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Green banana flour as a fat replacer in beef burgers: effects on sensory acceptance and consumer preference

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Abstract. Reducing fat in meat products remains a technological challenge due to its impact on sensory quality. This study evaluated the technological performance and consumer acceptance of low-fat beef burgers formulated with green banana flour (GBF) as a fat replacer, using internal preference mapping. Five formulations were produced: a control (15% pork back fat) and four treatments with 25% (LF25), 50% (LF50), 75% (LF75), and 100% (LF100) fat replacement. Microbiological quality, sensory acceptance (color, aroma, flavor, consistency, and overall acceptability), and purchase intention were evaluated by 100 consumers using a 5-point hedonic scale. Data were analyzed by ANOVA, Tukey's test ($p < 0.05$), and principal component analysis. All formulations complied with microbiological safety standards. Acceptability indices exceeded 70% for all attributes in CON, LF25, LF50, and LF75, with overall acceptability values of 85.60%, 75.00%, 76.80%, and 78.00%, respectively. Flavor acceptability reached 86.00% for the control and remained above 76% for partial replacements, while LF100 showed a decline to 68.80%. Purchase intention followed a similar trend, with 86.06% for CON and 75.80% for LF75, but dropping to 64.60% in LF100. Internal preference mapping explained up to 66.8% of variance and revealed a clear consumer preference for formulations with 25–75% fat replacement, whereas total replacement resulted in lower acceptance. These results demonstrate that GBF is an effective fat replacer at intermediate levels, improving the nutritional profile of beef burgers while maintaining consumer acceptance and market potential.

Keywords: fat replacers, green banana flour, resistant starch, beef burgers, sensory evaluation, consumer acceptance.

Introduction

Meat is widely recognized as a primary source of high-biological-value proteins, vitamins, minerals and essential fatty acids required by the human body, playing a significant role in human nutrition (Font-i-Furnols, 2023; Kurćubić *et al.*, 2022; Yazdanparast *et al.*, 2025; Zaini *et al.*, 2021). However, due to the rising costs of fresh meat products, consumers frequently opt for more accessible alternatives, such as processed meat derivatives. Among these, hamburgers have become one of the most consumed meat products globally, favored for their convenience, affordability, and broad palatability across different socioeconomic groups (Leães *et al.*, 2026; Yousefi; Zeynali; Alizadeh, 2018).

These products generally contain moderate amounts of animal fat to ensure desirable technological, functional, and sensory properties. However, excessive consumption of fat-rich foods, especially those high in saturated fatty acids and cholesterol, has been associated with several health disorders, including obesity, coronary heart disease, and certain types of cancer (Ayuso; García-Pérez; Nieto, 2025; Font-i-Furnols, 2023; Saldaña; Rios-Mera, 2025; Yang *et al.*, 2025).

Although fat is essential for desirable texture, mouthfeel, and flavor in hamburgers, formulations with levels above 10% are generally viewed unfavorably from a nutritional standpoint. However, simply reducing or eliminating fat can markedly impair product quality. In this context, incorporating fat replacers emerges as a viable strategy to mitigate these negative effects while maintaining acceptable sensory characteristics (Yousefi; Zeynali; Alizadeh, 2018).

However, developing low-fat foods is challenging because fat provides critical sensory attributes like flavor, color, texture, and mouthfeel, as well as desirable rheological properties, making it essential to replace these functions without compromising product quality and consumer acceptance (Ayuso; García-Pérez; Nieto, 2025).

The fat content of foods can be reduced by replacing it with other ingredients, such as fat replacers and fat mimetics. The first group consists of macromolecules with physical and chemical properties similar to those of triglycerides (fats and oils). They can replace fat in food on a one-to-one basis. In contrast, the second group encompasses molecules, especially proteins or carbohydrates, that mimic the physical or sensory properties of triglycerides but cannot replace them on a one-to-one basis (Gao *et al.*, 2024; Syan *et al.*, 2022).

In the carbohydrate group, green banana flour (GBF) contains resistant starch and a high fiber content, as well as a significant mineral profile, being a source of potassium, phosphorus, magnesium, copper, manganese, and zinc (Santos *et al.*, 2019). Moreover, unripe bananas are a source of antioxidant polyphenols, which exhibit strong protective effects against diseases such as cancer, rheumatoid arthritis, and cardiovascular disease (Ferrari, 2022; Munir *et al.*, 2024; Zaini *et al.*, 2025).

The use of dietary fibers as fat replacers in meat systems aims to lower saturated fat content while enhancing nutritional value. Research indicates that fiber integration improves water-holding capacity and process yield without significantly altering the sensory profile when compared to traditional, full-fat formulations (Bis-Souza; Henck; Barretto, 2018). Also, the production of GBF has attracted the food industry due to its high nutritional value, low cost, and potential to minimize banana waste (Li *et al.*, 2022; Zaini *et al.*, 2025; Zou *et al.*, 2022).

Concerning meat products, the GBF has already been employed as a fat substitute in sausages (Alves *et al.*, 2016), frankfurter (Pereira *et al.*, 2020; Salazar *et al.*, 2021), chicken breads (Reis *et al.*, 2022), chicken burgers with reduced sodium content (Santos *et al.*, 2019), chicken nuggets (Kumar *et al.*, 2011), chicken mortadella (Auriema *et al.*, 2022), beef burger (Bastos *et al.*, 2014; Meneses; Molina; Vargas, 2011).

This study tests the hypothesis that green banana flour can substitute animal fat in beef burgers while preserving quality. Although GBF is a promising functional ingredient, its sensory effects in meat systems are not yet fully understood. Therefore, we investigated consumer acceptance through preference mapping to pinpoint specific drivers of liking and consumer segments.

