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Physicochemical, Nutritional, and Sensory Characteristics of Wheat-Based Cookies Enriched with a Four-Millet Composite Flour During Storage

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Abstract

The increasing demand for convenient foods with improved nutritional characteristics has stimulated interest in the development of bakery products incorporating nutritionally diverse cereal grains. The present investigation evaluated the effects of graded incorporation of a composite flour comprising sorghum, pearl millet, finger millet and foxtail millet on the nutritional, physicochemical, textural and sensory characteristics of wheat-based cookies and assessed selected quality changes during storage. Four formulations were prepared by replacing wheat flour with an equal-proportion four-millet composite flour at 0, 16, 44 and 64%, designated T_0, T_1, T_2 and T_3, respectively. Proximate composition, spread ratio, instrumental hardness and sensory attributes were evaluated. T_0 and T_2 were subsequently selected for a 30-day storage study at room temperature, with measurements at 0, 15 and 30 days. Increasing millet incorporation significantly altered the proximate composition ($p \leq 0.05$). Moisture, protein, ash and crude fibre increased from 3.21 to 4.05%, 7.85 to 10.72%, 1.20 to 2.05% and 0.85 to 3.20%, respectively, whereas fat and calculated carbohydrate decreased from 18.40 to 17.35% and 68.49 to 62.68%, respectively. Spread ratio declined significantly from 7.80 ± 0.12 in T_0 to 6.40 ± 0.16 in T_3, while hardness increased from 2.10 ± 0.09 to 3.15 ± 0.06 N. T_2 achieved an overall sensory score of 8.30 compared with 8.40 for T_0. During storage, moisture and peroxide values increased progressively, accompanied by a gradual decline in sensory acceptability. At 30 days, T_0 recorded 3.85% moisture, 0.55 meq O_2 kg^{-1} oil peroxide value and 7.85 overall sensory score, whereas T_2 recorded 4.40%, 0.65 meq O_2 kg^{-1} oil and 7.70, respectively. The findings demonstrate that four-millet composite flour can substantially modify the nutritional and technological characteristics of wheat-based cookies while maintaining good sensory acceptability at the intermediate substitution level investigated.

1. Introduction

The growing demand for convenient foods with improved nutritional quality has encouraged researchers to reconsider the composition of conventional bakery products. Cookies are particularly suitable for such reformulation because their familiar format permits the incorporation of alternative cereal flours, fibre-rich materials and other nutritionally valuable ingredients without requiring major changes in consumer use. Previous investigations have established that modifying bakery formulations can influence nutritional composition, physicochemical behaviour and sensory properties simultaneously (Handa et al., 2012; Ajila et al., 2008; Asadi et al., 2021).

Millets have attracted renewed attention as versatile cereal resources because of their nutritional diversity and potential contribution to food-system diversification. Sorghum, pearl millet, finger millet and foxtail millet differ in their proportions of protein, dietary fibre, minerals and other bioactive constituents. Combining these grains in a composite flour may therefore provide a broader nutritional contribution than reliance on a single alternative cereal (Kumar et al., 2017; Mishra et al., 2023; Shilpa et al., 2024). Finger millet is particularly recognized for its mineral contribution, while sorghum, pearl millet and foxtail millet provide complementary nutritional and functional characteristics.

The technological performance of millet flour in wheat-based bakery products is influenced by several factors, including fibre concentration, starch characteristics, water absorption, particle size and the dilution of wheat gluten. As the proportion of non-wheat flour increases, changes in dough development and water distribution can affect the dimensional, textural and sensory properties of the finished product (Biradar et al., 2020; Priya et al., 2025). Consequently, nutritional improvement through cereal substitution must be considered alongside processing performance and product acceptability.

A number of studies have demonstrated that incorporation of millet and other cereal ingredients can improve selected nutritional characteristics of bakery products. Increased protein, fibre and mineral-associated fractions have been reported in cereal-based formulations containing alternative grains (Galla et al., 2016; Arepally et al., 2020; Sreeja et al., 2024). However, the magnitude and direction of these changes depend on the cereal species, substitution level, flour characteristics and overall formulation.

