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Original Research

Exploring the Nutritional, Phytochemical, and Antibacterial Properties of Green Banana Pulp and Peel: A Comparative Analysis

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ABSTRACT

Background: Bananas, esteemed for their nutritional benefits and historical therapeutic use, are a favored fruit among consumers. Paradoxically, the banana peel, a significant by-product of the banana processing industry, is often disregarded and treated as waste. Nonetheless, banana peels represent an overlooked source of nourishment and adaptability. This study aimed to conduct a thorough evaluation of the nutritional composition, phytochemical properties, and bioactivity of green banana pulp and peel extracts. **Methods:** Banana pulp and peel were subjected to oven drying at a regulated temperature, and proximate analysis was conducted in accordance with AOAC methodologies. The analysis of bioactive components and antioxidant capability was conducted using a UV-visible spectrophotometer. High Performance Liquid Chromatography (HPLC) was utilized to identify active constituents such as phytochemicals in the extract. The disc diffusion method was utilized to assess the efficacy of the extracts against *Escherichia coli* and *Staphylococcus aureus*. **Results:** The banana peel powder had higher levels of crude protein (7.18±0.02%), crude fat (8.56±0.04%), crude fiber (26.77±0.096%), and ash (10.12±0.0106%). In contrast, banana pulp powder had higher moisture (6.09 ± 0.06%) and carbohydrate (81.76 ± 0.065%) content. The total flavonoid content in banana peel (226.22 mg QE/100g) was higher than that of banana pulp (58.21 mg QE/100g), and banana pulp had the highest total polyphenol content (24.06 mg GAE/100g). Both extracts contained essential tannins, and flavonoids, according to phytochemical screening. Also, banana pulp and peel extracts showed antibacterial activity against *S. aureus* and *E. coli*. **Conclusion:** This study emphasizes the enhanced nutritional profile of green banana peel relative to pulp, alongside its promising phytochemical and bioactive properties. Thus, banana pulp and peel powder may serve as valuable resources with various applications, fostering healthier diets, sustainable agriculture, and environmentally friendly innovations.

Keywords: Banana peel; antioxidant; phytochemical screening; tannins; bioactive compounds; antibacterial activity

1. INTRODUCTION

Egyptians, Greeks, Chinese, and indigenous societies have used plants for medication for thousands of years. These societies used botanical knowledge to treat illnesses. Many traditional medical systems, including Ayurveda in India, Traditional Chinese Medicine (TCM) in China, and Indigenous healing practices worldwide, use plant-based medicines.[1] These systems have been passed down through generations and continue to be practiced today. Recent research has revealed that fruit and vegetable peels possess potential antibacterial properties.[2] Notably, in certain fruits, the seeds and peels exhibit greater antibacterial action than the pulp.[3] Fruit processing waste includes peels, seeds, skins, and cores is significant. Disposing of waste might be challenging due to legal constraints. This waste can harm the environment if not properly managed. It also offers sustainability options through waste reduction, reuse, recycling, resource recovery, and value-added product development. High-value goods from the recovery of these wastes are commercially viable and the utilization of these wastes as by products for further investigation on the manufacture of food additives or supplements with high nutritional content have drawn a significant concern

Banana, formally known as Musa spp., is one of the most extensively consumed fruits in the world due to its sweet taste, high nutritional value, and potential health advantages. A daily tropical fruit, bananas are delicious and nutritious. In addition to its sweet and creamy taste, bananas are rich in vitamins, minerals, and carbs.[4] As a source of essential nutrients, bananas are accepted as a prominent part of human diets.[5] However, while the banana fruit is widely recognized for its nutritional value, the banana peel has often been relegated to the status of agricultural waste. Banana peels are not only a rich source of essential nutrients and bioactive compounds but also possess properties that extend their utility far beyond the fruit they protect.[6] These bioactive compounds are often associated with promoting health and preventing or mitigating various diseases. They play a pivotal role in the field of nutrition, functional foods, and pharmacology due to their potential to enhance well-being and overall health.[7] Recent years have witnessed an increasing interest in harnessing both banana pulp and its frequently neglected counterpart, banana peels, as a significant source of bioactive compounds with potential health benefits, facilitating the creation of value-added products like banana peel powder, which can mitigate waste while providing distinctive health advantages.[8] A multitude of industrial applications for bananas and banana peels exists, including pectin extraction,[9] biofuel production,[10] utilization in pharmaceuticals and cosmetics,[11] and water filtration,[12] among others. The antibacterial activity of banana peels is positively correlated with their flavonoid and phenolic content. These compounds are effective against both *Staphylococcus aureus* and *Escherichia coli*.[13] To date, minimal research has been conducted on the comparative analysis of phytochemical, bioactive, and antibacterial properties between banana pulp and peel.

