Development and Characterization of Corn Crackers Incorporated with Banana Peel and Pulp

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Abstract: *Snacking is a common dietary habit worldwide, and crackers represent one of the most frequently consumed low-moisture baked snack products. Recently, there has been growing consumer interest in fiber-enriched snacks due to their associated health benefits. Agro-industrial fruit by-products are valuable sources of nutrients, particularly dietary fiber, yet they are often discarded as waste. Banana peel, which constitutes approximately 40% of the total fruit weight, possesses a rich chemical composition but is largely underutilized. Corn flour, commonly used in cracker formulations, already provides a moderate level of dietary fiber; however, its nutritional value can be further enhanced through* *functional ingredient incorporation. In the present study, corn flour was partially substituted with banana peel flour at levels of 5%, 10%, 15%, and 20%, while banana pulp powder was maintained at a constant level of 5%, to develop nutritionally improved corn crackers. The developed formulations were evaluated for proximate composition, phytochemical content, antioxidant capacity, mineral profile, color attributes, textural properties, and sensory acceptability. Statistical analysis showed notable variations ($p \leq 0.05$) among treatments as the proportion of banana peel flour increased. Moisture, ash, crude fat, crude protein, and crude fiber contents ranged from 1.29–4.14%, 1.95–3.70%, 0.31–1.70%, 7.20–9.20%, and 6.90–14.70%, respectively. Total phenolic content, total flavonoid content, and DPPH radical scavenging activity varied between 64.57–90.77 mg GAE/g, 10.30–30.30 mg QE/g, and 64.57–83.77%, respectively. Mineral analysis indicated calcium levels of 25.9–57.9 mg/100 g and potassium levels of 18.7–42.7 mg/100 g. Increasing banana peel concentration resulted in higher L* and a* values, whereas b* and c* values showed a decreasing trend. Texture analysis demonstrated hardness values ranging from 2.88–26.20 N and cohesiveness between 0.609–0.784%. Sensory evaluation using a 9-point hedonic scale identified formulation T2 (85% corn flour, 10% banana peel flour, and 5% banana pulp powder) as the most acceptable in terms of overall sensory quality.*

Introduction

Food plays a fundamental role in human health by providing essential macronutrients, including carbohydrates, proteins, fats, and dietary fiber, along with vital micronutrients such as vitamins and minerals that support growth, physiological functions, and overall well-being. Despite the nutritional importance of fruits and vegetables, a considerable proportion of edible plant components is discarded and remains underutilized for human consumption. Reducing food waste has become a global priority, as it not only lowers economic losses but also conserves natural resources and contributes to improved food security. Globally, over one billion people suffer from hunger and malnutrition, while approximately one-third of all food produced for human consumption is wasted annually (Khalid et al., 2019).

Food losses are generally categorized into avoidable, potentially avoidable, and unavoidable losses. Avoidable losses include food items that are edible but discarded due to factors such as spoilage, improper storage, overproduction, or expiration. Potentially avoidable losses consist of food materials that are acceptable to certain consumers but rejected by others, such as fruit peels or misshapen produce. Unavoidable losses comprise inedible fractions, including banana peels, coffee residues, and slaughterhouse by-products, as well as losses that cannot be prevented even with advanced processing technologies (Beretta et al., 2013). Food waste represents a major sustainability challenge, with an estimated 1.3 billion tons lost worldwide each year (FAO, 2011). In the United Kingdom alone, households contribute approximately 8.3 million tons of food waste annually (WRAP, 2011).

In recent years, consumers have become increasingly aware of the health benefits associated with fruit and vegetable consumption. These foods are rich sources of antioxidants, vitamins A, C, and E, vital minerals such as magnesium, potassium, calcium as well as dietary fiber, all of which support the maintenance and prevention of illness. (Wall et al., 2006). In response to these benefits, the United States Department of Agriculture (USDA) recommends that fruits and vegetables constitute half of a balanced daily meal. Among commonly consumed fruits, bananas (Musa spp.), belonging to the Musaceae family, are widely appreciated due to their nutritional value, palatability, and ease of digestion (Sidhu and Zafar, 2018). Bananas rank second after citrus fruits in global production and represent an economically significant crop in several countries, including Egypt, where annual production exceeds 1.1 million tons (FAO, 2013).