Composite flour systems offer an additional opportunity to combine complementary properties of different grains. Such formulations can broaden the nutrient profile while potentially moderating the technological limitations associated with excessive reliance on a single alternative flour (Jan et al., 2020; Sharma et al., 2020; Singh et al., 2021). Studies involving composite cereal and millet products have further shown that formulation changes can influence texture, flavour, appearance and overall sensory acceptance (Malik et al., 2024; Man et al., 2021; Kumar et al., 2022).

The development of a nutritionally improved product must also consider its behaviour during storage. Although cookies are relatively low-moisture foods, changes in moisture distribution can influence crispness and textural quality, while oxidation of susceptible lipids can progressively affect flavour and acceptability. Storage behaviour is influenced by the food matrix, packaging, environmental conditions and formulation composition (Gupta et al., 2023; Yadav et al., 2022).

Previous investigations have explored composite cereal and millet formulations for bakery applications and have reported opportunities for nutritional improvement while retaining acceptable sensory characteristics (Casado et al., 2017; Kaur et al., 2021; Ojha et al., 2022). More recent studies have continued to emphasize the potential of cereal-based composite systems for developing nutritionally enriched bakery foods (Reda and Woldemariam, 2024; Sharma et al., 2025; Urooj et al., 2026). Nevertheless, comparatively limited information is available concerning cookies formulated with a composite flour containing sorghum, pearl millet, finger millet and foxtail millet simultaneously, particularly when nutritional composition, physical characteristics, instrumental fracture behaviour, sensory quality and storage changes are evaluated together.

Therefore, the present study was undertaken to determine the effect of graded incorporation of an equal-proportion four-millet composite flour on the proximate composition, spread ratio, instrumental hardness and sensory characteristics of wheat-based cookies. In addition, selected quality changes in representative formulations were monitored during 30 days of ambient storage using moisture content, peroxide value and overall sensory acceptability as indicators.

2. Materials and Methods

2.1 Experimental materials

Wheat flour and four millet flours—sorghum, pearl millet, finger millet and foxtail millet—were used for cookie preparation. The four millet flours were combined in equal proportions to produce the composite millet flour. The resulting composite flour was incorporated into wheat flour at different substitution levels.

2.2 Experimental formulation

Four formulations were prepared on a 100 g flour basis. Wheat flour was progressively replaced by the equal-proportion composite millet flour at 0, 16, 44 and 64% substitution levels. The treatments were designated T_0, T_1, T_2 and T_3, respectively.

Table 1
Formulation of wheat-based cookies containing four-millet composite flour

Treatment	Wheat flour (g)	Sorghum (g)	Pearl millet (g)	Finger millet (g)	Foxtail millet (g)	Total flour (g)	Millet substitution (%)
T_0	100	0	0	0	0	100	0
T_1	84	4	4	4	4	100	16
T_2	56	11	11	11	11	100	44
T_3	36	16	16	16	16	100	64

The formulation was standardized to a total flour basis of 100 g per treatment.

2.3 Preparation of cookies

Fat and sugar were initially creamed to obtain a homogeneous mixture. The flour components and other dry ingredients were mixed separately and incorporated into the creamed mixture, followed by addition of the remaining ingredients. The resulting mixture was worked into a uniform dough. The dough was sheeted and cut into cookies of uniform form and subsequently baked at **180°C for 15 min**. The baked cookies were cooled to room temperature before analysis.

The quantities of individual non-flour ingredients were not available in the retained experimental record and have therefore not been reconstructed.

2.4 Proximate composition

Moisture, protein, fat, ash and crude fibre contents were determined using standard analytical procedures. Carbohydrate content was calculated by difference. Three observations were considered for each treatment, and the results are presented as mean ± standard deviation.

2.5 Determination of spread ratio

Cookie diameter and thickness were measured after baking, and spread ratio was calculated as:

Spread ratio = Cookie diameter / Cookie thickness

Three independent observations were obtained for each treatment. The individual observations supplied for analysis were:

- T_0: 7.76, 7.94 and 7.70
- T_1: 7.07, 7.31 and 7.22
- T_2: 6.71, 6.99 and 6.85
- T_3: 6.30, 6.31 and 6.59

The resulting treatment means and standard deviations were calculated from these observations.

2.6 Instrumental hardness

Hardness was determined using a **Stable Micro Systems TA.XTplus texture analyser** fitted with the **HDP/3PB three-point bending rig**. This configuration is appropriate for assessing the fracture or break strength of rigid products, including biscuits and cookies.

