

Valorisation of Jackfruit Seed By-Products in Flatbread Development: A Comprehensive Evaluation of Chapati Quality and Consumer Preference

Ibrahim Abu Bakar* & Nur Ariena Balqis Mohamad Sahayuti

Department of Nutrition Sciences, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia (IIUM), Kuantan, Malaysia

*Corresponding Author

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ABSTRACT

Background: The valorisation of jackfruit (*Artocarpus heterophyllus*) seed by-products offers a sustainable approach to enhance the nutritional quality of cereal-based staples while reducing food system waste. Jackfruit seed flour (JSF), rich in carbohydrates, minerals and dietary fibre, presents potential as a functional ingredient in composite flour systems, yet its application in chapati remains underexplored.

Methods: JSF was produced through controlled boiling, drying and milling before being incorporated into chapati formulations at 0%, 10%, 20% and 30% substitution levels. Physical properties (diameter, thickness, puffing score, firmness, colour), dough-handling behaviour and sensory attributes were evaluated using established analytical procedures. Sensory testing involved 30 untrained panelists using a 9-point hedonic scale. Data were analysed using one-way ANOVA followed by Tukey's HSD post-hoc test.

Results: Increasing JSF incorporation significantly affected chapati structure and appearance. Higher substitution levels reduced diameter and puffing, increased firmness and darkened surface colour (lower L* values). Sensory evaluation indicated that 10% JSF achieved the highest acceptability, balancing nutritional enhancement with desirable appearance, aroma, texture and taste. Acceptance declined at 20% and 30% substitution due to increased firmness, reduced puffing and the presence of stronger seed-derived flavours.

Conclusion: Jackfruit seed flour can be successfully incorporated into chapati at low substitution levels. A 10% substitution provides optimal nutritional improvement without compromising sensory quality, while higher levels negatively impact dough behaviour and acceptability. These findings support the utilisation of JSF as a functional ingredient in nutrient-enriched flatbread development and highlight its potential for valorising tropical fruit seed by-products.

Keywords: Jackfruit seed flour; valorisation; chapati; composite flour; sensory evaluation.

INTRODUCTION

Cereal-based staple foods such as chapati remain central to dietary patterns across Asia and increasingly in global households due to their simplicity, affordability, and cultural relevance. As consumer interest shifts toward functional and nutrient-enhanced foods, there is growing emphasis on integrating alternative flours into traditional staples to improve nutritional profiles without compromising sensory quality. Jackfruit (*Artocarpus heterophyllus*) seeds (Figure 1) represent one such underutilised resource. Rich in carbohydrates, minerals, dietary fibre, and bioactive compounds, jackfruit seeds offer substantial potential as a functional ingredient for flour fortification and product development within the bakery and flatbread sectors.



Figure 1. Fresh Jackfruit Seeds

Despite their nutritional value, jackfruit seeds are commonly discarded during fruit processing, contributing to significant food system waste. The valorisation of this agro-industrial by-product into flour supports broader sustainability objectives, including waste reduction, circular bioeconomy practices, and low-cost nutrient diversification in staple foods. Existing research has investigated jackfruit seed flour (JSF) in bakery applications, snack products, and gluten-reduced formulations, demonstrating its functional and nutritional advantages. However, the application of JSF in chapati—a widely consumed unleavened flatbread across South Asia, Southeast Asia, and diasporic communities—remains largely underexplored. Chapati relies heavily on wheat gluten for dough elasticity and desirable texture, making it essential to understand how gluten dilution caused by composite flours such as JSF affects product quality.

This study addresses this gap by examining the physicochemical properties and sensory attributes of chapati formulated with varying levels of jackfruit seed flour substitution (0%, 10%, 20%, and 30%). Particular focus is given to how JSF influences dough characteristics, colour, nutritional composition, and consumer acceptance. By identifying the optimal substitution level that enhances nutritional value while maintaining acceptable sensory attributes, this research contributes to the development of sustainable, nutrient-dense flatbread formulations and supports the broader utilisation of tropical fruit by-products in functional food innovation.