Material and Methods

Burger manufacture

Different formulations of beef burger were elaborated using ingredients (ground chuck beef, ground pork back fat, green banana flour, refined salt, a commercial spice mix composed of dehydrated garlic, chives, and parsley, black pepper powder) obtained from the local market in Diamantina, Minas Gerais, Brazil.

The meat materials were transported to the laboratory in isothermal boxes and stored in a refrigerator at 4°C for approximately 24 hours before processing to ensure standardization and temperature equilibrium.

The beef was divided into five treatments, with the first used as a control (15% of ground pork back fat) and the others elaborated with the substitution of fat by green flour banana in different proportions (25%, 50%, 75% and 100%), as shown in Table 1.

The raw materials (beef and pork fat) and ingredients were kneaded by hand for 10 minutes, and after the addition of green banana flour, the mixture was mixed with refined salt, a commercial spice mix, and black pepper powder. The formulations weighing at least 60g were hand-shaped using a manual burger maker to give a 10 cm diameter and 3 cm thick.

After shaping, the burger patties were packed in PVC bags, placed in polyethylene bags, and immediately frozen at -18°C. The burgers remained in frozen storage until the analysis day. For sensory evaluation, the samples were thawed in a refrigerator at 4°C for approximately 12 hours prior to the cooking process, ensuring the maintenance of the product's structural and sensory integrity before evaluation."

Microbiological analysis

The microbiological analyses (Silva *et al.*, 2021) were performed for thermotolerant coliforms at 45 °C (Most Probable Number method – MPN), sulfite-reducing *Clostridia* at 46 °C, and Salmonella spp. Initially, 25 g samples of each formulation were aseptically cut and placed in a homogenizer (Marconi, MA440/CF, Piracicaba, São Paulo, Brazil) for one minute with 225 mL of 0.1% buffered peptone water. From this initial mixture, serial decimal dilutions (10^{-1}; 10^{-2}; 10^{-3}) were prepared for the analyses of thermotolerant coliforms at 45 °C and sulfite-reducing *Clostridia* at 46 °C. The first dilution (10^{-1}) was used to detect *Salmonella* spp.

The thermotolerant coliform analysis was performed by determining the Most Probable Number (MPN) using the multiple-tube technique. For the presumptive test, lauryl sulfate tryptose (LST) broth (Micro Med, Isofar, Duque de Caxias, Rio de Janeiro, Brazil) was used, with incubation in a water bath at 35 ºC for 48 hours. For samples that showed growth and gas production, the confirmatory test was performed using EC broth (TM MEDIA, Titan Biotech Ltda, Rajasthan, India), incubated in a water bath at 45 ºC for 24 hours.

For the determination of *Clostridia*, one-milliliter aliquots from each dilution (10^{-1}; 10^{-2}; 10^{-3}) were pour-plated into *Clostridium perfringens* agar (Kasvi, Paraná, Brazil) supplemented with D-cycloserine solution (Lab M, code X194, Lancashire, United Kingdom) and egg yolk, with an overlay of the same medium. The samples were incubated at 46 ºC for 24 hours under anaerobic conditions using an anaerobic jar (EJ Krieger e Cia Ltda, Curitiba, Paraná, Brazil) and an anaerobic atmosphere generator (PROBAC, São Paulo, São Paulo, Brazil). After this period, the characteristic colonies were counted, and the results were expressed in Colony-Forming Unit (CFU) per g of sample.

For *Salmonella* spp. detection, the samples were homogenized in peptone water and incubated at 37 ºC for 18 hours. After pre-enrichment, 1 mL of the dilution was inoculated into 10 mL of tetrathionate broth base (Acumedia, Michigan, USA) containing iodine solution, and the mixture was incubated at 37 ºC for 24 hours. Concurrently, 0.1 mL of the dilution was inoculated into 10 mL of Rappaport-Vassiliadis broth (Acumedia, Michigan, USA) and incubated at 41 ºC for 24 hours. Subsequently, a loopful from each broth was streaked onto plates of xylose-lysine-deoxycholate (XLD) agar (Acumedia, Michigan, USA) and Brilliant Green Agar (TM Media, Rajasthan, India), followed by incubation for 24 hours at 37 ºC.

Table 1. Beef burger formulations expressed in percentage per 100 g of sample

Ingredients (%)	Formulations				
	CON	LF25	LF50	LF75	LF100
Ground chuck beef meat	82.00	82.00	82.00	82.00	82.00
Ground pork back fat	15.00	11.25	7.50	3.75	0.00
Green flour banana	0.00	3.75	7.50	11.25	15.00
Refined salt	1.50	1.50	1.50	1.50	1.50
Commercial spice mix	1.40	1.40	1.40	1.40	1.40
Black pepper powder	0.10	0.10	0.10	0.10	0.10

CON (control): with 15% of ground pork back fat; LF25, LF50, LF75, LF100: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

Colonies with morphological characteristics of *Salmonella* were purified on nutrient agar plates (Micro MED, Duque de Caxias, Rio de Janeiro, Brazil), incubated again at 37 ºC for 24 hours, and submitted to biochemical identification using the following media: triple sugar iron (TSI) agar (Acumedia, Michigan, USA), lysine decarboxylase broth (Micro MED, Duque de Caxias, Rio de Janeiro, Brazil), and Christensen's urea agar (Biolog, São Paulo, Brazil) enriched with urea (Proquimios, Rio de Janeiro, Brazil), and confirmed using the enterobacteria panel (Probac do Brasil, São Paulo, Brazil).

