

DEVELOPMENT AND NUTRITIONAL EVALUATION OF FOOD PRODUCTS INCORPORATING BANANA PSEUDOSTEM POWDER: A SUSTAINABLE APPROACH TO DIETARY FIBRE FORTIFICATION

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Abstract

Banana pseudostem, an abundant agricultural byproduct generated during fruit harvest, represents a significant source of dietary fibre and minerals that is traditionally discarded as waste. This research investigated the potential of dried banana pseudostem powder as a functional ingredient for nutritional enhancement of conventional food products. The study aimed to develop and comprehensively evaluate food products (biscuits, crisps, and sweets) incorporating banana pseudostem powder at varying substitution levels (10%, 20%, and 30%) and to assess their nutritional composition, physicochemical properties, sensory acceptability, and storage stability. In the study, the banana pseudostem powder was prepared through systematic drying and grinding procedures. A comprehensive nutritional and physicochemical characterization were conducted by standard AOAC methods. Nine food products were developed at three substitution levels alongside control formulations. Products were evaluated for nutritional composition, sensory attributes using a 9-point hedonic scale with 30 trained panelists, and shelf-life stability was evaluated over 28 days under ambient storage conditions. The results indicated that banana pseudostem powder demonstrated exceptional nutritional properties with 39.0 g/100g crude fibre (13-20 fold higher than wheat flour), 1200 mg/100g potassium (9-fold higher), and 250 mg/100g calcium (12-17 fold higher). Water absorption capacity was 4.50 ± 0.12 g/g. Substitution resulted in systematic increases in dietary fibre content across all products, with biscuits showing fibre increases from 2.5 g/100g (control) to 11.0 g/100g (30% substitution), representing a 340% enhancement. Sensory evaluation revealed that 10% substitution maintained high acceptability (overall scores 7.6-7.9), while 20% substitution approached threshold acceptability (scores 6.8-7.1). The 30% substitution level provided maximum nutritional benefits but showed marginal consumer acceptance (scores 5.9-6.1). Shelf-life studies demonstrated adequate stability at lower substitution levels with appropriate packaging. The study concluded that banana pseudostem powder represents a viable functional ingredient for developing fibre-enriched food products that address dietary fibre inadequacy while promoting agricultural waste valorization. The 10% substitution level is optimal for commercial applications, balancing substantial nutritional enhancement (125-250% fibre increase) with high consumer acceptability and adequate shelf stability. This research provides evidence-based guidance for food manufacturers seeking sustainable ingredients for nutritional fortification.

Keywords: Banana pseudostem; dietary fibre; functional foods; agricultural waste valorization; food fortification; sensory evaluation

Introduction

The global imperative for sustainable food systems has intensified focus on agricultural waste valorization as a strategy for simultaneously addressing environmental concerns and nutritional deficiencies. Dietary fibre inadequacy represents a widespread public health challenge, with average intake levels falling substantially below recommended values of 25-30 g per day in most populations (Anderson *et al.*, 2009). This deficiency contributes to increased prevalence of chronic diseases including cardiovascular disorders, type 2 diabetes, obesity, and colorectal cancer (Dhingra *et al.*, 2012). Concurrently, agricultural systems generate substantial quantities of byproducts that are underutilized despite containing valuable nutrients and bioactive compounds (Pathak *et al.*, 2017).

Banana (*Musa spp.*) cultivation ranks among the world's most important fruit crops, with global production exceeding 100 million tons annually (FAO, 2020). The banana plant exhibits a unique growth characteristic wherein the pseudostem, which supports fruit development, is traditionally discarded after a single harvest cycle. This agricultural practice generates approximately 60-70 million tons of banana pseudostem waste annually worldwide (Mohapatra *et al.*, 2010). The pseudostem, despite its fibrous nature and substantial biomass, receives limited attention for value-added applications, with the majority left to decompose in fields or used minimally as animal feed or organic compost (Padam *et al.*, 2014).

Recent research has begun to elucidate the nutritional potential of banana pseudostem, revealing composition that justifies its consideration as a functional food ingredient. Studies have documented substantial dietary fibre content ranging from 35-45% on a dry weight basis, predominantly comprising insoluble fibre fractions of cellulose, hemicellulose, and lignin (Anhwange *et al.*, 2009; Mohapatra *et al.*, 2010). The pseudostem also demonstrates notable mineral content, particularly potassium, which accumulates in plant tissues to support physiological functions during growth (Padam *et al.*, 2014). These compositional characteristics suggest potential applications in developing fibre-enriched food products that could contribute to addressing dietary inadequacies.

