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Nutritional Content and Bioactive Compounds of Banana Peel and Its Potential Utilization: A Review

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***Abstract*— Banana is one of the popular fruits among consumers due to their excellent nutritional value. However, banana peel, the fruit's main secondary product or a significant by-product in banana processing, is generally abandoned and discarded as waste. Banana peels are rich in nutritional content such as protein, carbohydrates, fat, moisture, and ash contents. They are also high in bioactive compounds such as phenolic (flavonoids) and various types of carotenoids (lutein, alpha-carotene, and beta-carotene). Phenolic compounds effectively protect the human body against various diseases, specifically oxidative stress-related diseases. Due to all the advantages of banana peels, plenty of potential utilization could be explored, including citric acid production by *Aspergillus niger*, traditional medicine, foods, and pharmaceutical industries, as well as dietary incorporation. Thus, this paper discussed the nutritional contents and bioactive compounds of banana peel and their potential utilization as food additives, supplements, and pharmaceuticals. This could then help to minimize the number of agro-solid waste disposal from the food industry by processing the waste into value-added products.**

***Keywords*—** banana peel, nutritional content, bioactive compound, phenolic compounds, waste disposal

I. INTRODUCTION

Food waste has been an environmental problem for the past ten years [1]. It is estimated that a third of the edible components of the food produced for human eating or used are received, misplaced, or wasted globally, amounting to approximately 1.3 billion tons over a year [2]. According to the United Nations Food and Agriculture Organization (FAO), fruit and vegetable losses and waste are the greatest of all food types, reaching up to 60% [3]. Most of the waste comprises seed, peel, rind, and pomace, which are high in bioactive compounds such as carotenoids, polyphenols, dietary fibres, vitamins, enzymes, and oils.

The banana is an herbaceous plant that belongs to the genus *Musa* [4]. The fruit is usually eaten raw or produced into a variety of goods on a large or small scale, including dried fruit, snacks, smoothies, ice cream, bread, wheat, winemaking, and functional food additives [5]. The peel and the pulp are the two main sections of the banana fruit. The peel, the secondary product of bananas, contributes about 40% of the total weight of the fruit. Banana peels were generally discarded as waste, resulting in massive amounts of organic waste being disposed to landfill [6]. The pulp, which is the edible section of the fruit, is highly nutritious.

Banana peel is an example of common fruit waste that is discarded instead of eaten or used due to its unpleasant taste. Most people think that only fruits have nutritional content but not their peel. Surprisingly, the banana peel has rich nutritional contents and bioactive compounds that provide many benefits to one health even though its nutritional content and bioactive compound vary depending on the banana cultivar, environmental circumstances, methods for extraction, and evaluation methods. For example, banana peel is found to be rich in phytochemical compounds as compared to the pulp. It also contains antifungal and antibiotic properties, which benefit human health [7]. Many studies on banana pulp have been done, ranging from being used as a food fortification element to extracting and recovering various healthful ingredients, such as bioactive phytochemicals, starch, and cellulose [8]. As the production of the fruit increases, the waste of their peel is also expected to increase. According to Vu et. al. (2018) [5], banana peels, which are about one-third of the fruit weight, are mostly thrown away as waste instead of being used for further utilization. Food waste is described as any meals and inedible components of meals that have been eliminated from the food supply chain, which may be restored or discarded [1]. Inedible parts of the food include fruit peels [1].

Recent estimation proposes that about 15,000 metric tonnes of meals are thrown away daily in Malaysia. Banana peel is also suggested to be included in this category of waste products. A total of 200 tonnes of banana peel waste are generated daily, increasing yearly [9]. The peels are typically disposed of at municipal landfills, contributing to current environmental issues [9]. With the advancement and expansion of industrial manufacturing processes that use green or ripe bananas, the quantity of trash generated by banana peels is predicted to increase. In addition, within a few years, this problem is projected to exacerbate due to the growing population and urbanization, of which the population of Malaysia is expected to increase by 37.4 million by 2030 [10]. However, this issue could be resolved by employing its high-value constituents in further utilization.

As the previous findings on the nutrient content and potential utilization of banana peel are enormous, this paper aims to review the data related to the nutrition composition of the banana peel, and research has been done to discover its utilization comprehensively. Furthermore, various potentials of banana peel, such as producing citric acid using *Aspergillus niger*, application in folk medicine, and food, agricultural, and pharmaceutical industries were also discussed. Fig 1 shows an example of the potential utilization of banana peel.

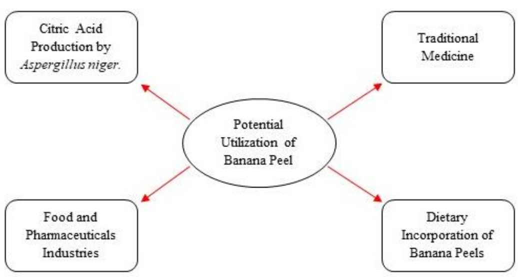

Fig 1. Examples of Potential Utilization of Banana Peel

II. BANANA AND BANANA PEEL

A. *Banana*

The banana is an herbaceous flowering plant belonging to the family *Musaceae* and the genus *Musa* [4]. It is also categorized as one of the most popular tropical fruits and is cultivated by more than 130 nations [11]. It has two primary species: *Musa acuminata* Colla and *Musa balbisiana* Colla, and mostly all the edible banana fruits are seedless (parthenocarpic) [4]. The plant is native to India and the eastern Asian region, including Malaysia and Japan. However, some variations are genetically connected to African species. *M. sapientum*, *M. paradisiaca*, and *M. cavendishii* are three common Musa species widely cultivated worldwide [11]. Banana plants are stenothermic plants that thrive in the humid tropical lowlands at a temperature ranging between 15°C-38°C, with a preferred temperature of 27°C [12]. The fruits grow in clusters, with each banana measuring around 1 inch in diameter. The fruit takes between two and a half to four months after shooting to mature into harvestable fruit or about eight to twelve months following planting. The fruit hangs in clusters of 20 fruits for each knot and 3 to 20 times per group. Banana fruit is shielded with its skin, and the skin is removed as waste after the fleshly interior portion is consumed [9].