Bananas are an excellent source of energy, low in fat and abundant in micronutrients, including dietary fiber, manganese, vitamin C, and vitamin B6. Additionally, they include bioactive substances with potent antioxidant qualities, such as flavonoids, phenolic acids, and carotenoids. (Chala and Yetenayet, 2018). Previous studies have demonstrated that banana peels and seeds possess higher antioxidant activity and greater phenolic content compared to the edible pulp (Soong et al., 2004). Peels from bananas make up around 40% of the fruit's weight and are frequently thrown away, which greatly contributes to pollution in the environment. However, these peels are a valuable source of functional components such as pectin and phenolic compounds, which have been associated with a reduced risk of chronic diseases, including cardiovascular disorders and cancer (Emaga, 2008).

Banana peel exhibits a complex and nutritionally rich chemical composition, making it suitable for various nutritional, functional, and industrial applications. The peels of banana and plantain contain approximately 8–11% protein, including essential amino acids such as threonine, phenylalanine, leucine and valine, although lysine is present in lower amounts. Lipid content ranges from 2.2–10.9% and mainly consists of polyunsaturated fatty acids, particularly linoleic and α-linolenic acids. Potassium is the predominant mineral present in banana peel, contributing to its nutritional significance (Emaga et al., 2007). Dietary fiber constitutes a major portion of banana peel and includes both soluble fractions, such as pectin and gums, and insoluble components, including cellulose, lignin, and hemicellulose, with lignin being the most abundant fiber fraction (Emaga, 2008).

Peels from bananas are particularly high in gallocatechin, a potent antioxidant, while containing relatively lower amounts of water-soluble pectin (Someya et al., 2002). Considering that 30–40% of the fruit is made up of peels of bananas, the global banana production of around 151.34 million tons generates an estimated 45.4–60.5 million tons of peel waste annually (FAOSTAT, 2023). This waste stream offers substantial potential for valorization into functional food ingredients.

The antioxidant capacity of banana peel exceeds that of banana pulp due to its higher concentration of phenolic compounds, particularly gallocatechin, which is found in the peel at around 158 mg/100 g dry weight (DW) as opposed to the pulp's 29.6 mg/100 g DW. These biologically active substances are known to inhibit lipid oxidation and peroxidation, thereby providing protective effects against oxidative stress-related conditions such as cardiovascular diseases and cancer (Someya et al., 2002). Apart from phenolics, banana peels include a wide variety of bioactive components, including flavonoids, tannins, alkaloids, glycosides, anthocyanins, and terpenoids, which collectively contribute to antimicrobial, antidiabetic, antihypertensive, and anti-inflammatory activities (Rawat et al., 2024).

From an environmental perspective, improper disposal of banana peels exacerbates pollution; however, their utilization as value-added ingredients offer a sustainable alternative. Globally, banana peel waste is estimated to exceed 114 million metric tons and is rich in cellulose, hemicellulose, and natural fibers that can be exploited in the production of bioplastics, biofuels, activated carbon, and wastewater treatment materials (Alzate Acevedo et al., 2021). Furthermore, banana peels provide approximately 50 g/100 g of dietary fiber, including pectin (13.0–21.7 g/100 g) and insoluble fibers such as cellulose, lignin, and hemicellulose. These components remain within acceptable safety limits despite the presence of trace amounts of hydrogen cyanide and oxalates (Anhwange, 2008; Emaga et al., 2007).

Banana pulp, the edible portion of the fruit, is also a rich source of vitamins, phenolic compounds, dietary fiber, flavonoids, carotenoids, and essential minerals, particularly potassium. Organic acids including oxalic, citric and malic acids contribute to the characteristic acidity of bananas and influence overall fruit quality (Etienne et al., 2013). Peels of banana and its pulp include bioactive chemicals and dietary fiber that promote digestive health, assist in glycemic regulation, reduce cardiovascular risk, and lower the incidence of chronic diseases (Kaczmarczyk et al., 2012; Zoair et al., 2016; Anderson et al., 2009).

