
88. Ismail, S.; Dubey, P.K.; Mishra, A.A.; Ashka, F. Valorisation of banana peel and mango peel as functional ingredients in baked products: A review. *Int. J. Food Sci. Technol.* **2024**, *59*, 5938–5950. [CrossRef]
89. Aquino, C.F.; Salomão, L.C.C.; Ribeiro, S.M.R.; De Siqueira, D.L.; Cecon, P.R. Carbohydrates, phenolic compounds and antioxidant activity in pulp and peel of 15 banana cultivars. *Rev. Bras. Frutic.* **2016**, *38*, e-090. [CrossRef]
90. Aboul-Enein, A.M.; Salama, Z.A.; Gaafar, A.A.; Aly, H.F.; Bou-Elella, F.A.; Ahmed, H.A. Identification of phenolic compounds from banana peel (*Musa paradaisica* L.) as antioxidant and antimicrobial agents. *J. Chem. Pharmaceut. Res.* **2016**, *8*, 46–55.
91. El-Zawawy, N.A. Antioxidant, antitumor, antimicrobial studies and quantitative phytochemical estimation of ethanolic extracts of selected fruit peels. *Int. J. Curr. Microbiol. Appl. Sci.* **2015**, *4*, 298–309.
92. Waghmare, J.S.; Kurhade, A.H. GC-MS analysis of bioactive components from banana peel (*Musa sapientum* peel). *Eur. J. Exp. Biol.* **2014**, *4*, 10–15.
93. González-Montelongo, R.; Lobo, M.G.; González, M. Antioxidant activity in banana peel extracts: Testing extraction conditions and related bioactive compounds. *Food Chem.* **2010**, *119*, 1030–1039. [CrossRef]
94. Rasidek, N.A.M.; Nordin, M.F.M.; Shameli, K. Formulation and evaluation of semisolid jelly produced by *Musa acuminata* Colla (AAA Group) peels. *Asian Pac. J. Trop. Biomed.* **2016**, *6*, 55–59. [CrossRef]
95. Mokbel, M.S.; Hashinaga, F. Antibacterial and antioxidant activities of banana (*Musa*, AAA cv. Cavendish) fruits peel. *Am. J. Biochem. Biotechnol.* **2005**, *1*, 125–131. [CrossRef]
96. Kapadia, S.P.; Pudakalkatti, P.S.; Shivanaikar, S. Detection of antimicrobial activity of banana peel (*Musa paradisiaca* L.) on Porphyromonas gingivalis and Aggregatibacter actinomycetemcomitans: An in vitro study. *Contemp. Clin. Dent.* **2015**, *6*, 496–499. [CrossRef]
97. Kavitha, V.; Manonmani, G.; Devakumar, J. Antimicrobial efficacy of fresh and dried banana peel extracts: An in vitro study. *Drug Invent. Today* **2019**, *11*, 1237.
98. Semangoen, T.; Chotigawin, R.; Sangnim, T.; Chailerd, N.; Pahasup-anan, T.; Huanbutta, K. Evaluation of banana peel extract (*Musa sapientum* L.) as a natural antimicrobial for livestock farming. *J. Sustain. Agric. Environ.* **2024**, *3*, e12118. [CrossRef]
99. Lino, P.; Corrêa, C.; Archondo, M.; Leite-Dellova, D. Evaluation of post-surgical healing in rats using a topical preparation based on extract of *Musa sapientum* epicarp. *Rev. Bras. De Farmacogn.* **2011**, *21*, 491–496. [CrossRef]
100. Saleem, M.; Saeed, M.T. Potential application of waste fruit peels (orange, yellow lemon and banana) as wide range natural antimicrobial agent. *J. King Saud Univ. Sci.* **2020**, *32*, 805–810. [CrossRef]
101. Okorondu, S.I.; Akujobi, C.O.; Nwachukwu, I.N. Antifungal properties of *Musa paradisiaca* (plantain) peel and stalk extracts. *Int. J. Biol. Chem. Sci.* **2012**, *6*, 1527–1534. [CrossRef]

102. Kamal, A.M.; Taha, M.S.; Mousa, A.M. The radioprotective and anticancer effects of banana peels extract on male mice. *J. Food Nutr. Res.* **2019**, *7*, 827–835. [CrossRef]
103. Dahham, S.S.; Agha, M.T.; Tabana, Y.M.; Abdul Majid, A.M.S. Antioxidant activities and anticancer screening of extracts from banana fruit (*Musa sapientum*). *Acad. J. Cancer Res.* **2015**, *8*, 28–34.
