Research article

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Innovative methods: Banana peel powder to enhance nutritional, microbial, and sensory quality of bakery products

Métodos innovadores: polvo de cáscara de plátano para potenciar la calidad nutricional, microbiana y sensorial de los productos de panadería

Shaimaa Fadhil Weshah[1]*

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ABSTRACT
Fruit and vegetable peels are produced in large quantities as secondary waste during food processing, posing environmental challenges despite their valuable nutritional components. This study was designed to valorize banana peels to improve the nutritional quality and shelf life of baked products while reducing waste. The aim was to investigate the effects of partially substituting wheat flour with dried and ground banana peel powder at levels of 0% (T0, control), 10% (T1), and 20% (T2) on the nutritional, microbial, and sensory properties of cakes. Chemical analysis revealed that peel powder contains phenols (20.5 mg 100 g^{-1}), flavonoids (9.2 mg 100 g^{-1}), alkaloids (6.2 mg 100 g^{-1}), tannins (6.5 mg 100 g^{-1}), vitamin C (16.5 mg 100 g^{-1}), and exhibited antioxidant activity ranging from 24.89 to 89.99%. The powder was also rich in protein, ash, fat, and dietary fiber (13.22%), and contained essential minerals, with potassium being the highest (3,850%). Microbial evaluation demonstrated that peel powder reduced the growth of yeasts and molds, and its extract inhibited *Staphylococcus* and *Pseudomonas* but not *Escherichia coli.* Substitution increased cake weight while decreasing height and volume due to high fiber content. Sensory evaluation showed that T1 achieved the highest acceptance, with scores comparable to the control, indicating good sensory quality. Overall, the findings suggest that incorporating banana peel powder into baked products is an effective and promising strategy to enhance nutritional value, extend shelf life, improve sustainability, and maintain desirable sensory properties, thereby offering a practical approach for food fortification and reducing environmental waste.

KEYWORDS: Dietary fiber, Bioactive compounds, Food fortification, Antibacterial activity, Quality assessment

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RESUMEN
Las cáscaras de frutas y verduras se producen en grandes cantidades como residuos secundarios durante el procesamiento de alimentos, representando desafíos ambientales pese a sus valiosos nutrientes. Este estudio se diseñó para valorizar las cáscaras de plátano con el objetivo de mejorar la calidad nutricional y la vida útil de los productos horneados, (Ofreciendo y reduciendo el desperdicio ambiental). Se evaluaron los efectos de sustituir parcialmente la harina de trigo con polvo de cáscara de plátano seco y molido en niveles de 0% (T0), 10% (T1) y 20% (T2) sobre propiedades nutricionales, microbianas y sensoriales de pasteles. El análisis químico mostró que el polvo contiene fenoles (20,5 mg 100 g^{-1}), flavonoides (9,2 mg 100 g^{-1}), alcaloides (6,2 mg 100 g^{-1}), taninos (6,5 mg 100 g^{-1}), vitamina C (16,5 mg 100 g^{-1}) y actividad antioxidante entre 24,89 y 89,99%. Es rico en proteínas, cenizas, grasas, fibra dietética (13,22%) y

[1]College of Health and Medical Technologies, Northern Technical University, AL-Dour, Iraq.
shaimaa.fadhil.@ntu.edu.iq

*Corresponding author

minerales esenciales, siendo el potasio el más alto (3.850%). La evaluación microbiana indicó que el polvo redujo levaduras y mohos e inhibió *Staphylococcus* y *Pseudomonas*, pero no *Escherichia coli*. La sustitución aumentó el peso del pastel y redujo altura y volumen por el alto contenido de fibra. La evaluación sensorial mostró que T1 tuvo la mayor aceptación, con puntuaciones similares al control. En general, los resultados indican que incorporar polvo de cáscara de plátano en productos horneados es una estrategia eficaz para mejorar el valor nutricional, extender la vida útil, mantener propiedades sensoriales deseables, Ofreciendo y reduciendo el desperdicio ambiental.

PALABRAS CLAVE: Fibra dietética, Compuestos bioactivos, Fortificación de alimentos, Actividad antibacteriana, Evaluación de la calidad

INTRODUCTION

Nutrition plays a fundamental role in maintaining health and supporting physiological development throughout all stages of life. Childhood represents a critical period in which adequate and balanced nutrition is essential to ensure proper growth and to prevent nutritional deficiencies and associated disorders (Al-Jumaili 2020). In recent years, increasing attention has been directed toward developing functional food products that not only meet basic nutritional requirements but also contribute to disease prevention and overall well-being. Simultaneously, the rising quantities of agro-industrial byproducts generated from food processing have underscored the importance of sustainable utilization and valorization strategies to minimize environmental burdens while enhancing the nutritional value of food systems.

