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Formulation and standardisation of banana peel powder for food applications

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Abstract
Banana peel, a major agro-waste by-product that possesses several bioactive properties including antioxidant, antimicrobial, anti-inflammatory, and anti-ulcer effects, along with benefits in managing constipation, blood pressure, and digestive health. Its utilization through drying and processing offers an eco-friendly approach to reduce food waste while enhancing nutritional quality of value-added foods. The present study focused on the standardisation of Banana Peel Powder (BPP). Banana peels were subjected to various treatments which includes blanching (2-10 min), citric acid and salt combinations (0.1-0.5% + 1-3.5%), and salt immersion (5-25 min). The overall visual quality (OVQ) of peel was significantly influenced by treatment type and duration, with optimal results at blanching for 2 minutes, citric acid 0.3% + salt 2.5%, and salt immersion for 15 minutes. Blanching for 2 minutes gave the highest OVQ scores compared to other 2 different treatments and hence standardized peels were dried, powdered, and analyzed for physical, chemical, nutritional, and mineral characteristics. BPP showed poor flowability (Carr Index 29.90%; Hausner ratio 1.35), high hydration capacity (rehydration ratio 4.80; swelling index 6.50), slightly acidic pH (5.90), moderate TSS (12 °Brix), and notable reducing sugars (5.0%). Nutritional analysis revealed high fiber (19.02%), carbohydrate content (68.04%), moderate protein (6.77%), fat (15.61%), and mineral richness (8339.22 mg/100 g), with potassium (5580.73 mg/100 g) as the predominant element. Overall, this study highlights banana peel powder as a nutrient-dense, functional, and sustainable food ingredient. Its incorporation into other food products not only valorizes agro-waste but also enhances nutritional value, supporting food innovation for health and environmental sustainability.

Keywords: Banana peel, agro-waste, bioactive properties, antioxidant, antimicrobial

Introduction

Banana is one of the most extensively cultivated and economically important fruit crops worldwide, grown in more than 100 countries, Indonesia, and the Philippines. Globally, Bananas are the second most cultivated fruit after citrus and ranked among the leading agricultural commodities after rice, wheat, and milk (Dom *et al*., 2023) [2] Asia contributing more than half of the total output. India is the world's largest producer, yielding over 34 million tonnes annually, followed by China, Indonesia, and the Philippines. Together India and China account for nearly 38% of global production (Yasin *et al*., 2025) [9] Average worldwide consumption is estimated at 12 kg per person per year, though in banana-producing regions the consumption level is significantly higher, making it a staple fruit (Parmanik and Tewari 2022) [6]. Banana peel possesses various health promoting properties, including antioxidant, antimicrobial, anti-inflammatory and anti-ulcer effects which helps in managing constipation, blood pressure and digestive issues. Through innovative technologies like drying, which enhances storability and expands its uses in snacks, flour and other products (Farooq *et al* 2021). The increasing demand for sustainable and health promoting food products has emerged the use of agrowaste like banana peels in food innovation. Incorporation of Banana Peel Powder (BPP) into bakery products, noodles and other formulations, shown improvements in nutritional value without compromising sensory qualities. Advanced processing methods help retain its bioactivity, supporting its potential as a sustainable ingredient. This study was undertaken to standardise the banana peel powder by treating banana peels with different treatments.

Materials and Methods

Procurement of raw materials

Research was carried out in the Dept. Food and Nutrition, College of Agricultural Sciences, Iruvakki, Shivamogga. Bananas were procured from Aanandapura local mandi, peels were separated from Banana, collected and washed with water for further treatments. To standardise banana peel powder, peels were subjected to different treatments namely blanching at (2, 4, 6, 8 and 10 minutes), citric acid and salt treatment (0.1%+1%, 0.2%+2%, 0.3%+3%, 0.4%+4%, 0.5%+5%) and salt media immersion at (5, 10, 15, 20, 25 minutes) and then peels were spread uniformly on muslin cloth and allowed to sun dry for three days at 32 °C.

Nutritional composition of Banana peels

Moisture was analysed by (%AOAC, 2019), ash was analysed by (% AOAC, 2019), Crude fat (% AOAC 2019), Crude fiber (% AOAC, 2019), Crude protein (% AOAC, 2019). Carbohydrate was analysed by computation of Carbohydrate (% AOAC), Estimation of Ca^+ (mg/100g), by EDTA titrimetric method, Na^+ was estimated by (flame emission photometric method), K^+ was analysed by (flame emission photometric method, Fe^+ was estimated by FAAS 2020, Total minerals were estimated by ICP-OES method.

