RESEARCH PAPER

Formulation and Functional Characterization of Composite Bread Incorporating Green Banana Flour and Defatted Peanut Powder

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ABSTRACT
The development of cereal-based functional foods with improved nutritional profiles remains an area of active research. This study investigated the formulation and evaluation of functional composite bread (FCB) incorporating green banana flour (GBF) and defatted peanut butter powder (PBP). GBF is a documented source of resistant starch (~50% in raw flour) which is a starch fraction associated with attenuated postprandial glycemic response and improved colonic fermentation, while PBP provides high protein content (44 g/100 g). Three experimental formulations (FCB-1, FCB-2, FCB-3) and a wheat-based control were prepared and evaluated for sensory attributes and compositional characteristics. Sensory evaluation (n = 10, 9-point hedonic scale) indicated that FCB-2 achieved the highest overall acceptability (7.82 ± 0.16), not significantly different from the control. Compared with the control (per 25 g serving), FCB-2 demonstrated higher protein content (3.9 g vs. 1.7 g). Resistant starch, total phenolic content, antioxidant activity, and glycemic index were estimated based on ingredient compositional data, with FCB-2 showing greater theoretical values relative to the control. Statistical analysis indicated significant differences among formulations for calculated compositional parameters ($p < 0.05$). These findings suggest that incorporation of GBF and PBP enhances the compositional profile of bread while maintaining sensory acceptability. Direct analytical validation of resistant starch retention, antioxidant activity, and glycemic response is warranted to confirm functional effects in the final baked matrix.

KEYWORDS: Green banana flour, Functional Antidiabetic Bread, Peanut butter powder, Type2 diabetes mellitus, Cardiovascular diseases, Sensory evaluation
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1. INTRODUCTION

Type 2 diabetes mellitus (T2DM) represents a major public health concern globally, with increasing prevalence reported in India over recent decades. According to the National Family Health Survey (NFHS-5, 2019–21), approximately 16–18% of adults aged 15 years and above exhibit elevated blood glucose levels or are receiving treatment for diabetes (International Institute for Population Sciences [IIPS] & ICF, 2021). Dietary management remains central to the prevention and control of metabolic complications associated with T2DM (American Diabetes Association, 2023). Among modifiable dietary factors, the digestibility and structural characteristics of carbohydrate-rich staple foods significantly influence postprandial glycemic response.

Bread is one of the most widely consumed cereal-based foods worldwide and constitutes a major source of dietary carbohydrate. Conventional white bread formulations are predominantly composed of refined wheat flour and are characterized by high proportions of rapidly digestible starch, which contribute to elevated glycemic responses (González-Anton et al., 2015; Stamataki et al., 2017; Romão et al., 2021; España-Fariñas et al., 2025).During baking, starch gelatinization enhances enzymatic accessibility, further influencing starch digestibility. Consequently, reformulation strategies aimed at modifying starch digestion kinetics while maintaining product acceptability remain of considerable research interest.

Incorporation of resistant starch (RS) has emerged as a promising approach to modulate carbohydrate digestion. Resistant starch is defined as the fraction of starch that escapes digestion in the small intestine and undergoes fermentation in the colon (Birt et al., 2013). Unripe green banana flour (GBF) is particularly rich in resistant starch, especially resistant starch type 2 (RS2), which may constitute approximately 50% of total starch in raw flour (Menezes et al., 2011; Chuathong et al., 2021). Experimental and clinical investigations suggest that green banana–derived resistant starch may influence glycemic response and metabolic parameters (Oboh et al., 2021). However, thermal processing may alter starch structure and reduce resistant fractions, underscoring the importance of evaluating resistant starch retention within the final baked matrix.

Beyond carbohydrate modification, improvement of protein quality in cereal-based systems is nutritionally relevant. Wheat proteins are relatively deficient in lysine, whereas legume-derived proteins such as peanut contain comparatively higher lysine concentrations. Defatted peanut butter powder provides approximately 44 g protein per 100 g ingredient (Arkay Nutri Foods LLP, 2023), making it a suitable plant-based protein source for bakery applications. The integration of cereal and legume proteins may enhance amino acid complementarity while potentially influencing dough structure and starch–protein interactions.