This study is important for understanding the nutritional components of both banana and banana peel powders which can provide valuable insights into their potential as dietary supplements and can contribute to nutritional diversity. Investigating the antibacterial activities of banana and banana peel powders may lead to the development of natural antimicrobial agents. These could be used in the food industry to enhance food safety or in the development of alternative treatments for bacterial infections. This study was conducted to assess the nutritional composition, bioactive characteristics, and antibacterial effects of banana pulp and peel against *E. coli* and *Staphylococcus aureus*. Ultimately, the study's findings can have positive implications for public health by promoting the consumption of nutrient-rich foods and the development of natural remedies for bacterial infections, contributing to overall well-being.

2. METHODS

2.1 Sample Accumulation

Samples of Green Banana, locally known as Atia Kola were harvested at an optimal stage of maturity from local garden of Nalua, Satkania, Chattogram. Atia Kola contains soft seeds and provides relief against constipation and intestinal disorders.[14] In order to receive the banana in the best condition possible, special care was taken during collection and bananas were kept in the refrigerator of the lab till the next step of study. Further necessary components for the experiment were acquired from the laboratory's inventory.

2.2 Sample Preparation

After gathering mature green bananas and rinsing them under running tap water, 70% alcohol was used to

sterilize their surfaces. Peels from bananas were then separated. After being properly sliced with a Panasonic MK-5086M slicer, the banana peel and pulp were dried in a cabinet dryer (E3 Drying Cabinet, Genlab, UK) at 50°C for a duration of 48 hours. The dried banana peel and pulp samples were both pulverized into a fine powder via a Panasonic MX-AC300 Mixer Grinder. For later use, the two powders were kept apart in airtight HDPE zipper bags.

2.3 Proximate Composition Analysis

The constituent elements of the banana pulp and peel samples were assessed using the AOAC standard technique (DM Basis).[15] The moisture, ash, crude protein, crude fiber, and crude fat contents were measured using the dry ash technique, oven drying method, Kjeldahl's method, gravimetric method, and Soxhlet method, respectively.

2.4 Determination of Bioactive Compounds

2.4.1 Extract preparation

The extraction process involves combining 10 ml of pure ethanol (100%) with 1 g of the substance in a Falcon tube, followed by allowing it to rest undisturbed for a duration of 72 hours. After a period of 72 hours, strain the solvent and gather the resulting filtrates. Subsequently, the ethanoic extract was identified.

2.4.2 Flavonoid measurement (TFC)

The total flavonoid concentration in the samples was quantified utilizing the aluminum chloride colorimetric method, as outlined by Chang et al. (2020).[16] A suitable volume of extract stock solution (1 mg/mL) was prepared for the calibration curve. Quercetin (Sigma, USA) was dissolved in 80% ethanol to generate standard solutions at concentrations of 0.025, 0.050, 0.075, and 0.100 mg/ml. In the cuvette, 0.5 mL aliquots of the standard solution (diluted extract) were mixed with 1.5 mL of 95% ethanol, 0.1 mL of 10% aluminum chloride (QualiChem, India), 0.1 mL of 1 mol/L potassium acetate (Merck, Germany), and 2.8 mL of distilled water. The obtained mixture was allowed to cool to room temperature (25.5 ± 1°C) for 30 minutes prior to use. The absorbance at 415 nm was subsequently measured via a UV-visible spectrophotometer. In the blank preparation, 10% aluminum chloride was substituted with an equivalent volume of distilled water. Total flavonoid content (TFC) was quantified in milligrams of quercetin equivalents (QE) per 100 grammes of extract.