The development of food products incorporating agricultural byproducts faces several critical challenges that influence commercial viability. Successful integration requires that added ingredients enhance nutritional value without compromising sensory acceptability, which represents the primary determinant of consumer acceptance (Grunert *et al.*, 2011). High-fibre ingredients frequently introduce textural modifications, colour alterations, and flavour characteristics that may diverge from conventional product expectations, necessitating careful optimization of substitution levels (Elleuch *et al.*, 2011). Additionally, shelf-life stability must be maintained to ensure product safety and quality throughout distribution and storage periods (Labuza and Szybist, 2001).

Despite growing recognition of banana pseudostem's nutritional potential, comprehensive studies systematically evaluating its incorporation into diverse food matrices remain limited. Previous research has primarily focused on compositional characterization or single-product applications, lacking integrated assessment of multiple product categories, substitution levels, and quality parameters. Furthermore, the relationship between substitution level and consumer acceptability has not been thoroughly quantified, limiting practical guidance for food manufacturers. This research addresses these knowledge gaps through systematic development and evaluation of three distinct food product categories (biscuits, crisps, and sweets) incorporating banana pseudostem powder at multiple substitution levels, with comprehensive assessment of nutritional composition, physicochemical properties, sensory acceptability, and storage stability.

2. Materials and Methods

2.1 Materials and Raw Material Preparation

Fresh banana pseudostems were obtained from local agricultural farms immediately following fruit harvest. The outer fibrous sheath was manually removed, and the inner tender core was thoroughly washed with potable water to remove surface debris and soil particles. The cleaned pseudostem was sliced into uniform pieces (approximately 0.5 cm thickness) to facilitate uniform drying. Drying was conducted in a hot air oven (Model: Lab Companion, Korea) at $60 \pm 2^\circ\text{C}$ for 12-14 hours until constant weight was achieved, corresponding to final moisture content below 8%. The dried slices were ground using a laboratory grinder (Model: Mixer Grinder MG3753, Philips, India) and passed through a 60-mesh sieve to obtain fine powder with uniform particle size distribution. The banana pseudostem powder was stored in airtight polyethylene containers at ambient temperature ($25 \pm 2^\circ\text{C}$) until further use.

Commercial refined wheat flour, sugar, butter, milk powder, edible oil, and other ingredients were procured from local markets. All ingredients were food-grade quality and stored according to manufacturers' recommendations.

2.2 Experimental Design

A factorial completely randomized design was employed with two main factors: product type (biscuits, crisps, sweets) and banana pseudostem powder substitution level (0%, 10%, 20%, 30% replacement of wheat flour). This yielded twelve treatment combinations including three control formulations. All experiments were conducted in triplicate, and results were expressed as mean \pm standard deviation.

2.3 Nutritional and Physicochemical Analysis

Moisture content was determined by hot air oven method at 105°C until constant weight (AOAC 925.09). Ash content was measured by muffle furnace incineration at 550°C (AOAC 923.03). Protein content was determined using the Kjeldahl method with nitrogen-to-protein conversion factor of 6.25 (AOAC 2001.11). Fat content was analysed using Soxhlet extraction with petroleum ether (AOAC 920.85). Crude fibre was determined following acid-base digestion

(AOAC 962.09). Available carbohydrates were calculated by difference method. Mineral content (potassium, sodium, calcium) was analysed using atomic absorption spectrophotometry (AAS, Model: AA-6300, Shimadzu, Japan) following acid digestion (AOAC 999.10).

Water absorption capacity (WAC) was determined by mixing 1 g sample with 10 mL distilled water, centrifuging at 3000 rpm for 20 minutes, and expressing absorbed water per gram of sample. Oil absorption capacity (OAC) followed similar methodology using refined vegetable oil instead of water (Wang and Kinsella, 1976).

2.4 Product Development

Composite flours were prepared by blending banana pseudostem powder with wheat flour at ratios of 10:90, 20:80, and 30:70 (w/w) along with control formulation (0:100). Biscuits were prepared using standard cream method involving creaming of butter and sugar, followed by addition of composite flour and mixing to form dough. The dough was sheeted, cut into uniform shapes, and baked at 180°C for 15-18 minutes. Crisps were developed by preparing dough from composite flour with water and salt, sheeting to uniform thickness, cutting, and deep frying in refined oil at 180°C until golden brown. Sweets were formulated using milk, sugar, and composite flour, cooked with continuous stirring until desired consistency, and shaped after cooling.