Physical parameters of banana peel powder

The quality of banana peel powder was evaluated through various physical parameters using standard methods to determine their storage stability, handling properties, and consumer acceptability. Bulk and tapped densities were measured by recording the volume occupied by a fixed weight of sample before and after tapping, from which Hausner ratio and Carr Index were calculated to assess flowability. Hydration properties were studied through rehydration ratio, reconstitution ratio, and swelling index, indicating the water absorption and swelling capacity of samples. For cookies, diameter, thickness, and spread ratio were determined after baking to evaluate their shape, texture, and overall physical quality. These measurements together provided a comprehensive understanding of product performance and functional characteristics.

Chemical parameters of banana peel powder

The chemical quality of banana peel powder was assessed through key parameters such as pH, total soluble solids (TSS), titratable acidity, and reducing sugars, which are crucial for nutritional value, safety, and consumer acceptability. pH was measured by dissolving samples in distilled water and recording values with a calibrated pH meter. TSS was estimated using a refractometer, expressed in °Brix, to determine soluble solids. Titratable acidity was determined by titrating the filtrate of homogenized samples against NaOH using phenolphthalein as an indicator. Reducing sugar content was analyzed by Miller's DNS method, where absorbance was measured at 540 nm against a glucose standard curve, and results were expressed in mg/100 g sample. Together, these analyses ensured proper evaluation of product stability, compliance with food standards, and consistency in quality.

Statistical analysis

The experimental data obtained for different parameters were subjected to statistical analysis. The mean values of the observations were calculated for each treatment. The standard deviation (SD) was computed to measure the extent of variation of the mean. The results were presented as Mean ± S. Em (Standard Error of Mean), along with CD values at 1% to determine the statistical significance among treatments. The experiment was laid out in a Completely Randomized Design (CRD) to ensure uniformity and reliability of the treatments comparison.

Results and Discussion

Standardization of banana peel powder

Table 1 presents the Overall Visual Quality (OVQ) scores of banana peels, showing a clear decline with increasing blanching time. The maximum OVQ was obtained in T_1 (2 min) with 7.80 ± 1.77, followed by T_2 (4 min) at 7.00 ± 1.83. Prolonged blanching (6-10 min) resulted in a gradual reduction of quality, with the lowest score in T_5 (10 min) at 4.10 ± 2.25.

Table 2 illustrates the variation in OVQ scores of banana peels under different concentrations of citric acid and salt. The best visual quality was obtained in treatment T_3 with a score of 7.60 ± 0.05, follow.

Table 1: Effect of blanching on Overall Visual Quality (OVQ) of banana peels

SI. No	Treatments	OVQ Scores
1.	T_1 (2 min)	7.80 ± 1.77
2.	T_2 (4 min)	7.00 ± 1.83
3.	T_3 (6 min)	6.10 ± 2.06
4.	T_4 (8 min)	5.20 ± 2.10
5.	T_5 (10 min)	4.10 ± 2.25

The overall visual quality of banana peels was significantly influenced by blanching duration suggested by Kusmayanti *et al*. (2020) [5] However, extended blanching times resulted in a progressive decline in quality. This deterioration could be attributed to cell wall breakdown, pigment leaching, and non-enzymatic browning. These findings confirm that blanching for 2 minutes is optimal, whereas prolonged blanching compromises peel structure and visual attributes. T_4 which scored 7.00 ± 1.84. In contrast, T_2 showed a moderate score of 6.15 ± 2.08. The lowest ratings were recorded in T_1 and T_5 with values of 5.35 ± 2.01 and 6.35 ± 1.89. Citric acid and salt pre-treatments had a notable effect on the visual quality of banana peels has been shown by Gomes *etal*. (2016) [3]. The best results were observed in T_3 with 0.3% citric acid and 2.5% salt, where citric acid reduced enzymatic browning by lowering pH, and salt enhanced firmness through osmotic balance. The findings emphasize the need to carefully adjust treatment levels to control browning while preserving peel structure. When properly optimized, such treatments help retain both the functional properties and sensory attributes of banana peels, making them suitable for incorporation into flour-based products.