Snack foods are among the most widely consumed food categories globally and are popular across all age groups. Within this category, baked and extruded snack products play a significant role. High-fiber snacks have gained increasing popularity due to their potential health benefits, including improved digestive function and reduced risk of non-communicable diseases (Han and Tran, 2018). Crackers, a commonly consumed baked snack, may contain relatively high fat levels, reaching up to 30% (w/w), and therefore occupy an important position in the commercial snack food industry (Sedej et al., 2011).

Crackers are valued not only for their nutritional contribution but also for their convenience and versatility as cereal-based snack products. The classification of crackers as fermented or non-fermented is largely influenced by the protein content of the flour used in their formulation (Tiwari et al., 2023). Since crackers are generally perceived as having a lower energy density compared to sugar-based biscuits, they represent a major segment of the baking industry (Serna-Saldivar, 2012). Incorporation of banana peel, due to its favorable nutritional and functional properties, offers a promising strategy for the development of fiber-enriched crackers. The objective of this study includes:

- ✓ Development of banana peel and pulp-based crackers
- ✓ Nutritional, physicochemical and organoleptic evaluation of developed crackers

Materials and Methods

Materials

Fresh ripe bananas (Musa spp.) were procured from the local fruit market. Corn flour, salt, shortening, sugar, baking powder, and other ingredients required for cracker preparation were purchased from a local supermarket. All chemicals and reagents used for proximate, phytochemical, antioxidant, and mineral analyses were of analytical grade and obtained from certified suppliers.

Preparation of Banana Peel and Pulp Powder

Bananas were thoroughly washed under running tap water to remove surface impurities. The peels were manually separated from the pulp and cut into small uniform pieces. The peel pieces were soaked in a citric acid solution to prevent enzymatic browning, followed by rinsing with distilled water. The treated peels were dried at 60 °C in a hot air oven until they reached a consistent weight. Dried peels were ground using a laboratory grinder and sieved through a fine mesh to obtain uniform banana peel flour. The flour was stored in airtight containers at room temperature until further use.

Formulation and Preparation of Crackers

Corn crackers were made by partially replacing corn flour with flour made from peels of banana at concentrations of 5%, 10%, 15%, and 20%, while banana pulp powder was maintained at a constant level of 5% across all treatments. The control formulation consisted of 100% corn flour without banana peel flour. All dry ingredients were weighed accurately and mixed thoroughly. Shortening and water were gradually added to form a homogeneous dough. The dough was rested for a standardized period, flattened into thin sheets, and trimmed into uniform shapes. The crackers were cooked at 180 °C in a preheated oven until they were crisp and golden. Crackers were placed in sealed containers for analysis once they had cooled to room temperature.

Formulation of corn crackers incorporated with banana peel and pulp powder

Treatments	**Corn flour (%)**	**Banana pulp (%)**	**Banana peel (%)**
T_0	100	--	--
T_1	90	5	5
T_2	85	5	10
T_3	80	5	15
T_4	75	5	20

Proximate Composition

Ash, moisture, crude fiber, crude protein, and crude fat contents of the crackers were assessed using standard procedures described by the Association of Official Analytical Chemists

(AOAC, 2019). Carbohydrate content was calculated by difference. All analyses were conducted in triplicate, and results were expressed on a dry weight basis.

Phytochemical and Antioxidant Analysis

Methanolic extracts were prepared by combining 5 g of the sample with acidified methanol (0.1% HCl) and incubating the mixture at 60–65 °C for 2 hours. After that, the extracts underwent 20 minutes of centrifugation at 5000 rpm. The Folin-Ciocalteu technique was used to calculate the total phenolic content (TPC), which was then represented as milligrams of gallic acid equivalents (GAE) per gram of sample. Total flavonoid content (TFC) was measured by the aluminum chloride colorimetric method and reported as mg quercetin equivalents per gram. The DPPH radical scavenging test was used to measure antioxidant activity, which was then represented as a percentage of inhibition.

Mineral Analysis

Calcium and potassium contents were determined using a flame photometer after wet digestion of the samples with nitric and perchloric acids, following AACC (2010) procedures.

Color and Texture Analysis

Color parameters (L*, a*, b*) of crackers were measured using a colorimeter. A texture analyzer (TA-XT Plus, Stable Microsystems, UK) with a compression test setup and a 5 kg load cell was used to assess texture profiles.