104. Krinsky, N.I.; Johnson, E.J. Carotenoid actions and their relation to health and disease. *Mol. Asp. Med.* **2005**, *26*, 459–516. [CrossRef]
105. Mondal, A.; Banerjee, S.; Bose, S.; Das, P.P.; Sandberg, E.N.; Atanasov, A.G.; Bishayee, A. Cancer preventive and therapeutic potential of banana and its bioactive constituents: A systematic, comprehensive, and mechanistic review. *Front. Oncol.* **2021**, *11*, 697143. [CrossRef] [PubMed]
106. Navghare, V.V.; Dhawale, S.C. *In vitro* antioxidant, hypoglycemic and oral glucose tolerance test of banana peels. *Alex. J. Med.* **2017**, *53*, 237–243. [CrossRef]
107. Vasu, P.; Khan, N.D.; Khan, Z.H.; Mular, S.M. *In vitro* antidiabetic activity of methanolic extract of *Citrus limon*, *Punica granatum*, *Musa acuminata* peel. *Int. J. Appl. Res.* **2017**, *3*, 804–806.
108. Rao, U.S.M.; Ahmad, B.A.; Mohd, K.S.; Zin, T. Antiulcer activity of *Musa paradisiaca* (banana) tepal and skin extracts in ulcer induced Albino mice. *Malay. J. Anal. Sci.* **2016**, *20*, 1203–1216. [CrossRef]
109. Bansal, J.; Malviya, R.; Malaviya, T.; Bhardwaj, V.; Sharma, P.K. Evaluation of banana peel pectin as excipient in solid oral dosage form. *Glob. J. Pharmacol.* **2014**, *8*, 275–278. [CrossRef]
110. Khamsucharit, P.; Laohaphatanalert, K.; Gavinlertvatana, P.; Sriroth, K.; Sangseethong, K. Characterization of pectin extracted from banana peels of different varieties. *Food Sci. Biotechnol.* **2017**, *27*, 623–629. [CrossRef]
111. Venkatanagaraju, E.; Bharathi, N.; Sindhuja, R.H.; Chowdhury, R.R.; Sreelekha, Y. Extraction and purification of pectin from agro-industrial wastes. In *Pectins-Extraction, Purification, Characterization and Applications*; Masuelli, M., Ed.; IntechOpen: London, UK, 2020. [CrossRef]
112. Ibrahim, H.M.M. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. *J. Rad. Res. Appl. Sci.* **2015**, *8*, 265–275. [CrossRef]
113. Navaladian, S.; Viswanathan, B.; Viswanath, R.P.; Varadarajan, T.K. Thermal decomposition as route for silver nanoparticles. *Nanoscale Res. Lett.* **2006**, *2*, 44–48. [CrossRef] [PubMed]
114. Solano-Ruiz, E.; Berrú, R.S.; Ocotlán-Flores, J.; Saniger, J.M. Synthesis of silver nanoparticles by sonochemical induced reduction application in SERS. *J. Nano Res.* **2010**, *9*, 77–81. [CrossRef]
115. El-Faham, A.; Elzatahry, A.A.; Al-Othman, Z.A.; Elsayed, E.A. Facile method for the synthesis of silver nanoparticles using 3-hydrazino-isatin derivatives in aqueous methanol and their antibacterial activity. *Int. J. Nanomed.* **2014**, *9*, 1167–1174. [CrossRef]
116. Sreeram, K.J.; Nidhin, M.; Nair, B.U. Microwave assisted template synthesis of silver nanoparticles. *Bull. Mater. Sci.* **2008**, *31*, 937–942. [CrossRef]
117. Kokila, T.; Ramesh, P.S.; Geetha, D. Biosynthesis of silver nanoparticles from Cavendish banana peel extract and its antibacterial and free radical scavenging assay: A novel biological approach. *Appl. Nanosci.* **2015**, *5*, 911–920. [CrossRef]
118. Narayanamma, A. Natural synthesis of silver nanoparticles by banana peel extract and as an antibacterial agent. *IOSR J. Polymer Textile Eng.* **2016**, *3*, 17–25. [CrossRef]
119. Food and Agriculture Organization of the United Nations. *Crops and Livestock Products*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2024. Available online: https://www.fao.org/faostat/en/#data/QCL/metadata (accessed on 28 December 2024).