Table 3 shows the Overall Visual Quality (OVQ) scores of banana peels subjected to different durations of salt immersion. The highest OVQ was observed in the 15-minute treatment (7.72 ± 0.00). Immersion for 10 and 20 minutes also resulted in good quality with OVQ scores of 6.50 ± 2.33 and 6.80 ± 2.04, respectively. Shorter (5 min, 5.30 ± 2.45) and longer (25 min, 7.10 ± 1.77) immersion times were less effective in preserving visual quality, The variation in Overall Visual Quality (OVQ) with salt immersion time can be attributed to the balance between enzymatic browning inhibition and tissue stability.

The highest OVQ at 15 minutes (7.72 ± 0.00) indicates that this duration allowed the peels to maintain a uniform colour and appealing appearance, with consistent results across replicates. Shorter immersion times were less effective, likely because insufficient salt exposure failed to fully inhibit enzymatic browning, leading to reduced colour stability.

Table 2: Effect of pre-treatments on Overall Visual Quality (OVQ) of banana peels

SI. No	Treatments	OVQ Scores
1.	Citric acid (0.1%) + Salt (1%)	5.35 ± 2.01
2.	Citric acid (0.2%) + Salt (2%)	6.15 ± 2.08
3.	Citric acid (0.3%) + Salt (2.5%)	7.60± 0.05
4.	Citric acid (0.4%) + Salt (3%)	7.00 ± 1.84
5.	Citric acid (0.5%) + Salt (3.5%)	6.35 ± 1.89

Table 3: Effect of salt immersion on Overall Visual Quality (OVQ) of banana peels

SI. No	Treatments	OVQ Scores
1.	5 min	5.30 ± 2.45
2.	10 min	6.50 ± 2.33
3.	15 min	7.72 ± 0.00
4.	20 min	6.80 ± 2.04
5.	25 min	7.10 ± 1.77

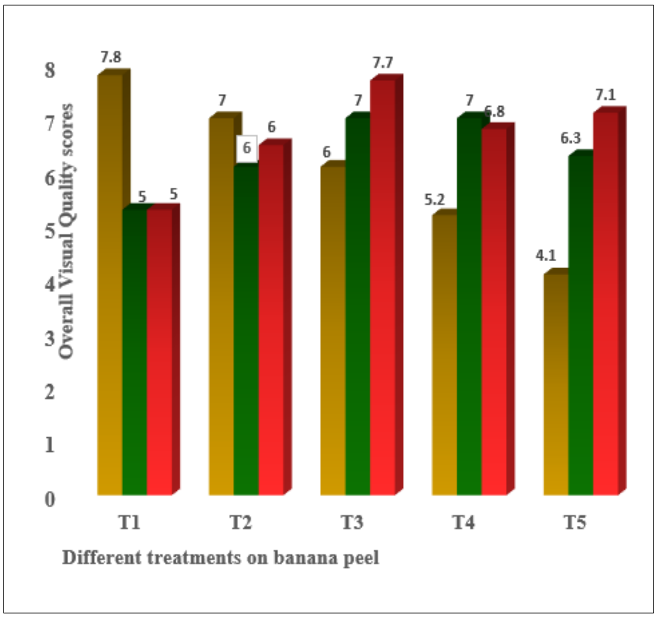

Fig 1: Overall Visual Quality (OVQ) of standardised banana peels

Among the three approaches studied, blanching, citric acid + salt, and salt immersion, distinct patterns emerged across treatment levels (T_1-T_5). Blanching at 2 minutes (T_1) yielded the highest initial OVQ, as heat inactivated polyphenol oxidase enzymes responsible for browning. However, with longer blanching durations, OVQ declined sharply due to thermal damage, pigment loss, and softening of peel tissues. In contrast, citric acid + salt and salt immersion demonstrated more sustained effects. Both treatments showed peak OVQ at intermediate levels (T_3), indicating that the controlled combination of antioxidant (citric acid) and osmotic regulation (salt) effectively inhibited browning and preserved peel texture. Notably, citric acid + salt treatment consistently outperformed salt alone, confirming the added benefit of antioxidant protection in maintaining colour and freshness. Unlike blanching, these treatments avoided rapid declines in quality, making them more suitable for longer processing times.