2.5 Sensory Evaluation

Sensory evaluation was conducted using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) by 30 semi-trained panellists selected based on familiarity with evaluated products. Six sensory attributes were assessed: appearance, colour, texture, flavour, taste, and overall acceptability. Products were presented in random order under controlled lighting conditions with palate cleansing between samples using water and unsalted crackers.

2.6 Shelf-Life Evaluation

Selected products were packaged in food-grade polyethylene pouches and stored at ambient conditions ($25 \pm 2^\circ\text{C}$, $65 \pm 5\%$ relative humidity) for 28 days. Quality parameters including moisture content, peroxide value (AOAC 965.33), free fatty acids (AOAC 940.28), and total plate count (APHA 2001) were monitored at 7-day intervals.

2.7 Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SPSS Statistics version 28.0 (IBM Corporation, USA). Mean separation was conducted using Tukey's Honestly Significant Difference (HSD) test at 5% significance level ($p < 0.05$). Results are presented as mean \pm standard deviation.

3. Results and Discussion

3.1 Nutritional Composition of Banana Pseudostem Powder

The comprehensive nutritional characterization of dried banana pseudostem powder revealed an exceptional profile justifying its utilization as a functional food ingredient (Table 1). The moisture content of 7.0 g/100g indicates adequate processing for extended shelf stability, as moisture levels below 10% generally inhibit microbial proliferation and enzymatic degradation (Labuza, 1980). This value aligns with findings of Padam et al. (2014), who reported moisture contents of 6.8-8.2% in banana pseudostem flour prepared through similar drying methodologies.

The most nutritionally significant component was crude fibre content of 39.0 g/100g, representing approximately 13-20 times higher fibre concentration than refined wheat flour (2-3 g/100g) and 3-4 times higher than whole wheat flour (10-12 g/100g) (Shewry and Hey, 2015). This exceptional fibre content positions banana pseudostem powder among the most concentrated dietary fibre sources available for food fortification applications. The fibre comprises predominantly insoluble fractions of cellulose, hemicellulose, and lignin that provide structural integrity to plant tissues (Mohapatra et al., 2010). These insoluble fibre components contribute to faecal bulking, accelerated intestinal transit, and potential reduction in colorectal cancer risk through dilution of luminal carcinogens and bile acids (Dhingra et al., 2012).

Table 1. Nutritional composition of dried banana pseudostem powder

Parameter	Value	Unit
Moisture content	7.0	g/100g
Ash content	8.0	g/100g
Protein content	6.0	g/100g
Fat content	1.5	g/100g
Available carbohydrates	37.5	g/100g
Crude fibre	39.0	g/100g
Energy value	265.5	kcal/100g
Potassium	1200	mg/100g
Sodium	20	mg/100g
Calcium	250	mg/100g

The potassium content of 1200 mg/100g represents a remarkable concentration approximately 9-fold higher than refined wheat flour (107-130 mg/100g) and 3.3-fold higher than whole wheat flour (340-363 mg/100g) (USDA, 2019).

Potassium serves critical physiological functions including regulation of fluid balance, muscle contractions, nerve signal transmission, and blood pressure modulation through its antagonistic relationship with sodium (Institute of Medicine, 2005). Contemporary diets frequently exhibit inadequate potassium intake coupled with excessive sodium consumption, contributing to hypertension prevalence (Perez and Chang, 2014). The sodium content of 20 mg/100g is remarkably low, creating an exceptionally favourable sodium-to-potassium ratio of approximately 1:60, far superior to typical Western diet ratios of 2:1.

Calcium content of 250 mg/100g provides substantial contribution to this essential mineral, representing 12-17 times higher concentration than refined wheat flour (15-20 mg/100g). This calcium level is comparable to many dairy products and holds particular significance for populations with limited dairy access or lactose intolerance (Weaver *et al.*, 2016). The ash content of 8.0 g/100g, reflecting total mineral content, demonstrates 11–14-fold elevation compared to refined wheat flour (0.5-0.7 g/100g), indicating comprehensive mineral enrichment beyond individually measured elements.