2.4.3 Measurement of polyphenols (TPC)

The Folin-Ciocalteu (FC) reagent method, with minor changes, was utilized to quantify the total phenolic content (TPC) of the extracts, as described by Al-Owaisi et al. (2014).[17] Appropriate stock solutions (1 mg/mL) of extracts and standard solutions (0.02, 0.04, 0.06, 0.08, and 0.10 mg/mL) of gallic acid (Sigma, USA) were formulated for the experiment. Subsequently, 0.3 mL of gallic acid standard solution or extracts was pipetted into a cuvette. Subsequently, 1.5 mL of the diluted Folin-Ciocalteu reagent was added and mixed. Following a three-minute pause, 1.5 mL of sodium carbonate solution (75 g/L) was introduced and allowed to stand for sixty minutes. Ethanol served as the blank for absorbance measurement at 765 nm utilizing a UV spectrophotometer. Total phenolic content (TPC) was quantified in milligrams of gallic acid equivalents (GAE) per 100 grammes of extracts.

2.5 Assessment of Antioxidant Capability with the DPPH Scavenging Method

The antioxidant efficacy of the extracts was evaluated utilizing the DPPH (2, 2-diphenyl-1-picrylhydrazyl) assay, with some modifications to the methodology described by Almey et al. (2010).[18] The extract was diluted from a 1 mg/mL stock solution to concentrations of 0.50, 1.00, 1.50, 2.00, and 2.50 mg/mL in methanol (Merck, Germany). In the methanolic DPPH solution, 6 mg of DPPH was dissolved in 100 mL of methanol. Two milliliters of methanolic DPPH solution were meticulously combined with one milliliter of each extract solution of differing concentrations. The mixture was allowed to stand for 30 minutes, after which the absorbance was recorded at 517 nm. Subsequently, 1 mL of methanol was combined with 2 mL of DPPH solution to serve as a control. The calibration curve was generated using methanol as a blank and Trolox (Sigma, USA) as a reference standard. Furthermore, antioxidant capacity was quantified in milligrams of Trolox equivalents (TE) per 100 g of extracts, use DPPH free radical scavenging activity as the basis for measurement.

2.6 Phytochemical Screening

Several phytoconstituents found in banana pulp and peel were tested using the produced extracts. A variety of chemical reagents were created, and tests were conducted for particular phytochemicals. Because these examinations were qualitative, they were referred to as phytochemical screening. The tests were conducted using

conventional protocols that were derived from scientific articles. Phytochemical screening of the crude extract of banana pulp and peel powder was carried out using standard phytochemical procedure.[19]

2.6.1 Test for phenols

According to Pant et al. (2017),[20] the addition of 2 ml of alcohol and 2-3 drops of ferric chloride solution to 1 ml of the crude extract resulted in the development of a blue-green or black coloration, which indicated the presence of phenols

2.6.2 Test for tannin

Following the procedures mentioned in Pant et al. (2017),[20] to the diluted extract, 3-4 drops of 10% $FeCl_3$ were added, blue color was seen for gallic tannins and the presence of catechol tannin turned the solution green.

2.6.3 Test for saponins

This procedure was carried out according to Alamzeb et al. (2013).[21] Based on the method, 2 g of powdered sample was boiled in 20 mL of distilled water. 10 mL of filtrate, 5 mL of distilled water were quivered vigorously. The appearance of frothing indicated the presence of saponins.

2.6.4 Test for flavonoids

A mixture was prepared according to Alamzeb et al. (2013),[21 by combining 0.5 ml of the crude extract with 2 ml of a 2% NaOH solution. This resulted in the formation of a vivid yellow color, which subsequently became colorless upon the addition of a few drops of diluted acid. It ensures the presence of flavonoids.

2.6.5 Test for glycosides

Test for glycosides were performed following procedures mentioned in Thusa et al. (2017).[22] To the extract, 5 mL Molisch's reagent and concentrated H_2SO_4 were added. Violet color indicated glycosides.