Among tropical fruits, bananas (*Musa paradisiaca* L.) rank among the most widely cultivated and consumed worldwide. They are an excellent source of carbohydrates, dietary fiber, and various essential vitamins (particularly vitamins C and E), as well as minerals such as calcium, iron, iodine, copper, manganese, zinc, and cobalt, alongside moderate levels of potassium, magnesium, sodium, and phosphorus (Putri et al. 2022). Although bananas are relatively low in protein, their high digestibility and rapid absorption make them a nutritionally efficient food source. Additionally, the pectin content of bananas contributes to their well-known laxative effect, which supports colon health and improves digestion Beyond the pulp (Cassettari et al. 2019). Banana peels constituting approximately 40% of the total weight, are a rich source of bioactive minerals. The green peels are abundant in phenolic compounds, which give them potent antioxidant properties. These compounds, such as polyphenols, carotenoids, and other active compounds, contribute to protection against heart disease and cancer (Ahmed et al. 2021).

Despite their valuable biochemical composition, banana peels are often treated as domestic and industrial waste and are discarded in substantial quantities without proper utilization. This practice contributes to environmental pollution and represents a missed opportunity for resource recovery. The high moisture and organic content of banana peel waste can accelerate microbial decomposition, generate unpleasant odors and contribute to ecological imbalance. Consequently, the development of eco-friendly and economically viable approaches for converting banana peels into functional ingredients aligns with the principles of sustainable food production and circular economy models.

Several studies have examined the incorporation of banana peel powder into bakery and other cereal-based products to improve their nutritional and functional attributes. Reported benefits include enhanced antioxidant activity, increased dietary fiber content, and improved microbial stability. The antibacterial activity of banana peel extracts has been attributed to their abundance of phenolic compounds, which inhibit bacterial proliferation by disrupting cell membranes, interfering with enzymatic systems, and inducing oxidative stress within microbial cells (Hikal et al. 2021). Despite these promising findings, further investigation is still required to establish the optimal levels of banana peel powder substitution that achieve a balance between nutritional improvement, functional enhancement, and sensory acceptability.

Therefore, the present study was designed to develop a nutritionally improved bakery product (cake enriched with banana peel powder) by incorporating dried banana peel powder as a partial replacement for wheat flour at different substitution levels (0, 10, and 20%). The work aimed to evaluate the physicochemical and sensory properties of the formulated product, with particular emphasis on their antioxidant potential, bioactive compound profile, and mineral composition. Moreover, the antibacterial activity of banana peel extract was assessed against selected microbial strains to explore its potential application as a natural functional ingredient in food formulation.

MATERIALS AND METHODS

Sample collection and preparation

Fully ripe bananas were used in this study according to ripeness indices. Fruits with yellow skin color, appropriate firmness, and moderate natural sugar content were selected. Bananas were collected from local markets in Salahaddin, Iraq and thoroughly washed to remove dirt and impurities. The peels were then separated from the pulp and cut into small pieces using a sterilized knife, ready for use in subsequent preparation steps.

Peel powder

The banana peels were prepared following the methodology described by Júnior et al. (2020) The sliced peels were placed in a hot air dryer at 60 °C for 24 hours until completely dry After drying, the peels were ground using a Sayona household electric grinder, and the resulting powder was sieved using a 0.5 mm sieve to obtain a fine, homogeneous powder (Figure 1B). The peel powder was then packaged in airtight containers to protect it from moisture and contamination and stored in a dark place away from direct sunlight until used in experiments.

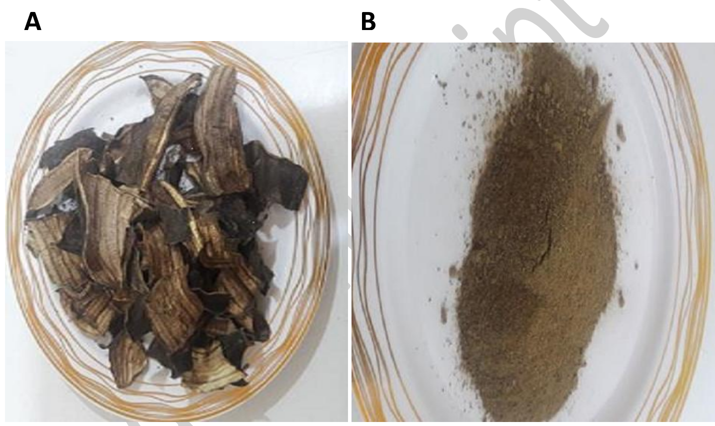

Figure 1. **A**. banana peel, and **B**. banana peel powder.

