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Utilization of Banana Peel Flour as a Sustainable Fiber Source in Biscuit Production: Physicochemical, Functional, and Sensory Evaluation

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Abstract

The increasing generation of agro-industrial waste has raised environmental concerns and encouraged the development of sustainable food processing strategies. Banana peel, which accounts for approximately 30–40% of total fruit weight, is often discarded despite being rich in dietary fiber, phenolic compounds, minerals, and antioxidant substances. This study evaluated the utilization of banana peel flour (BPF) as a sustainable fiber source in biscuit production and investigated its effects on physicochemical properties, functional characteristics, antioxidant activity, shelf-life stability, and sensory acceptance. Biscuits were prepared by replacing wheat flour with BPF at 0%, 5%, 10%, and 15% substitution levels.
Results demonstrated that increasing BPF levels significantly enhanced dietary fiber content, antioxidant activity, and water absorption capacity ($p < 0.05$). Biscuits containing 15% BPF exhibited the highest total dietary fiber content (12.84%) and antioxidant activity (72.6% DPPH inhibition). However, excessive substitution negatively affected color and texture acceptance. Sensory evaluation revealed that biscuits containing 10% BPF achieved the highest overall acceptability score, demonstrating that banana peel flour can be successfully incorporated into biscuits as a functional ingredient while supporting circular economy principles and reducing food waste.

Keywords: Banana peel flour, food waste valorization, dietary fiber, antioxidant activity, functional biscuits, circular economy

1. Introduction

Food waste has become one of the most pressing global sustainability challenges, with approximately one-third of food produced worldwide lost or wasted throughout the food supply chain [1].

Among various fruit processing residues, banana peel represents one of the most abundant agricultural by-products generated globally, accounting for approximately 30–40% of total fruit weight and generally discarded as waste despite its significant nutritional and functional value [2].

Recent studies have demonstrated that banana peels contain considerable amounts of dietary fiber, resistant starch, phenolic compounds, flavonoids, carotenoids, and essential minerals, making them attractive candidates for functional food development [3, 4].

Therefore, the objectives of this study were to evaluate the effects of banana peel flour incorporation on the physicochemical, functional, antioxidant, shelf-life, and sensory characteristics of biscuits and to determine the optimal substitution level that maximizes nutritional benefits while maintaining acceptable product quality.

2. Literature Review

2.1. Nutritional and Functional Properties of Banana Peel

Banana peel contains cellulose, hemicellulose, lignin, pectin, and resistant starch at concentrations substantially higher than those found in banana pulp, along with bioactive compounds such as gallic acid, catechins, ferulic acid, and flavonoids [3, 11].

2.2. Dietary Fiber Fortification in Bakery Products

Fiber-enriched bakery products have been associated with improved digestive health, glycemic regulation, and satiety, though excessive fiber incorporation may alter dough characteristics, texture, and sensory acceptance [5, 9].

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2.3. Circular Economy and Food Waste Valorization

Circular economy principles emphasize resource efficiency and waste minimization through the upcycling of agricultural by-products into value-added food ingredients, reducing environmental burdens while creating new economic opportunities [6, 15].

3. Methodology

3.1. Experimental Design

A Completely Randomized Design (CRD) was employed with four treatments: B0 (0%), B1 (5%), B2 (10%), and B3 (15%) banana peel flour substitution. Each treatment was conducted in triplicate.

3.2. Preparation of Banana Peel Flour

Ripe Cavendish banana peels were collected from local markets in West Sumatra, Indonesia, washed, cut into small pieces, blanched at 90°C for 2 minutes, dried at 60°C for 24 hours, ground, and sieved through a 60-mesh screen.

3.3. Biscuit Formulation

Biscuits were prepared by substituting wheat flour with BPF at the designated levels, combined with sugar, margarine, egg, and baking powder. The dough was mixed, molded, and baked at 180°C for 15 minutes.

3.4. Analytical Parameters

Physicochemical analysis included moisture, ash, protein, fat, carbohydrate, and total dietary fiber, determined according to AOAC methods [7]. Functional properties evaluated included water absorption capacity (WAC). Antioxidant analysis included total phenolic content (TPC) and DPPH radical scavenging activity. Shelf-life analysis was conducted over 90 days, evaluating peroxide value. Sensory evaluation was conducted by 30 semi-trained panelists using a 9-point hedonic scale.

4. Results and Discussion

4.1. Proximate Composition and Dietary Fiber

Dietary fiber increased significantly with increasing BPF substitution ($p < 0.05$), rising from 2.31% in the control to 12.84% in biscuits containing 15% BPF.

Table 1. Nutritional composition of biscuits (%).

Parameter	B0	B1	B2	B3
Moisture	3.42	3.56	3.74	3.88
Protein	8.52	8.61	8.74	8.86
Ash	1.24	1.68	2.15	2.84
Dietary Fiber	2.31	6.24	9.83	12.84
Carbohydrate	66.06	61.53	57.23	53.33

Source: Proximate analysis of biscuit samples.

4.2. Water Absorption, Antioxidant Activity, and Texture

The high fiber content of BPF significantly enhanced water absorption properties, and antioxidant activity increased proportionally with BPF incorporation. Higher fiber content also contributed to increased biscuit hardness.

Table 2. Functional and bioactive properties of biscuit samples.

Treatment	WAC (g/g)	TPC (mg GAE/100g)	DPPH (%)	Hardness (N)
B0	1.42	28.5	18.7	24.5
B1	1.76	62.4	41.6	26.8
B2	2.08	94.8	59.3	29.2
B3	2.37	121.7	72.6	33.7

Source: Functional property, antioxidant, and texture analysis of biscuit samples.

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4.3. Shelf-Life Stability

BPF-enriched biscuits exhibited improved oxidative stability due to their natural antioxidant content, with peroxide values increasing more slowly in fortified biscuits compared with the control over 90 days of storage.

Table 3. Peroxide value during storage (meq O2/kg).

Treatment	Day 0	Day 90
B0	1.4	8.8
B1	1.3	6.9
B2	1.3	5.4
B3	1.2	4.8

Source: Oxidative stability analysis of biscuit samples during storage.

4.4. Sensory Evaluation

The 10% substitution level (B2) achieved the highest overall acceptability score, indicating an optimal compromise between nutritional functionality and palatability.

Table 4. Sensory scores of biscuit samples on a nine-point hedonic scale.

Attribute	B0	B1	B2	B3
Color	7.8	8.1	8.3	7.2
Aroma	7.5	8.0	8.4	7.8
Texture	7.6	8.2	8.5	7.4
Taste	7.7	8.3	8.6	7.1
Overall Acceptability	7.7	8.2	8.7	7.3

Values represent mean scores from 30 semi-trained panelists.

5. Conclusion

The incorporation of banana peel flour significantly improved the nutritional, functional, and antioxidant properties of biscuits. Dietary fiber content, total phenolic content, antioxidant activity, water absorption capacity, and oxidative stability increased progressively with increasing levels of banana peel flour. Biscuits containing 10% banana peel flour achieved the highest overall sensory acceptability while providing substantial nutritional and functional improvements, representing a sustainable and economically viable strategy for functional biscuit production and food waste valorization.

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