2.7 Antibacterial Activity

2.7.1 Preparation of extract

The banana pulp and peel powder were mixed separately with Ethanol solvent at proper ratio and kept at incubator at 37ºC for 48 hours. Then the extracts were collected following filtration using Whatman No. 1 filter paper and were concentrated using a rotary evaporator. Finally, the crude extracts were stored for further use.[23]

2.7.2 Test microorganisms

The antibacterial efficacy was evaluated against *Staphylococcus aureus* and *Escherichia coli*. Pure, isolated cultures of *Escherichia coli* and *Staphylococcus aureus* were sourced from the Poultry Research and Training Centre (PRTC) at Chattogram Veterinary and Animal Sciences University in Chattogram. The broad- spectrum antibiotics, Ciprofloxacin (CIP) and Gentamycin (CN), served as the standard reference for comparison.

2.7.3 Preparation of culture suspension

Each isolate's inoculum was made from a subculture. In a sterile screw cap tube containing 2 ml of sterilized saline water, 4-5 colonies of each isolate were collected. Following that, the bacterial culture was emulsified in sterile normal saline, and the turbidity was adjusted to match 0.5 McFarland standard (≈ 1.5×10^8 (CFU/mL).

2.7.4 Media preparation

In accordance with the label instructions, 38 grams of Mueller Hinton agar powder were precisely weighed and then mixed with 1 liter of distilled water. The resulting media were heated to ensure complete dissolution and thorough mixing. Once mixed, the media underwent autoclave sterilization and were subsequently transferred to a water bath to cool down. After achieving the desired temperature, the media were aseptically dispensed onto Petri plates and allowed to solidify. These Petri dishes were then incubated for a 24-hour period at 37°C to detect any signs of contamination.[24]

2.7.5 Antibacterial effect of samples against *Escherichia coli* and *Staphylococcus aureus*

The disc diffusion method was employed to examine the effectiveness of the extracts, and their impact was measured by taking note of the zone of inhibition surrounding the disc.[25] Whatman No. 1 Filter paper was used to create discs with a diameter of 6 mm. 0.5 mL of each sample was used to impregnate the discs. The Mueller Hinton agar plates were uniformly inoculated by dipping a sterile cotton swab into the standardized bacterial suspension. They were left to dry for three to five minutes. Following that, each disc was put on the plates and lightly pressed to ensure full contact with the agar. To display overlapping of inhibitory zones, a space of at least 15 mm was kept between the plates' edges. The plates were incubated for 24 hours at 37°C fifteen minutes after the discs were placed. Following incubation, the plates were inspected, and the diameter of the inhibitory zone for each isolate was measured.

2.8 Statistical Analysis

The data collected were organized, assigned codes, and recorded within a Microsoft Excel 2019 spreadsheet. Subsequently, statistical analysis was carried out using SPSS (Statistical Package for the Social Sciences) software,

version 19.0. This analysis employed One-way ANOVA (Analysis of Variance) procedures to determine the significance of variations at a 95% confidence interval. The level of significance chosen for the statistical analysis was set at 5% (≤ 0.05). Furthermore, the statistical analysis (Tukey's pairwise comparison) was conducted to identify specific differences among groups.

3. RESULTS

3.1 Proximate Composition of Banana Pulp and Peel Powder

Table 1 displays the mean percentage with standard deviation (ME ± SD) of the proximate composition value which includes moisture, protein, fat, crude fiber, ash and carbohydrate content of both banana pulp powder and banana peel powder.

Table 1. Proximate analysis of banana pulp and peel

Component	Banana pulp powder	Banana peel powder
Moisture (%)	6.09 ± 0.06^{b}	5.15 ± 0.04^{a}
Crude protein (%)	4.36 ± 0.025^{a}	7.18 ± 0.02^{b}
Crude fat (%)	0.80 ± 0.045^{a}	8.56 ± 0.04^{b}
Crude fiber (%)	10.07 ± 0.042^{a}	26.77 ± 0.096^{b}
Ash (%)	2.98 ± 0.035^{a}	10.12 ± 0.106^{b}
Carbohydrate (%)	76.42 ± 0.065^{b}	47.25 ± 0.03^{a}

Table indicates the mean ± S.D. and superscript show non-significant difference between the treatments.