Sensory Evaluation

A 9-point hedonic scale was used for sensory evaluation in order to evaluate taste, color, mouthfeel, aroma, texture and overall acceptability. Ten trained panelists from the University of Agriculture, Faisalabad participated in the evaluation following the method of Meilgaard *et al.* (2016).

Statistical Analysis

Each analysis was performed three times. One-way analysis of variance (ANOVA) was used to evaluate the data, and Tukey's test was used to compare means at a significance level of $p < 0.05$. Statistical analysis was conducted using Minitab 19 software (Montgomery, 2017).

RESULTS AND DISCUSSION

Proximate analysis

Moisture Content: Table X shows the moisture level in corn crackers made with different amounts of pulp powder and peels of banana Analysis of variance revealed that formulation had a significant impact upon moisture content ($p < 0.05$). The control treatment (T0) exhibited the highest moisture level (4.14 ± 0.53%), whereas T4, containing 20% banana peel flour, had the lowest (1.29 ± 0.04%). Intermediate values were recorded for T1 (2.25 ± 0.05%), T2 (2.51 ± 0.10%), and T3 (1.89 ± 0.01%). A clear decrease in moisture content was observed with increasing banana peel flour, likely due to the peel's elevated level of dietary fiber, which retains water and decreases free moisture in the product matrix (Gomes et al., 2022). Additionally, the low intrinsic moisture of dehydrated banana peel flour further contributed to the reduction (Kusmayanti *et al.,* 2021). Similar reductions have been reported in baked goods fortified with banana peel flour, improving shelf stability and crispness (Shafi *et al*., 2022).

Ash Content: Higher amounts of banana peel and pulp powder resulted in a substantial ($p < 0.05$) increase in ash content. The corresponding values for T0, T1, T2, T3, and T4 were 1.95 ± 0.05%, 2.30 ± 0.30%, 2.80 ± 0.40%, 3.40 ± 0.40%, and 3.70 ± 0.20%, with the highest ash content observed in T4. This rise is explained by the flour made from banana peels' strong mineral makeup, which contains potassium, calcium, magnesium, and phosphorus. Similar enhancements in ash content have been reported in banana peel flour (6.79–15.56%) and in baked products fortified with it, reflecting improved nutritional value (Bakar *et al*., 2018; Deb *et al*., 2022; Alemu, 2023).

Crude Fat: The crude fat content of crackers also increased significantly ($p < 0.05$) with the incorporation of banana peel and pulp powders. Fat content ranged from 0.308 ± 0.14% in T0 to 1.697 ± 0.22% in T4, with intermediate values in T1 (0.859 ± 0.04%), T2 (1.12 ± 0.12%), and T3 (1.333 ± 0.14%). This increase may be due to the presence of phospholipids, sterols, and free fatty acids, including linoleic and oleic acids, in banana peel and pulp. Previous studies have similarly reported higher fat content in food products fortified with banana peel flour (Akram *et al*., 2022; Akhter *et al*., 2024). While fruits and vegetables generally contain low fat levels, this modest increase can enhance sensory qualities such as flavor and mouthfeel.

Crude Fiber: Crude fiber content significantly increased ($p < 0.05$) with higher levels of banana peel and pulp powder. Values for T0, T1, T2, T3, and T4 were 6.90 ± 0.10%, 7.77 ± 0.15%, 8.10 ± 0.52%, 11.73 ± 0.15%, and 14.70 ± 0.45%, respectively. The highest fiber content was observed in T4, reflecting the high dietary fiber of banana peel and pulp, particularly cellulose, hemicellulose, and lignin. Banana peel flour contains around 37.12% crude fiber on a dry weight basis, substantially higher than wheat and other composite flours (Mahlobo *et al.*, 2019), confirming its effectiveness as a functional ingredient for fiber enrichment in baked snacks.

Crude Protein: Crude protein content also increased significantly ($p < 0.05$) with the progressive substitution of corn flour by banana peel and pulp powders. Protein levels ranged from 7.20 ± 0.10% in T0 to 9.20 ± 0.15% in T4, with intermediate values of T1 (8.00 ± 0.13%), T2 (8.50 ± 0.49%), and T3 (8.90 ± 0.30%). The rise is explained by banana peel's comparatively greater protein content (8–11%), which includes vital amino acids including threonine, leucine, valine, and phenylalanine. These results align with previous reports showing higher protein content in banana peel flour compared to pulp, supporting its use as a protein-enhancing ingredient in cereal-based products (Bin Ramli *et al*., 2010; Khatun *et al*., 2021). Enrichment of flour from peels of banana improves the nutritional profile of crackers without compromising their functional properties.