The instrument conditions were:

Instrumental parameter	Setting
Instrument	Stable Micro Systems TA.XTplus
Fixture	HDP/3PB three-point bending rig
Pre-test speed	1.5 mm s^{-1}
Test speed	1.5 mm s^{-1}
Post-test speed	10.0 mm s^{-1}
Trigger force	5.0 g (0.049 N)
Deformation	3.0–5.0 mm or until complete fracture
Data acquisition rate	500 pps

Hardness was expressed as the maximum force required to fracture the cookie. The three observations supplied for analysis were:

- T_0: 2.17, 2.13 and 2.00 N
- T_1: 2.48, 2.51 and 2.36 N
- T_2: 2.90, 2.71 and 2.79 N
- T_3: 3.09, 3.16 and 3.20 N

The mean and sample standard deviation were calculated from these three observations for each treatment.

2.7 Sensory evaluation

Sensory quality was assessed using a **9-point hedonic scale** with 20 trained panelists. The attributes evaluated were appearance, colour, taste, texture, aroma and overall acceptability. A score of 1 represented “dislike extremely” and 9 represented “like extremely”.

2.8 Storage study

T_0 and T_2 were selected for storage evaluation. The cookies were packed in airtight polyethylene pouches and stored at room temperature. Measurements were recorded at 0, 15 and 30 days for moisture content, peroxide value and overall sensory acceptability.

2.9 Peroxide value

Peroxide value was determined according to **AOAC Official Method 965.33, Peroxide Value of Oils and Fats: Titration Method**. The official method specifies a blank-corrected sodium thiosulfate titration and expresses peroxide value as milliequivalents of peroxide per kilogram of oil or fat.

For the present study, oil was isolated from the cookie samples by cold solvent extraction using **chloroform**, followed by solvent removal using a rotary evaporator. The extracted oil was subsequently subjected to peroxide-value analysis.

The peroxide value was calculated using:

PV (meq O_2 kg^{-1} oil) = S × M × 1000 / W

where:

S = blank-corrected volume of sodium thiosulfate used for titration (mL);

M = molarity of sodium thiosulfate solution; and

W = mass of oil used for analysis (g).

The calculation corresponds to the official AOAC 965.33 formulation.

2.10 Statistical analysis

The experimental observations were subjected to analysis of variance to evaluate treatment effects. Statistical significance was considered at **$p \leq 0.05$**.

For spread ratio and hardness, the supplied three replicate observations per treatment were used to calculate the treatment mean and sample standard deviation. One-way ANOVA indicated significant treatment effects for spread ratio (**$F = 54.38$, $p < 0.001$**) and hardness (**$F = 92.80$, $p < 0.001$**).

Proximate composition and sensory data are reported as mean ± SD according to the experimental records.

3. Results and Discussion

3.1 Proximate composition

The incorporation of composite millet flour resulted in distinct changes in the proximate composition of the cookies (Table 2).

Table 2
Proximate composition, spread ratio and hardness of four-millet composite cookies

Parameter	T_0	T_1	T_2	T_3
Moisture (%)	3.21 ± 0.05	3.45 ± 0.04	3.72 ± 0.06	4.05 ± 0.05
Protein (%)	7.85 ± 0.08	8.92 ± 0.06	9.85 ± 0.07	10.72 ± 0.09
Fat (%)	18.40 ± 0.10	18.10 ± 0.09	17.80 ± 0.08	17.35 ± 0.07
Ash (%)	1.20 ± 0.03	1.45 ± 0.02	1.72 ± 0.04	2.05 ± 0.03
Crude fibre (%)	0.85 ± 0.02	1.60 ± 0.03	2.45 ± 0.05	3.20 ± 0.04
Carbohydrate (%)	68.49 ± 0.12	66.48 ± 0.10	64.46 ± 0.11	62.68 ± 0.09
Spread ratio	7.80 ± 0.12	7.20 ± 0.12	6.85 ± 0.14	6.40 ± 0.16
Hardness (N)	2.10 ± 0.09	2.45 ± 0.08	2.80 ± 0.10	3.15 ± 0.06

Proximate composition values are mean ± SD (n = 3). Spread-ratio and hardness values are calculated from three supplied observations per treatment. Different superscript letters within a row indicate significant differences at p ≤ 0.05 where the corresponding multiple-comparison procedure was applied.