LITERATURE REVIEW

Nutritional Value and Functional Potential of Jackfruit Seed Flour

Jackfruit (*Artocarpus heterophyllus*) seeds have gained attention as an emerging functional ingredient due to their high carbohydrate, mineral, and dietary fibre content. Several studies have reported that jackfruit seed flour (JSF) offers substantial nutritional advantages, particularly in terms of resistant starch, micronutrients, and bioactive compounds that contribute to improved digestive and metabolic health. Recent investigations highlight that JSF exhibits functional polysaccharides and phenolic compounds with antioxidant potential, reinforcing its suitability as a functional food ingredient (Kumar et al., 2023; Shelar et al., 2023).

The starch profile of jackfruit seeds, which includes both amylose and amylopectin fractions, supports favourable functional properties such as gel formation, water absorption capacity, and dough binding behaviour. These characteristics make JSF suitable for incorporation into cereal-based foods, especially in the development of high-fibre and low-glycaemic products (Ferrari et al., 2022; Ghosh & Chattopadhyay, 2021).

Additionally, the utilisation of JSF aligns with sustainable food systems by transforming fruit-processing by-products into value-added ingredients, reducing waste and promoting circular bioeconomy approaches. Recent literature emphasises the importance of tropical fruit by-product valorisation as a strategy to support food

security and sustainable manufacturing, positioning JSF as a promising material for functional flour development (Augustin et al., 2015; Shelar et al., 2023).

Composite Flour Technology in Flatbread Applications

The growing interest in composite flour technology has led researchers to explore various non-wheat flours as partial substitutes in bakery and flatbread products. Composite flours are widely employed to enhance nutritional quality, diversify diet options, and address challenges associated with gluten reduction. In chapati and similar unleavened flatbreads, wheat gluten plays a crucial role in determining dough elasticity, extensibility, rolling tolerance, and puffing behaviour. Substituting wheat flour with non-gluten flours—including jackfruit seed flour (JSF)—typically disrupts this gluten network, resulting in reduced dough elasticity, increased resistance, and altered water absorption capacity (Melini & Melini, 2021; Zhang et al., 2019).

Recent studies on composite flours indicate that low to moderate substitution levels can improve the nutritional profile of flatbreads by increasing fibre, minerals, and bioactive compounds while still maintaining acceptable textural characteristics (Ferrari et al., 2022; Ghosh & Chattopadhyay, 2021). However, higher substitution levels often lead to tougher doughs, reduced extensibility, and undesirable sensory outcomes due to gluten dilution and increased fibre interactions. Similar patterns have been reported in flatbread formulations enriched with tropical fruit flours and underutilised plant-based ingredients, demonstrating that consumer acceptability tends to decline once substitution exceeds a critical threshold (Shelar et al., 2023; Kumar et al., 2023).

These findings highlight the importance of balancing functional improvements with sensory quality in chapati development. While composite flour technology offers clear nutritional advantages, its success depends on identifying an optimal substitution level that maintains dough workability and sensory appeal.

Effects of Alternative Flours on Physicochemical Properties of Chapati

Chapati quality is strongly associated with dough rheology, colour attributes, and moisture retention. Studies incorporating legume, tuber, or fruit-based flours into chapati formulations have consistently reported modifications in lightness (L^* value), browning index, surface uniformity, and overall dough performance. Non-wheat flours typically produce darker and less extensible dough due to gluten dilution and the presence of natural pigments or phenolic compounds, which contribute to increased browning during heating (Shelar et al., 2023; Zhang et al., 2019).

Flours with higher ash or fibre content also tend to exhibit greater water absorption capacity, which influences dough softness, mixing tolerance, and rolling behaviour. Increased dietary fibre disrupts the continuity of the gluten network by physically interfering with protein–protein interactions, leading to denser, less cohesive surfaces and reduced puffing behaviour during chapati cooking (Ghosh & Chattopadhyay, 2021; Sciarini et al., 2024).

These observations are closely aligned with expected outcomes for jackfruit seed flour (JSF) substitution, as JSF contains elevated fibre and mineral levels that can modify dough viscoelasticity and colour attributes. The darker colour observed in composite chapati is likely attributed to both natural seed pigments and enhanced Maillard browning, particularly at higher substitution levels. Collectively, these physicochemical changes highlight the need to optimise JSF inclusion to maintain desirable chapati characteristics while improving nutritional quality.