Physical parameters of banana peel powder

Flowing properties of BPP

Table 4 represents the flow properties of Banana Peel Powder (BPP). Bulk density (0.27 ± 0.02 g/cm³) was lowest compared to tapped density (0.36 ± 0.01 g/cm³), The Carr's index (29.90 ± 0.40%) was higher and Hausner ratio was low (1.35 ± 0.02).

Table 4: Flowing properties of BPP

Parameters	Banana peel powder
Bulk density(g/mL)	0.27 ± 0.02
Tapped density(g/mL)	0.36 ± 0.01
Carr Index	29.90 ± 0.40
Hausner ratio	1.35 ± 0.02
Flowability	Poor

The flow properties of banana peel powder (BPP) indicated poor flowability, as reflected by its low bulk density (0.27 ± 0.02 g/mL) and higher tapped density (0.36 ± 0.01 g/mL), suggesting loose packing with significant void spaces that compact upon tapping. The Carr Index (29.90 ± 0.40) further confirmed poor flow characteristics, as values above 25% indicate cohesiveness and reduced free-flowing nature. Similarly, the Hausner ratio (1.35 ± 0.02) fell within the poor flow range, showing high interparticle friction. These findings suggest that the irregular particle morphology and high fiber content of BPP contribute to its poor flow properties, which may pose challenges during handling, mixing, packaging and large-scale processing.

Table 5: Hydration properties of BPP

Parameters	Banana peel powder
Rehydration ratio	4.80 ± 0.10
Reconstitution ratio	4.20 ± 0.40
Swelling index	6.50 ± 0.30

Hydration properties of BPP

Table 5 represents Hydration properties of banana peel powder (BPP). Rehydration ratio was 4.80 ± 0.10, Reconstitution ratio was 4.20 ± 0.40, and Swelling index score was 6.50 ± 0.30.

The hydration properties of Banana peel powder (BPP) revealed its high water absorption and swelling ability. The rehydration ratio indicates that powder can absorb nearly five times its weight of water, which reflects its porous and fibrous structure. The reconstitution ratio showed that BPP possesses a good ability to regain its structure after drying when water is added, although slightly lower than its rehydration capacity, possibly due to structural modifications during processing. The swelling index suggested a strong tendency of powder to expand in volume upon absorption. Viana *et al*. (2024) [8] observed that (Banana Peel Powder) BPP had improved handling and structural stability of These values collectively highlight that BPP has good hydration characteristics, largely attributed to its high content of dietary fiber, cellulose and pectin, making it suitable for incorporation into food formulations that require high water-holding and swelling capacity. The developed BPP exhibited desirable hydration properties, moderate acidity, and notable reducing sugar content, alongside high levels of dietary fiber, carbohydrates, and essential minerals, particularly potassium. These findings establish banana peel powder as a functional and sustainable food ingredient with significant potential for incorporation into value-added products. Its utilization not only enhances the nutritional profile of foods but also contributes to reducing agro-waste, thereby supporting both human health and environmental sustainability.

Chemical parameters of banana peel powder

Banana peel powder (BPP) exhibited a slightly acidic pH (5.90 ± 0.10. The total soluble solids (TSS) content of BPP was moderate (12.00 ± 0.30). Titratable acidity was relatively high (0.60 ± 0.02%).

Table 6: Chemical parameters of BPP

Parameters	Banana peel powder
pH	5.90 ± 0.10
TSS	12.00 ± 0.30
Titratable acidity	0.60 ± 0.02
Reducing sugars	5.00 ± 0.20

Banana peel powder (BPP) which has a characteristic fruit-derived materials and can be attributed to the presence of organic acids and phenolic compounds. This acidity not only influences its flavour profile but also contributes to its stability and potential antimicrobial activity. The total soluble solids (TSS) content of BPP reflects the presence of soluble carbohydrates, minerals, and small amounts of soluble fibers, although its overall solubility is limited by its high fiber content. Titratable acidity was relatively high confirming its acidic nature and the presence of bioactive compounds that may enhance functional properties such as antioxidant capacity. Reducing sugar indicates that BPP contains naturally occurring simple sugars derived from the peel's carbohydrate composition. Overall, these chemical properties suggest that BPP is a nutrient-rich ingredient with functional potential, combining acidity, moderate solubility, and natural sugar content that could influence flavour, stability, and health-promoting attributes in food formulations.

