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Banana Blossom Powder as a Partial Wheat Flour Replacer in Cookies: Effects on Proximate Composition, Functional Properties and Sensory Acceptability

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Abstract

Purpose

To evaluate banana blossom powder (BBP), an underutilised banana by-product, as a partial wheat flour replacer in cookies and to identify a substitution level that balances nutritional enhancement with sensory acceptability.

Methods

Banana blossoms were blanched, treated with a vinegar–salt solution, oven-dried at 60°C and milled. Cookies were prepared with 0% (T0, control), 5% (T1) and 10% (T2) BBP and analysed in triplicate for proximate composition, pH, vitamin C, water-holding capacity (WHC) and oil-holding capacity (OHC). Ten semi-trained panellists rated colour, aroma, taste, texture and overall acceptability on a 5-point hedonic scale. Data were analysed by one-way ANOVA with Tukey's post hoc test ($p < 0.05$).

Results

Increasing BBP significantly increased ash (1.20 to 3.60%), crude fibre (1.00 to 5.00%), vitamin C (0 to 0.057 mg/100 g), WHC (2.89 to 3.33 g/g) and OHC (2.90 to 3.28 g/g), and decreased moisture (3.18 to 1.31%), protein (6.72 to 6.32%), crude fat (23.00 to 21.00%), carbohydrate (64.91 to 62.78%) and pH. T1 received the highest mean sensory scores and was statistically comparable to the control, whereas T2 was significantly less accepted for all attributes, mainly because of darker colour from enzymatic browning.

Conclusion

Replacing 5% of wheat flour with BBP improved the mineral and fibre content and functional properties of cookies without reducing acceptability, offering a low-cost route to valorise banana blossom in banana-producing regions such as Rwanda.

1. Introduction

The growing global demand for functional and sustainable food products is pushing food science towards ingredients that are simultaneously nutritionally beneficial, cost-effective, and environmentally responsible [1, 2]. Within this shift, agro-industrial by-products that were formerly regarded as waste are increasingly re-evaluated as circular-economy feedstocks for the food, cosmetic and pharmaceutical sectors; a recent comprehensive review of banana (Musa spp.) by-products confirmed that stems, leaves, peels and inflorescences retain substantial nutritional and bioactive value long after the primary fruit has been harvested [3, 4]. Banana is one of the most widely cultivated fruit crops in tropical and

subtropical regions, and the scale of global production means that even a small underutilised fraction of the plant represents a very large, recurring biomass stream that is presently discarded in most producing countries [5].

Among these residual fractions, the banana blossom (also called the banana heart or male bud) has attracted particular interest as a functional food ingredient because of its favourable nutrient and phytochemical profile. Comprehensive nutritional surveys of banana inflorescence report high concentrations of dietary fibre, protein, phenolic compounds and essential minerals such as potassium, calcium, magnesium and iron, together with appreciable antioxidant capacity [6, 7]. Despite this composition, banana blossom continues to be treated as an agricultural residue or a minor vegetable in most producing regions rather than as a systematically valorised functional ingredient, and it is routinely discarded during commercial banana harvesting and processing [2].

Phytochemical and pharmacological reviews published over the past five years have consistently identified banana blossom as a rich source of flavonoids, tannins, saponins and ascorbic acid, with demonstrated antioxidant, antimicrobial and anti-inflammatory activity in vitro [8, 9]. Extraction-method comparisons have further shown that both conventional and advanced extraction techniques (e.g., ultrasound-assisted and supercritical-fluid extraction) recover substantial phenolic and antioxidant fractions from banana blossom tissue, underscoring the ingredient's potential beyond simple dietary fibre enrichment [10, 11]. Complementary compositional work on edible banana parts grown under tropical conditions similarly confirms that banana tissues, including the inflorescence, are a meaningful dietary source of vitamins and minerals relative to refined cereal-based staples such as wheat flour [12, 13]. At the same time, the phenolic and polyphenol-oxidase-active fraction responsible for much of this bioactivity is also implicated in the enzymatic browning that darkens banana-blossom-derived ingredients during processing, a trade-off that has practical consequences for the colour and consumer acceptability of finished bakery products incorporating them [8, 9].