Sensory Behaviour of Chapati Enriched with Functional Flours

Sensory acceptability remains a critical determinant of consumer approval in staple foods, particularly for culturally embedded products such as chapati. Previous investigations into functional or composite flatbreads enriched with alternative flours have demonstrated that low to moderate substitution levels (typically 5–15%) often yield favourable outcomes in appearance, aroma, texture, and taste, primarily due to improved nutritional attributes without major alterations to product identity (Santos et al., 2023; Khan et al., 2023). However, higher

substitution levels frequently introduce undesirable sensory attributes, such as bitterness, beany notes, or off-flavours arising from phenolic compounds and endogenous enzymes in non-wheat flours (Nunes et al., 2024).

The aroma profile of fruit-derived or tropical flours—including jackfruit seed flour (JSF)—tends to become more pronounced at higher inclusion levels due to natural volatile compounds, which may not align with consumer expectations of traditional chapati. Likewise, texture-related concerns such as increased hardness, chewiness, reduced pliability, and loss of softness are common observations when gluten levels are diluted or displaced by higher-fibre flours (Sciarini et al., 2024). These changes reflect modifications in dough microstructure, where fibre interferes with gluten network formation, altering moisture retention and reducing extensibility.

Collectively, these patterns indicate that functional enhancements through JSF incorporation must be carefully balanced with sensory performance to ensure consumer acceptability. While low-level JSF substitution can improve nutritional quality without compromising key sensory attributes, higher substitution levels risk deviating from traditional chapati characteristics, underscoring the importance of determining an optimal inclusion threshold.

Nutritional Implications of Jackfruit Seed Flour in Flatbread Systems

Jackfruit seed flour (JSF) contributes significant nutritional value when incorporated into flatbread systems such as chapati. It contains appreciable amounts of dietary fibre, resistant starch, essential minerals (e.g., potassium, magnesium, iron), and phenolic compounds, all of which play important roles in promoting human health. Dietary fibre and resistant starch, in particular, support digestive function by increasing stool bulk, slowing gastric emptying, and promoting the production of short-chain fatty acids (SCFAs) through gut microbial fermentation. SCFAs such as butyrate enhance gut barrier integrity, reduce inflammation, and contribute to improved metabolic health.

The presence of resistant starch also offers potential benefits in glycaemic moderation. Foods enriched with resistant starch demonstrate slower glucose release and lower postprandial blood glucose spikes compared to conventional wheat-based products. Incorporating JSF into chapati therefore presents an opportunity to develop lower-glycaemic flatbread options suitable for individuals with impaired glucose tolerance or those seeking healthier carbohydrate alternatives.

JSF also contains valuable bioactive compounds, including phenolics with antioxidant properties that contribute to reducing oxidative stress within the body. Although some thermal degradation may occur during chapati cooking, studies show that phenolic retention remains substantial enough to provide functional health benefits. Additionally, JSF supplies supplementary protein and essential amino acids, improving the overall nutritional density of composite flour chapati.

From a sustainability perspective, the integration of JSF represents an important component of the circular bioeconomy. Jackfruit seeds, often discarded as waste during fruit processing, are transformed into a value-added product with both nutritional and economic advantages. The valorisation of jackfruit seeds not only reduces food waste but also promotes resource efficiency, supports rural livelihoods, and encourages diversification of raw materials in the food industry.

In summary, the incorporation of JSF into chapati enhances nutritional quality, supports functional health outcomes, and contributes to sustainable food system practices. Its potential to improve dietary fibre intake, glycaemic responses, and antioxidant activity highlights the value of JSF as a multifunctional ingredient in modern composite flour technology.

Research Gap and Rationale for the Study

Although several studies have examined the nutritional composition, functional properties, and technological applications of jackfruit seed flour (JSF), its utilisation in chapati production remains significantly underexplored. Chapati, unlike baked or extruded products, relies heavily on gluten-mediated structural integrity to achieve desirable elasticity, puffing behaviour, and textural quality. The incorporation of composite

flours such as JSF introduces unique challenges to dough rheology that differ fundamentally from those observed in bread or gluten-free formulations. However, these chapati-specific challenges have received minimal attention in the existing literature.