Nutritional composition of banana peel powder

Table 7 shows the nutritional composition of banana peel powder (BPP) characterized by moderate moisture content (7.89 ± 0.12). The ash content was relatively low (1.69 ± 0.05), Fat content was moderate (15.61 ± 0.50). A notable feature of BPP is its exceptionally high fiber content (19.02 ± 0.60). Protein levels were also relatively high (6.77 ± 0.18). Carbohydrates formed the major component (68.04 ± 0.70).

Banana peel powder (BPP) exhibited a well-balanced nutritional profile, characterized by moderate moisture content which is typical of dehydrated peel powder and ensures extended shelf stability when stored under proper conditions.

Table 7: Nutritional composition of banana peel powder and its products

Parameters	Banana peel powder
Moisture (%)	7.89±0.12
Ash (%)	1.69±0.05
Fat (%)	15.61±0.50
Fiber (%)	19.02±0.60
Protein (%)	6.77±0.18
Carbohydrates (%)	68.04±0.70

The ash content was relatively low indicating a modest mineral contribution compared to formulated products Youssef *et al* (2023) [10] reported that incorporation of ripened banana peel powder into bread enhanced its ash content, which still reflects the natural mineral present in banana peel. Fat content was moderate derived mainly from intrinsic lipids present in the peel, which can contribute to energy density and improve palatability in formulations. Similarly Singh *et al*. (2023) [7] demonstrates that 9% banana peel powder increased fat content in chocolates. A notable feature of BPP is its exceptionally high fiber content making it a valuable functional ingredient for promoting digestive health and enhancing the textural quality of biscuits, bread and pasta upto 10% incorporation confirmed by Badilla *et al*. (2022) [1]. Protein levels were also relatively high suggesting its potential role in improving the protein content of composite foods suggested by Youssef *et al*. (2023) [10] that 15% peel incorporation improved the protein content of bread. Carbohydrates formed the major component (68.04 ± 0.70), largely representing starches and non-starch polysaccharides, which provide energy and contribute to its functional properties such as bulk and binding capacity. Overall, these results confirm that BPP is a nutrient-dense ingredient, particularly rich in fiber and carbohydrates, with additional contributions from protein and natural lipids, thereby offering both nutritional and functional benefits for food product development.

Mineral composition of banana peel powder

Table 8 shows the mineral content of Banana peel powder (BPP) which was found to be exceptionally rich in minerals, with a total mineral content of 8339.22 ± 10.50 mg. Potassium was the most abundant mineral (5580.73 ± 1.50 mg). Calcium levels were also appreciable (140.44 ± 2.10 mg). Sodium was present in moderate amounts (387.95 ± 5.80 mg). Iron content (7.44 ± 6.20 mg) was moderate.

Table 8: Mineral composition of banana peel powder and its products

Minerals	Banana peel powder
Calcium	140.44 ± 2.10
Sodium	387.95 ± 5.80
Potassium	5580.73 ± 1.50
Iron	7.44 ± 6.20
Total minerals	8339.22 ± 10.50

Potassium mineral which is consistent with the natural composition of banana peel, highlights its importance for maintaining electrolyte balance, supporting nerve function, and regulating blood pressure. Calcium mineral which contributes to bone strength, muscle activity, and overall structural health. Sodium was present in moderate amounts, naturally occurring in plant tissues, which makes BPP a low-sodium ingredient compared to processed foods, thereby suitable for health-conscious formulations. Iron content (7.44 ± 6.20 mg) was moderate, offering potential benefits for haemoglobin synthesis and anaemia prevention. Overall, these results suggest that BPP is a natural, mineral-rich ingredient—particularly high in potassium—with additional contributions from calcium and iron, making it a valuable, sustainable option for functional food development and dietary mineral fortification. The findings resonates with the study of Singh *et al.* (2023) [7], who demonstrated that incorporation of unripe banana peel powder into dark chocolates at 5-10% levels enhanced the mineral content. A comparable trend was reported by Kaushik *et al*. (2019) [4], where fortification of soup mixes with Sinensis mycelia powder significantly improved the ash (mineral content) demonstrating soups as a versatile carriers for nutrient enrichment.

Conclusion

The present study successfully standardized the processing of banana peel into Banana Peel Powder (BPP) by optimizing pre-treatments such as blanching, citric acid + salt combination, and salt immersion. Among the treatments, blanching for 2 minutes proved most effective in preserving the overall visual quality of peels, enabling the production of a stable and nutritionally rich powder.

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