Moisture increased progressively from 3.21% in T_0 to 4.05% in T_3. The increase may be associated with the greater contribution of fibre and other hydrophilic components from the millet flours. These constituents can influence water retention and distribution within composite flour systems. Similar formulation-dependent changes in moisture have been described in cereal- and millet-based bakery products (Biradar et al., 2020; Priya et al., 2025).

Protein increased from 7.85% in T_0 to 10.72% in T_3. The progressive increase indicates that replacement of wheat flour with the composite millet flour altered the protein contribution of the cookie matrix. Comparable increases in protein content following millet incorporation have been reported by Kumar et al. (2017), Mishra et al. (2023) and Shilpa et al. (2024).

Crude fibre exhibited a marked increase from 0.85% in T_0 to 3.20% in T_3. The increase is consistent with the greater contribution of whole-grain millet components. Similar improvements in fibre content have been reported in millet-enriched and composite cereal bakery products (Arepally et al., 2020; Sreeja et al., 2024; Kaur et al., 2021).

Ash content increased from 1.20 to 2.05% as millet substitution increased from 0 to 64%. This trend suggests an increased contribution of mineral-containing constituents from the composite flour. Comparable increases in ash and mineral-associated fractions have been reported in cereal-based products incorporating millet flours (Galla et al., 2016; Jan et al., 2020; Ojha et al., 2022).

In contrast, fat content decreased from 18.40% in T_0 to 17.35% in T_3. The relatively gradual reduction may reflect the compositional differences between wheat flour and the composite millet flour under otherwise standardized cookie-processing conditions.

Calculated carbohydrate decreased from 68.49% in T_0 to 62.68% in T_3. Because carbohydrate was determined by difference, this decline occurred concurrently with increases in protein, fibre, ash and moisture. The result therefore represents a shift in the measured proximate profile rather than direct evidence of carbohydrate destruction during baking. Similar compositional shifts have been reported in composite cereal formulations (Man et al., 2021; Kumar et al., 2022; Parmar and Deshmukh, 2023).

Overall, increasing millet substitution shifted the proximate composition toward higher protein, fibre and ash contents. This compositional modification demonstrates the capacity of a multi-millet flour system to alter the nutritional profile of conventional wheat-based cookies.

3.2 Spread ratio

Spread ratio decreased consistently with increasing millet incorporation, from **7.80 ± 0.12 in T_0 to 6.40 ± 0.16 in T_3**. The reduction was statistically significant, with one-way ANOVA indicating a strong treatment effect ($F = 54.38$, $p < 0.001$).

The lower spread ratio at higher millet substitution suggests restricted lateral expansion during baking. One plausible explanation is the greater water-binding capacity of fibre-rich millet components, which can reduce the availability of free water and consequently influence dough flow. Dilution of wheat gluten may also alter the structural behaviour of the dough during heating. Similar effects have been observed in bakery products prepared with increasing levels of alternative cereal flours (Arepally et al., 2020; Sharma et al., 2020; Singh et al., 2021).

The progressive pattern was clear across the treatments: T_0 had the greatest spread ratio, followed by T_1, T_2 and T_3. The reduction was therefore associated with the level of composite flour incorporation rather than an isolated response at a particular substitution level.

These observations are technologically relevant because spread ratio is an important physical characteristic of cookies and reflects the interaction of dough composition, moisture availability, fat behaviour and structural development during baking. The present findings are consistent with the broader observation that alternative cereal incorporation can alter dough functionality and baked-product geometry (Malik et al., 2024).

3.3 Instrumental hardness

Hardness increased progressively from **2.10 ± 0.09 N in T_0 to 3.15 ± 0.06 N in T_3**, and the treatment effect was statistically significant ($F = 92.80$, $p < 0.001$).

The increase in fracture force indicates that higher millet substitution produced a more resistant cookie structure. Several interacting mechanisms may account for this response. Increasing fibre concentration can alter the internal matrix and water distribution, while simultaneous dilution of wheat gluten can change the structural organization of the dough. The reduction in spread ratio may also contribute to a comparatively compact baked structure.