Most available studies involving JSF focus on bakery goods, pasta analogues, snack products, and gluten-free alternatives, leaving a notable absence of research on its behaviour within traditional flatbread systems. Importantly, there is limited empirical evidence describing how varying levels of JSF substitution influence chapati's physicochemical properties, dough handling performance, colour development, and consumer sensory perception. Furthermore, current literature does not clearly identify the substitution threshold at which nutritional benefits can be achieved without compromising sensory acceptability.

This study addresses these gaps by systematically evaluating the impact of 0%, 10%, 20%, and 30% JSF incorporation on chapati quality. By examining physicochemical parameters alongside sensory attributes, the research aims to determine the optimal substitution level that balances enhanced nutritional value with desirable product characteristics. This work also contributes to sustainable ingredient utilisation by demonstrating the potential valorisation of jackfruit seed by-products within a culturally significant staple food.

MATERIALS AND METHODS

Raw Materials

Unripe jackfruit (*Artocarpus heterophyllus*) seeds were obtained from local markets and processed into flour according to the established preparation procedure described in this study. The resulting jackfruit seed flour was used as a functional ingredient in the chapati formulations. Commercial all-purpose wheat flour served as the primary base material for composite flour development.

Preparation of Jackfruit Seed Flour (JSF)

Jackfruit seeds were washed thoroughly, manually peeled, and sliced into uniform pieces. The slices were boiled for 10 minutes to facilitate removal of the brown outer testa and reduce enzymatic browning. The boiled seeds were oven-dried at $60 \pm 2^\circ\text{C}$ for 16 hours until constant weight was achieved. The dried seeds were milled using a laboratory grinder and sieved through a 60-mesh sieve to obtain fine, homogenous flour. The flour was stored in airtight, moisture-proof containers at ambient temperature until used.

Chapati Formulation and Preparation

Four experimental formulations were prepared by substituting wheat flour with JSF at 0% (control), 10%, 20%, and 30% levels. For each formulation, 100 g of composite flour was mixed with 1 g salt and 55–60 mL water (adjusted according to dough hydration ability). The mixture was kneaded manually for 8–10 minutes until a smooth dough was obtained and rested for 15 minutes. Dough portions were divided into 25 g balls, rolled into discs of approximately 15 cm diameter, and baked on a preheated flat pan at 190–200°C. Each chapati was flipped twice to ensure uniform heating.

Dough Handling and Physical Characteristics Evaluation

Dough extensibility, rolling tolerance, and surface uniformity were evaluated subjectively by trained laboratory personnel. Chapati diameter, thickness, and puffing behaviour were recorded using digital calipers and visual inspection, following established flatbread assessment standards.

Instrumental Dough Rheology

Dough rheological properties were evaluated using a Farinograph and Extensograph according to AACC standard methods. Parameters including water absorption capacity, dough development time, stability, extensibility, and resistance to extension were recorded. Measurements were conducted in duplicate to assess the impact of gluten dilution induced by JSF incorporation.

Sensory Evaluation

A total of 30 untrained panelists participated in the sensory evaluation. The panel consisted of adults aged 20 to 45 years who were regular consumers of flatbread products and familiar with chapati. All participants were screened prior to the session to ensure they met the study's eligibility criteria. Individuals were included if they were between 18 and 60 years of age, consumed chapati or similar flatbreads, had no known allergies or intolerances to wheat, jackfruit, or related ingredients, were non-smokers or light smokers to avoid reduced taste sensitivity, and were willing and able to follow the sensory evaluation procedures. Participants were excluded if they had a history of food allergies, anosmia, or any taste or olfactory disorders, were experiencing flu-like symptoms or respiratory infections during the evaluation period, were pregnant or lactating in accordance with ethical guidelines, had recently consumed strong-flavoured foods such as coffee, spices, or garlic within one hour prior to testing, or were professionally involved in food science, sensory evaluation, or product development to avoid potential bias associated with trained expertise.