Ingredients

White wheat flour (Besler, Turkey), vegetable butter (ONA, Turkey), fresh eggs purchased from local markets in Salahaddin, Iraq, dried milk (Al-Mudhesh, Saudi Arabia), baking powder (Kenton, Turkey), vanilla flavoring (Kenton, Turkey), and table salt (Al-Mansour, Saudi Arabia) were used for cake preparation.

Cake preparation

Table 1 shows method of cake preparation according to the method described by Alazb et al. (2021). The eggs, butter, and vanilla were mixed until a homogeneous mixture was obtained. Powdered sugar was then gradually added to the previous mixture, and the mixture was whipped using a mixer for 5–10 minutes. In a separate step, the flour and baking powder were thoroughly mixed. This dry mixture was then gradually added to the first mixture, followed by the addition of milk. The entire mixture was whipped for 3 minutes using a mixer at low speed.

After preparing the cake mixture, it was poured into a pre-greased mold and placed in an oven preheated to 180 °C for 35 minutes. Care was taken not to open the oven during baking to prevent the cake from sinking. After baking, the cake was left to cool at room temperature for 1 hour, then placed in a plastic container and stored at room temperature for chemical testing and sensory evaluation.

Table 1. Ingredients used in cake preparation.

Ingredients	Quantity
Flour	100 g
Eggs	85 g
Sugar	85 g
Butter	55 g
Milk with added water	50 mL
Baking powder	3.8 g
Salt	1.0 g
Vanilla	0.6 g

Treatments

T0: Consisted of only the basic ingredients without the addition of banana peel powder and served as the control treatment. **T1**: Consisted of the basic ingredients with 10% of the wheat flour replaced by an equivalent of dried banana peel powder, and **T2**: Consisted of the basic ingredients with 20% of the wheat flour replaced by an equivalent of dried banana peel powder (Figure 2).

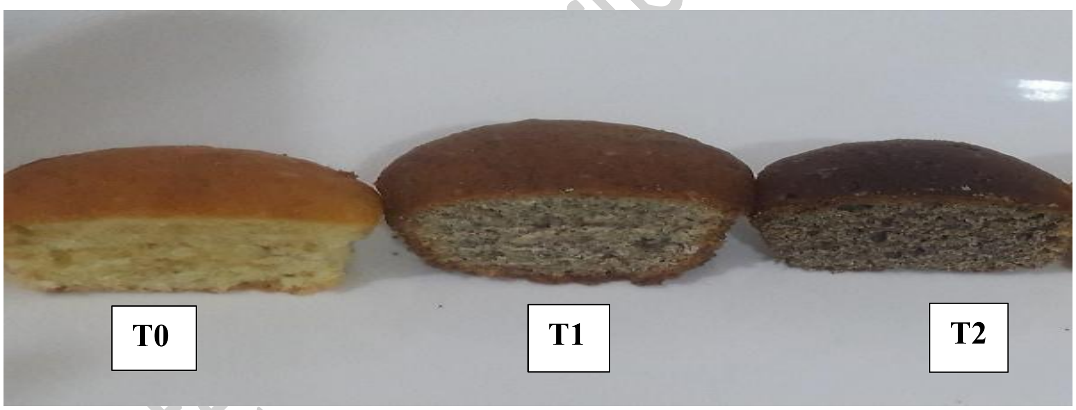

Figure 2. Cake product samples.

Screening and quantification of bioactive compounds in dried banana peel powder and cake products

The screening and quantification of bioactive compounds in dried banana peel powder and the formulated cake products were conducted using established analytical methods. The total tannin content was quantified following the procedure described by Abdelkader et al. (2014). Total alkaloid content was determined according to the method outlined by Ajanal et al. (2018), while total phenolic content was measured using the protocol established by Laouini and Ouahrani (2017). Additionally, total flavonoid content was assessed based on the method reported by Habibatni et al. (2017).

Chemical tests of dried banana peel powder and cake product

Moisture percentage (%)

The moisture percentage was determined according to the method in Source (AOAC 2008).

Ash content

The ash content was carried out cording to Nielsen (2010).

Protein content

It was determined according to the method by AOAC (2008) using a Kjeldahl apparatus. The protein content was calculated by multiplying the percentage of nitrogen in the sample by the conversion factor of 6.25. The protein content was calculated according to the following Equation 1:

$$\text{Protein} = \text{Volume of HCl consumed} \times \text{Normality} \times 0.014 \times 6.25 / \text{Sample weight} \times 100 \quad (1)$$

Fat percentage (%)

The percentage of fat was determined according to the method in the source (AOAC 2008).