Banana is well-known as one of the edible fruits that people love to eat and consume. It is usually consumed by consumers as a fruit in raw form and used in cooking. It is famous among consumers due to its inexpensive cost and excellent nutritional value [7]. Furthermore, bananas are known for their richness in dietary fibre, carbohydrates, minerals, and some vitamins. Unfortunately, banana peel or its skin is typically considered discarded food and is thrown mainly by consumers instead of using or eating it. Due to the high nitrogen and phosphorus content, its skin is considered waste and contributes to environmental problems [13].

B. *Banana Peel*

Banana peel weight is around 30-40 g/100g from the overall weight, considered industrial by-products [9]. Natural bioactive compounds found in banana peels, such as polyphenols, carotenoids, and dietary fibre, provide advantages for our health, such as preventing cardiovascular disease, cancer, and other degenerative diseases [13]. According to Syukriani et. al., (2021) [14], flour from banana peel has 32.3 mg of ascorbic acid per 100g, while the fruit and pulp provide 7.18 mg and 4.97 mg of vitamin C, respectively. Flour from banana peels seems to have the ability as a health and beauty product, which includes facial masks, skin oil reduction, and the diminishing of scars due to their high amount of vitamin C and minerals [14]. Vitamin C, also known as ascorbic acid, offers many advantages, including an immunity booster, enhancing skin health, and protecting cells from cancer.

Banana peels possess exceptional scientific benefits and have been used to treat intestinal sores, constipation, diarrhea, ulcerative colitis, nephritis, gout, coronary heart infection, high blood pressure, and diabetes [15]. Banana peel is high in fibre, with approximately 50% on a dry matter basis, while its proteins contain 7% of essential amino acids. It also contains potassium and polyunsaturated fatty acids [15]. It also restores the soil's nutrients, where the banana peel has historically been used as fertilizer by simply decomposing it. However, with biotechnological advancements and strong demand for organic fertilizers, the peel has been utilized to create numerous kinds of organic fertilizers [5].

Fruit peel is an essential raw material used in several applications as it contains many nutritional compounds and is high in fibre. The fruit processing company produces enormous amounts of fruit pomace, which may be a good resource of phenol substances that may be employed as herbal treatments as well as antibacterial and antioxidant agents in the food sector. The fruit peels are filled with nutrients and offer so many health advantages. In addition, its utilization provides enterprises with a source of income as well as aids in increasing economic output. Here are a few examples of fruit peels that have been utilized in the food industry in many ways. Table I shows a few examples of fruit peels application in the food industry. From the previous data found, banana peel is used in the making of low-calorie biscuits [16], orange peel is incorporated in the formulation of cake [17], and apple peel was added as a source of fibre to produce bakery products [18]. In addition, the production of cookies, beef sausages, cheese, and fermented milk [19] [20] [21] [22] from pomegranate peel and grape peel-enriched yogurt [23] has also been reported in the articles related to the utilization of fruit waste. Among the agro-waste peels reported, pineapple peel is commonly used as a substrate for ethanol, methanol, and hydrogen generation Choonut et. al., (2014) [24].

TABLE I. FRUIT PEELS APPLICATION IN THE FOOD INDUSTRY

Fruit Peels	**Utilization**	**References**
Banana Peel	Low-calorie biscuits	Joshi et. al., (2007)
Orange Peel	Utilization in cake	Iftikhar et. al., (2019)
Pineapple Peel	Substrate for ethanol, methanol, and hydrogen generation	Choonut et. al., (2014)
Apple Peel	Fibre enriched in bakery products	Masoodi et. al., (2002)
Pomegranate Peel	Cookies, beef sausages, cheese, and fermented milk	Mahajan et. al., (2015), Chan et. al., (2018), El-Nashi et. al., (2015), Ismail et. al., (2014)
Grape Peel	Enriched yogurt	Marchiani et. al., (2016)

III. NUTRITIONAL CONTENT OF BANANA PEEL

A. Proximate composition

Generally, protein, carbohydrate, fat, moisture content, and ash content are the key to proximate analysis for sampling food, including fruit. Moisture content is associated with the quality and shelf sustainability of foods (total solids) [25]. Meanwhile, ash content is the inorganic residual (mineral composition), which remains upon full oxidation of organic materials with the elimination of moisture through heat (ashing) the sample of food inside the furnace [26]. Furthermore, fat, carbohydrate, and protein are the macronutrients of foods and are known as the main components in proximate composition analysis.

Table II summarises the proximate composition of banana peel studied by Dibanda Romelle et. al., (2016) [27] and Pyar & Peh (2018) [28] using a variety of *Musa acuminata* var. Cavendish (banana Cavendish) while Hassan et. al., (2018) [9] and Anhwange et. al., (2009) [29] used samples of banana peels from *Musa Sepientum*. However, Tsado et. al., (2021) [30] did not state the species of banana peel used in their project. A study has shown that a banana peel's nutritional content is determined using a proximate analysis [28]. Moisture, crude protein, fat, crude fibre, ash, nitrogen-free extract (carbohydrate), and gross energy were determined. However, in this paper, only moisture content, crude protein, fat content, crude fibre, ash content, and carbohydrate content were discussed. Table II shows the proximate analysis of banana peel by Pyar & Peh, (2018) [28], Dibanda Romelle et. al. (2016) [27], Anhwange et. al. (2009) [29], Hassan et. al. (2018) [9] and Tsado et. al., (2021) [30]. The samples of banana peels were analyzed using two approaches which were based on a wet basis and a dry basis. Samples with lower values (less than 15%) are assumed to be in dry form during the analysis. There was a significant difference in moisture content for the analyzed sample. This could be due to many factors, including variety, the method used, and the storage condition of the sample's initial analysis. Here, moisture content plays an essential part in controlling the product's life expectancy. Moisture content is influenced by genetics, crop management, and environmental circumstances [28].