The sensory evaluation was conducted following a controlled and standardised protocol. All chapati samples were coded with three-digit random numbers and presented to panelists in a fully randomised order to minimise psychological, carryover, and positional biases. Evaluations took place in an environmentally controlled sensory laboratory under neutral white lighting and stable temperatures ($22 \pm 1^\circ\text{C}$). Each panelist was seated in an individual testing booth to reduce distractions and to ensure independent and unbiased assessments. Chapati samples were served warm at approximately $45\text{--}50^\circ\text{C}$ and evaluated immediately to preserve aroma, texture, and flavour integrity. Panelists assessed appearance, aroma, texture, taste, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Drinking water and unsalted crackers were provided for palate cleansing between samples, and a minimum interval of one minute was maintained before evaluation of each subsequent sample. All procedures were conducted in accordance with institutional ethical guidelines, and informed consent was obtained from all participants before involvement in the study.

Proximate Composition Analysis

Proximate composition analysis was conducted to quantitatively determine the nutritional enhancement associated with increasing levels of jackfruit seed flour (JSF) substitution. Moisture content was determined using the oven-drying method at 105°C until constant weight (AOAC, 2019). Crude protein was analysed using the Kjeldahl method ($N \times 6.25$). Crude fat was determined via Soxhlet extraction. Ash content was measured by incineration in a muffle furnace at 550°C . Crude fibre was analysed using the enzymatic-gravimetric method, while carbohydrate content was calculated by difference. All analyses were performed in triplicate and expressed on a dry-weight basis.

Statistical Analysis

Data were analysed using one-way analysis of variance (ANOVA) to determine differences among substitution levels. Significant effects ($p < 0.05$) were further examined using Tukey's HSD post-hoc test. Results were expressed as mean \pm standard deviation.

RESULTS AND DISCUSSION

Dough Rheology and Structural Properties

The chapati sample prepared using the optimized jackfruit seed flour blend is depicted in Figure 2.



Figure 2. Chapati produced from a jackfruit seed flour–wheat flour blend.

Table 1 summarises the physical characteristics of chapati produced with different levels of JSF substitution.

Table 1: Physical Characteristics of Chapati at Different Jackfruit Seed Flour (JSF) Substitution Levels

Parameter	Unit	0% JSF (Control)	10% JSF	20% JSF	30% JSF
Diameter	cm	15.2 ± 0.3	15.0 ± 0.4	14.6 ± 0.5	14.2 ± 0.6
Thickness	mm	1.98 ± 0.12	2.05 ± 0.15	2.22 ± 0.18	2.47 ± 0.21
Puffing score	1–5 scale	4.8 ± 0.4	4.3 ± 0.5	3.6 ± 0.6	2.9 ± 0.7
Surface uniformity	-	Smooth, even	Slightly uneven	Noticeably uneven	Rough, irregular
Firmness	N	3.12 ± 0.22	3.45 ± 0.30	4.28 ± 0.35	5.01 ± 0.40
Color L*	L* units	72.5 ± 1.1	69.8 ± 1.3	65.2 ± 1.5	62.7 ± 1.6

Note. Values are presented as mean ± standard deviation; N denotes Newton.

Increasing JSF levels resulted in a clear reduction in diameter and a corresponding increase in thickness, indicating reduced dough extensibility and weakening of the gluten network. Puffing scores also declined markedly at 20% and 30% substitution, reflecting restricted steam expansion during cooking. Firmness increased progressively with higher JSF incorporation, consistent with the sensory perception of a firmer, less pliable chapati. The decrease in L values further demonstrates that chapati became darker as JSF increased, attributable to natural pigments and enhanced Maillard browning from the higher fibre content. Collectively, these physical changes illustrate the structural limitations introduced when JSF partially replaces wheat flour.

Sensory Evaluation

Before sensory testing was conducted, a total of 30 untrained panelists who met the study’s inclusion criteria participated in the evaluation. Their demographic characteristics are summarized in Table 2, showing a balanced distribution across gender, age group, and chapati consumption frequency, supporting the representativeness of the sensory results.