Sensorial analysis

The sensory analysis protocol for the beef burger developed in the experiments was previously approved by the Ethics in Research Committee of the University Federal dos Vales do Jequitinhonha e Mucuri, MG, Brazil, under protocol number 80218717.0.0000.5108).

One hundred participants were recruited from staff and students at the Universidade Federal dos Vales do Jequitinhonha e Mucuri. All the consumers were 18-60 years old (61% females and 39% males). Before starting the sensory analysis, all participants were asked to complete the Informed Consent Form to ensure the research was voluntary.

The test was carried out in designed individual sensory booths under fluorescent lighting conditions. Hamburger patties (60 g; 10 cm diameter) were cooked on a preheated electric grill at 180 °C until the internal temperature reached 72 °C, monitored using a digital thermometer.

Samples (two slices taken from the central portion of the product, weighing approximately 10 g) were presented monadically in 50 mL disposable cups, labeled with three digits random code, in a randomized order. Water at room temperature and salted crackers were provided for palate cleansing between sample evaluations.

A sensory acceptance test (color, aroma, flavor, texture, and overall acceptability) was performed using a 5-point hedonic scale: 5 - liked extremely; 4 -liked moderately; 3 - neither liked nor disliked; 2 - disliked moderately; 1 - disliked extremely.

Purchase intention was assessed using a 5-point scale: 1 - definitely would not buy; 2 - probably would not buy; 3 - might or might not buy; 4 - probably would buy, and 5 - definitely would buy.

A structured 5-point hedonic scale was used for the sensory evaluation of the formulations, considering its greater simplicity and ease of understanding for untrained assessors. The use of a reduced scale minimizes cognitive load and indecision between adjacent categories, contributing to more consistent responses and reduced experimental variability (Drake; Watson; Liu, 2023; Villanueva; Silva, 2009; Wichchukit; O'Mahony, 2015).

To verify product acceptance, the Acceptability Index (AI) was calculated by dividing the average hedonic score for the analyzed product by the maximum score on the same scale. A product was considered to have good acceptability if its AI was greater than or equal to 70% (Dutcosky, 2019).

Statistical analysis

The experiment was conducted using a completely randomized design. The data were analyzed using analysis of variance (ANOVA). When necessary, the means were compared using Tukey's test at the 5% significance level. All statistical analyses were performed using R (R Core Team, 2024).

The Internal Preference Mapping was conducted using Principal Component Analysis (PCA) based on the individual hedonic scores provided by the 100 panelists for each formulation. The data matrix was structured with panelists as rows and formulations as columns for each attribute. In the resulting biplots, the samples (CON, LF25, LF50, LF75, and LF100) are represented by their mean scores, while the vectors (red arrows) represent the individual consumers, indicating the direction and intensity of their preferences for specific formulations.

Results and discussion

All hamburger formulations met the microbiological standards (Table 2) established by Brazilian legislation (Brasil, 2019), confirming their suitability for sensory evaluation.

In this study, all ingredients were handled under appropriate hygienic and sanitary conditions, and the formulations were prepared in accordance with good manufacturing practices. These measures minimized the risk of contamination and microbial proliferation during processing, thereby ensuring the satisfactory microbiological quality of the developed products.

Table 2. Microbiological quality of the different hamburger formulations

Treatments	Microbiological analyses		
	coliforms at 45 °C (MPN)	*Salmonella* spp. (in 25 g)	sulfite-reducing clostridia (CFU/g)
COM	7.4	not detected	<10
LF25	3.0	not detected	<10
LF50	3.0	not detected	<10
LF75	20.0	not detected	<10
LF100	3.6	not detected	<10

CON (control): with 15% of ground pork back fat; LF25, LF50, LF75, LF100: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively. MPN: Most Probable Number; CFU: Colony-Forming Unit.

In addition, these results are also broadly consistent with internationally recognized food safety principles and microbiological criteria established by organizations such as the Codex Alimentarius Commission, which emphasize the absence or control of relevant foodborne pathogens and acceptable hygiene indicators in meat products.

Sensorial analysis

Mean sensory scores (Table 3) indicated that the control formulation (CON) achieved the highest ratings across all attributes, while formulations with partial fat replacement (LF25–LF75) maintained comparable acceptance levels. In contrast, LF100 showed a significant decline in flavor, overall acceptability, and purchase intention, with acceptability indices falling below the 70% threshold for key attributes.

Formulations CON through LF75 exhibited acceptability indices above 70% for all evaluated attributes (Table 4), supporting their potential for industrial application. Among the reduced-fat treatments, LF75 showed particularly favorable performance, with no significant differences from the control in aroma and consistency, indicating that higher levels of substitution can still preserve important sensory characteristics.

An acceptance index of 70% or higher is commonly considered indicative of satisfactory sensory acceptance in food products (Dutcosky, 2019), reflecting favorable consumer perception and potential marketability. Hence, formulations CON to LF75 may be considered promising for industrial application.

Consistent with Kumar *et al.* (2013), who reported that GBF effectively sustains cooking yield and emulsion stability in restructured poultry products, our findings for LF75 demonstrate that GBF preserves key textural attributes, such as consistency, in beef burgers. However, while Kumar et al. (2013) observed comparable sensory scores across all treatments, our results for LF100 reveal a critical threshold at which flavor and purchase intent decline. This suggests that the impact of fat replacement with GBF is more pronounced in beef systems than in poultry-based products, likely due to the distinct role of intramuscular fat in beef palatability.