Ash is an inorganic material's left over, produced after the water and organic stuff were eliminated through a heat process. Ash component also refers to the quantity of minerals component present in the food. Generally, the ash content in banana peels ranges from 8.50% - 12.45%, with the highest amount of ash content recorded by Dibanda Romelle et al. (2016) [27]. Ash content in crops is usually associated with the soil and fertilizer used in the plantation. Furthermore, the concentration of protein performed by Dibanda Romelle et al. (2016) [27] (10.44 ± 0.38%) was the highest among other researchers. Protein contains amino acids as its building block, which is essential for protein production and cell protein regulation. The amount of crude protein in fruits is lower as fruits are not a significant source of protein [28].

Table II showed that the banana peels were high in fibre content. The range of fibre in banana peels was reported to be between 8.37% [9] and 31.70% [29]. It is known that banana peels are high in carbohydrates, and it agrees with the data reported by Anhwange et. al.,2009 [29] (59.00%); Dibanda Romelle et. al.,2016 [27] (43.40%); Tsado et. al., [30] (2021 63.82%). Though fibre is also a carbohydrate, Hassan et. al., (2018) [9] did not report it as a part of carbohydrate content due to the low value of carbohydrates reported in the article. All the different values obtained from the proximate analysis could be attributed to various reasons, including variances in geographical conditions, plant species, ambient conditions, and sample processing methods. The differences might also be linked to the section of the fruit utilized in the extract and the solvent used.

TABLE II. PROXIMATE ANALYSIS OF BANANA PEEL

Proximate Analysis	**Wet sample (%)**		**Dry sample (%)**		
	Pyar & Peh (2018)	*Hassan et. al., (2018)*	*Anhwange et. al., (2009)*	*Dibanda Romelle et. al., (2016)*	*Tsado et. al., (2021)*
Moisture content	50.50 ± 2.70	62.33 ± 0.14	6.70 ± 02.22	-	9.83±0.03
Protein	5.30 ± 0.02	1.95 ± 0.14	0.90 ± 0.25	10.44 ± 0.38	3.23±0.05
Fat	1.60 ± 0.14	5.93 ± 0.13	1.70 ± 0.10	8.40 ± 1.15	0.89±0.04
Fibre	19.20 ± 0.54	8.37 ± 0.18	31.70 ± 0.25	11.81 ± 0.06	12.67±0.08
Ash	8.80 ± 0.54	9.60 ± 0.02	8.50 ± 1.525	12.45 ± 0.38	9.56±0.06
Carbohydrates	-	11.82 ± 2.17	59.00 ± 1.36	43.40 ± 0.55	63.82±0.32

B. Mineral content

A mineral is an inorganic solid that is abundantly found in nature. They play an essential role in many bodies' physiological functions, such as metabolic pathway management, important organ formation, pH balancing, and muscular action [26] [27]. Fruits are one of many food sources that possess minerals in the diet. Not only that, their by-products, including peels, are also known to have a good source of nutrients.

In this review, the mineral content that is discussed is significant components such as potassium (K), calcium (Ca), and sodium (Na), and some trace components, which are zinc (Zn), iron (Fe), and manganese (Mn). K, Ca, and Na are called significant components as they are essential, with an estimated consumption of more than 50 mg per day; the trace components are needed for less than 50 mg per day [31].

Banana peels were reported to have high mineral content. According to Anhwange et. al., (2009) [28], potassium is the highest mineral content recorded in banana peels compared to other mineral content, with a concentration of 78.10 ± 6.58 mg/g. In this context, it is worth mentioning that if the banana peel was consumed with the fruit, it could improve the management of body fluids and maintain normal blood pressure as the peel contains a significant amount of potassium. In addition, potassium can also aid with managing renal damage, cardiac irregularities, and breathing difficulties. Furthermore, the calcium content of banana peel was 19.86 ± 0.24 mg/100g, which is the amount observed by Dibanda Romelle et. al., (2016) [27]. However, the amount recorded was slightly different from those obtained by Anhwange et. al., (2009) [29], with a concentration value of 19.20 ± 0.00 mg/g. Calcium is an important component of teeth and the skeleton and plays a key role in muscle and nerve activity control. While for sodium, the concentration obtained by Anhwange et. al., (2009) [29] was 24.30 ± 0.12 mg/g.

As for the trace elements, iron was determined at 15.15 ± 0.36 mg/100g by Dibanda Romelle et. al., (2016) [27] and was comparable to 0.61 ± 0.22 mg/g observed by Anhwange et. al., (2009) [29], which has a significant difference between the two values. Iron aid in the proper immune system's function, transports oxygen to the body, and is required in energy generation and collagen formation. Due to its low concentration, the peel tends to be an ideal supply of iron as excess intake has been linked to irregular immune response, cell development, and cardiovascular system function. The concentration level of manganese obtained by Anhwange et. al., (2009) [29] was higher at 76.20 ± 0.00 mg/100g compared to Dibanda Romelle et. al., (2016) [27], which was 9.05 ± 0.34 mg/100g. Both amounts exhibited a higher significant difference. Manganese aid in the development of the skeleton and cartilage. The deficiency of manganese is rare. However, it could have an impact on blood sugar control, good reproduction, skeletal as well as the development of cartilage.