3.2 Physicochemical Properties

The water absorption capacity (WAC) of 4.50 ± 0.12 g water/g powder and oil absorption capacity (OAC) of 1.20 ± 0.08 g oil/g powder (Table 2) reflect the functional properties influencing processing behaviour and final product characteristics. The elevated WAC derives from hydroxyl groups present in fibre components, particularly cellulose and hemicellulose, which form hydrogen bonds with water molecules (Raghavendra *et al.*, 2006). This high water binding capacity affects dough consistency, requiring formulation adjustments in product development to maintain appropriate handling characteristics. The moderate OAC indicates potential for fat binding in food systems, contributing to emulsion stability and textural properties in fried products.

Table 2. Physicochemical properties of banana pseudostem powder

Property	Value	Unit
Water Absorption Capacity (WAC)	4.50 ± 0.12	g water/g powder
Oil Absorption Capacity (OAC)	1.20 ± 0.08	g oil/g powder

3.3 Nutritional Composition of Developed Products

The incorporation of banana pseudostem powder at varying substitution levels resulted in systematic modifications to the nutritional profile of all developed products. For biscuits (Table 3), crude fibre content increased progressively from 2.5 g/100g in the control formulation to 5.0, 7.5, and 11.0 g/100g at 10%, 20%, and 30% substitution levels, respectively. This represents fibre enrichment of 100%, 200%, and 340% relative to control, demonstrating substantial nutritional enhancement even at the lowest substitution level. The 10% substitution would contribute approximately 12.5% of the recommended daily fibre intake per 25g serving, while 30% substitution would provide 27.5% of daily requirements.

Table 3. Nutritional composition of biscuits with varying levels of banana pseudostem powder substitution

Parameter (g/100g)	Control (0%)	10% Substitution	20% Substitution	30% Substitution
Moisture	3.0	3.5	4.0	4.5
Protein	7.5	7.0	6.8	6.5
Fat	20.0	19.8	19.5	19.2
Available carbohydrates	65.0	62.2	59.7	56.3
Crude fibre	2.5	5.0	7.5	11.0
Ash	2.0	2.5	2.5	2.5
Energy (kcal/100g)	475	465	455	440

Available carbohydrate content decreased from 65.0 g/100g in control to 56.3 g/100g at 30% substitution, reflecting the replacement of starch-rich wheat flour with fibre-rich pseudostem powder. This reduction in available carbohydrates, coupled with increased fibre content, suggests potential for improved glycaemic response, as dietary fibre slows carbohydrate digestion and glucose absorption (Jenkins *et al.*, 2008). Energy density decreased from 475 kcal/100g to 440 kcal/100g at 30% substitution, representing a 7.4% reduction. This energy reduction derives from the lower caloric value of fibre (approximately 2 kcal/g) compared to digestible carbohydrates (4 kcal/g), supporting development of reduced-calorie bakery products without complete reformulation.

3.4 Sensory Evaluation

Sensory evaluation represents a critical determinant of product success, as nutritional superiority alone cannot ensure market acceptance if products fail to meet consumer expectations (Grunert *et al.*, 2011). Results for biscuits (Table 4)

revealed that overall acceptability scores decreased progressively with increasing substitution levels, from 8.3 ± 0.5 in control to 7.8 ± 0.6 , 7.0 ± 0.8 , and 6.0 ± 1.0 at 10%, 20%, and 30% substitution, respectively.

Table 4. Sensory evaluation of biscuits (9-point hedonic scale)

Attribute	Control (0%)	10%	20%	30%
Appearance	8.3 ± 0.6	7.9 ± 0.7	7.2 ± 0.9	6.4 ± 1.1
Colour	8.2 ± 0.5	7.8 ± 0.6	7.1 ± 0.8	6.3 ± 1.0
Texture	8.4 ± 0.5	7.9 ± 0.7	7.0 ± 0.9	6.1 ± 1.1
Flavour	8.3 ± 0.6	7.7 ± 0.7	6.9 ± 0.9	5.8 ± 1.2
Taste	8.4 ± 0.5	7.8 ± 0.6	7.0 ± 0.8	6.0 ± 1.1
Overall acceptability	8.3 ± 0.5	7.8 ± 0.6	7.0 ± 0.8	6.0 ± 1.0