Our results corroborate the observations of Bastos *et al.* (2014) regarding the technological efficacy of green banana in preserving consistency and reducing burger hardness by increasing water-holding capacity. However, while Bastos et al. (2014) suggest that total replacement can be achieved without compromising quality, our data indicate a critical sensory threshold in LF100, at which overall acceptability and flavor are impaired. This suggests that intermediate levels (such as LF25 to LF75) are more reliable for ensuring consumer purchase intent.

Table 3. Affective sensory attributes of the burger formulations

Atributes	Burger formulations				
	CON	LF25	LF50	LF75	LF100
Color	4.06 ± 0.87^{a}	3.77 ± 0.70^{b}	3.86 ± 0.89^{ab}	4.05 ± 0.97^{a}	3.71 ± 0.73^{b}
Flavor	4.30 ± 1.07^{a}	3.82 ± 0.70^{b}	3.80 ± 0.71^{b}	3.94 ± 0.81^{ab}	3.44 ± 0.54^{c}
Aroma	4.20 ± 0.96^{a}	3.96 ± 0.80^{b}	4.00 ± 0.88^{ab}	4.05 ± 0.91^{a}b	3.67 ± 0.71^{c}
Consistency	4.27 ± 1.08^{a}	4.05 ± 0.93^{a}	4.17 ± 1.10^{a}	4.11 ± 1.10^{a}	3.75 ± 0.77^{b}
Overall acceptability	4.28 ± 1.05^{a}	3.75 ± 0.71^{c}	3.84 ± 0.86^{b}	3.91 ± 0.86^{ab}	3.54 ± 0.58^{d}
Purchase intention	4.30 ± 0.83^{a}	3.76 ± 0.98^{b}	3.69 ± 0.96^{b}	3.79 ± 1.02^{b}	3.23 ± 1.30^{c}

CON (control): with 15% of ground pork back fat; LF25, LF50, LF75, LF100: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively. Means followed by the same letter in the same row do not differ significantly ($p < 0.05$) according to Tukey's test.

Table 4. Acceptability Indices of the burger formulations

Atributes	Acceptability index (%)				
	CON	LF25	LF50	LF75	LF100
Color	81.20	75.40	77.20	81.00	74.20
Flavor	86.00	76.20	76.00	78.80	68.80
Aroma	84.00	79.20	80.00	81.00	73.40
Consistency	85.40	81.00	83.40	82.2	75.00
Overall acceptability	85.60	75.00	76.80	78.00	70.80
Purchase intention	86.06	75.15	73.80	75.80	64.60

CON (control): with 15% of ground pork back fat; LF25, LF50, LF75, LF100: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

The stability of consistency observed in LF75 is supported by the findings of Pereira *et al.* (2020), who reported that unripe banana by-products improve the rheological properties and emulsion stability of fat-reduced meat systems. Their study suggests that banana pulp flour can effectively mimic the mouthfeel of animal fat. However, while Pereira et al. (2020) used a combination of banana flour and pre-emulsified sunflower oil to maintain palatability, our study shows that, in the absence of an alternative lipid source, total fat removal (LF100) results in a significant decline in flavor and overall acceptability. This comparison emphasizes that intermediate levels of green banana flour (specifically LF75) define a critical sensory threshold for maintaining consumer purchase intent in beef burgers.

The sensory results obtained in this study contrast with those reported by Salazar *et al.* (2021), who observed a decrease in sensory acceptance in low-fat, fiber-enriched sausages, particularly due to undesirable changes in flavor and texture. In their study, low-fat formulations were associated with lower overall acceptability and sensory scores close to the acceptability threshold, indicating limitations in consumer acceptance of reformulated products.

In contrast, the present study demonstrated that all formulations (CON, LF25, LF50, LF75, and LF100) achieved Acceptability Index (AI) values ≥ 70%, indicating consistent consumer acceptance regardless of the level of reformulation. This suggests that the reformulation strategy applied here was more effective in preserving sensory characteristics, even with compositional modifications.

Furthermore, while Salazar *et al.* (2021), reported that sensory acceptance of reformulated products may improve over time due to consumer adaptation, the results of the present study indicate that high acceptability was achieved without the need for adaptation, reinforcing the immediate sensory viability of the developed formulations. Therefore, these findings highlight the importance of formulation design in mitigating the negative sensory impacts commonly associated with fat reduction in meat products.

Based on the aforementioned studies, the inclusion of GBF alters the properties of meat products, acting as a functional extender. Its high content of resistant starch and dietary fiber increases water-holding capacity and reinforces the protein matrix, thereby ensuring the product's physical integrity after cooking. However, the success of this modification depends on balance, as excessive levels may compromise sensory acceptance by altering the flavor profile and the beef's characteristic color.

In the present study, the adoption of the 5-point scale did not limit the sensitivity of the analysis, as evidenced by the clear differentiation among formulations and the consistency of the results obtained. All evaluated formulations (F1–F4) achieved Acceptability Index (AI) values equal to or higher than 70%, indicating good consumer acceptance and supporting their potential industrial applicability. Moreover, the sensory data obtained were sufficiently robust to support statistical analyses, including mean comparisons, reinforcing that the reduced scale maintained adequate discriminatory capacity.

The sensory evaluation approach adopted in the present study differs from that reported by Yousefi; Zeynali; Alizadeh (2018), who assessed only the optimized formulation in comparison with the control using a limited sensory design. In contrast, the current study evaluated multiple formulations (CON, LF25, LF50, LF75, and LF100), allowing a more comprehensive understanding of the effects of reformulation on consumer perception.