120. Guerrero, A.B.; Aguado, P.L.; Sánchez, J.; Curt, M.D. GIS-based assessment of banana residual biomass potential for ethanol production and power generation: A case study. *Waste Biomass Valor.* **2016**, *7*, 405–415. [CrossRef]
121. Oji, C.; Okoro, I.; Nnaji, J. Optimization of bioethanol production from banana peels: An alternative energy source. *J. Chem. Soc. Nigeria* **2024**, *49*, 487–499. [CrossRef]
122. Guerrero, A.B.; Ballesteros, I.; Ballesteros, M. The potential of agricultural banana waste for bioethanol production. *Fuel* **2018**, *213*, 176–185. [CrossRef]
123. Li, D.; Wang, M.-Q.; Lee, C. The waste treatment and recycling efficiency of industrial waste processing based on two-stage data envelopment analysis with undesirable inputs. *J. Clean. Prod.* **2020**, *242*, 118279. [CrossRef]
124. Alharbi, O.M.L.; Basheer, A.A.; Khattab, R.A.; Ali, I. Health and environmental effects of persistent organic pollutants. *J. Mol. Liq.* **2018**, *263*, 442–453. [CrossRef]
125. Ali, I.; Alothman, Z.A.; Alwarthan, A. Supra molecular mechanism of the removal of 17-β-estradiol endocrine disturbing pollutant from water on functionalized iron nano particles. *J. Mol. Liq.* **2017**, *241*, 123–129. [CrossRef]
126. Zhou, L.; Yu, Q.; Cui, Y.; Xie, F.; Li, W.; Li, Y.; Chen, M. Adsorption properties of activated carbon from reed with a high adsorption capacity. *Ecol. Eng.* **2017**, *102*, 443–450. [CrossRef]
127. Kyzas, G.Z.; Bikiaris, D.N. Recent modifications of chitosan for adsorption applications: A critical and systematic review. *Mar. Drugs* **2015**, *13*, 312–337. [CrossRef] [PubMed]

128. Akpomie, K.G.; Conradie, J. Banana peel as a biosorbent for the decontamination of water pollutants. A review. *Environ. Chem. Lett.* **2020**, *18*, 1085–1112. [CrossRef]
129. Ashraf, M.A.; Hussain, M.; Mahmood, K.; Wajid, A.; Yusof, M.; Alias, Y.; Yusoff, I. Removal of acid yellow-17 dye from aqueous solution using eco-friendly biosorbent. *Desalin. Water Treat.* **2013**, *51*, 4530–4545. [CrossRef]
130. Al-Shaalan, N.H.; Ali, I.; Alothman, Z.A.; Al-Wahaibi, L.H.; Alabdulmonem, H. High performance removal and simulation studies of diuron pesticide in water on MWCNTs. *J. Mol. Liq.* **2019**, *289*, 111039. [CrossRef]
131. Beni, A.A.; Esmaeili, A. Biosorption, an efficient method for removing heavy metals from industrial effluents: A review. *Environ. Technol. Innov.* **2020**, *17*, 100503. [CrossRef]
132. Singh, S.; Kumar, V.; Datta, S.; Dhanjal, D.S.; Sharma, K.; Samuel, J.; Singh, J. Current advancement and future prospect of biosorbents for bioremediation. *Sci. Total Environ.* **2020**, *709*, 135895. [CrossRef]
133. Vilardi, G.; Di Palma, L.; Verdone, N. Heavy metals adsorption by banana peels micro-powder: Equilibrium modeling by non-linear models. *Chin. J. Chem. Eng.* **2018**, *26*, 455–464. [CrossRef]
134. Ayawei, N.; Ebelegi, A.N.; Wankasi, D. Modelling and interpretation of adsorption isotherms. *J. Chem.* **2017**, *2017*, 3039817. [CrossRef]
135. Iftekhar, S.; Ramasamy, D.L.; Srivastava, V.; Asif, M.B.; Sillanpää, M. Understanding the factors affecting the adsorption of Lanthanum using different adsorbents: A critical review. *Chemosphere* **2018**, *204*, 413–430. [CrossRef]
136. Mahindrakar, K.V.; Rathod, V.K. Utilization of banana peels for removal of strontium (II) from water. *Environ. Technol. Innov.* **2018**, *11*, 371–383. [CrossRef]