Incorporating banana-derived flours and powders into bakery products is a well-established strategy for improving the nutritional adequacy of everyday foods while simultaneously reducing agricultural waste and formulation cost [7, 14, 15]. Because cookies and biscuits are consumed across all age groups owing to their affordability, long shelf life and sensory versatility, they represent a practical vehicle for nutrient fortification with plant-based by-products [14]. Studies substituting banana blossom powder and other banana by-product powders into biscuit formulations report that low-to-moderate inclusion levels are well tolerated sensorially and measurably improve the mineral and nutrient density of the finished product, whereas colour darkens progressively and acceptability declines as the substitution level increases [12, 14]. Parallel work using banana pulp and green banana flour in cookies, muffins and composite bread confirms the same general pattern across product types: fibre, resistant starch, antioxidant activity and mineral content rise with substitution level, while moisture, fat and refined carbohydrate content fall, and sensory acceptability follows an inverted-U relationship that typically peaks at a modest inclusion level before falling away at higher substitution [15, 16]. Agama-Acevedo et al. [15], for example, showed that partially replacing wheat flour with unripe banana flour in cookies

increased dietary fibre and resistant starch and lowered the predicted glycaemic index, while Ayoub et al. [14] identified 10% banana peel powder as the most acceptable substitution level for fibre-enriched biscuits. These converging findings from geographically diverse studies (Mexico, India and Indonesia) suggest that the physicochemical and sensory trade-offs associated with banana-based ingredients are a general phenomenon rather than an artefact of any single cultivar or product matrix, which strengthens the rationale for testing banana blossom powder specifically, rather than banana pulp or peel flour, in a widely consumed bakery product such as cookies.

Despite this expanding evidence base, almost all of the published work on banana-blossom-enriched bakery products originates from South and Southeast Asian producing countries, where banana blossom already has an established culinary role. There is markedly less empirical evidence from East African banana-growing contexts, even though East Africa (including Rwanda) is among the world's leading banana-producing regions and faces the same waste-management and food-security challenges that motivate valorisation research elsewhere [17]. In Rwanda specifically, banana blossom is presently discarded as agricultural waste at the point of harvest, while commercially available bakery products are typically manufactured from refined wheat flour and sugar with limited micronutrient density; converting a locally abundant, currently wasted by-product into a functional flour substitute therefore represents both a waste-reduction and a nutrition-enhancement opportunity with direct relevance to regional food systems and to the wider circular-economy agenda in food science [3, 5].

This study therefore investigated the physicochemical, functional and sensory characteristics of cookies produced by partially substituting wheat flour with banana blossom powder at 0, 5 and 10% levels. The specific objectives were (i) to determine the proximate and physicochemical composition (moisture, ash, protein, crude fat, crude fibre, carbohydrate, pH and vitamin C) of the resulting cookies, (ii) to characterise their functional properties (water- and oil-holding capacity), and (iii) to evaluate their sensory attributes (colour, aroma, taste, texture and overall acceptability), to identify a substitution level that balances nutritional enhancement against consumer acceptability and to provide the first quantitative dataset of this kind for an East African production context.

2. Materials and Methods

2.1 Plant material and reagents

Wheat flour, granulated sugar, baking powder, unsalted butter, eggs, vinegar and milk were purchased from a local market in Musanze, Rwanda. Fresh banana blossoms (Musa spp.) were harvested from a banana farm at Gashangiro, Musanze District, Northern Province. All physicochemical analyses and cookie preparation were carried out at the Food Processing Laboratory of the Institut d'Enseignement Supérieur de Ruhengeri (INES-Ruhengeri), Rwanda.

2.2 Preparation of banana blossom powder

Mature banana blossoms were cleaned, and the outer bracts were removed to expose the edible florets, which were washed thoroughly. The florets were blanched by boiling in water for 5 minutes and then immersed in a solution of vinegar and salt for 20 minutes to reduce bitterness and minimise enzymatic browning. The pretreated florets were spread on stainless-steel trays and dried in a hot-air oven at 60°C for approximately 12 hours, until the moisture content fell below 10%. The dried material was cooled, milled into a fine powder using a laboratory blender, and sieved through a 60-mesh sieve to obtain a uniform particle size. The resulting banana blossom powder (BBP) was packed in airtight containers and stored at ambient temperature until use.

2.3 Cookie formulation and preparation

Cookies were formulated by partially substituting wheat flour with BBP at three levels: 0% (T0, control), 5% (T1) and 10% (T2), based on a flour weight of 500 g (Table 1). Dry ingredients (sugar, baking powder, salt) were mixed thoroughly with the flour blend. Butter and sugar were creamed until light and fluffy, one egg was beaten in, and the flour blend was folded in, with milk added gradually to obtain a soft, workable dough. The dough was sheeted to a uniform thickness of approximately 5 mm, cut into circular shapes, and baked at 180°C for 15–20 minutes. Baked cookies were cooled to room temperature and stored in airtight containers prior to analysis.

2.4 Physicochemical analyses

All analyses were performed in triplicate on the cooled, milled cookie samples using standard AOAC methods [18], unless otherwise stated.

2.4.1 Moisture content

Moisture content was determined by the oven-drying method: 5 g of sample was dried at 105°C for 2 hours, cooled in a desiccator, and reweighed; moisture (%) was calculated from the weight loss on drying.

2.4.2 Ash content

Ash content was determined by incinerating 5 g of sample in a muffle furnace at 550°C until a constant, organic-matter-free residue was obtained, which was cooled and weighed.