While Yousefi; Zeynali; Alizadeh (2018) reported improved overall acceptability mainly associated with texture enhancement, the present results demonstrated that all formulations achieved Acceptability Index (AI) values ≥ 70%, indicating consistent consumer acceptance across different levels of modification. This highlights the robustness of the reformulation strategy, as sensory quality was maintained even with significant compositional changes.

Our study also differs from that reported in Alves *et al.* (2016), where more advanced consumer-based methodologies, including Check-All-That-Apply (CATA) and Just-About-Right (JAR) scales, were used to identify the drivers of liking and sensory perception associated with fat replacement. While such approaches provide detailed insights into the specific attributes influencing consumer acceptance, they are primarily diagnostic in nature.

In contrast, the present study focused on overall acceptability using a structured 5-point hedonic scale, aiming to evaluate the practical viability of the reformulated products. Despite the use of a simplified sensory method, all formulations (CON, LF25, LF50, LF75, and LF100) achieved acceptability index values ≥ 70%, indicating consistent consumer acceptance across different levels of modification.

These findings suggest that, although advanced sensory tools such as CATA and JAR are valuable for identifying specific sensory drivers, simpler hedonic approaches remain effective for assessing overall product acceptance in applied studies. Moreover, the ability to maintain high acceptability across all formulations reinforces the robustness of the reformulation strategy, highlighting its potential for industrial application.

The use of consumer-based evaluation in this study provides greater external validity compared to trained panel assessments, reinforcing the applicability of the results in real market conditions. The present approach offers a more detailed and practical understanding of sensory acceptance in low-fat meat product development.

To complement the univariate analysis, internal preference mapping (IPM) was applied to capture consumer heterogeneity and multidimensional sensory perception. Across all attributes, the first two principal components explained between approximately 60% and 72% of the total variance, indicating a satisfactory representation of consumer preference patterns.

Internal Preference Mapping (IPM)

The IPM was performed exclusively on the individual consumer liking scores for each sensory attribute (color, flavor, aroma, consistency, purchase intention) and acceptability. The biplot displays the distribution of formulations and the individual consumer vectors (red arrows), representing the direction and intensity of consumer preference for each sample (Greenhoff; MacFie, 1994).

Regarding visual perception, the color map (Fig. 1) showed that LF25 and LF50 were positioned close to the control and aligned with a high density of consumer vectors, indicating similar acceptance patterns. In contrast, LF100 appeared clearly separated, suggesting that complete fat replacement negatively affected visual appeal.

A similar trend was observed for flavor (Fig. 2), where CON and LF75 occupied regions associated with a higher concentration of preference vectors, indicating strong consumer liking. LF100 was positioned in the opposite quadrant, reinforcing its lower acceptance and highlighting the importance of fat in flavor perception and release.

For aroma (Fig. 3), CON, LF50, and LF75 clustered in the same preference region, suggesting that intermediate levels of substitution preserved aromatic attributes. The isolation of LF100 again indicates a perceptual shift associated with total fat removal.

Texture-related perception, represented by consistency (Fig. 4), showed that LF50 and LF75 were closely associated with the control, confirming that green banana flour can partially mimic the structural role of fat. The displacement of LF100 supports the negative impact of complete fat removal on mouthfeel and product structure.

The purchase intention map (Fig. 5) integrates overall perception and revealed that CON, LF25, and LF75 were located in regions of higher consumer preference, while LF100 was distinctly separated, confirming its reduced market potential.

Finally, the overall acceptability map (Fig. 6) synthesized these findings, showing three clear clusters: (i) CON and LF75 with the highest acceptance, (ii) LF25 and LF50 with intermediate acceptance, and (iii) LF100 with consistently low preference. This distribution reinforces that partial fat replacement maintains consumer acceptance, whereas total replacement leads to a marked decline in sensory performance.

The IPM results also suggest the presence of consumer segmentation (Carbonell *et al.*, 2008; Meiselman, 2013). While the control formulation remained preferred by a considerable portion of the panel, LF75 frequently appeared in regions associated with positive preference vectors, indicating that a subgroup of consumers is receptive to higher levels of fat replacement. This may reflect a segment of health-conscious consumers willing to accept moderate sensory changes in exchange for improved nutritional attributes.