Plant-based ingredients such as green banana flour and peanut powder also contain phenolic compounds and other bioactive constituents that may contribute to antioxidant capacity. Functional and compositional modifications in green banana–fortified products, including alterations in starch and volatile profiles, have been previously reported (Khoozani et al., 2022; Yangilar, 2015). Evaluating antioxidant properties in composite bread systems may therefore provide additional insight into functional enhancement beyond macronutrient composition.

Although previous studies have examined fibre enrichment or protein fortification in bread systems (Bansal & Kochhar, 2013), limited research has investigated the combined incorporation of resistant starch–rich green banana flour and high-protein defatted peanut powder within a single composite bread matrix and its integrated effects on physicochemical and functional properties. Therefore, the present study aimed to develop a resistant starch–enriched composite bread and to systematically evaluate its proximate composition, resistant starch content, antioxidant activity, and sensory characteristics relative to a conventional wheat-based control. It was hypothesized that incorporation of green banana flour and defatted peanut powder would enhance resistant starch and protein content while maintaining acceptable sensory quality.

2. MATERIALS AND METHODS

2.1. Materials

Banana flour (GBF) and defatted peanut butter powder (PBP) were procured from the local commercial market. Refined wheat flour, fresh yeast, sugar, table salt, milk powder, olive oil and vital wheat gluten were also obtained from local suppliers. All ingredients were food-grade and intended for human consumption. Ingredients were stored under ambient conditions until use.

2.2. Experimental Bread Formulations

A control bread formulation and three experimental formulations were prepared. The control formulation comprised refined wheat flour and standard bread ingredients. Experimental formulations were developed by substituting portions of refined wheat flour with GBF and PBP at predetermined levels to examine the effects of functional ingredient incorporation.

The formulations were designated as follows:

Control: 240 g refined wheat flour, 10 g fresh yeast, 15 g sugar, 10 g milk powder, 10 g gluten, 5 g salt, 10 mL olive oil (per 300 g dough).

FCB-1: 3.3% PBP + 8.3% GBF (relative to total dough weight).

FCB-3: 8.3% PBP + 13.3% GBF.

FCB-2: 16.7% PBP + 25% GBF.

In the FCB-2 formulation (highest incorporation), 50 g PBP and 75 g GBF were added to a total dough weight of 300 g. All percentages are weight/weight (w/w) relative to total dough mass.

2.3. Dough Preparation and Baking

a) Bread doughs were prepared following a modified straight-dough method.

b) Dry ingredients (refined wheat flour, GBF, PBP, vital gluten, sugar, salt and milk powder) were weighed accurately and mixed in a stainless-steel bowl.

c) Fresh yeast was dissolved in lukewarm water (~30–35°C) before incorporation.

d) The dry mixture was combined with the yeast solution and kneaded. Olive oil was gradually added during kneading to improve dough rheology and prevent stickiness. Tap water was added incrementally to achieve consistent dough hydration (final dough yield standardized across all formulations).

e) Doughs were kneaded manually for 10–12 minutes until smooth and elastic.

f) Kneaded dough was placed in greased proofing pans and allowed to ferment in a proofing chamber at 30°C and ~80% relative humidity for 60 minutes.

g) After proofing, doughs were baked in a preheated oven at 180°C for 40 minutes.

h) Baked loaves were cooled at room temperature (22–25°C) for 2 hours, then sliced (25 g per slice) and stored in polyethylene bags until further analysis.

Figure-1 : Ingredients were measured. Figure-2 : dough was placed in bread mold for proofing

2.4. Estimation of Resistant Starch and Antioxidant Content

Resistant starch and antioxidant activity values for experimental formulations were estimated based on the known compositional data of green banana flour (GBF) obtained from published literature and manufacturer specifications (Menezes et al., 2011; Chuathong et al., 2021). The theoretical contribution of resistant starch and antioxidant compounds to each formulation was calculated proportionally according to the percentage inclusion of GBF in the dough matrix.

No direct enzymatic quantification of resistant starch or in vitro antioxidant assays were performed on the final baked bread samples. Therefore, reported resistant starch and antioxidant values represent calculated estimates rather than experimentally determined values in the baked product.