2.4.3 Crude fat

Crude fat was determined by Soxhlet extraction of 5 g of dried, ground sample using petroleum ether (boiling point 40–60°C) for 6–8 hours; the extracted fat was recovered by solvent evaporation, dried at 105°C, and weighed [18].

2.4.4 Crude fibre

Crude fibre was determined by sequential acid–alkali digestion of a 5 g sample with dilute sulfuric acid followed by dilute sodium hydroxide; the indigestible residue was filtered, washed, incinerated, and the

weight loss on ashing was taken as the crude fibre content.

2.4.5 Crude protein

Crude protein was determined by the Kjeldahl method: 1 g of sample was digested with concentrated sulfuric acid in the presence of a catalyst, the liberated ammonia was distilled into boric acid and titrated with standard acid, and the nitrogen content obtained was multiplied by a conversion factor of 6.25 [18].

2.4.6 Carbohydrate content

Carbohydrate content was estimated by difference, subtracting the percentages of moisture, ash, crude fat, crude protein and crude fibre from 100% [18].

2.4.7 pH

For pH determination, 10 g of finely ground cookie sample was mixed with 100 mL distilled water (1:10, w/v), stirred, allowed to stand for 30 minutes, filtered, and the pH of the filtrate was measured with a calibrated digital pH meter [18].

2.4.8 Vitamin C

Vitamin C (ascorbic acid) content was determined titrimetrically using 2,6-dichlorophenolindophenol (DCPIP): 10 g of sample was homogenised with 50 mL of 3% metaphosphoric acid, filtered, and an aliquot of the extract was titrated against standardised DCPIP solution to a persistent light-pink endpoint [18].

2.5 Water- and oil-holding capacity

Water-holding capacity (WHC) and oil-holding capacity (OHC) were determined by a centrifugation method based on AACC International procedures [19]. Briefly, 1 g of sample was mixed with 5 mL of distilled water or vegetable oil, vortexed for 10 seconds, left to stand for 30 minutes at room temperature (25 ± 2°C), and centrifuged at 500 g for 10 minutes. WHC and OHC were expressed as grams of water or oil absorbed per gram of sample, calculated from the weight of the sediment relative to the initial sample weight, and reported as the mean of three replicates.

2.6 Sensory evaluation

Sensory evaluation was carried out by a panel of ten semi-trained student panellists (male and female) from the Department of Food Biotechnology at INES-Ruhengeri. Coded cookie samples (three-digit random codes) were presented to panellists in random order in a clean, well-lit, well-ventilated room. Panellists rinsed their mouths with water between samples and independently rated colour, aroma, taste, texture and overall acceptability on a 5-point hedonic scale (1 = dislike very much to 5 = like very much), following standard hedonic testing procedures [20].

2.7 Statistical analysis

All physicochemical determinations were carried out in triplicate, and sensory scores were obtained from ten independent panellists. Data were analysed by one-way analysis of variance (ANOVA) using SPSS software, with treatment (BBP substitution level) as the independent factor. Where ANOVA indicated a significant treatment effect, means were separated using Tukey's honestly significant difference (HSD) post hoc test, and differences were considered statistically significant at $p < 0.05$. Reported values are means ± standard deviation, which provide a measure of the precision of the triplicate physicochemical determinations; formal measurement-uncertainty budgets and inter-laboratory validation were beyond the scope of this study and are noted as a limitation in Section 3.4.

Table 1
Formulation of cookies enriched with banana blossom powder (BBP) at 0, 5 and 10% substitution levels

Ingredient	T0 (0%) (g)	T1 (5%) (g)	T2 (10%) (g)
Wheat flour	500	475	450
Banana blossom powder	0	25	50
Sugar	50	50	50
Baking powder	2	2	2
Salt	1	1	1
Butter (unsalted)	40	40	40
Egg	1 whole	1 whole	1 whole
Milk (mL)	15	15	15

T0 = control (100% wheat flour); T1 and T2 = wheat flour substituted with banana blossom powder at 5% and 10%, respectively. All quantities are in grams unless otherwise stated.

3. Results and Discussion

One-way ANOVA showed that BBP substitution had a statistically significant effect ($p < 0.05$) on every physicochemical, functional, and sensory parameter measured, ranging from a comparatively modest effect on crude fat ($p = 0.005$) to very strong effects on ash, fibre, and vitamin C content ($p < 0.001$ in each case) (Table 2).