The 10% substitution formulation maintained ratings in the 'like moderately to like very much' range (7-8 on the 9-point scale), indicating that moderate incorporation of banana pseudostem powder did not significantly compromise consumer acceptance. These scores suggest commercial viability for the 10% formulation. The 20% substitution approached the threshold between 'like moderately' and 'like slightly' (scores around 7.0), representing the upper limit for broad consumer acceptance. The 30% substitution, while providing maximum nutritional benefits, scored in the 'like slightly' to 'neither like nor dislike' range (5-6), indicating marginal acceptability that would likely limit market penetration. Texture scores declined more substantially than other attributes at higher substitution levels, reflecting the impact of dietary fibre on crumb structure and mouthfeel. High fibre content disrupts gluten network formation during mixing and baking, resulting in modified textural characteristics compared to conventional products (Sudha *et al.*, 2007). The appearance and colour modifications at higher substitution levels stem from the darker colour of banana pseudostem powder compared to refined wheat flour, though these changes were less objectionable to panellists than textural alterations.

3.5 Shelf-Life Evaluation

Storage stability assessment over 28 days revealed that moisture content increased in all formulations due to hygroscopic nature of dietary fibre, which absorbs ambient moisture (Table 5). The moisture uptake rate was directly proportional to fibre content, with 30% substitution showing highest moisture gain. However, all formulations maintained moisture levels below critical thresholds for microbial growth (<15%) throughout the storage period when packaged in appropriate materials.

Table 5. Changes in moisture content during storage (28 days) for biscuits

Storage Day	Control (%)	10% (%)	20% (%)	30% (%)
Day 0	3.0	3.5	4.0	4.5
Day 7	3.5	4.2	4.8	5.5
Day 14	4.0	4.8	5.5	6.2
Day 21	4.3	5.3	6.0	6.8
Day 28	4.6	5.7	6.5	7.3

Peroxide values and free fatty acid content remained within acceptable limits for all formulations throughout the 28-day period, indicating adequate oxidative stability. Total plate counts remained below 4 log CFU/g for all products, demonstrating microbiological safety under ambient storage conditions. These shelf-life findings suggest that banana pseudostem powder incorporation at 10-20% substitution levels does not significantly compromise product stability when appropriate packaging is employed.

4. Conclusion

This research successfully demonstrates that banana pseudostem powder represents a highly valuable functional ingredient for developing nutritionally enhanced food products that address contemporary public health challenges related to inadequate dietary fibre and micronutrient intake. The exceptional nutritional profile featuring 39.0 g dietary fibre per 100 g, 1200 mg potassium per 100 g, and 250 mg calcium per 100 g positions this agricultural byproduct as a nutritionally superior alternative to conventional wheat flour for specific fortification applications.

The systematic evaluation of three food product categories at multiple substitution levels provides comprehensive insights into the relationship between fortification level, nutritional enhancement, and consumer acceptability. Results establish that 10% substitution represents the optimal balance for commercial applications, achieving substantial nutritional enhancement (125-250% fibre increase depending on product type) while maintaining high consumer acceptability (overall scores 7.6-7.9). This substitution level requires minimal formulation adjustments and maintains adequate shelf stability with standard packaging.

The 20% substitution level provides enhanced nutritional benefits (250-500% fibre increase) but approaches the threshold of consumer acceptance, making it suitable for health-focused market segments or products specifically marketed for their nutritional attributes. The 30% substitution level, while maximizing nutritional enhancement (400-900% fibre increase), presents sensory acceptability challenges that would require additional formulation optimization or market positioning targeting specialized dietary applications.

From a sustainability perspective, this research demonstrates viable pathways for agricultural waste valorization, potentially diverting millions of tons of banana pseudostem from disposal to productive use in the food industry. The transformation of agricultural waste into functional food ingredients exemplifies circular economy principles, creating economic value while addressing environmental concerns. The research provides evidence-based guidance for food manufacturers, nutritionists, and policymakers seeking sustainable approaches to improve population nutrition through accessible, affordable, fibre-enriched food products.

Future research directions should include comprehensive bioavailability studies to assess the physiological impact of fibre and mineral components, extended shelf-life evaluations under various storage conditions, consumer acceptance testing with diverse demographic groups, and techno-economic assessments of commercial-scale production. Additionally, investigation of processing modifications to enhance sensory acceptability at higher substitution levels and exploration of synergistic combinations with other functional ingredients would further advance the practical application of banana pseudostem powder in food product development.

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