Results of proximate analysis

Treatments	Moisture	Ash content	Crude fat	Crude fiber	Crude protein
T_0	4.14 ± 0.53^{d}	1.95 ± 0.05^{d}	0.308 ± 0.14^{e}	6.9 ± 0.10^{d}	7.2 ± 0.10^{c}
T_1	2.25 ± 0.05^{cd}	2.3 ± 0.3^{cd}	0.859 ± 0.04^{d}	7.77 ± 0.15^{cd}	8.2 ± 0.13^{b}
T_2	2.51 ± 0.10^{bc}	2.8 ± 0.4^{bc}	1.12 ± 0.12^{c}	8.1 ± 0.52^{c}	8.37 ± 0.49^{ab}
T_3	1.89 ± 0.01^{ab}	3.4 ± 0.4^{ab}	1.333 ± 0.14^{b}	11.73 ± 0.15^{b}	8.6 ± 0.30^{a}
T_4	1.29 ± 0.04^{a}	3.7 ± 0.2^{a}	1.697 ± 0.22^{a}	14.7 ± 0.45^{a}	8.77 ± 0.15^{a}

Phytochemical and antioxidant analysis

Total Phenolic Content (TPC): The Folin-Ciocalteu technique was used to determine the total phenolic content (TPC). Cracker extracts were prepared using an appropriate solvent, and a UV-visible spectrophotometer was used to measure absorbance at 765 nm. The results were reported in milligrams of gallic acid equivalents (mg GAE/g), with gallic acid serving as the benchmark.

Total Flavonoid Content (TFC): The Folin-Ciocalteu technique was used to determine the total phenolic content (TPC). A UV-visible spectrophotometer was used to measure absorbance at 765 nm after cracker extracts were made with the proper solvent. Results were reported in milligrams of gallic acid equivalents (mg GAE/g), with gallic acid serving as the benchmark.

Antioxidant Activity (DPPH Scavenging): The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging test was used to assess antioxidant capability. Antioxidant activity was computed as a percentage inhibition in comparison to the control, and the decrease in absorbance was observed at 517 nm.

Results of Phytochemical and antioxidant analysis

Treatments	TPC	TFC	DPPH
T_0	64.57±0.58[d]	10.3±0.11[e]	64.57±0.58[d]
T_1	73.00±0.45[c]	15.4±0.18[d]	61.57±0.40[e]
T_2	72.10±0.56[c]	20.5±0.19[c]	68.4±0.30[c]
T_3	82.83±0.47[b]	25.6±0.17[b]	75.6±0.30[b]
T_4	90.77±0.51[a]	30.3±0.26[a]	83.77±0.35[a]

Mineral analysis

Calcium: The calcium content of corn crackers was substantially impacted by the addition of banana peel and pulp powders ($p < 0.05$). The calcium levels for T0, T1, T2, T3, and T4 were 25.9 ± 0.12, 38.5 ± 0.17, 45.4 ± 0.15, 51.5 ± 0.20, and 57.9 ± 0.15 mg/100 g, respectively, with

T4 (75% corn flour, 20% banana peel flour, and 5% banana pulp powder) showing the highest calcium content and T0 (100% corn flour) the lowest. The high mineral content of banana peel flour (67.13 mg/100 g), which is significantly greater than that of banana pulp (22.02 mg/100 g), is responsible for the rise in calcium. These results align with previous studies demonstrating that substitution with banana peel flour enhances the mineral composition of baked products, particularly calcium (Debabandya *et al.*, 2010; Shammari, 2023). Furthermore, the presence of organic acids and dietary fiber in banana peel may improve mineral bioavailability, indicating that enriching corn-based snacks with banana peels is a successful way to improve their nutritional value.