3.1 Proximate and physicochemical composition

Table 2
Physicochemical composition of cookies enriched with banana blossom powder (mean ± SD, n = 3)

Parameter	T0 (0%)	T1 (5%)	T2 (10%)
Moisture (%)	3.18 ± 0.07	1.75 ± 0.04	1.31 ± 0.04
Ash (%)	1.20 ± 0.02	2.40 ± 0.02	3.60 ± 0.03
Protein (%)	6.72 ± 0.04	6.52 ± 0.04	6.32 ± 0.04
Crude fibre (%)	1.00 ± 0.02	3.00 ± 0.05	5.00 ± 0.10
Crude fat (%)	23.00 ± 0.15	22.00 ± 0.17	21.00 ± 0.09
Carbohydrate (%)	64.91 ± 0.11	64.33 ± 0.11	62.78 ± 0.11
pH	6.78 ± 0.06	6.52 ± 0.02	6.39 ± 0.03
Vitamin C (mg/100 g)	0.000 ± 0.000	0.028 ± 0.001	0.057 ± 0.001
WHC (g/g)	2.89 ± 0.03	3.06 ± 0.03	3.33 ± 0.03
OHC (g/g)	2.90 ± 0.03	3.04 ± 0.03	3.28 ± 0.03

Values are means ± SD of triplicate determinations. Within a row, means bearing different superscript letters (a, b, c) differ significantly according to Tukey's HSD test ($p < 0.05$). T0 = control (100% wheat flour); T1 and T2 = cookies substituted with banana blossom powder at 5% and 10%, respectively.

Moisture content decreased significantly and progressively with increasing BBP level, from 3.18 ± 0.07% in the control (T0) to 1.75 ± 0.04% in T1 and 1.31 ± 0.04% in T2 ($p < 0.001$; Table 2, Fig. 1). This decline most likely reflects a simple dilution effect, since the dried BBP itself carries substantially less residual moisture than wheat flour, together with the strong water-binding capacity of its fibre fraction, which reduces the amount of free water available for evaporation during mixing and promotes its loss during baking [21, 22]. From a shelf-life perspective, the significantly lower moisture content of the enriched cookies is a favourable outcome, since it reduces water activity and the risk of microbial spoilage relative to the all-wheat control, a pattern also reported for banana-blossom-enriched biscuits [12].

Ash content increased significantly and near-linearly with substitution level, from 1.20 ± 0.02% (T0) to 2.40 ± 0.02% (T1) and 3.60 ± 0.03% (T2) ($p < 0.001$), representing the largest relative treatment effect observed among the proximate parameters (Table 2, Fig. 1). This trend is consistent with the dense mineral content of banana blossom, which is a reported source of potassium, magnesium, calcium and iron [6, 23] and confirms that BBP incorporation shifts the cookie matrix from a mineral-lean, refined-wheat base towards a more mineral-dense functional product, in line with the ash gains reported for banana-flour composite breads and cookies of comparable substitution range [15, 16].

Protein content declined significantly with increasing substitution, from 6.72 ± 0.04% (T0) to 6.52 ± 0.04% (T1) and 6.32 ± 0.04% (T2) ($F(2,6) = 92.3$, $p < 0.001$; Table 2). This reduction reflects the comparatively

low protein content of banana blossom tissue relative to the gluten-forming proteins naturally present in wheat flour, which are diluted as substitution increases [8, 12]. Although statistically significant, the absolute decline was modest (0.40 percentage points at the highest substitution level) and is unlikely to substantially compromise the protein contribution of the cookies within the overall diet; comparable modest protein dilution has been reported for other banana-based composite bakery products [15, 16].

Crude fibre increased significantly and markedly with substitution level, from 1.00 ± 0.02% (T0) to 3.00 ± 0.05% (T1) and 5.00 ± 0.10% (T2) ($p < 0.001$; Table 2, Fig. 1), a fivefold increase at the highest inclusion level. This enrichment reflects the abundance of non-starch polysaccharides, cellulose and lignin in banana blossom tissue [8, 24], and is large enough that the 10% formulation could potentially qualify as a source of dietary fibre under standard food-labelling thresholds, subject to applicable regulations. Higher dietary fibre intake is generally associated with metabolic benefits including improved glycaemic response and gut motility, an outcome consistently highlighted in recent banana-by-product valorisation literature [3, 6].

Crude fat decreased significantly with increasing substitution, from 23.00 ± 0.15% (T0) to 22.00 ± 0.17% (T1) and 21.00 ± 0.09% (T2) ($p = 0.005$), the weakest, though still significant, treatment effect recorded among the physicochemical parameters (Table 2, Fig. 1). This decline is consistent with a dilution effect, as banana blossom contributes negligible lipid content and displaces a proportional share of the fat naturally present in wheat flour and butter-based dough. A lower fat content may be viewed favourably from a health perspective, although it can also influence tenderness and mouthfeel.