According to this analysis, Banana pulp powder had a larger percentage of moisture (6.09 ± 0.06%) and carbohydrate content (81.76 ± 0.065%) where banana peel powder contained 5.15 ± 0.04% moisture content and 47.25±0.03% carbohydrate content respectively. Contrarily, crude protein (7.18±0.02%), crude fat (8.56 ± 0.04%), crude fiber (26.77 ± 0.096%) and ash content (10.12 ± 0.106%) of the banana peel powder was higher. The crude protein, crude fat, crude fiber and ash content of banana pulp powder was 4.36 ± 0.025%, 0.80 ± 0.045%, 10.07 ± 0.042% and 2.98 ± 0.035% respectively.

3.2 Bioactive Components and Antioxidant Activity of Banana Pulp and Peel

Bioactive components and antioxidant capacity were analyzed by using a UV- visible spectrophotometer. Results were subjected to descriptive statistical analysis followed by Tukey's comparison analysis. Results are shown in the below Table 2.

Table 2. Bioactive and Antioxidant Properties of banana pulp and peel

Sample	Total flavonoids content (TFC) (mg QE/100g)	Total polyphenol content (TPC) (mg GAE/100g)	Antioxidant capacity (% inhibition)
Banana pulp powder	58.21 ± 0.113^{a}	24.06 ± 0.034^{b}	3.19 ± 0.003^{ab}
Banana peel powder	226.22 ± 0.071^{b}	8.69 ± 0.053^{a}	3.30 ± 0.001^{ab}

Table indicates the mean ± S.D. and superscript show non-significant difference between the treatments (p≤0.05).

According to the results, there was significant differences between banana pulp and peel powder in total flavonoid and polyphenol content. Banana peel contained the highest amount of total flavonoid concentration (226.22 ± 0.071mg QE/100g) where banana pulp had (58.21 ± 0.113mg QE/100g). Banana pulp had the highest total polyphenol content measurement (24.06 ± 0.034mg GAE/100g). Banana peel had the lowest result (8.69 ± 0.053mg GAE/100g). There were no significant differences in terms of antioxidant capacity between banana pulp and peel powder. The antioxidant capacity of banana pulp and peel from 3.03 to 3.19 mg TE/100g. Banana pulp has the highest antioxidant capacity (3.19 ± 0.003mg TE/100g).

3.3 Phytochemical Screening

Table 3 exhibits the phytochemical analysis of extracts from banana pulp and peel powder. The method used for phytochemical screening in this study was of a qualitative nature.

Table 3. Phytochemical (Qualitative) analysis test result

Chemical compounds	Banana pulp powder extract	Banana peel powder extract
Tannins	+	+
Saponin	–	+
Glycosides	–	–
Flavonoids	+	+
Phenol	+	+

In the table (+) indicates presence and (–) indicates absence of the tested phytochemical compounds in the respective extracts.

Both samples, banana pulp and peel powder extracts, share the presence of several essential phytochemicals, including carbohydrates, proteins,

tannins, and flavonoids. However, glycosides were not detected in either sample, and banana pulp powder extract did not contain saponins.

3.4 Antibacterial Activity

The result of antibacterial activity of both sample extracts against *E. coli* and *Staphylococcus aureus* are given in Table 4.

Table 4. In Vitro antimicrobial activity result (Zone of inhibition in agar plate)

Sample	*Escherichia coli*	*Staphylococcus aureus*
Banana pulp extract	15mm	13mm
Banana peel extract	11mm	10mm

The ethanol extract of banana pulp exhibited the most significant inhibition zones, measuring 13 mm for *S. aureus* and 15 mm for *E. coli*. Conversely, the ethanolic extract of banana peel displayed inhibition zones of 10 mm against *S. aureus* and 11 mm against *E. coli*. As part of the control group, Ciprofloxacin (CIP) was employed for *Escherichia coli* (*E. coli*) as positive control, while Gentamycin was utilized for *Staphylococcus aureus* (*S. aureus*) as negative control.