Potassium: Potassium content was also significantly influenced ($p \leq 0.05$) by the inclusion of banana peel and pulp powders. The measured values for T0, T1, T2, T3, and T4 were 18.7 ± 0.27, 25.9 ± 0.40, 31.2 ± 0.41, 36.8 ± 0.35, and 42.7 ± 0.27 mg/100 g, respectively, with T4 again showing the highest content and T0 the lowest. The progressive increase in potassium levels is because of the naturally elevated potassium concentration of peels of banana (78–110 mg/100 g) and pulp (65–80 mg/100 g) (Emaga *et al.*, 2007). These findings highlight that increasing the proportion of banana peel flour substantially improves the potassium content of corn crackers. Incorporation of banana by-products not only enhances the nutritional profile of the product but also supports sustainable food processing by valorizing agricultural waste. Potassium-enriched snacks may provide additional health benefits, particularly for hypertensive individuals, by contributing to dietary blood pressure regulation (Aburto *et al.*, 2013; Ekmekcioglu *et al.*, 2016).

Results of Mineral analysis

Treatment	Calcium	Potassium
T_0	25.9±0.115[e]	18.7±0.265[e]
T_1	38.5±0.173[d]	25.9±0.404[d]
T_2	45.4±0.145[c]	31.2±0.406[c]
T_3	51.5±0.203[b]	36.8±0.346[b]
T_4	57.9±0.145[a]	42.7±0.265[a]

Color analysis

Color characteristics of crackers were measured using a colorimeter based on the CIE L*, a*, and b* color system. Lightness (L*), redness/greenness (a*), and yellowness/blueness (b*) values were recorded, and chroma (c*) values were calculated accordingly.

Results of Color analysis

Treatment	L* values	a* values	b* values	c* values
T_0	33.2±0.2[c]	8.76±0.05[a]	21.39±0.04[b]	23.12±0.04[a]
T_1	34.19±0.04[b]	8.58±0.08[b]	20.86±0.06[c]	20.56±0.04[b]

T_2	20.62±0.04^{d}	3.76±0.04^{d}	12.02±0.02^{d}	12.6±0.10^{c}
T_3	39.65±0.05^{a}	8.47±0.2^{b}	21.86±0.06^{a}	23.28±0.06^{a}
T_4	1.65±0.05^{e}	4.46±0.06^{c}	1.93±0.40^{e}	4.86±0.10^{d}

Texture analysis

Textural properties of crackers, including hardness and cohesiveness, were determined using a texture analyzer. Samples were analyzed under standardized test conditions, and results were expressed in Newtons (N) for hardness and percentage values for cohesiveness.

Results of Texture analysis

Treatment	Cohesiveness	Hardness
T_0	0.609±0.03^{b}	2.88±0.03^{e}
T_1	0.784±0.01^{a}	15.27±0.07^{c}
T_2	0.632±0.012^{b}	12.94±0.04^{d}
T_3	0.624±0.012^{b}	21.58±0.03^{b}
T_4	0.614±0.014^{b}	26.2±0.4^{a}

Sensory analysis of corn crackers

Color: Color is a key quality attribute that strongly influences consumer acceptance, as it provides visual cues regarding baking degree, aroma, and flavor development. The ANOVA results revealed significant color differences ($p < 0.05$) among corn crackers prepared with different proportions of corn flour, banana peel flour (BPF), and banana pulp flour (PPF). The measured color scores for T0, T1, T2, T3, and T4 were 7.78 ± 0.11, 7.33 ± 0.12, 8.33 ± 0.22, 8.00 ± 0.12, and 7.00 ± 0.13, respectively, with T2 (85% corn flour, 5% banana pulp powder, and 10% banana peel flour) exhibiting the highest color intensity. This improvement at moderate BPF levels is likely due to the optimal incorporation of natural pigments and Maillard reaction products, which enhance visual appeal without causing excessive darkening. These findings are in line with those of Abubakar *et al*. (2019), who found that a moderate amount of banana peel flour, who found that a moderate addition of banana peel flour can enhance color attributes while maintaining acceptable sensory quality in baked products.