Carbohydrate content, estimated by difference, decreased significantly with substitution level, from 64.91 ± 0.11% (T0) to 64.33 ± 0.11% (T1) and 62.78 ± 0.11% (T2) ($p < 0.001$; Table 2, Fig. 1). Because carbohydrate was calculated as the residual fraction, this decline is mathematically linked to the significant increases recorded for fibre and ash, reflecting partial replacement of readily digestible wheat starch with the comparatively indigestible fibre and mineral fractions supplied by BBP [25, 26].

pH decreased significantly with increasing BBP level, from 6.78 ± 0.06 (T0) to 6.52 ± 0.02 (T1) and 6.39 ± 0.03 (T2) ($p < 0.001$; Table 2), consistent with the mildly acidic character of banana blossom tissue and the residual effect of the vinegar-salt pretreatment used to limit enzymatic browning during powder preparation. Vitamin C, absent in the control, rose significantly and dose-dependently with substitution, from 0.000 mg/100 g (T0) to 0.028 mg/100 g (T1) and 0.057 mg/100 g (T2) ($p < 0.001$; Table 2). Although the absolute concentrations are small relative to fresh fruit, this represents a measurable, statistically robust nutritional gain attributable entirely to BBP incorporation, consistent with reports that banana blossom retains appreciable ascorbic acid even after blanching and oven-drying [27].

3.2 Functional properties: water- and oil-holding capacity

Water-holding capacity (WHC) increased significantly with substitution level, from 2.89 ± 0.03 g/g (T0) to 3.06 ± 0.03 g/g (T1) and 3.33 ± 0.03 g/g (T2) ($p < 0.001$; Table 2), paralleling the significant increase in fibre content. This is consistent with the porous, capillary structure of plant fibre, which exposes hydroxyl

groups capable of hydrogen-bonding with water and trapping it within the food matrix. A higher WHC generally improves dough handling and yields a moister final product, although very high fibre levels may reduce spread and crispness, a trade-off also noted in banana-flour cookie formulations [15, 16].

Oil-holding capacity (OHC) also increased significantly with substitution level, from 2.90 ± 0.03 g/g (T0) to 3.04 ± 0.03 g/g (T1) and 3.28 ± 0.03 g/g (T2) ($p < 0.001$; Table 2), mirroring the trend observed for WHC and pointing to the same underlying driver: the higher fibre content of BBP. This increase is likely also driven by hydrophobic protein fractions and structural components in the blossom powder that help trap fat droplets during mixing, which can limit oil separation ("weeping") during storage and contribute to an improved mouthfeel [24, 28]. Taken together, the concurrent rise in WHC and OHC indicates that BBP behaves functionally as a bifunctional hydrocolloid-fibre ingredient rather than simply as an inert diluent, which is relevant to cookie dough rheology and for the moisture-retention behaviour of the baked product during storage.

3.3 Sensory evaluation

Table 3
Sensory scores of cookies enriched with banana blossom powder (mean ± SD, 5-point hedonic scale, n = 10 panellists)

Attribute	T0 (0%)	T1 (5%)	T2 (10%)	p-value
Colour	4.50 ± 0.53	5.00 ± 0.00	2.90 ± 0.74	< 0.0001
Aroma	4.20 ± 0.63	4.50 ± 0.53	3.30 ± 0.67	< 0.0005
Taste	4.30 ± 0.67	4.50 ± 0.53	3.10 ± 0.74	< 0.0001
Texture	4.30 ± 0.67	4.50 ± 0.53	3.30 ± 0.67	< 0.0004
Overall acceptability	4.30 ± 0.48	4.50 ± 0.53	2.70 ± 0.67	< 0.0001

Values are means ± SD (n = 10 panellists). Scores were recorded on a 5-point hedonic scale (1 = dislike very much; 5 = like very much). p-values were obtained by one-way ANOVA. T0 = control (100% wheat flour); T1 and T2 = cookies substituted with banana blossom powder at 5% and 10%, respectively.

All five sensory attributes differed significantly among treatments (colour: $p < 0.0001$; aroma: $p < 0.0005$; taste: $p < 0.0001$; texture: $p < 0.0004$; overall acceptability: $p < 0.0001$; Table 3, Fig. 2), confirming that BBP substitution level had a real effect on how the cookies were perceived by the panel. For colour, panellists rated T1 highest (5.00 ± 0.00), followed by T0 (4.50 ± 0.53), while T2 scored significantly lower (2.90 ± 0.74). A similar pattern held for aroma (T0: 4.20 ± 0.63; T1: 4.50 ± 0.53; T2: 3.30 ± 0.67), taste (T0: 4.30 ± 0.67; T1: 4.50 ± 0.53; T2: 3.10 ± 0.74) and texture (T0: 4.30 ± 0.67; T1: 4.50 ± 0.53; T2: 3.30 ± 0.67). For overall acceptability, T1 again scored highest (4.50 ± 0.53), although it did not differ significantly from the control (4.30 ± 0.48), while T2 was the least accepted formulation (2.70 ± 0.67). Across all five attributes, T0 and T1 were statistically comparable, whereas T2 scored significantly lower than both.