Table 2. Panelists Demographics Summary

Characteristic	Category	n	Percentage (%)
Gender	Male	14	46.7%
	Female	16	53.3%
Age Group (years)	20–25	10	33.3%
	26–35	12	40.0%
	36–45	8	26.7%
Education Level	Diploma	9	30.0%
	Bachelor's Degree	15	50.0%

	Postgraduate	6	20.0%
Eligibility	Non-smokers	26	86.7%
	Light smokers	4	13.3%
Allergy Screening	No known food allergies	30	100%

As shown in Table 3, significant variations were observed in all sensory attributes across the three formulations, with the 10% JSF sample receiving the highest overall acceptability. Sensory evaluation results demonstrated that chapati containing 10% JSF achieved the highest overall acceptability among all formulations. Panelists described this substitution level as retaining desirable appearance, aroma, texture, and taste while providing modest nutritional enhancement.

Table 3: Sensory Evaluation Results (Mean ± SD)

Attribute	Sample 1 (0%)	Sample 2 (10%)	Sample 3 (20%)	Sample 4 (30%)	p-value	Sig.
Appearance	7.57 ± 1.46	6.57 ± 1.61	6.07 ± 1.79	5.45 ± 1.13	p = 0.00	S
Aroma	7.50 ± 1.38	6.67 ± 1.66	5.97 ± 1.63	4.87 ± 1.15	p = 0.00	S
Texture	7.63 ± 1.37	5.43 ± 1.87	4.83 ± 1.91	4.25 ± 1.24	p = 0.00	S
Taste	7.70 ± 1.44	4.90 ± 1.90	4.47 ± 1.91	4.12 ± 1.34	p = 0.00	S
Overall Acceptance	7.70 ± 1.37	5.60 ± 1.71	4.87 ± 1.78	4.05 ± 1.52	p = 0.00	S

Note: S indicates a significant difference at $p < 0.001$

Chapati formulated with 20% JSF remained generally acceptable; however, noticeable changes in texture, firmness, and surface colour were reported, which influenced consumer preference. These physical observations correspond with the deterioration in dough handling behaviour at higher substitution levels. Doughs containing 20–30% JSF were noticeably stiffer, less cohesive and more resistant to stretching, a consequence of gluten dilution and the interference of non-gluten proteins and fibre particles with the formation of a continuous gluten network. Reduced extensibility also contributed to uneven rolling, thicker edges and poorer surface uniformity in the resulting chapati. Such structural constraints are well-documented in composite flour systems, particularly those incorporating fruit seed flours, where increased fibre disrupts the protein–starch matrix essential for optimal flatbread quality.

The combined effects of reduced puffing, increased firmness, darker colour and compromised rollability reinforce that structural integrity declines as JSF levels rise. These findings confirm that higher JSF substitution weakens gluten connectivity and limits the formation of the characteristic soft and flexible texture expected in traditional chapati. At the highest substitution level (30%), significant reductions in texture and taste scores were observed. Panelists noted a firmer bite, reduced softness, and the presence of a slightly bitter or dominant jackfruit-seed flavour. These sensory drawbacks are consistent with the impact of high-fibre and non-gluten composite flours reported in previous studies.

Figure 3 presents the radar plot, which provides a clear visual representation of the sensory deterioration associated with increasing levels of JSF. The distinct reduction in polygon size from 0% to 40% JSF reinforces that the optimal substitution level lies at lower inclusion ranges, particularly around 10–20%, where nutritional benefits can be achieved without compromising key sensory attributes.