Flavor: Flavor is a primary sensory attribute affecting consumer preference. Flavor assessments showed significant variations ($p < 0.05$) across treatments. Scores for T0, T1, T2, T3, and T4 were 8.33 ± 0.10, 6.66 ± 0.32, 7.00 ± 0.22, 5.66 ± 0.13, and 8.33 ± 0.33, respectively, with T2 receiving the highest rating. The decline in flavor scores at higher BPF levels (T3 and T4) is potentially because banana peels have a higher phenolic content, which might give them a slightly bitter taste. These findings align with Silva and Conti (2017), who noted that using a lot of flour made from banana peels might enhance bitterness, color, and aroma in baked goods.

Texture: ANOVA analysis also indicated significant differences ($p \leq 0.05$) in texture among treatments. Texture scores for T0, T1, T2, T3, and T4 were 8 ± 0.32, 7 ± 0.23, 7.66 ± 0.35, 5.33 ± 0.44, and 5.66 ± 0.21, respectively, with T2 exhibiting the most favorable texture. Increased hardness may result from using more banana peel flour and reduce fracturability, which adversely affects texture (Ahsan *et al.,* 2024). Overall Acceptability: Overall acceptability scores also showed significant differences ($p \leq 0.05$). Scores for T0, T1, T2, T3, and T4 were 8.67 ± 0.32, 6.66 ± 0.22, 8 ± 0.43, 6.67 ± 0.11, and 5.33 ± 0.13, respectively, with T2 achieving the highest overall acceptability. Incorporation of 10% banana peel flour in corn crackers enhances the nutritional profile while maintaining favorable sensory attributes, making it a promising strategy for developing functional snack products (Silva and Conti, 2017).

Results of Sensory analysis of corn crackers

Treatments	Color	Flavor	Texture	Overall Acceptability
T_0	7.78 ± 0.11^{c}	8.33 ± 0.1^{a}	8 ± 0.32^{a}	8.67 ± 0.32^{a}
T_1	7.33 ± 0.12^{ab}	6.66 ± 0.32^{ab}	7 ± 0.23^{abc}	6.66 ± 0.22^{bc}
T_2	8.33 ± 0.22^{a}	7 ± 0.22^{ab}	7.66 ± 0.35^{ab}	8 ± 0.43^{ab}

T_3	8±0.12^{b}	5.66±0.13^{b}	5.33±0.44^{c}	6.66±0.11^{bc}
T_4	7±0.13^{d}	8.33±0.33^{b}	5.66±0.21^{ab}	5.33±0.13^{c}

Conclusion

Banana peels, a rich source of dietary fiber, minerals, and bioactive compounds, were incorporated into corn crackers to enhance nutritional quality while promoting the valorization of agro-industrial waste. Five formulations were developed: T0 (100% corn flour), T1 (90% corn flour + 5% banana peel flour [BPF] + 5% banana pulp flour [PPF]), T2 (85% corn flour + 10% BPF + 5% PPF), T3 (80% corn flour + 15% BPF + 5% PPF), and T4 (75% corn flour + 20% BPF + 5% PPF). Proximate analysis revealed a reduction in moisture content with increasing BPF (from 4.14% in T0 to 1.29% in T4), while ash, fat, protein, and crude fiber increased, reaching maximum values in T4 (3.7% ash, 1.70% fat, 9.2% protein, and 14.7% crude fiber). Phytochemical evaluation showed a marked rise in total phenolic content (TPC, 64.57–90.77 mg GAE/g) and total flavonoid content (TFC, 10.3–30.3 mg QE/g), accompanied by enhanced DPPH radical scavenging activity (64.57–83.77%), indicating improved antioxidant potential with higher BPF levels. Mineral analysis demonstrated significant increases in calcium (25.9–57.9 mg/100 g) and potassium (18.7–42.7 mg/100 g), highlighting the functional enrichment of the crackers. Color and texture analyses revealed darker products with increasing BPF, reflected by decreasing L*, a*, b*, and c* values, as well as higher hardness (2.88–26.2 N) and variable cohesiveness, peaking in T1 (0.784). Sensory evaluation indicated that T2 (85% corn flour + 10% BPF + 5% PPF) achieved the highest overall acceptability, suggesting that moderate BPF levels optimize both nutritional quality and consumer preference. Overall, the incorporation of banana peel flour into corn crackers effectively enhances proximate composition, bioactive content, mineral levels, antioxidant activity, and sensory properties, offering a sustainable and functional bakery product.

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