The consistently high scores recorded for T1 across every attribute suggest that a low-level (5%) inclusion of BBP imparts an appealing golden-brown tint and a rustic visual quality without noticeably compromising taste, aroma or texture. Increasing substitution to 10% (T2), however, caused a sharp and significant decline in colour and overall acceptability scores, most plausibly attributable to high polyphenol oxidase activity and tannin/phenolic content in banana blossom, which promotes enzymatic browning during processing and produces a darker, less visually appealing cookie. A comparable inverted-U relationship between substitution level and sensory acceptability, peaking at a low-to-moderate inclusion level before declining at higher substitution, has now been reported consistently across banana-blossom biscuits [12] and banana-flour and banana-peel cookies and biscuits [14, 15], which strengthens confidence that the trade-off observed here reflects an intrinsic property of banana-derived ingredients rather than a formulation artefact specific to this study. Taken together, the sensory results indicate that T1 (5% BBP) achieved the highest mean overall balance, matching the control on every attribute while significantly outperforming the 10% formulation, whereas T2, despite its superior mineral, fibre and vitamin C profile, was significantly less acceptable to the panel. This trade-off between nutritional enhancement and sensory acceptability is an important consideration for selecting the optimal commercial formulation [14, 29].

3.4 Limitations and practical implications

Several limitations should be considered when interpreting these results. First, the sensory panel comprised ten semi-trained student panellists rather than a larger, formally trained or consumer-representative panel, which limits the statistical power and generalisability of the hedonic scores; replication with a larger, more demographically diverse panel and, ideally, instrumental colour and texture measurements (e.g., CIELab colorimetry, texture profile analysis) would strengthen future work and align with best practice in comparable banana-flour bakery studies [14]. Second, while triplicate physicochemical determinations provide a measure of analytical precision (reported as means ± SD), formal measurement-uncertainty estimation, method validation against certified reference materials, and inter-laboratory comparison were not performed and are recommended for subsequent studies intended for regulatory or nutritional-labelling purposes. Third, the vitamin C values reported here, while statistically robust, are modest in absolute terms and were determined titrimetrically; more sensitive methods (e.g., HPLC) would allow more precise quantification and would also permit characterisation of the wider phenolic and mineral profile of BBP-enriched cookies, which was outside the analytical scope of the present study.

Notwithstanding these limitations, the practical implications of the study are clear. Banana blossom, which is presently discarded as agricultural waste in Rwanda and across much of East Africa, can be converted with simple, low-cost unit operations (blanching, oven-drying, milling) into a functional flour substitute that measurably improves the mineral, fibre and vitamin C density of a widely consumed bakery product without compromising consumer acceptability at a 5% inclusion level. This is directly consistent with the wider circular-economy rationale for banana by-product valorisation identified in recent reviews [3, 23], and provides, to our knowledge, the first quantitative physicochemical and sensory

dataset of this kind generated in an East African production context, complementing the predominantly South/Southeast Asian evidence base on which most prior banana-blossom bakery research has relied.

4. Conclusion

Partial substitution of wheat flour with banana blossom powder (BBP) significantly affected every physicochemical, functional and sensory parameter measured in cookies ($p < 0.05$). Increasing BBP inclusion produced a highly significant, near-linear increase in ash (1.20 to 3.60%) and a fivefold increase in crude fibre (1.00 to 5.00%), introduced measurable vitamin C (up to 0.057 mg/100 g), lowered moisture to a level favourable for shelf stability (1.31%), and enhanced both water-holding (3.33 g/g) and oil-holding (3.28 g/g) capacity, at some cost to protein, fat and carbohydrate content. Sensory evaluation showed that the 5% BBP formulation (T1) achieved the best overall acceptability, scoring comparably to the control and significantly higher than the 10% formulation across colour, aroma, taste, texture and overall acceptability, while the 10% formulation was least accepted owing largely to enzymatic browning. These findings indicate that a 5% BBP substitution level offers a practical formulation balance, meaningfully enhancing the mineral, fibre and vitamin C density of cookies while preserving the colour, texture and flavour attributes expected by consumers. Banana blossom powder therefore offers a viable, low-cost means of valorising an underutilised banana-processing by-product into a functional bakery ingredient, with particular relevance for banana-growing regions such as Rwanda that currently discard this resource. Future work should quantify specific micronutrients (e.g., iron, zinc, potassium) and antioxidant/phenolic profiles of BBP-enriched cookies using more sensitive analytical methods (e.g., HPLC), assess shelf-life and microbiological stability under commercial storage conditions, and evaluate consumer acceptance and glycaemic response in a larger, more demographically diverse panel beyond the laboratory setting.

Declarations

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics approval

The sensory evaluation protocol was reviewed and approved by the Research Committee of the Institut d'Enseignement Supérieur de Ruhengeri (INES-Ruhengeri). The study was performed in line with the principles of the Declaration of Helsinki. The sensory test involved no more than minimal risk and used food-grade ingredients only.