While for zinc, it is involved in the formation of cellular and immune reactions. The zinc concentration level in banana peels is the lowest at 1.72 ± 0.17 mg/100g. The variation of mineral compositions and concentration in banana peel mineral concentrations could be due to various aspects such as the maturity of the fruits, different types and quality of soils, and the watering system [27]. The mineral level for the non-essential elements such as niobium, zirconium, strontium, rubidium, and bromine were 0.02 ± 0.00 mg/g, 0.02 ± 0.00 mg/g, 0.03 ± 0.01 mg/g, 0.21 ± 0.05 mg/g and 0.04 ± 0.00 mg/g, respectively. This concentration indicates that banana peel exhibits a low amount of non-essential minerals [29]. Table III summarises the mineral content found in the banana peel.

TABLE III. MINERAL CONTENT OF BANANA PEEL

Mineral Content	**Concentrations**	
	Dibanda Romelle et. al., (2016)	*Anhwange et. al., (2009)*
Potassium (K)	-	78.10 ± 6.58 mg/g
Calcium (Ca)	19.86 ± 0.24 mg/100g	19.20 ± 0.00 mg/g
Sodium (Na)	-	24.30 ± 0.12 mg/g
Iron (Fe)	15.15 ± 0.36 mg/100g	0.61 ± 0.22 mg/g
Manganese (Mn)	9.05 ± 0.34 mg/100g	76.20 ± 0.00 mg/100g
Zinc (Zn)	1.72 ± 0.17 mg/100g	-

IV. BIOACTIVE COMPOUND OF BANANA PEEL

Bioactive components are important due to their medicinal qualities, which include anti-inflammatory, antibacterial, antioxidant, and anticancer, and their ability to prevent various chronic illnesses. Regardless of their origin, bioactive compounds have always played a key role as innovative therapeutic agents. They have a significant direct and indirect impact on human health and extensive therapeutic characteristics [32]. Banana peels are suggested to contain many bioactive compounds such as phenolic and carotenoids. Their biological function and amount in banana peel were extensively discussed.

A. *Phenolic compound*

Fruit peel waste contains a sizable number of phenolic substances. Phenolic is a vital secondary metabolite abundant in banana peels compared to other fruits [5]. Phenolic is the most visible secondary metabolite in plants, and its dispersion may be seen across the metabolic process [33]. Simple flavonoids, phenolic acids, complex flavonoids, and colorful anthocyanin are among the components of these phenolic compounds, or polyphenols [34]. Flavonoids, one of the most researched classes of phenolic chemicals, have been shown to possess important biological functions such as antioxidant, antibacterial, antimutagenic, cytotoxic, as well as anticancer properties [32]. In addition, phenolic chemicals are frequently linked to plant defensive responses. Nevertheless, other processes involving phenolic metabolites include adding appealing compounds to speed pollination, coloration for concealment and protection against herbivores, as well as antibacterial and antifungal capabilities.

Phenolic acid molecules are important antioxidants and are the most abundant antioxidants in plant diets. They possess anticancer properties and could prevent oxidative stress-induced tissue damage caused by chronic illnesses [32]. Phenolic substances have been linked to positive effects generated by eating fruits and vegetables, notably due to their antioxidant activity [33]. Natural antioxidants are usually found in agriculture and industrial leftovers such as peel. Phenolic components were related to various health advantages, including cardiovascular disease prevention, cancer prevention, diabetes prevention, and obesity prevention. They have been successfully employed as functional additives in meals since they could inhibit lipid oxidation and the growth of molds and bacteria [5]. Plant polyphenols could provide some prevention over oxidative damage as dietary antioxidants through human health and illness. Phenolic substances are found in plant food and drinks as natural antioxidants, and therefore they play an essential role in pabulum and healthcare. According to several studies, phenolic substances are the most abundant in the average human diet [33]. As a result, recovering these secondary metabolites from banana peel could provide valuable components and increase the banana industry’s value.

Total phenolic compounds in banana peels range from 0.90 to 3.0 g/100g of dry weight [35]. A study has discovered that banana peels contain more phenolic substances as compared to banana pulps [36]. In *Musa cavendish*, total phenolics are found abundantly in the peel, which was 907 mg/100g dry weight, compared to the pulp, which was 232 mg/100g dry weight [35]. According to Vu et. al., (2018) [5], banana peels are exceptionally high in phenolic compounds and come second on the list of total phenolic as compared to other fruit peels, including melon, watermelon, avocado, pineapple, papaya, and passion fruit. In comparison to other fruit peels, banana peel possesses stronger radical scavenging activity and reducing ability, with many studies findings a substantial link between phenolic content and oxygen radical absorbance capacity, free radical scavenging, as well as the ferric reducing ability [5].

Vu et. al., (2018) [5] found over 40 individual phenolic compounds in banana peels. They are divided into four categories which are catecholamines, flavan-3-ols, flavonols, and hydroxycinnamic acids. Within the flavonols, rutin and its conjugate are found as the most prominent compounds. Secondly, ferulic acid seems to surpass other components in hydroxycinnamic acids. The hydroxycinnamic acids can be found in their acid state, either conjugated with sugars or other hydroxycinnamic acids. The flavan-3-ols, which include monomers, dimers, and polymers (tannin), are the most abundant phenolics discovered in the banana peel. The polymers, also called proanthocyanidins, have the largest net concentration of (+)-catechin equivalents, at 3952 mg/kg, followed by dimers, which have a total concentration of 126 mg/kg as (+)-catechin equivalents.