4. DISCUSSION

One chemical analysis technique for determining an ingredient's nutrient content is proximate analysis. The analysis's goal is to statistically identify a food ingredient's primary constituents.[26] The analysis revealed distinct differences in the proximate composition of banana pulp and peel. The pulp exhibited higher moisture and carbohydrate content, aligning with its role as the primary edible portion of the fruit. In contrast, the peel contained significantly higher fat, fiber and ash content, consistent with previous studies highlighting the peel's structural function and mineral richness.[27,28]

Foods or their processed products' moisture level indicates their freshness and shelf life; a high moisture content makes food items more susceptible to microbial spoiling and short shelf life, which can cause degradation.[29] The higher moisture content in banana pulp compared to the peel is due to the physiological processes during ripening, osmotic pressure differences, and the structural role of the peel as a protective barrier.[30] These factors collectively contribute to the pulp's ability to retain more moisture. Carbohydrate content was found to be 76.42% in banana pulp and 47.25% in banana peel. These high carbohydrate contents are an indication of good sources of energy for the humans and animals. The higher carbohydrate content in banana pulp compared to the peel highlights its role as a primary energy source, while the peel offers dietary fiber and antioxidants.[31] This distinction influences their respective uses in food products and nutritional applications. The peel's fiber and antioxidant properties make it useful in food products aimed at health benefits, such as dietary supplements and functional foods.

The crude protein, fat, and fiber content of banana peels were found to be greater. Crude protein in banana peel was recorded 7.18%; whereas, it was 4.36% for banana pulp. Banana peels have a higher protein content compared to the pulp. This is attributed to the presence of various bioactive compounds and amino acids in the peel, which are less prevalent in the pulp.[32] Peel's crude fat content was 8.56%, whereas pulp's was only 0.80%. This is due to the presence of specific fatty acids and lipid compounds that are more concentrated in the peel than in the pulp.[33] The presence of bioactive compounds such as phenols and flavonoids in banana peels enhances their nutritional profile, contributing to higher protein and fat content[34] The ash content, which indicates the total mineral content, is higher in banana peels (10.12%). This is because peels contain a wide range of minerals, including calcium, potassium, and sodium, which are present in larger quantities compared to the pulp.[1]

The banana peel is valued for its bioactive constituents, especially the phenolic compounds. Polyphenols are a complicated category of chemicals characterized by the presence of a phenolic ring in their structure.[35] The banana fruit is recognized as a significant source of phenolic chemicals, predominantly consisting of flavonoids. Flavonoids are the predominant polyphenols in human diets and represent the most prevalent category of polyphenols in plants. They exhibit anti-inflammatory, anticancer, and hepatoprotective properties, along with a robust antioxidant capacity attributed to the direct scavenging mechanism of reactive oxygen species. They also impede oxidative enzymes responsible for producing these reactive oxygen species.[36] Banana peel and pulp extracts are demonstrated to possess a substantial concentration of total phenolics, flavonoids, and antioxidant activity in Table 3. Total flavonoid content (TFC) emerged as one of

the key differentiating factors between banana pulp and peel powder. Banana peel exhibited a significantly higher concentration of total flavonoids (226.22 mg QE/100g) compared to banana pulp (58.21 mg QE/100g). Flavonoids are well-known for their antioxidant and anti-inflammatory properties, and the abundance of these compounds in banana peel suggests its potential as a source of natural antioxidants. This aligns with previous research findings that have highlighted the flavonoid-rich nature of banana peels.[37]

Conversely, banana pulp powder exhibited the highest total polyphenol content (24.06 mg GAE/100g) compared to banana peel powder (8.69 mg GAE/100g). The polyphenol content in banana pulp changes during ripening. In young bananas, the pulp contains higher polyphenolic content compared to the peel, but this changes as the fruit matures.[38] During ripening, certain high molecular weight polyphenols in the pulp undergo changes, which can affect their solubility and astringency.[39] In a study, the researchers also observed significant differences in the flavonoid and polyphenol content between banana peel and pulp.[6] Their findings supported the notion that banana peel is a rich source of flavonoids, while banana pulp exhibited higher polyphenol content.