Carbohydrates percentage (%)

The percentage of carbohydrates was determined using the following Equation 2, according to Capitani et al. (2015).

$$\text{Carbohydrate (\%)} = 100 - (\text{Moisture} + \text{Ash} + \text{Protein} + \text{Fat}) \quad (2)$$

Fiber percentage (%)

The Fiber content was determined according to the method described in (AOAC 2008).

Determination of mineral elements

The concentrations of mineral elements (Fe, Ca, Mg, Zn, and Na) in dried banana peel powder and cake samples were determined using atomic absorption spectrophotometry (AAS), following the procedure described by Roni et al. (2021).

Antioxidant activity of dried banana peel powder and cake product

Estimation of the antioxidant activity of dried banana peel powder and cake product parameters were determined according to Okunade (2002) and Koleva et al. (2002).

Inhibitory activity of the alcoholic extract of dried banana peel powder

The inhibitory activity of the alcoholic extract of dried banana peel powder was determined on several bacterial isolates. This study used bacterial isolates identified at the Food Contamination Research Center, Department of Environment and Water, Ministry of Science and Technology. The isolations included *Pseudomonas aeruginosa, Escherichia coli*, and *Staphylococcus aureus*. The well diffusion method was used to study the inhibitory activity of the alcoholic extract on the bacterial isolates according to the method described by Al-Marshadi (2012).

Microbial testing of cake samples during storage

Microbial testing of cake product treatments over different storage periods. Potato dextrose agar (PDA) medium was used to detect molds and yeasts. One milliliter of the dilution was transferred to a Petri dish, the agar medium was poured into sterile Petri dishes, and the medium was left to solidify. The dishes were then inverted and incubated at 25-28 °C for 3-5 days, and the colonies were counted.

Physical parameters of cake products

Cake weight

A digital scale was used to measure the weight of the cake samples (g) according to the method by El-Kholie et al. (2021).

Cake height

The height (cm^3) was measured by the ruler in the center of the cake according to the method by El-Kholie et al. (2021).

Cake volume

The volume of the cake was determined using the grain displacement method. A deep bowl was filled with clean millet grains and leveled. The grains were poured and the cake placed. The bowl was refilled with grains and leveled. The excess grains were taken as cake volume by measuring them with a cylinder, according to the method of Azari et al. (2020) and Bitrus et al. (2020).

Sensory evaluation

Ten (10) panelists performed the sensory evaluation of cake samples to assess the product's quality and taste based on a set of sensory attributes, including crumb color, aroma, porosity, appearance, flavor, texture, and overall acceptability. The plates were coded with random numbers without indicating the sample names, and the evaluation was carried out using a 1–10 hedonic scale, according to Farimani et al. (2019).

Statistical analysis

The Statistical Analysis System (2012) software was used to analyze experimental data in order to study the effect of different treatments on the investigated traits according to a Completely Randomized Design (CRD). Significant differences among the means were compared using the Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Analysis of active compounds

Table 2 presents the results of the analysis of bioactive compounds in dried banana peel powder and its incorporation into different cake treatments. The compounds analyzed included phenolics, flavonoids, alkaloids, tannins, and vitamin C. The results indicate that banana peel powder contains relatively high levels of these bioactive compounds, with values recorded as follows: 20.5, 9.2, 6.2, 6.5, and 16.5 mg 100 g^{-1}, respectively. Statistical analysis revealed a significant increase ($P<0.05$) in the concentrations of bioactive compounds across the cake treatments. In treatment T2, the levels of the respective compounds were 16.28, 11.59, 7.99 8.49, and 10.99 mg 100 g^{-1}, compared to the control treatment (T0), which showed significantly lower values of 8.00, 6.559, 3.29, 4.29, and 4.19 mg 100 g^{-1}, respectively. The data clearly demonstrate that treatments T1 and T2 resulted in higher concentrations of bioactive compounds, which increased proportionally with the substitution level of banana peel powder. Treatment T2 recorded the highest values, which can be attributed to the rich content of functional compounds in the banana peels and the effect of dietary fiber on gluten network formation and the retention of bioactive compounds. These findings suggest that incorporating banana peel powder into wheat flour enhances the nutritional quality and functional properties of the final baked product. This aligns with the findings of previous researchers by Zhang et al. (2022) who highlighted the potential of banana peel powder as an economical and effective source of phenolic compounds for bakery product fortification.