On the other hand, gallocatechin has been identified as having greater concentrations among the monomers with the value of 158 mg/100g degree of methylation (DM)and is five times larger than the fruit pulp. It is worth noting that this molecule has been linked to the banana extract’s powerful antioxidant potential. Furthermore, studies have shown considerable quantities of L-dopa and dopamine, which belong to the family of catecholamines showing significant antioxidant action in the banana peel. Dopamine is a powerful antioxidant that is thought to play a role in the antioxidant activity of the banana extract. The peel’s dopamine concentration at 80–560 mg/100g was discovered to be a couple of times greater than in the pulp, which was 2.5–10 mg/100g at 6 to 7 ripening stages in the reported studies. However, all these values, particularly in phenolic compounds, including individual phenolic compounds that different researchers produced, vary depending on the varieties of bananas, the ripening stage, the fruit’s maturity, environment conditions, soils, and cultivation techniques.

Table IV shows the phenolic compounds found in banana peel [5], citrus fruit [37], pomegranate peel [38], kiwi fruit peel [39] [40] and mango peel [41]. Different phenolic compounds were obtained from other fruit peels studied by the respective researchers. The citrus industry generates significant quantities of peel and seeds leftovers that make up around 50% of the whole fruit [42]. Citrus peels contain a lot of phenolic substances. The banana peel has a significant amount of polyphenolic chemicals and a greater level of radical scavenging action than other fruit peels. According to Pathak et. al., (2017) [43], banana peel comprises about 30 to 40% (w/w) of a fresh banana. The ripe banana peel consists of soluble sugar (13.8%), crude protein (8%), ether extract (6.2%), and total phenolic compounds (4.8%). Chlorophyll, cellulose, hemicellulose, and other low-molecular-weight compounds are the primary ingredients of banana peel (Pathak et. al., 2017) [43].

TABLE IV. PHENOLIC COMPOUNDS IN OTHER FRUIT PEEL WASTES

Fruit Peel	Phenolic Compound	References
Banana peel	Dopamine, rutin, ferulic acid, proanthocyanidins	Vu et. al., (2018) [5]
	Simple flavonoids, phenolic acids, complex flavonoids, and colorful anthocyanin	Babbar et. al., (2014) [34]
	- Total phenolic range from 0.90 to 3.0 g/100g of dry weight. - Total phenolic in *Musa Cavendish* peel is 907 mg/100g dry weight compared to pulp 232 mg/100g dry weight.	Someya et. al., (2002) [35]
	Banana peels contain more phenolic compared to banana pulps.	Fatemeh et. al., (2012) [36]
Citrus peel	Caffeic acid (Minor), Ferulic acid (Major)	Gorinstein et. al., (2001) [37]
Pomegranate peel	Hydroxybenzoic acid, hydrocinnamic acids, anthocyanins, hydrolyzable tannins, and gallotannins	Akhtar et. al., (2015) [38]
Kiwifruit peel	Protocatechuic acid, caffeic acid, p-coumaric acid	Mattila et. al., (2006) [39], Wijngaard et. al., (2009) [40]
Mango peel	Flavonol glycosides	Schieber et. al., (2000) [41]

There are 48 polyphenolic chemicals found in pomegranate peels. Research on the anticancer, antitumor, antiviral, and antioxidant properties of pomegranate peel has shown that these properties prevent our bodies against Low-Density Lipoprotein (LDL) cholesterol and lower the probability of heart disease and cancer. Similar to citrus peel, pomegranate peel contains many phenolic substances which have antibacterial, anti-allergic, antimutagenic, antioxidant, anti-inflammatory, and anticancer properties [42]. According to Srividhya et. al., (2013) [44], citrus fruit peels showed antimicrobial and antioxidant activities and were potentially used as an inhibitory agent for gastrointestinal tract disorder. Norepinephrine, dopamine found in banana peels, increases intestinal muscle smoothness, and raises blood pressure. Ehiowemwenguan et. al., (2014) [45] stated that banana peel had been postulated to reduce discomfort, including mosquito bites effectively.

B. *Carotenoids*

Carotenoids are pigments that possess antioxidant qualities and positively impact the human body. Carotenoids, such as lycopene, alpha-carotene, and beta-carotene, aid in light absorption by plants. Carotenoids are mainly collected throughout the hepatic organ and discharged into the bloodstream as lipoproteins. It is generally discharged in the liver and high concentrations of free radical species, contributing to the anti-oxidative defense mechanism. As a result, carotenoid physiological activities could interfere with or prevent liver problems, including hepatocellular carcinoma, cirrhosis, chronic hepatitis, hepatic steatosis, and acute hepatitis. Moreover, dietary carotenoids can diminish aging-related disorders by inhibiting cellular dysfunction and oxidative stress through the mechanism of reactive oxygen species generation, commonly associated with a compound’s antioxidant capability [46].

The banana peel was reported to contain alpha-carotene, beta-carotene, and lutein. Lutein, the yellow color pigment, is amongst the most significant carotenoids present in the banana peel and a member of the xanthophyll family [47]. It possesses almost 70% of the total carotenoids, while other dominant carotenoids’ value is less than 3.3%. Lutein is responsible for the clear vision of pictures and works together with zeaxanthin. Furthermore, lutein has been linked to various health benefits, including a lower chance of developing age-related macular degeneration (AMD) and protection against atherosclerosis, cataracts, cancer, and other disorders. Additionally, lutein has antioxidant properties to protect the cells from oxidative damage [48].