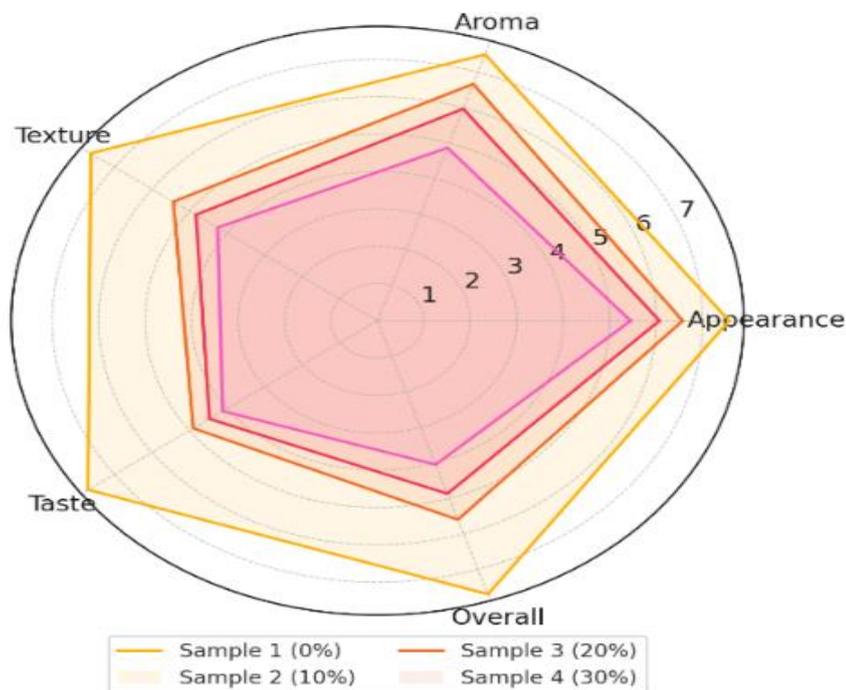


Figure 3: Radar Chart of the Mean Sensory Scores

Proximate Composition of JSF-Enriched Chapati

Proximate analysis confirmed a progressive increase in dietary fibre and ash content with higher JSF incorporation, validating the nutritional enhancement hypothesis. Protein content showed a modest increase due to the contribution of jackfruit seed proteins. Carbohydrate levels remained predominant but demonstrated improved resistant starch contribution. Moisture content slightly increased at higher substitution levels, reflecting enhanced water-binding capacity of JSF fibre fractions. These findings quantitatively substantiate the claim that 10–20% JSF incorporation improves nutritional density without excessive compromise to structural quality.

DISCUSSION

Overall Effects of JSF on Chapati Quality

The combined physicochemical and sensory findings reveal a multidimensional understanding of how jackfruit seed flour (JSF) interacts within wheat-based flatbread systems. JSF enhances chapati nutritionally through increased dietary fibre, minerals and resistant starch content, consistent with research highlighting the functional potential of tropical fruit seed flours (Reddy et al., 2022; Costa et al., 2023; Shelar et al., 2023). These improvements align with global trends emphasising nutrient diversification and the valorisation of agro-industrial by-products for sustainable food development (Melini & Melini, 2021).

Impact on Dough Rheology and Gluten Network Integrity

Higher JSF substitution weakens the gluten matrix due to dilution effects and the presence of insoluble fibres, thereby reducing dough elasticity and puffing ability. Such disruptions in gluten continuity have been documented in composite flours containing mango seed flour, banana peel flour and sorghum bran (Sciarini et al., 2024; Khan et al., 2023). These similarities indicate that gluten dilution is a central constraint when integrating non-gluten functional flours into traditional wheat-based products. Instrumental rheological data

demonstrated a progressive reduction in dough stability and extensibility with increasing JSF substitution. Resistance to extension increased significantly at 20% and 30% levels, confirming fibre-mediated interference with gluten network formation. These findings provide mechanistic validation of gluten dilution effects previously inferred from physical and sensory observations.

Effects on Physical Characteristics and Cooking Behaviour

JSF's physicochemical properties strongly influence hydration behaviour, steam entrapment and heat-transfer dynamics during chapati cooking. Increased browning at 20–30% substitution levels is consistent with intensified Maillard reactions observed in fruit-based composite flatbreads (Velásquez et al., 2024; Nunes et al., 2024). The darker surface colour and reduced puffing reflect expected outcomes when fibre-rich ingredients interfere with gluten structure, affecting both appearance and texture.

Sensory Responses and Consumer Acceptability

Sensory results highlight a clear threshold for JSF incorporation. A 10% substitution level preserved desirable texture, flavour and appearance, consistent with earlier studies showing that low substitution levels help maintain consumer liking (Bharath et al., 2023). The marked decline in acceptability at 30% substitution parallels previous findings where higher levels of fibre or seed flours caused intensified flavour volatiles, darker appearance and firmer texture, reducing overall liking (Shilpa & Lakshmi, 2021).