Table 2. Analysis of the active compounds in dried banana peel powder and the cake product samples**.**

Samples	T. Phenols (mg 100 g^{-1})	T. Flavonoids (mg 100 g^{-1})	T. Alkaloids (mg 100 g^{-1})	T. Tannins (mg 100 g^{-1})	Vit C (mg 100 g^{-1})
Banana peel powder	20.5±0.71	9.2±0.56	6.2±0.57	6.5±0.25	16.5±0.87
T0	8.0±0.52	6.559±0.27	3.29±0.15	4.29±0.18	4.19±0.22
T1	12.2±0.75	9.39±0.61	5.89±0.17	6.29±0.25	8.59±0.38
T2	16.28±0.61	11.59±0.52	7.99±0.26	8.49±0.30	10.99±0.42

($P<0.05$) *

The numbers represent the average of three replicates, where the sample represents T0 (control group), T1 (10% banana peels + 90% flour), T2 (20% banana peels + 80% flour).

Chemical Tests

Table 3 presents the chemical composition of dried banana peel powder, as well as that of the different cake treatments. The analyzed components included protein, fat, moisture, ash, fiber, and carbohydrates. The corresponding values for these components in banana peel powder were 0.50, 1.14, 1.9, 5.6, 13.22, and 82.86%, respectively.

Table 3 Chemical analyses of dried banana peel powder and cake product samples.

Samples	Protein	Fat	Moisture	Ash	Fiber	Carbohydrates
Banana peel powder	0.50±0.08	1.14±0.57	1.9±0.07	5.6±0.42	13.223±0.57	82.86±3.51
T0	4.4±0.33	13.28±0.63	22.00±1.07	1.12±0.74	2.15±0.08	59.2±1.86
T1	4.7±0.26	14.14±094	22.18±1.35	1.124±0.65	3.81±0.12	57.856±1.55
T2	4.9±0.24	14.52±0.85	22.26±1.06	1.248±0.57	4.09±0.24	57.072±2.52
(*P*<0.05) *						

The numbers represent the average of three replicates, where the sample represents T0 (control group), T1 (10% banana peels + 90% flour), T2 (20% banana peels + 80% flour).

The results revealed statistically significant differences ($P<0.05$) among the treatments in terms of their chemical composition. A noticeable increase in protein, fat, moisture, ash, and fiber contents was observed in treatments T1 and T2, which is consistent with the higher levels of banana peel powder substitution, compared with the control treatment (T0). Specifically, treatment T2 recorded the following values: 4.9, 14.52, 22.26, 1.248, and 4.09%, respectively, while the control treatment (T0) showed lower values: 4.4, 13.28, 22.00, 1.12, and 2.15%, respectively.

About carbohydrate content, a gradual decrease was observed with increasing substitution levels, reaching 57.072% in treatment T2 compared with 59.2% in the control treatment (T0). This reduction is attributed to the higher fiber content, which increases water-binding capacity in the sample and consequently lowers the energy density of the final product.

According to Alam et al. (2020), banana peels contain higher levels of moisture, ash, and fiber compared to wheat flour, which is consistent with the findings of the present study. Furthermore, Khatun et al. (2021) confirmed that fortification of food products with banana peel powder enhances their nutritional value, particularly in light of the growing consumer interest in functional foods rich in vitamins, minerals, unsaturated fatty acids, bioactive compounds, and dietary fiber, all of which are recognized for their health benefits.

Mineral Elements

Table 4 presents the results of the mineral content analysis of dried banana peel powder and its incorporation into various cake treatments. The analyzed minerals include zinc, iron, magnesium, potassium, sodium, and calcium. The results indicate statistically significant differences ($P<0.05$) among the treatments. The concentrations of these minerals in dried banana peel powder were 1.5, 2.6, 3850, 270, 50, and 10 ppm for zinc, iron, magnesium, potassium, sodium, and calcium, respectively. A noticeable increase in the mineral content was observed in treatments T1 and T2 compared to the control treatment T0. Specifically, the mineral levels in treatment T2 were 2.44, 2.11, 66.58, 88.95, 148.9, and 72.6 ppm whereas the corresponding values in treatment T0 were 1.68, 1.88, 12.58, 45.91, 143.6, and 63.5 ppm.

These findings demonstrate that substituting a portion of wheat flour with dried banana peel powder led to a significant improvement in the mineral content of the final product. Furthermore, Eshak (2016) reports that banana peel powder is rich in essential minerals, particularly potassium, iron, and magnesium, with levels exceeding those found in wheat flour. Therefore, incorporating banana peel powder can effectively enhance the nutritional value of baked products.

Table 4. Estimation of mineral elements in dried banana peel powder and cake product samples.