Three different cultivars from *Indonesia, Raja, Ambon Kuning, and Kepok Kuning,* were observed for relative concentrations of alpha-carotene, beta-carotene, and lutein [49]. The concentrations were recorded from their peak areas detected at λ_{max} and the percentage of peak area (% area) detected at 450 nm. For the lutein concentration of peak area at $\lambda_{max,}$ Ambon Kuning recorded the highest value (11,702), followed by Raja (11,655) and Kepok Kuning, which was 5,774. For the alpha-carotene, Raja recorded the highest value, which was 332. This was followed by Ambon Kuning (35) and Kepok Kuning (30). For the beta-carotene, Raja recorded the highest concentration, which was 482, followed by Ambon Kuning (71), and Kepok Kuning (49). Determination of the percentage of peak area (% area) detected at 450 nm, Kepok Kuning recorded the highest lutein concentration, which was 72.9, followed by Raja (72.2) and Ambon Kuning (70.6). Furthermore, for the alpha-carotene, Raja recorded the highest concentration, which was 2.4, followed by Kepok Kuning (1.1) and Ambon Kuning (0.2). Similar results were also recorded for the beta-carotene, of which Raja gave the highest value, 3.3, followed by Kepok Kuning (2.2) and Ambon Kuning (0.4) [49]. Based on these analyses, the major carotenoids that have been identified in banana peels by high-performance liquid chromatography are lutein, alpha-carotene, and beta-carotene.

V. POTENTIAL UTILIZATION

Potential utilization or applications for banana peel depend on its nutritional contents and bioactive compounds. A few of these potential utilizations of banana peel were also discussed. Table V summarizes the potential utilization of banana peel and other fruit peel waste (orange/citrus peel, pineapple peel, apple peel, pomegranate peel, and grape peel). Banana peels were reported to have the potential for citric acid production by fermentation using *Aspergillus nige*r [50] [51], as traditional medicine [52] [53] [54] [55] [56] [5], in food and pharmaceuticals industries [57] [58] [59] [60] [61] [5] and as dietary incorporation [62] [46]. The high-fibre cake was formulated by incorporating orange and/or citrus peels [17] and apple peels [18]. These peels ingredient was first transformed into a powder form before adding the formulation.

Pomegranate peel was used as a natural preservative in cheese [19] and beef sausage [21] while Chan et. al., (2018) [20], El-Nashi et. al., (2015) [21] and Ismail et. al., (2014) [22] incorporated the peels in fermented milk, beef sausage, and cookies, as antioxidant sources. The addition of pomegranate peels has also increased the fibre content in cookies from 0.32-1.96 g/100g [22]. Marchiani and co-researchers (2016) [23] have stated the addition of grape peel powder in yogurt formulation was significantly high in total phenolic compounds (+55%) and antioxidant activity (+80%). On the other hand, pineapple peels are often used as substrates for ethanol, methanol, and hydrogen generation by fermentation using *Saccharomyces Cerevisiae* and *Enterobacter Aerogenes* [24]. Most of the findings reported in Table V showed that the fruit peels generally contain high fibres and could be used as fibre enrichment in food products. The presence of bioactive compounds such as phenolic and carotenoid could also be beneficial as antimicrobial and antioxidant ingredients in food products.

TABLE V. POTENTIAL UTILIZATION OF BANANA PEEL AND OTHER FRUIT PEEL WASTE

Fruit Peel Waste	Bioactive Compounds	Potential Utilization	References
Banana Peel	• Phenolic compounds (Dopamine, rutin, ferulic acid, proanthocyanidins) • Carotenoids (Alpha-carotene, beta-carotene, lutein)	• Citric acid production by Aspergillus *niger.*	• Khairan et. al., (2019), Kareem et. al., (2013)
		• Traditional medicine	• Rabbani et. al., (2001), Imam & Akter (2011), Kurtoğlu & Yildiz (2011), Sampath Kumar et. al., (2012), Pereira & Maraschin (2015), Vu et. al., (2018)
		• Food and pharmaceuticals industries	• Cheng et. al., (2007), Anal et. al., (2014), Devatkal et. al., (2014), Wu et. al., (2015), Kurhade et. al., (2016), Vu et. al., (2018)
		• Dietary incorporation of banana peels	• Happi Emaga et. al., (2008), Oyeyinka & Afolayan (2020)
Orange Peel / Citrus Peel	• Caffeic acid (Minor), Ferulic acid (Major)	• Utilization in cake	• Iftikhar et. al., (2019)
Pineapple Peel		• Substrate for ethanol, methanol, and hydrogen generation	• Choonut et. al., (2014)
Apple Peel		• Fibre enriched in bakery products	• Masoodi et. al., (2002)
Pomegranate Peel	• Hydroxybenzoic acid, hydrocinnamic acids, anthocyanins, hydrolyzable tannins, and gallotannins	• Cookies, beef sausages, cheese, and fermented milk	• Mahajan et. al., (2015), Chan et. al., (2018), El-Nashi et. al., (2015), Ismail et al. (2014)
Grape Peel		• Enriched yogurt •	• Marchiani et. al., (2016)

A. *Citric Acid Production by Yeast*

Citric acid is extensively used in modern industries, including drinks, foods, pharmaceuticals, textiles, metals, chemicals, and others [50]. Citric acid was first discovered in lemon juice, and Scheele crystallized it in 1784, which is known as a natural element among several other citrus fruits. Around 70% of citric acid generated is utilized in various applications in the food and drinks sector, which are 12% in medicines and 18% for other commercial applications. Banana peel is used as a substrate for citric acid production by

Aspergillus niger as it contains high carbohydrates and other nutrients. Citric acid is often commercially produced by the submerged fermentation process of sucrose or molasses with the filamentous fungus *Aspergillus niger* or artificially either acetone or glycerol [51]. However, due to better and increased yields, water utilization is decreasing, and operational cost reduces, solid state fermentation (SSF) has recently been proposed as a viable option for citric acid manufacturing. Due to the high demand for citric acid in manufacturing industries, particularly in the pharmaceutical companies, many attempts or strategies have been made to enhance citric acid production by improving the manufacturing that is quick, cost-effective, environmentally safe, eco-friendly, and thus, not rely on citrus acid as the primary sources of citric acid [50]. Many experts utilize various microorganisms to produce citric acid, including *Aspergillus fumaricus, Aspergillus funicus, Aspergullus flavus, Penicillium restrictum, Trichoderma viride, and Penicillium janthinellum. Aspergillus niger is a* fungal strain that is generally used in citric acid manufacturing as they are easy to handle and produced high yields of citric acid. These microorganisms could be used with other inexpensive agricultural wastes such as carrots, oranges, pear, kiwi peels, pineapple, cane molasses, and cotton waste to produce citric acid.