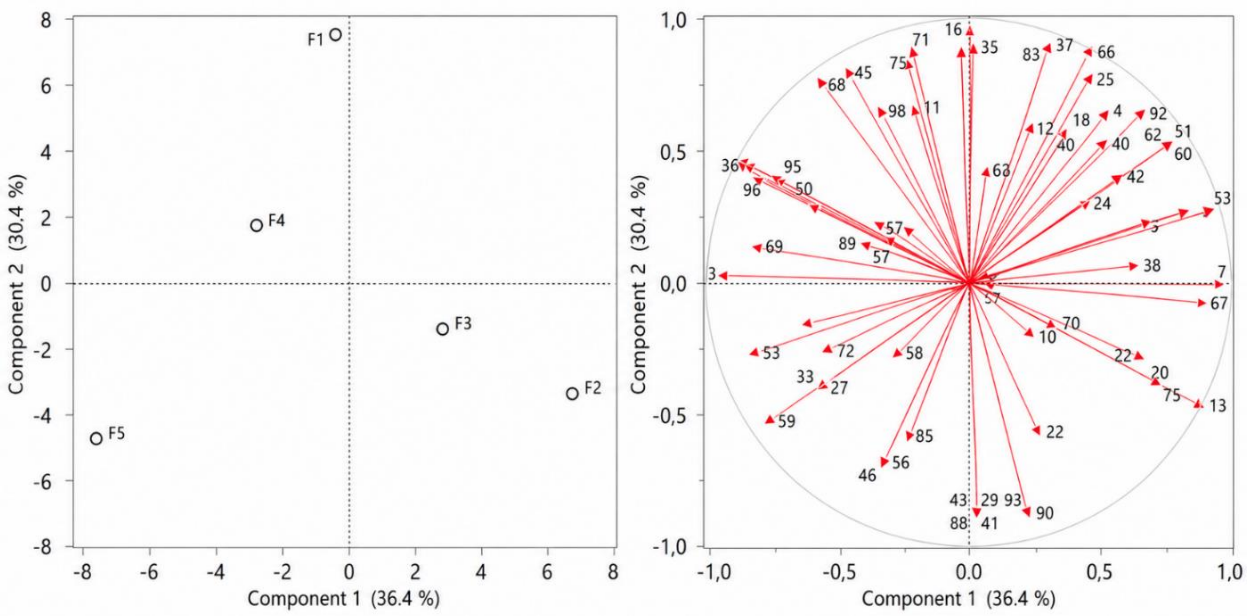

Figure 1. Internal preference map for product color. F1 (control): with 15% of ground pork back fat; F2, F32, F4, and F5: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

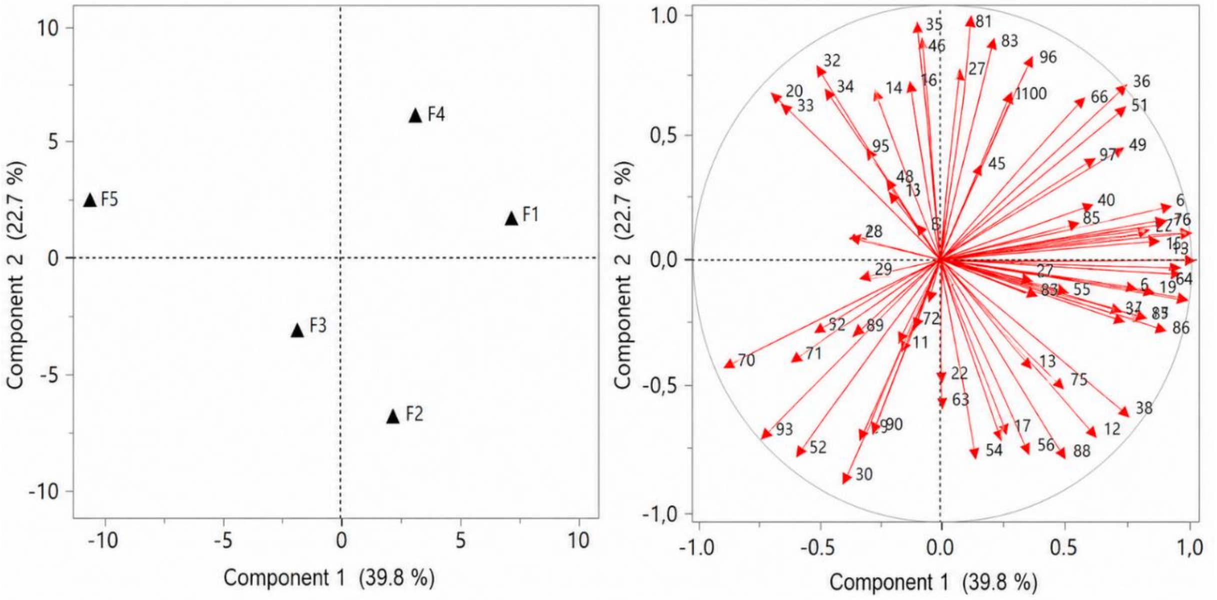

Figure 2. Internal preference map for product flavor. F1 (control): with 15% of ground pork back fat; F2, F32, F4, and F5: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

The dispersion of consumer vectors across all maps highlights the inherent variability in individual perception, particularly for flavor and aroma, reinforcing that acceptance depends not only on formulation but also on consumer expectations and prior experiences.

Overall, the integration of ANOVA and IPM demonstrates that intermediate levels of fat replacement (50–75%) represent an optimal balance between nutritional improvement and sensory quality. While partial substitution preserves acceptance and market potential, total replacement leads to a perceptual shift that negatively impacts consumer preference, limiting its practical application.

In recent decades, meat production and consumption have been increasingly scrutinized due to concerns related to environmental sustainability, animal welfare, and potential health risks (Font-i-Furnols, 2023; Macdonald, 2025). In this context, the emergence of flexitarian dietary patterns, characterized by a reduced but not excluded intake of meat (Dagevos, 2021; Derbyshire, 2017), reflects a shift in consumer behavior driven by these concerns. This trend has stimulated the development of alternative protein sources and reformulated meat products, aiming to meet consumer expectations regarding nutritional quality, technological functionality, and sensory acceptance.