Samples	Zinc (ppm)	Iron (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Calcium (ppm)
Banana peel powder	1.5±0.08	2.6±0.11	270±12.8	3850±245.1	10±0.63	50±2.48
T0	1.68±0.06	1.88±0.10	12.58±0.73	45.91±2.6	143.6 ±7.4	63.5±2.5
T1	1.89±0.08	1.98±0.13	30.28±1.5	65.98±2.9	145.6±6.1	66.5±2.9
T2	2.44±0.12	2.11±0.15	66.58±2.37	88.95±3.7	148.9±6.4	72.6±3.2
(P<0.05) *						

The numbers represent the average of three replicates. The sample T0 represents the control group, T1 (10% banana peel + 90% flour), and T2 (20% banana peel + 80% flour).

Antioxidant Activity

Table 5 presents the percentage of free radical scavenging activity of dried banana peel powder, along with the results for cake treatments enriched with varying proportions of this powder. The data indicates statistically significant differences among the treatments at a significant level of (P<0.05). The free radical scavenging activity of dried banana peel powder at concentrations of 30, 60, 120, 250, and 500 ppm was 24.89, 42.59, 56.99, 67.99, and 89.99%, respectively. The results demonstrate an increase in scavenging activity with increasing concentration. For the cake treatment T2, the scavenging activities at the same concentrations were 17.59, 33.69, 42.59, 50.59, and 61.49%, while the control treatment (T0) showed lower values of 11.59, 18.99, 26.99, 35.89, and 49.89%, respectively. These findings highlight that banana peels are potent sources of natural antioxidants due to their content of various phenolic compounds. Antioxidants contribute to prolonging the shelf life of food products by inhibiting oxidation and reducing nutritional loss. Furthermore, Al-Habib (2017) reports that incorporating dried banana peel powder into food acts as a natural preservative with antioxidant properties. This not only maintains food quality but also extends shelf life and enhances nutritional value. The results also showed a clear increase in scavenging activity with increasing concentration.

Table 5. Estimation of the Antioxidant Activity of Dried Banana Peel Powder and Cake Product Treatments**.**

Samples	30 (ppm)	60 (ppm)	120 (ppm)	250 (ppm)	500 (ppm)
Banana peel powder	24.89±1.08	42.59±2.66	56.99±2.47	67.99±2.15	89.99±3.02
T0	11.5±0.57	18.99±0.76	26.99±1.42	35.89±1.365	49.89±2.71
T1	13.6±0.52	24.8±1.25	33.69±1.06	41.59±2.15	53.99±2.68
T2	17.59±0.64	33.69±1.58	42.59±2.51	50.59±2.73	61.49±2.97
(P<0.05) *					

The numbers represent the average of three replicates. The sample T0 represents the control group, T1 (10% banana peel + 90% flour), and T2 (20% banana peel + 80% flour).

Inhibitory activity of dried banana peel ethanolic extract

Table 6 illustrates the inhibitory activity of the alcoholic extract of dried banana peels against several bacterial isolates at different concentrations (25, 50, and 100%). Statistical analysis revealed significant differences (P<0.05) in the inhibitory effect of the alcoholic extract on bacterial growth. The banana peel extract at 100% concentration exhibited the highest inhibition against *Staphylococcus aureus*, with an inhibition zone diameter of 12.4 mm. The lowest inhibition against this bacterium was observed at 50% concentration, with a zone diameter of 4 mm, while no inhibitory effect was detected at 25% concentration. Regarding *Pseudomonas aeruginosa*, the inhibition zone diameters were 9 and 1.2 mm at 100 and 50% concentrations, respectively, with no inhibitory activity observed at 25%. Conversely, the alcoholic extract showed no inhibitory effect against *Escherichia coli* at any tested concentration, indicating a lack of antibacterial activity against this bacterium.

These results are consistent with those reported by Chabuck et al. (2013), which demonstrated that the alcoholic extract of banana peels exhibits inhibitory activity against *Staphylococcus aureus* but not against *E. coli*. The antibacterial effect of banana peel extracts is attributed to their content of phenolic compounds (polyphenols), dopamine, and tannins, which collectively inhibit bacterial growth (Hikal et al. 2021).

Table 6. The Inhibitory Activity of the Ethanolic Extract of Dried Banana Peels Against Several Bacterial Isolates.

	Inhibition zones (mm)		
Extract concentration (mg mL^{-1})	***Staphylococcus***	***Pseudomonas***	***E. coli***
100	12.4±0.74	9±0.63	0±0
50	4.0±0.19	1.2±0.06	0±0
25	0±0	0±0	0±0
	($P<0.05$) *		

The values represent the meaning of three replicates.