Table-1 : Average values of the proximate composition of Green banana flour (GBF) and peanut butter powder (PBP) (functional ingredients)

Sr. No.	Approximate Nutritional Composition (100g)	Green Banana Flour (Elizabete Wenzel Menezes et al. Plant Foods Hum Nutr. 2011 Sep.)	Peanut Butter Powder (Arkay nutri foods lip. , 2023)
1	Moisture	10.50±0.71	-
2	Ash content	3.5g	-
3	Protein	4.33g	35.6g
4	Fat	0.52±0.00	11.8g
5	Total carbohydrate	81.88±1.4	48.15g
6	Resistant starch	52.7-54.2g	
7	Total sugar		26.25g
8	Added sugar		22.5g
9	Total dietary fibre	1.27g	10g
10	Energy (kcal/100g)	347.5	443.75
11	Antioxidant content(mg TE / 100g)	474.23	-
12	Total phenolic	524.87 mg GAE/100g	-
13	Sodium (mg/100g)		573.75
14	Potassium (mg/100g)	1033.25mg/100g	-

Table-2 : Average values of the proximate composition of Non- functional ingredients

Sr. No.	Approximate Nutritional Composition (per 100g)	Refined wheat flour (nutritionix)	Fresh yeast (nutritionix)	Gluten (nutritionix)	Skimmed Milk powder (fatsecret Platform API , 2024)	Sugar (nutritionix)	Salt (nutritionix)	Olive oil (nutritionix)
1	Energy	364 kcal	115 kcal	370 kcal	357 kcal	387 kcal	-	900 kcal
2	Carbohydrates	76g	4.5g	14g	52g	100g	-	-
3	Protein	10g	15g	75g	35g	-	-	
4	Fat	1g	1.8g	1.9g	1g	-	-	100ml
5	Fibre	2-3g	8.5g	0.6g	-	-	-	-
6	Iron	2-3mg	-	5.2mg	-	-	-	-
7	Calcium	-	-	142mg	-	-	-	-
8	Potassium	-	-	100mg	-	-	-	-
9	Sodium	-	-	29mg	549mg	-	38.8mg	-
10	Cholesterol	-	-	-	18mg	-	-	-

2.5. Sensory evaluation of Green Banana Flour and Peanut Butter Powder based bread

Sensory evaluation was conducted using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). A panel of semi-trained judges (n = 10) evaluated the bread samples for colour, aroma, texture, appearance, taste, and overall acceptability.

Samples were coded and presented in randomized order to minimize bias. Panellists evaluated samples independently under standardized conditions. Overall acceptability scores were calculated as the mean of individual overall ratings provided by each panellist

The sensory evaluation of paneer was conducted using a 9-point hedonic scale, evaluating attributes such as appearance, flavour, texture, colour, and overall acceptability (Singh et. al, 2026)

3. RESULTS AND DISCUSSION

3.1. Sensory Evaluation of Green Banana Flour (GBF) and Peanut Butter Powder (PBP) Composite Bread:

3.1.1. Colour:

Increasing levels of PBP and GBF produced a progressive darkening of crumb colour, with FCB2 (16.7% PBP and 25% GBF) exhibiting a slightly deeper brown hue compared to control. The mean colour score for FCB2 (7.9 ± 1.13) was the highest among formulations, indicating that moderate browning did not negatively affect consumer perception.

The darker appearance is likely attributable to enhanced Maillard reaction intensity due to increased protein (from PBP) and reducing sugar interactions during baking. Similar observations have been reported by Yangilar (2015), who demonstrated that incorporation of green banana flour significantly influenced colour parameters in enriched products ($p < 0.05$), reflecting the contribution of banana-derived solids to pigment development and browning reactions. Although instrumental colour values (L*, a*, b*) were not determined in the present study, the sensory findings suggest that moderate incorporation levels maintained visual acceptability.

Importantly, excessive darkening was not reported by panellists, indicating that the formulation remained within acceptable sensory thresholds.