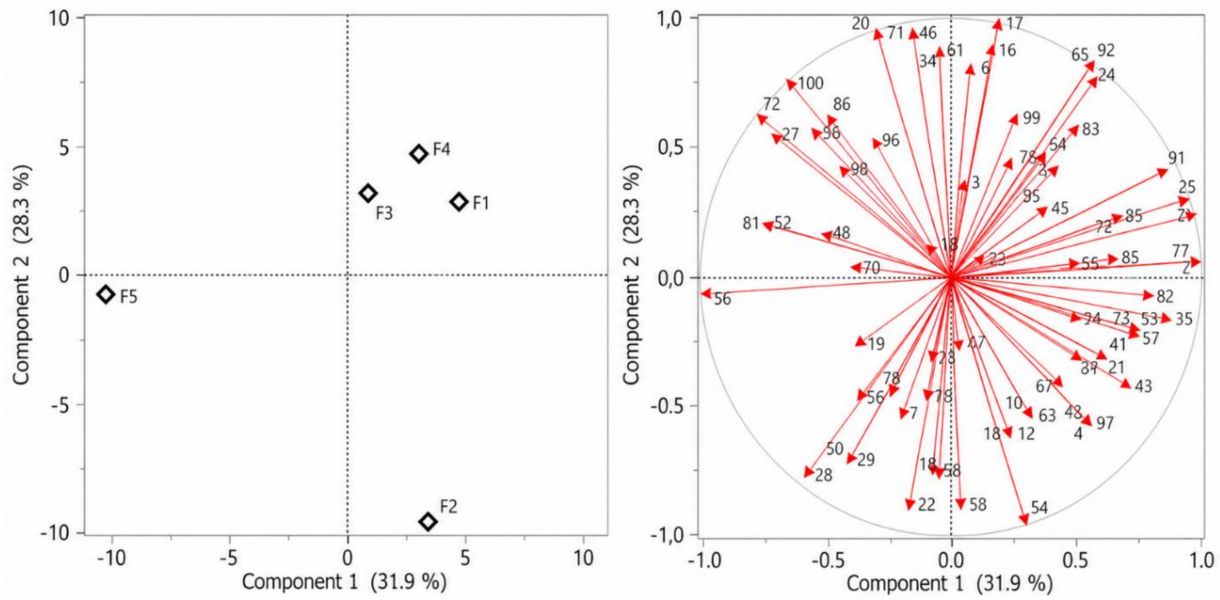

Figure 3. Internal preference map for product aroma. F1 (control): with 15% of ground pork back fat; F2, F32, F4, and F5: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

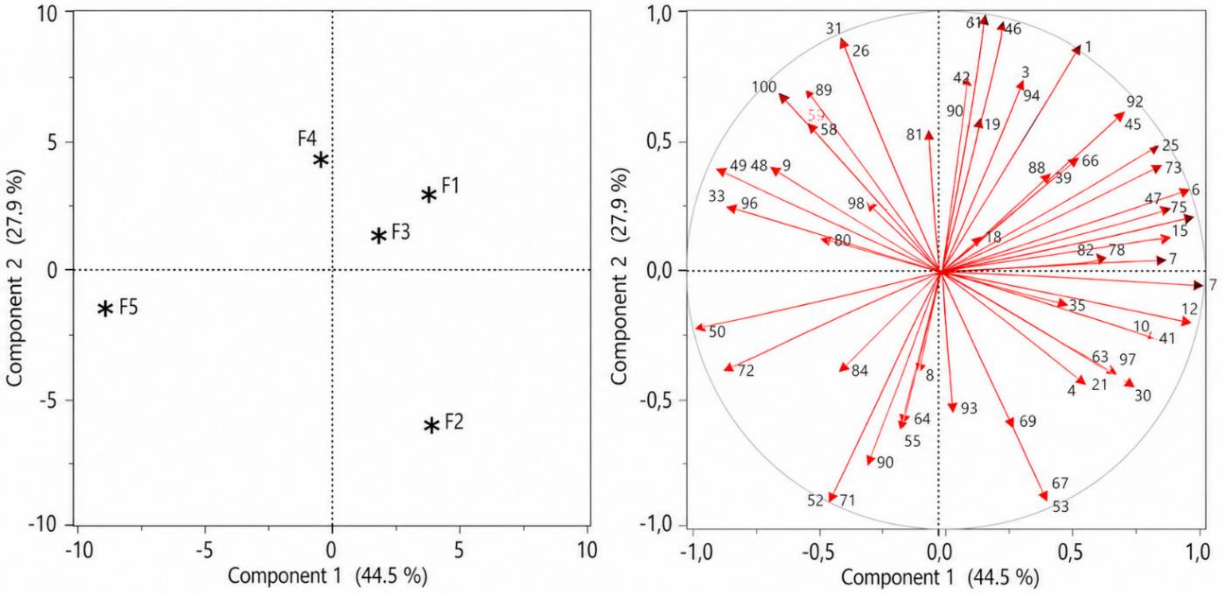

Figure 4. Internal preference map for product consistency. F1 (control): with 15% of ground pork back fat; F2, F32, F4, and F5: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

In this context, the present results are particularly relevant, as all formulations (CON, LF25, LF50, LF75, and LF100) achieved acceptability index values equal to or higher than 70%, indicating satisfactory consumer acceptance even with progressive modification of the product composition. This suggests that the applied reformulation strategy was effective in balancing technological improvements and sensory attributes, which is a key requirement for flexitarian-targeted products.

Therefore, the IPM results not only confirm the sensory feasibility of partial fat replacement but also highlight its strategic relevance for product development, supporting the design of meat products that align with current consumer trends toward healthier and more sustainable food systems. (Ares & Jaeger, 2015; Dagevos, 2021)."