137. El-Din, G.A.; Amer, A.A.; Malsh, G.; Hussein, M. Study on the use of banana peels for oil spill removal. *Alex. Eng. J.* **2018**, *57*, 2061–2068. [CrossRef]
138. Agama-Acevedo, E.; Islas-Hernandez, J.J.; Osorio-Díaz, P.; Rendón-Villalobos, R.; Utrilla-Coello, R.G.; Angulo, O.; Bello-Pérez, L.A. Pasta with unripe banana flour: Physical, texture, and preference study. *J. Food Sci.* **2009**, *74*, S263–S267. [CrossRef]
139. Segundo, C.; Román, L.; Lobo, M.; Martinez, M.M.; Gómez, M. Ripe banana flour as a source of antioxidants in layer and sponge cakes. *Plant Foods Hum. Nutr.* **2017**, *72*, 365–371. [CrossRef]
140. Ho, L.-H.; Abdul Aziz, N.A.; Azahari, B. Physico-chemical characteristics and sensory evaluation of wheat bread partially substituted with banana (*Musa acuminata* × *balbisiana* cv. Awak) pseudo-stem flour. *Food Chem.* **2013**, *139*, 532–539. [CrossRef] [PubMed]
141. Eshak, N.S. Sensory evaluation and nutritional value of balady flat bread supplemented with banana peels as a natural source of dietary fiber. *Ann. Agric. Sci.* **2016**, *61*, 229–235. [CrossRef]
142. Yancy, W.S., Jr.; Foy, M.; Chalecki, A.M.; Vernon, M.C.; Westman, E.C. A low-carbohydrate, ketogenic diet to treat type 2 diabetes. *Nutr. Metab.* **2005**, *2*, 34. [CrossRef] [PubMed]
143. Arun, K.B.; Persia, F.; Aswathy, P.S.; Chandran, J.; Sajeev, M.S.; Jayamurthy, P.; Nisha, P. Plantain peel—A potential source of antioxidant dietary fibre for developing functional cookies. *J. Food Sci. Technol.* **2015**, *52*, 6355–6364. [CrossRef]
144. Rehman, S.-u.; Nadeem, M.; Ahmad, F.; Mushtaq, Z. Biotechnological production of xylitol from banana peel and its impact on physicochemical properties of rusks. *J. Agric. Sci. Technol.* **2013**, *15*, 747–756.
145. Ahmed, Z.; El-Sharnouby, G.A.; El-Waseif, M.A. Use of banana peel as a by-product to increase the nutritive value of the cake. *J. Food Dairy Sci.* **2021**, *12*, 87–97. [CrossRef]
146. Borges, A.d.M.; Pereira, J.; Júnior, A.S.; de Lucena, E.M.P.; de Sales, J.C. Stability of cake pre-mixture made with 60% of green banana flour. *Ciênc. Agrotecnol.* **2010**, *34*, 173–181. [CrossRef]
147. Amini Khoozani, A.; Birch, J.; Bekhit, A.E.-D.A. Production, application and health effects of banana pulp and peel flour in the food industry. *J. Food Sci. Technol.* **2019**, *56*, 548–559. [CrossRef] [PubMed]
148. Mohd Zaini, H.B.; Bin Sintang, M.D.; Pindi, W. The roles of banana peel powders to alter technological functionality, sensory and nutritional quality of chicken sausage. *Food Sci. Nutr.* **2020**, *8*, 5497–5507. [CrossRef] [PubMed]
149. Devatkal, S.K.; Kumboj, R.; Paul, D. Comparative antioxidant effect of BHT and water extracts of banana and sapodilla peels in raw poultry meat. *J. Food Sci. Technol.* **2014**, *51*, 387–391. [CrossRef] [PubMed]
150. Santhoskumar, A.U.; Vaishnavi, R.; Karunakaran, T.; Chitra, N.J. Studies on mechanical properties and biodegradation of edible food wrapper from banana peel. *Asian J. Adv. Basic Sci.* **2019**, *7*, 1–4. [CrossRef]
151. Sarkar, D.; Prajapati, S.; Poddar, K.; Sarkar, A. Ethanol production by *Klebsiella* sp. SWET4 using banana peel as feasible substrate. *Biomass Conv. Bioref.* **2022**, *12*, 1479–1491. [CrossRef]