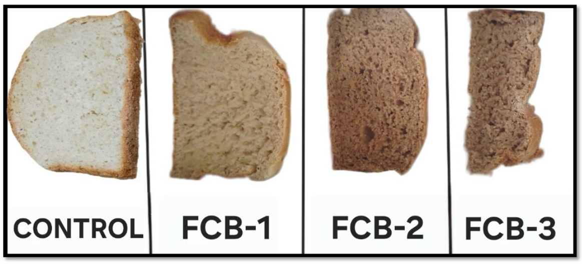

Figure-3: The different samples of Functional composite bread (FCB)

3.1.2. Aroma and Taste

Aroma intensity increased with higher PBP inclusion, particularly in FCB2. Panellists described a mild nutty note and slight sweetness, which contributed positively to taste acceptability. The highest taste scores were observed in FCB2. Previous work by Khoozani et al. (2022) reported that GBF fortification alters the volatile profile of bread, increasing furans and Strecker aldehydes formed during Maillard and Strecker reactions. These compounds contribute roasted, nutty, and caramel-like notes. The present findings are consistent with those observations, suggesting that the interaction between peanut proteins and banana-derived carbohydrates may have enhanced flavour complexity during baking.

3.1.3. Texture

Formulations containing higher levels of GBF and PBP exhibited slightly firmer and more cohesive crumb structures compared to control. This may be attributed to multiple structural factors:

- Dilution of gluten network by non-wheat components
- Increased protein content from PBP
- Altered starch composition due to GBF incorporation

While resistant starch content was estimated based on ingredient composition rather than directly quantified, previous literature indicates that banana flour inclusion can influence crumb firmness and structural properties through starch–protein interactions (Bansal & Kochhar, 2013; Khoozani et al., 2022). The increased chewiness observed in higher inclusion levels is therefore likely multifactorial rather than solely due to resistant starch presence.

Importantly, firmness did not negatively impact overall acceptability, suggesting that textural modifications remained within acceptable consumer ranges.

3.1.4. Overall Acceptability

Among all formulations, FCB2 demonstrated the highest overall acceptability (8.15 ± 0.89), indicating an optimal balance between functional enrichment and sensory quality. Lower inclusion levels produced minimal sensory differentiation from control, whereas the highest combined incorporation level enhanced perceived flavour and nutritional appeal without compromising texture or appearance.

Comparable findings have been reported in peanut-enriched traditional products, where optimized peanut inclusion improved overall acceptability scores (Yadav et al., 2018). These results support the concept that plant-protein fortification can enhance sensory attributes when appropriately balanced within the food matrix.

Most individual sensory attributes (colour, aroma, texture, appearance, and taste) did not differ significantly among samples ($p > 0.05$), suggesting that incorporation of GBF and PBP did not adversely affect key sensory properties.

For overall acceptability, FCB1 showed a statistically significant reduction compared to control ($t = 3.80$, p

< 0.05). FCB3 also demonstrated a significant difference relative to control (t = 2.61, $p < 0.05$). In contrast, FCB2 recorded the highest numerical overall acceptability score (7.82 ± 0.16); however, this difference was not statistically significant when compared with the control (t = –1.51, p = 0.15).

Although FCB2 did not demonstrate statistical superiority, its comparable acceptability relative to control indicates that higher incorporation levels of GBF and PBP can be achieved without compromising consumer perception.

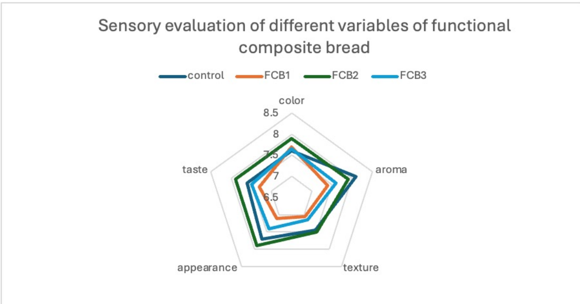

Figure 4: Sensory evaluation of different variables of functional composite bread

Attributes	colour	aroma	texture	appearance	taste	Overall acceptability
control	7.6±0.76	8.1±0.83	7.45±1.05	7.7±0.78	7.6±0.91	7.69±0.22
FCB1	7.7±1.18	7.4±1.01	7.05±1.05	7.1±1.13	7.3±1.26	7.31±0.23
FCB2	7.9±1.13	7.9±1.22	7.5±1.43	7.9±1.13	7.9±1.51	7.82±0.16
FCB3	7.65±0.83	7.6±0.8	7.15±0.83	7.4±1.01	7.5±1.20	7.46±0.17