Table VI summarises the studies on the fermentation of banana peel for citric acid production from banana peel. A few parameters are studied, such as substrate concentration, inoculum level, phosphate source, nitrogen source, incubation period, pH, and moisture content, to improve the citric acid yield obtained from banana peel fermentation using different microorganisms. Yellow banana peels were found to possess a higher yield of citric acid in comparison to green banana peels [63]. Various species of banana peels also produced a different yield of citric acid, with Pisang Nipah (*Musa balbisiana*) exhibiting the highest value, followed by Pisang Raja (*Musa Paradisiaca* cv. *Raja Genom AAB*) and Pisang Ayam (*Musa acuminate*) [50]. Abbas et. al., (2016) [64] reported that the highest yield of citric acid was found using a 25% of substrate concentration (52.08 g/l), inoculum level of 5% (28.56 g/l), the addition of potassium dihydrogen phosphate (24.09 g/l) with an incubation period of 8 days (51.68 g/l and moisture content of 1:3 (52.08 g/l). However, different nitrogen sources did not significantly affect the yield obtained in this study. The finding also suggested that substrate concentration, incubation days, and moisture content play important roles in the production of a higher yield of citric acid.

Another study done on the effect of parameters was published by Karthikeyan & Sivakumar (2010) [65]. The following parameters produced approximately 170 g/kg of citric acid: moisture content of 70%, 28˚C of incubation temperature, initial pH of 3, and inoculum level of 108 spores/ml for 72 hours of incubation periods. The concentration of citric acid extracted from banana peel using *A.niger* supplemented with 0.3% nitrogen (ammonium nitrate) and phosphorus (ammonium phosphate) is #increased from 0.172 mg/L (day 1) to 1.304 mg/L (day 7). This culture was incubated for 7 days at a temperature of 27˚C with a moisture content of 60% [66]. While fermentation of banana peels using *Trichoderma viride* and *Saccharomyces cerevisiae* was carried out in 0.5% potassium dihydrogen phosphate and 0.5% peptone for 3 days, yielding citric acid at a value of 75% [67].

B. Traditional Medicines and Pharmaceuticals Industries

Generally, bananas possess various pharmacological properties, including antioxidant, anticancer, antiulcer, antidiabetic, antimicrobial, wound healing, and atherosclerosis. Due to its extensive effects, banana, specifically the fruit peel, has been traditionally used as a herbal remedy for various diseases such as burns, coughs, ulcers, and diarrhea. The peels have been used to enhance burn-healing wounds [56] by creating a wound poultice that is placed around the lesion to relieve inflammation and discomfort [5]. The wound-healing properties of the banana peel are often associated with the predominant effects of the peel on the mucosal defensive factor that could enhance DNA synthesis and promotes mucosal cell proliferation. An *in vivo* study involving mice showed that methanol and aqueous extracts of plantain banana (*Musa sapientum var. paradisiaca*) had increased the amount of hydroxyproline, hexuronic acid, hexosamine, superoxide dismutase levels, and the wound tensile strength. The extracts also improved wound healing by reducing lipid peroxidation, the wound areas and scar formation.

Furthermore, the inside part of the banana peel has been suggested to possess medicinal properties to treat skin warts caused by mosquito bites by applying the peel onto the affected region. This could minimize the inflammation and discomfort around the affected area. On the other hand, banana peel (green color) is often used to treat diarrhea [55] by reducing feces volume and improving oral rehydration and vomiting [52]. Many studies have been done on both yellow and green peels of the banana, which exhibited high antimicrobial activity against several bacteria, including *Bacillus subtilis* (20.60%), *Staphylococcus aureus* (19.75 mm), *Escherichia coli* (18.15 mm), and *Pseudomonas aeruginosa* (19.57 mm). This antimicrobial effect of banana peels has been suggested due to the presence of phytochemicals such as phenolic compounds and tannins.

Leucocyanidin, a flavonoid found in banana peels, was demonstrated to enhance the density of the gut mucous membrane surface [53]. The concentration of tryptophan in bananas has been suggested to treat depression, while the iron present in the peel could increase the hemoglobin production to treat anemia [55]. In addition, it is also stated that the great potassium quantity in banana peels could reduce the risk of heart disease by lowering blood pressure. This study is then supported by a finding found in *in vivo* study using Ambon (*Musa paradisiaca*) peel extract, which exhibits an anti-atherosclerotic effect by inhibiting nuclear factor kappa beta (NF-κB) and increasing endothelial nitric oxide synthase (e-NOS) expression in atherogenic rats using the immunohistochemical method. The results showed that the extract significantly decreased NF-κβ activity and increased e-NOS activity dose-dependently. This has proven that banana peel could potentially prevent atherosclerosis.