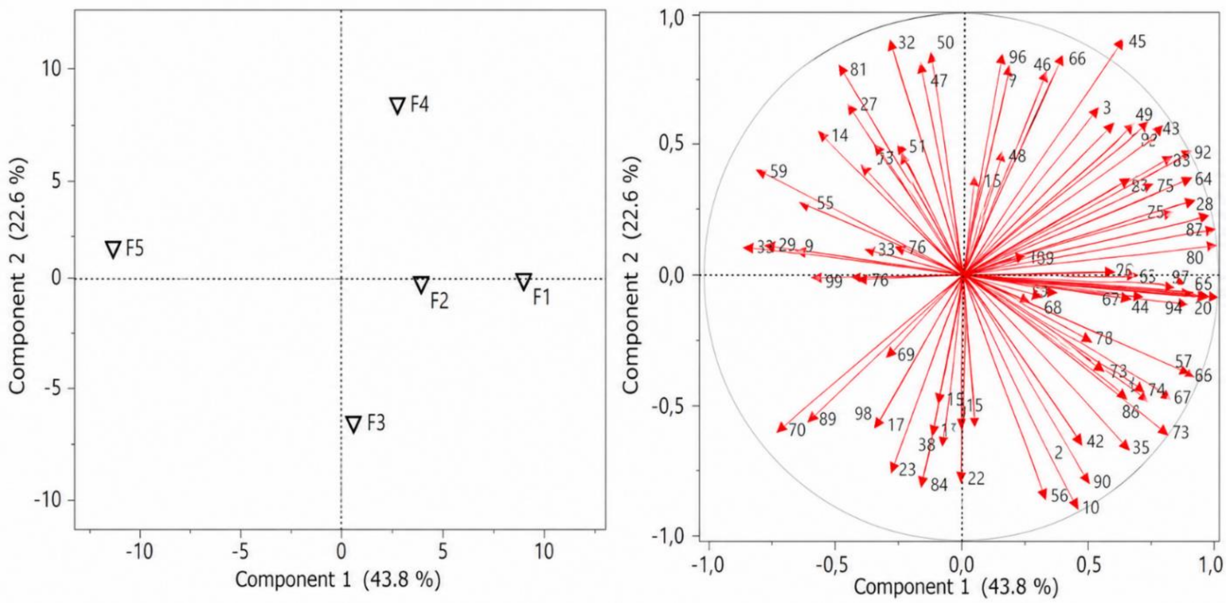

Figure 5. Internal preference map for purchase intention. F1 (control): with 15% of ground pork back fat; F2, F32, F4, and F5: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

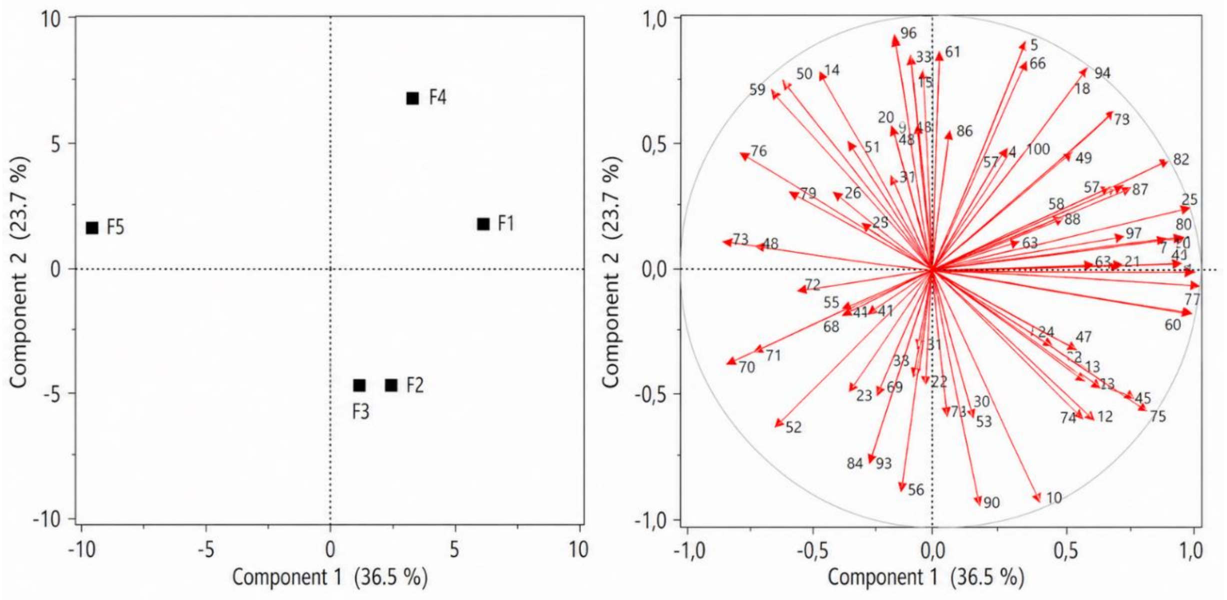

Figure 6. Internal preference map for overall acceptability of the formulations. F1 (control): with 15% of ground pork back fat; F2, F32, F4, and F5: low-fat burgers with replacement of pork fat by 25%, 50%, 75%, and 100% of green flour banana, respectively.

Conclusion

The results demonstrated that GBF has potential as a partial replacer of pork fat in hamburger formulations, since substitution levels of 25% to 50% maintained sensory acceptance comparable to the control product, while 75% replacement showed satisfactory performance for specific attributes such as aroma and consistency. In contrast, 100% replacement negatively affected consumer preference, indicating that complete fat substitution compromises sensory quality. Therefore, moderate incorporation of green banana flour represents a promising strategy to improve the nutritional profile of hamburgers without significant losses in consumer acceptability.

In addition, future studies may corroborate and expand the present findings by evaluating narrower replacement intervals, which could allow a more precise identification of the most suitable GBF incorporation level. Further investigations involving comprehensive instrumental analyses (e.g., texture, color, cooking loss, water-holding capacity, and lipid oxidation), shelf-life studies, and validation with larger consumer panels would also be valuable to confirm the technological applicability and commercial potential of this reformulation strategy.

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