Total yeast and mold counts in cake treatments during storage

Table 7 demonstrates the inhibitory efficacy of banana peel powder against the growth of yeasts and molds in cake samples. No microbial growth was observed in the treatments (T0, T1, T2) during the first day of storage.

Table 7. Bacterial Count Table for Yeasts and Molds in Treatments During Different Storage Periods, Measured in CFU**.**

Samples	First day of storage	Third day of storage	Sixth day of storage	Tenth day of storage	Fourteenth day of storage
T0	0	392±14.5	478.1±27.3	534±19.6	886.3±41.3
T1	0	72.2±2.8	89±3.5	91±4.2	108±5.8
T2	0	26±1.4	34±1.9	28.7±1.7	34±1.6
		($P<0.05$) *			

The numbers represent the average of three replicates. The samples are T0 (control group), T1 (10% banana peel + 90% flour), and T2 (20% banana peel + 80% flour). CFU: Colony Forming Unit.

By the third day of storage, significant differences ($P<0.05$) were observed among the treatments in terms of yeast and mold counts. The recorded counts for treatments T0, T1, and T2 were 392, 72.2, and 26 cells, respectively. Treatment T2 showed the lowest microbial growth (26 cells) compared to the control treatment T0 (392 cells), indicating a reduction in microbial load with increased substitution levels of banana peel powder. On the 6 days of storage, the inhibitory trend continued, with microbial counts for T0, T1, and T2 reaching 478.1, 89, and 34 cells, respectively. Again, T2 showed the lowest level of yeast and mold growth. By the 10 days, the yeast and mold counts in treatments T0, T1, and T2 were 534, 91, and 28.7 cells, respectively, with T2 maintaining the lowest microbial load compared to the control. On the 14 days of storage, an increase in yeast and mold counts was observed across all treatments. The counts reached 886.3, 108, and 34 cells for T0, T1, and T2, respectively. Despite the increase, treatment T2 consistently exhibited the lowest fungal cell count, highlighting the effective role of banana peel powder in reducing microbial activity over extended storage periods.

The results indicate that yeast and mold growth in the cake treatments fortified with banana peel powder (T1 and T2) was lower during various storage periods compared to the control treatment (T0). This reduction reflects the strong inhibitory effect of banana peels, which is attributed to their content of bioactive compounds such as tannins, flavonoids, alkaloids, and phenolics. These compounds inhibit the growth of microorganisms by disrupting their cell division processes, interfering with vital metabolic functions, and damaging fungal cell walls.

Nasution et al. (2012) confirmed the antifungal activity of banana peel powder against yeast and mold growth, suggesting that banana peels possess antifungal properties that make them suitable for enhancing the shelf life of health-oriented food products such as bread and pastries. Olakunle et al. (2019) also reported the inhibitory effect of banana peel powder against several fungal species, including *Aspergillus niger*, *Alternaria alternata*, and *Aspergillus flavus*. This antimicrobial activity is attributed to the presence of phytochemicals in the peels, particularly alkaloids and flavonoids, which play a critical role in suppressing the growth of harmful microorganisms.

Physical tests

Table 8 presents the physical properties of the cake product treatments, including weight, height, and volume. Regarding weight, the treatments (T0, T1, T2) recorded weights of 335, 354, and 345 g, respectively. An increase in weight was observed with higher substitution levels of banana peel powder. This increase is attributed to dietary fiber's high water-holding capacity. As the fiber content in the batter increases, more water is absorbed, which results in an overall increase in product weight. This finding is supported by El-Kholie et al. (2021), who report a direct relationship between fiber content and the weight of baked products.

Table 8. Physical Measurements of Cake Treatments.

Samples	Weight (g)	Height (cm)	Volume (cm³)
T0	335±22.7	6±0.32	650±31.8
T1	345±25.1	5±0.17	610±26.3
T2	354±24.9	4.5±0.12	573±9.8
	(P<0.05) *		

The values represent the average of three replicates. The samples are T0 (control group), T1 (10% banana peel + 90% flour), and T2 (20% banana peel + 80% flour).

As for height, it was found that increasing the substitution levels of banana peel powder had a negative impact on the cake's height. The heights recorded for T1 and T2 were 5 and 4.5 cm³, respectively, compared to 6 cm³ for the control sample (T0). This decrease is attributed to the higher fiber content derived from banana peel powder, which is a rich source of dietary fiber. These fibers interfere physically with the dough structure, limiting its expansion during baking and thus reducing the final product height. Additionally, the swollen fibers, due to water absorption, increase dough viscosity, which hinders its expansion and natural rise during baking. Türker et al. (2016) also report that the increased viscosity caused by fiber content impairs the rising and expansion of baked products.