TABLE VI. CITRIC ACID PRODUCTION USING BANANA PEEL

Sample/samples	Parameters	Yield %	References
Banana peel	Fermentation using Aspergillus niger using the following parameters. • Substrate concentration (20%, 25%, 30% and 35)	• The highest yield obtained was as follows for the respective parameter: • 52.08 g/l (25%)	Abbas et. al., 2016
	• Inoculum level (3%, 4%, 5% and 6%)	• 28.56 g/l (5%)	
	• Phosphate sources (disodium hydrogen phosphate, potassium dihydrogen phosphate, and dipotassium hydrogen phosphate)	• 24.09 g/l (potassium dihydrogen phosphate)	
	• Nitrogen sources (Ammonium nitrate, ammonium phosphate)	• No significant effect	
	• Incubation days (6, 7,8, and 9 days)	• 51.68 g/l (8 days)	
	• Moisture content (1:2, 1:3 and 1:4)	• 52.08 g/l (1:3)	
Yellow banana peel	Fermentation using *Aspergillus niger* supplemented with a nitrogen source and moistened to 60% moisture content. The incubation temperature was 30°C in a rotary shaking incubator for 5 days	87%	Damari priscilla & Gnaneel 2020
Green banana peel		45%	
Banana peel	Fermentation using *Aspergillus niger* was carried out for 7 days, and the parameters used were as follows: • 0.3% nitrogen (ammonium nitrate) and phosphorus (ammonium phosphate) supplements and moistened to 60% moisture content. • Incubated temperature: 27˚C	Increase from 0.172 mg/L (day 1) to 1.304 mg/L (day 7)	Chukwuemeka et. al., 2019
Banana peel	Fermentation using *Trichoderma viride* and *Saccharomyces cerevisiae* was carried out for 3 days in potassium dihydrogen phosphate of 0.5% and peptone of 0.5%	75%	Raagapriya et al. (2016)
Banana peel (Musa acuminata)	Fermentation using *Aspergillus Niger* • Moisture content (50, 60, 70,80 & 90%) • Temperature (26, 28, 30, 32 and 34˚C) • pH (2, 3, 4, 5, 6 and 7) • inoculum level (104, 106, 108, 1010 and 1012 spores/ml) • Incubation time (1-5 days)	Maximum citric acid production with a yield of approximately 170g/kg was obtained through the following parameters. • Moisture (70%), • 28˚C temperature, • an initial pH of 3, • 108 spores/ml as inoculum • 72 h incubation	Karthikeyan & Sivakumar (2010)
Pisang Ayam (Musa acuminate), Pisang Raja (Musa Paradisiaca cv. Raja genom AAB), and Pisang Nipah (Musa balbisiana)	Fermentation using *Aspergillus Niger* (9.0 × 106) and incubated at 30ºC in a rotary shaking incubator at 60 rpm for 10 days	The highest yield of citric acid was obtained through 8 days incubation period for Pisang Ayam (Musa acuminate), Pisang Raja (Musa Paradisiaca cv. Raja Genom AAB) 59.76% and (63.6%), and 10 days incubation period for Pisang Nipah (Musa balbisiana) (69.84%)	Khairan et. al., (2019)

Another study revealed that the phytochemicals found in banana peel, such as saponin, tannin, and flavonoid, could reduce the total cholesterol level in obese mice. Furthermore, the banana peel contains high fructooligosaccharides, a prebiotic that feeds good bacteria in the human colon [54]. These bacteria create vitamins as well as digestive enzymes, which aid in the absorption of nutrients. This showed that the banana peel has many therapeutic benefits and value for health [5]. Therefore, more studies on these bioactive compounds and their biological activity are required [55].

C. Dietary Incorporation of Banana Peels

Banana peels, a common by-product of the banana processing industry, are suggested to contain various nutrients and fibre, with potassium, magnesium, and calcium dominating the list. Commercial usage, on the other hand, has not been maximized. As a result, after the fruit is consumed, the peels are discarded as waste. According to Happi Emaga et. al., (2008) [62], the peels of bananas possess valuable stocks of cellulose (7.6% to 9.6%), hemicelluloses (6.4% to 9.4%), as well as lignin (6% to 12%). These qualities make banana peels useful as a digestive aid. The peels could be used to make the smoothie mix or therapeutic banana tea, similar to how the pulp has been utilized in the banana smoothie. Additionally, various culinary procedures have been proposed to increase the attractiveness of banana peel, including using ripened banana fruits as the ripened fruit is sweeter and thinner, allowing complete peel washing. Plantain peels also offer nutritional as well as dietary potentials, with plantain peel flour containing appropriate antioxidant levels, dietary fibre, and protein. Plantain peel flour has been used to substitute wheat flour in the binding of sausage snacks. The high dietary fibre content of plantain peels has also been used to produce biscuits with high fibrous content. Combining plantain peel flour with a pasta meal, which is generally associated with semolina flour, provides another nutritional choice [46]. Banana peel, in essence, has intrinsic nutritional diversification potential.

VI. CONCLUSION

Banana peel is a fruit waste or a by-product that is not consumed due to its unpleasant taste. Banana peels generally contain beneficial nutritional contents such as protein, carbohydrate, fat, moisture, ash content and bioactive compounds such as phenolic compounds and carotenoids. Phenolic are important secondary metabolites found abundantly in banana peels compared to the other fruits. Flavonoids are an example of phenolic compounds in the banana peel that have been shown to have important biological functions, such as antioxidants. Antioxidant activity is essential and often associated with the treatment of various diseases. Furthermore, phenolic components also possess many health benefits, including the prevention of obesity, diabetes, cancer, and cardiovascular disease. Flavan-3-ols, which include monomers, dimers, and polymers (tannin), is the most abundant phenolic found in the banana peel. In contrast, carotenoid is thought to prevent liver diseases such as hepatocellular carcinoma, cirrhosis, chronic hepatitis, hepatic steatosis, and acute hepatitis. Lutein, beta-carotene, and alpha-carotene are examples of carotenoids found in the banana peel. Lutein has been reported as the most significant carotenoid present in the banana peel. Lutein also has been linked with many benefits, such as protection against atherosclerosis, cataracts, and cancer. In addition, many studies have shown that banana peel has broad therapeutic actions such as anti-inflammatory, antidiabetic, wound healing, antibacterial, antioxidant, and anti-psoriasis activities. Therefore, further study is needed to characterize the active constituents responsible for the biological activities and potential utilization of banana peels in either food, pharmaceutical, or cosmetic industries to minimize the disposal of the peels as waste.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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