Table-8 : Sensory acceptability of different variables of functional composite bread

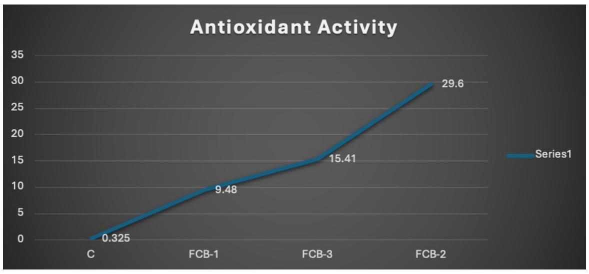

Figure-5 Estimated antioxidant activity (mg TE/25 g) of control and different variables of functional composite bread, calculated based on ingredient composition.

3.2. Antioxidant Capacity

The estimated antioxidant capacity increased proportionally with the incorporation of green banana flour (GBF) and peanut butter powder (PBP). The control formulation demonstrated negligible antioxidant contribution based on ingredient composition (0.325 mg TE/25 g), whereas FCB-1, FCB-3, and FCB-2 showed progressively higher estimated values of 9.48, 15.41, and 29.6 mg TE/25 g, respectively.

This apparent dose-dependent increase reflects the documented presence of phenolic compounds in green banana flour and peanut-derived constituents reported in previous literature. Plant-based ingredients such as GBF are known to contain both free and bound phenolics, while peanut components contribute additional bioactive compounds. It is important to note that antioxidant values in the present study were calculated based on compositional data of individual ingredients rather than directly measured in the final baked product. Thermal processing may influence phenolic stability; however, certain bound phenolics and Maillard reaction products formed during baking have been reported to exhibit antioxidant properties. Therefore, the estimated trend suggests potential enhancement of antioxidant capacity with increasing functional ingredient inclusion, although direct analytical validation would be required to confirm retained activity in the final bread matrix.

Sr. No.	Approximate Nutritional Composition per serving (25g)	FCB 2 (16.7% PBP 25% GBF)
1	Energy	93kcal (approx.)
2	Protein	3.9g
3	Fat	1.5g
4	Fibre	0.84g
5	Iron	0.52mg
6	Calcium	10.17mg
7	Potassium	100.2mg
8	Sodium	185.8mg
9	Cholesterol	0.15mg
10	Antioxidant content (mg TE / 25g)	29.6mg TE/25g
11	Total phenolic content (mg GAE / 25g)	32.8mg GAE/25g
12	Resistant Strach	3.34g
13	Total sugar	1.09g
14	Added sugar	0.94g
15	Total carbohydrates (incl. Fibre, resistant starch, total sugar)	16g
16	Predicted Glycemic index (theoretical calculation based on ingredient GI values)	45-50

Table-9 : Average values of the proximate composition of FCB 2 per serving (25g)

4. CONCLUSION

The incorporation of green banana flour (GBF) and defatted peanut butter powder (PBP) into bread formulations increased estimated protein and resistant starch content while maintaining overall sensory acceptability comparable to the control. Among the tested formulations, FCB2 demonstrated the most favourable balance between functional enrichment and consumer acceptance.

Although resistant starch and antioxidant values were calculated based on ingredient composition rather than directly measured in the baked product, the formulation approach indicates potential for developing nutritionally enhanced composite breads. Further analytical validation and in vivo glycemic studies are required to confirm the physiological relevance of the observed compositional modifications.

5. FUTURE SCOPE

Future research should include in vitro starch digestibility analysis and direct quantification of resistant starch and antioxidant activity in the final baked matrix to validate compositional estimates. Controlled human studies evaluating postprandial glycemic response and insulin dynamics would further clarify the metabolic implications of the composite formulation. Long-term intervention trials may explore potential effects on glycemic control (HbA1c), lipid profile, and gut microbiota composition. Additionally, studies examining shelf-life stability, textural changes during storage, and resistant starch retention over time would support product optimization.

Investigation of scale-up feasibility and adaptation to alternative cereal systems may facilitate broader commercial application.

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7. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest associated with this study.

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