Regarding volume, the results show a gradual decrease in cake volume with increasing substitution levels of banana peel powder in treatments T1 and T2, where the recorded volumes were 610 and 573 cm³, respectively, compared to the control treatment (T0), which reached 650 cm³. This reduction in volume is attributed to the effect of banana peel powder on dough properties. Higher substitution levels lead to increased dough viscosity due to the water absorption capacity of the fibers, in addition to a reduction in gluten content, as banana peel flour does not contain gluten. Gluten is essential for forming an elastic network that retains gases during baking; its absence limits dough expansion and consequently reduces the final product volume. In contrast, the larger volume observed in the control sample (T0) is attributed to the dough's ability to retain more air, allowing better expansion and increased volume of the final product, as confirmed by Ahmed et al. (2021).

Sensory evaluation of cake treatments

Table 9 presents sensory evaluation results for the different cake treatments, including attributes such as color, aroma, porosity, external appearance, flavor, texture, and overall acceptability. The table shows significant differences ($P<0.05$) in color among treatments T2 and T1, with scores of 9 and 8, respectively, compared to the control treatment T0, which scored 10. The results indicate a gradual decrease in color score with increasing substitution levels, as the samples' color becomes relatively darker due to the inherent darker color of the banana peel fibers.

Regarding aroma, the results revealed no significant differences ($P>0.05$) among treatments T0, T1, and T2, indicating that aroma remained stable despite increasing substitution levels. For porosity, significant differences ($P<0.05$) were observed among the three treatments, with porosity scores of 10, 9, and 8.5 for T0, T1, and T2, respectively. As for other attributes such as external appearance, flavor, texture, and overall acceptability, the sensory evaluation showed significant differences ($P<0.05$) among all treatments. Treatment T1 showed superior results, with evaluation scores very close to those of the control sample T0, indicating good acceptability of the cake enriched with a certain percentage of banana peel powder.

Ismai et al. (2014) report a decrease in sensory evaluation scores with increasing concentrations of fruit peel powder added to the product, indicating that as the substitution level increases, sensory acceptability decreases. On the other hand, Türker et al. (2016) showed that the optimal substitution level was 10%, which did not differ from the control treatment in terms of sensory evaluation tests. Vegetable and fruit peels can be utilized as a rich source of dietary fiber and added to bakery products, as they provide added nutritional value along with health benefits, in addition to being low-cost and easily accessible.

Table 9. Sensory Evaluation Results of Laboratory Cake Product Treatments.

Samples	Crumb color	Aroma	Porosity	External appearance	Flavor	Texture	Overall acceptability
T0	10±0.0	9.9±0.03	10±0.0	9.8±0.08	9.8±0.09	9.9 ±0.01	9.9±0.01
T1	9±0.07	9.4±0.10	9±0.07	9.0±0.07	9 ±0.11	9.1±0.10	9.5±0.03
T2	8±0.07	9.1±0.05	8.5±0.12	8.0±0.10	8.5±0.09	8.0±0.08	8.0±0.06
($P<0.05$) *							

The samples are T0 (control group), T1 (10% banana peel + 90% flour), and T2 (20% banana peel + 80% flour).

CONCLUSION

Banana peel powder is a promising addition to the bakery industry due to its content of bioactive compounds, especially antioxidants and phenolic compounds, which contribute to enhancing the nutritional value of baked products. The results showed that the addition of this powder improved both the sensory and nutritional properties of the baked products and extended their shelf life. Samples T1 and T2 showed an increase in storage period compared to the control sample T0, indicating that partial replacement of wheat flour with banana peel powder contributed to improving microbial stability and extending the product's shelf life, thanks to its inhibitory activity against some pathogenic bacteria. In the sensory evaluation, sample T1, which contained a 10% substitution level, showed remarkable superiority, achieving results similar to the control sample T0 and demonstrating good sensory acceptance at this substitution level.

This study highlights the importance of sustainable and efficient reuse of agricultural waste, opening new prospects in the food industry, particularly in the development of healthier and safer products that promote consumer health and reduce food waste. It is recommended that future studies expand the research scope to include the effectiveness of the powder against a broader range of bacterial strains, including antibiotic-resistant bacteria.

These results highlight the potential of banana peels as a nutrient- and fiber-rich ingredient that can help reduce agricultural waste and support sustainable food production. Additionally, using banana peels adds value to the food industry by transforming fruit and vegetable peels into useful and environmentally friendly components.

CONFLICT OF INTERESTS

The authors declare no potential conflicts of interest.

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