The banana blossoms (Musa spp.) used in this study were collected from cultivated banana plants on a private farm at Gashangiro, Musanze District, Northern Province, Rwanda, with the permission of the farm owner. The collection of the plant material complied with relevant institutional, national and

international guidelines and legislation. Banana is a widely cultivated, non-endangered food crop, and no specific permits or licences were required for the collection of this plant material.

Consent to participate

Verbal informed consent was obtained from all individual panellists before sensory evaluation. Panellists were informed of the study purpose and of all ingredients beforehand, and participation was voluntary.

Consent to publish

Not applicable.

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Author Contribution

Conceptualization: Scolastique Mukamasabo, Fabien Gisubizo; Methodology: Scolastique Mukamasabo, Jean Claude Dusabumuremyi; Investigation and data curation: Scolastique Mukamasabo; Formal analysis: Scolastique Mukamasabo, Elias Kubwimana, Christine Mukantwali, Marcel Bahizi; Validation: Marc Antoine Ndisanze; Writing – original draft: Scolastique Mukamasabo; Writing – review and editing: Fabien Gisubizo, Jean Claude Dusabumuremyi, Marc Antoine Ndisanze, Elias Kubwimana, Christine Mukantwali, Marcel Bahizi; Supervision: Fabien Gisubizo, Jean Claude Dusabumuremyi. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