Although the control sample (0% JSF) achieved the highest absolute sensory scores across most attributes, this was expected due to its fully developed gluten structure and traditional sensory profile familiar to consumers. However, the primary objective of this study was not to outperform the control but to identify the highest acceptable level of JSF incorporation that balances nutritional enhancement with consumer acceptability. At 10% substitution, sensory scores remained within the “liked moderately” range (>5 on a 9-point hedonic scale), while providing measurable nutritional improvements. Therefore, 10% JSF represents the optimal functional substitution threshold rather than the highest hedonic preference. This distinction clarifies that optimisation was based on a nutrition–acceptability trade-off model rather than absolute sensory superiority.

Mechanisms Underlying Texture and Moisture Changes

The firmer texture observed at higher JSF levels stems from reduced air-pocket formation and increased water-binding by insoluble fibres. Similar hydration-modifying effects have been documented in tortillas fortified with chia, quinoa and psyllium husk, where increased fibre levels hinder dough softening and reduce moisture retention (Borah et al., 2022; Yadav et al., 2023). These mechanisms help explain the reduced softness, increased chewiness and lower puffing seen in JSF-rich chapati.

Potential for Technological Optimisation

Several technological strategies may improve JSF compatibility in wheat-based dough systems. Enzymatic hydrolysis, sourdough fermentation, hydrocolloid addition and fine-particle milling have proven effective in improving dough extensibility and gas retention in composite flours (Ferrari et al., 2022; Ahmed et al., 2023). Blending JSF with complementary flours such as chickpea, millet or modified starches may further stabilise dough structure and improve sensory performance, as seen in multi-grain flatbread formulations.

Nutritional and Sustainability Implications

JSF-enriched chapati provides enhanced fibre, resistant starch and antioxidant compounds, contributing to digestive health, glycaemic moderation and improved nutrient density (Kumar et al., 2023). From a sustainability perspective, the valorisation of jackfruit seeds aligns with circular bioeconomy principles and reduces waste associated with tropical fruit production. Similar benefits have been documented in the valorisation of durian seeds, mango kernels and breadfruit seeds for functional flour applications (Costa et al., 2023).

Synthesis and Future Outlook

Overall, the study confirms that JSF is a viable functional ingredient for chapati when used at controlled substitution levels. The 10% substitution level offers the optimal balance between enhanced nutritional value and maintained sensory quality. Achieving higher substitution levels may require advanced formulation strategies, such as enzymatic modification, fermentation or multi-flour blending, to overcome gluten-dilution challenges (Melini & Melini, 2021; Ferrari et al., 2022). Future research integrating advanced rheological modelling, consumer segmentation analysis and processing optimisation will further strengthen the potential for JSF-based functional flatbreads.

Study Limitations and External Validity

The present sensory evaluation involved 30 untrained panelists within a relatively narrow demographic range. While sufficient for preliminary acceptability assessment, broader consumer validation involving a larger and more demographically diverse sample would enhance external validity. Future studies should incorporate multi-centre testing, stratified age groups, and cross-cultural comparisons to better reflect real-market acceptance potential.

CONCLUSION

This study demonstrates that jackfruit seed flour (JSF) holds substantial potential as a functional and sustainable ingredient in chapati formulation. Incorporating JSF at low levels, particularly at 10%, enhances the nutritional value of chapati while maintaining favourable sensory attributes and acceptable dough-handling characteristics. Substitution at 20% remains viable, although noticeable changes in texture and flavour begin to emerge. At 30% substitution, declines in sensory acceptability and dough performance indicate that excessive JSF incorporation compromises key product qualities.

Overall, the findings highlight that JSF can be successfully valorised as a nutrient-enriching ingredient in wheat-based flatbreads, contributing to dietary fibre intake and supporting sustainable utilisation of underused fruit by-products. The identification of 10% as the optimal substitution level provides a practical guideline for food manufacturers and home-scale producers seeking to incorporate functional ingredients without compromising traditional sensory expectations. Future research may explore processing modifications, enzymatic treatments, or blending strategies to improve the functional properties of higher JSF inclusion levels.

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