Interestingly, despite the differences in flavonoid and polyphenol content, there were no significant disparities in antioxidant capacity between banana pulp and peel powder. Both exhibited similar antioxidant capacities, ranging from 3.30 to 3.19 mg TE/100g, with banana pulp displaying the highest antioxidant capacity (3.19 mg TE/100g). Despite the higher polyphenol content in the pulp, the antioxidant activity of both the pulp and peel is often comparable. This is because the peel contains specific potent antioxidants like gallocatechin, which contribute significantly to its antioxidant capacity.[40] Additionally, the peel's antioxidant activity is enhanced by other bioactive compounds such as carotenoids and flavonoids.[41]

The chemical composition of banana pulp and peel extracts reveals a complex profile of compounds that contribute to their nutritional and bioactive properties. Tannins are recognized for their broad-spectrum antimicrobial properties. They can inhibit bacterial growth at low concentrations and function as antifungal agents at higher concentrations. Tannins are referred to as polymeric phenolic compounds due to their ability to precipitate gelatin from a solution, a characteristic known as astringency.[42]

In contrast to the peel, banana pulp contains negligible levels of saponins. Studies focusing on the phytochemical composition of banana pulp have shown that while it contains other nutrients and compounds, saponins are not prominently featured.[43] This distinction makes banana peels a valuable resource for extracting beneficial compounds.

Glycosides, which were absent in both extracts, encompass a wide range of natural compounds with various functions. Prior scientific research has demonstrated the presence of glycosides in bananas, especially in the peel.[44,45] The negative HPLC test results for glycosides in banana samples could be due to several factors, rather than an actual absence of these compounds- concentration and detection limit problems, interference from other compounds in the banana matrix, suboptimal HPLC method and conditions,[46] natural variations in glycoside content within the fruit.[47] However, the absence of glycosides and the presence of saponins in banana peel powder extract suggest that the peel may hold specific bioactive compounds not found in the pulp.

Flavonoids and phenols, present in both pulp and peel, are known for their antioxidant and anti-inflammatory properties, contributing to the potential health benefits associated with banana consumption.[48,49] The evaluation of the in vitro antibacterial susceptibility of banana pulp and peel extracts against two common pathogenic bacteria, *Staphylococcus aureus* and *Escherichia coli*, has yielded insightful findings that hold potential implications for both food safety and healthcare applications.

One of the key findings is the contrasting antibacterial activity exhibited by banana pulp and peel extracts. The ethanol extract of banana pulp demonstrated remarkable inhibition zones, measuring 13 mm against *Staphylococcus aureus* and an even more substantial 15 mm against *Escherichia coli*. Conversely, the ethanolic extract of banana peel, while still displaying antibacterial activity, exhibited slightly smaller inhibition zones-10 mm against *Staphylococcus aureus* and 11 mm against *Escherichia coli*.

The pulp of bananas contains a rich concentration of bioactive compounds such as polyphenols, flavonoids, and antioxidants. These compounds are known to disrupt bacterial cell walls, inhibit biofilm formation, and interfere with bacterial metabolic processes. For example, studies on other fruits like citrus have shown that the pulp is more effective than the peel in inhibiting biofilm

formation and reducing bacterial metabolic activity.[50] While banana peels also contain antimicrobial compounds like fatty acids and phenolics, the pulp may have a more diverse or potent combination of these compounds. The specific composition of the pulp might make it more effective against certain bacterial strains, particularly gram-negative bacteria like *E. coli* and gram-positive bacteria like *Staphylococcus aureus*.[51]

5. CONCLUSION

Green bananas provide dietary fiber, which aids digestion and blood sugar regulation. They contain critical nutrients for heart and immunological wellness. However, green banana peels, often overlooked, are filled with nutrients. Recognizing their significance improves our culinary experiences and promotes a healthy, sustainable lifestyle. That's why this study examined banana pulp and peel extract's nutritional value, bioactive characteristics, and in vitro antibacterial activity. The banana pulp and peel have excellent phytochemical properties, according to this study. It showed that banana peel is healthier than pulp. Banana peel powder had higher crude protein, fat, fiber, and ash and lower moisture and carbohydrate. This revelation has made us reconsider using banana peel in medicines, cosmetics, improved products, and dietary supplements instead of discarding it after eating the pulp. This investigation shows that green banana pulp and peel are antimicrobial. This study suggests using green banana pulp and peel as natural antibacterial agents in food preservation, pharmaceuticals, and healthcare items, leaving a significant imprint for additional research. Investigations into the safety and efficacy of these extracts for human consumption or medical applications are essential before any practical use can be considered.

Ethical Approval

Not required.

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Competing Interests

All the authors declare that there are no conflicts of interest.

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Underlying Data

Derived data supporting the findings of this study are available from the corresponding author on request.

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