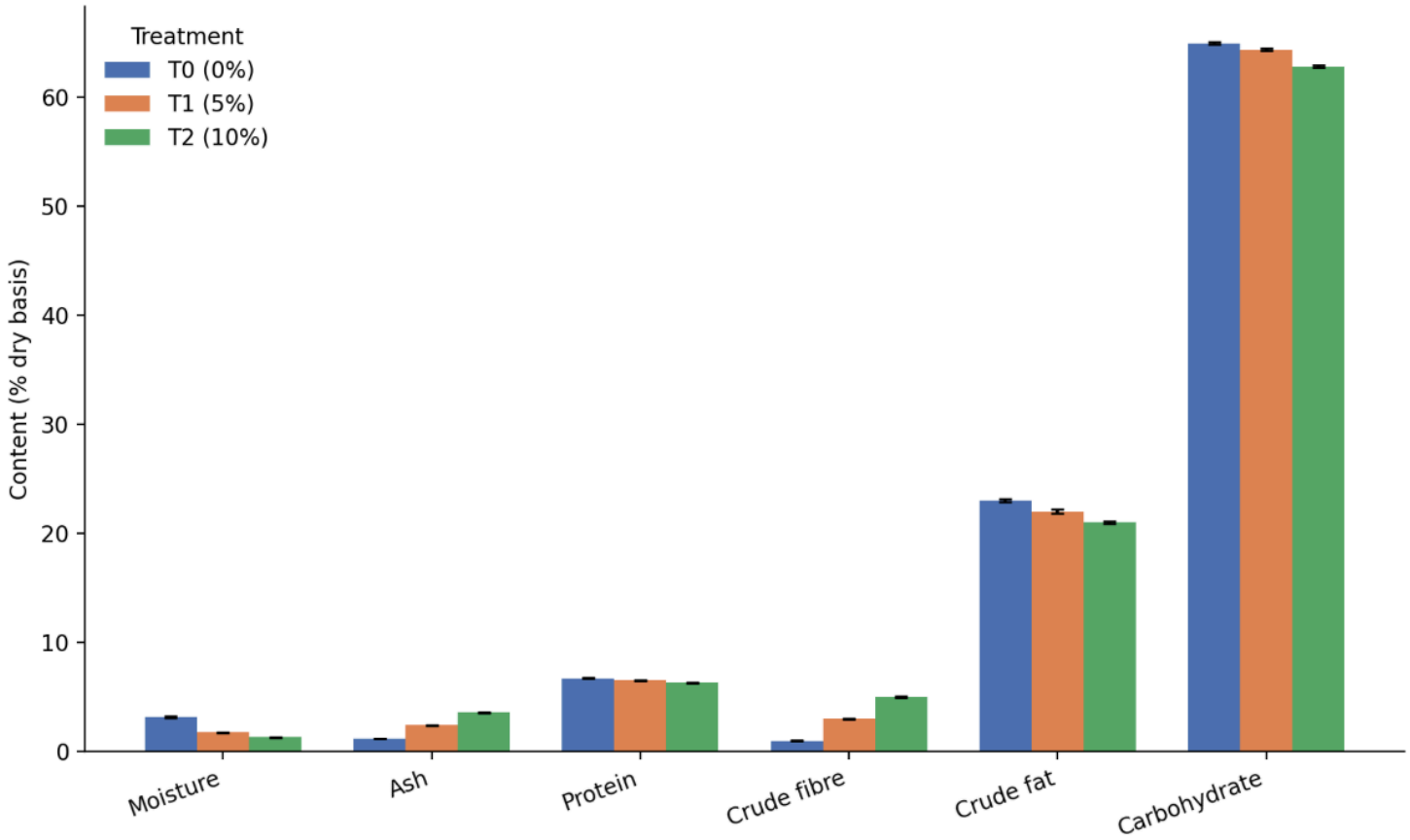


Figure 1

Proximate composition (moisture, ash, protein, crude fibre, crude fat and carbohydrate) of cookies enriched with banana blossom powder at 0% (T0), 5% (T1) and 10% (T2) substitution. Bars represent mean ± SD (n = 3)

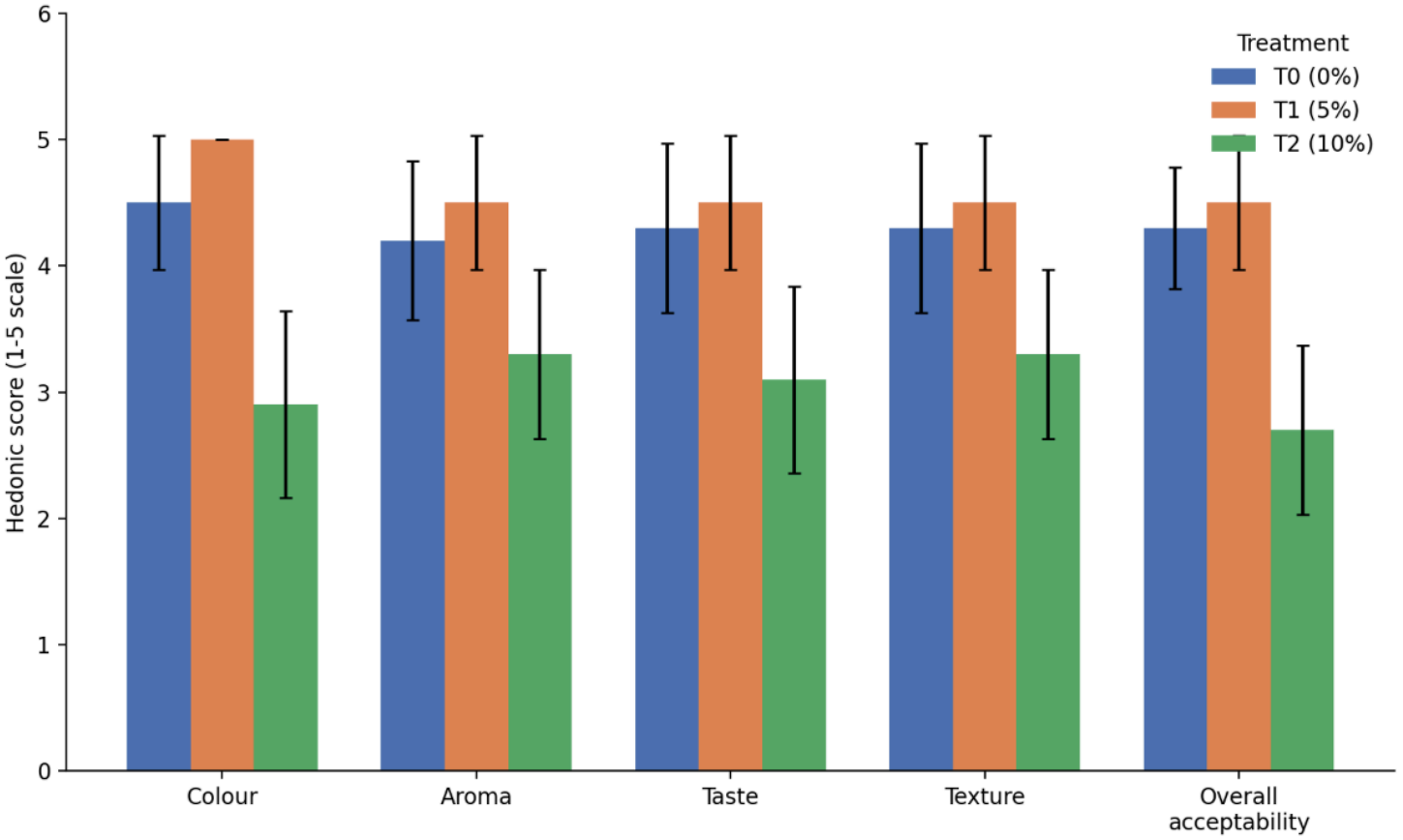


Figure 2

Sensory scores (colour, aroma, taste, texture and overall acceptability) of cookies enriched with banana blossom powder at 0% (T0), 5% (T1) and 10% (T2) substitution. Bars represent mean ± SD (n = 10 panellists)