The three-point bending configuration used for the present analysis is particularly relevant to cookies because the HDP/3PB system is designed to determine breaking strength and fracture behaviour in rigid products. Stable Micro Systems specifically identifies the small HDP/3PB attachment for assessing the fracturability and break strength of biscuits, cookies and crackers.

The progressive increase in hardness is also consistent with observations reported for bakery products in which alternative cereal ingredients modify dough structure and final texture (Biradar et al., 2020; Sharma et al., 2020).

From a product-development perspective, the increase in hardness should be interpreted alongside sensory texture scores rather than independently. Excessive structural firmness can reduce palatability, whereas an appropriate degree of fracture resistance can contribute to the characteristic bite expected of cookies.

3.4 Sensory characteristics

Table 3
Sensory characteristics of four-millet composite cookies

Treatment	Appearance	Colour	Taste	Texture	Aroma	Overall acceptability
T_0	8.50 ± 0.10	8.40 ± 0.08	8.30 ± 0.09	8.45 ± 0.07	8.35 ± 0.08	8.40 ± 0.09
T_1	8.20 ± 0.09	8.10 ± 0.07	8.05 ± 0.08	8.00 ± 0.06	8.00 ± 0.07	8.05 ± 0.08
T_2	8.35 ± 0.08	8.25 ± 0.09	8.40 ± 0.07	8.20 ± 0.08	8.30 ± 0.06	8.30 ± 0.07
T_3	7.90 ± 0.07	7.85 ± 0.08	7.70 ± 0.09	7.65 ± 0.08	7.80 ± 0.07	7.78 ± 0.08

Values are mean ± SD (n = 20). Different superscript letters within a column indicate significant differences at $p \leq 0.05$.

The sensory evaluation showed that the control received the highest overall acceptability score of 8.40, while T_2 achieved a closely comparable score of 8.30. T_1 recorded 8.05 and T_3 7.78. Thus, the sensory response did not decline proportionally with every incremental increase in millet flour.

T_2 displayed particularly favourable taste acceptance, recording 8.40, while its appearance, colour and aroma scores also remained high. The formulation therefore demonstrated that a substantial replacement of wheat flour can be achieved while maintaining strong sensory acceptance.

At the highest substitution level, T_3 recorded lower scores for all evaluated attributes. The decline may be associated with stronger cereal-derived flavour, darker colour development and the greater hardness observed instrumentally. Similar relationships between increasing alternative cereal incorporation and sensory characteristics have been described in composite bakery products (Kumar et al., 2022; Reda and Woldemariam, 2024).

The present pattern is also consistent with the concept that intermediate substitution levels may provide a better balance between nutritional modification and sensory familiarity than very high substitution levels. Comparable formulation-dependent sensory responses have been reported in cereal and millet-based products (Casado et al., 2017; Kaur et al., 2021; Urooj et al., 2026).

Importantly, the sensory findings should not be interpreted as indicating that millet incorporation inherently reduces product quality. Rather, they demonstrate that the level of incorporation determines the balance between nutritional modification and sensory characteristics.

3.5 Storage changes in moisture, peroxide value and sensory quality

Table 4
Changes in selected quality characteristics during 30 days of ambient storage

Storage period (days)	T_0 Moisture (%)	T_0 Peroxide value (meq O_2 kg^{-1} oil)	T_0 Overall sensory score	T_2 Moisture (%)	T_2 Peroxide value (meq O_2 kg^{-1} oil)	T_2 Overall sensory score
0	3.21	0.40	8.40	3.72	0.48	8.30
15	3.50	0.47	8.12	4.03	0.56	8.00
30	3.85	0.55	7.85	4.40	0.65	7.70

Moisture increased progressively during storage in both formulations. T_0 increased from 3.21% at day 0 to 3.50% at day 15 and 3.85% at day 30. T_2 showed a corresponding increase from 3.72 to 4.03 and 4.40%.

The consistently higher moisture content of T_2 is consistent with its greater proportion of composite millet flour and the associated presence of hydrophilic components. Moisture redistribution can influence the crispness and fracture characteristics of low-moisture bakery products and may contribute to subsequent changes in sensory texture.

The observed storage trend is consistent with previous reports that moisture behaviour can contribute substantially to quality changes in cereal-based bakery products during storage (Gupta et al., 2023; Yadav et al., 2022).

Peroxide value increased progressively in both formulations. T_0 increased from 0.40 meq O_2 kg^{-1} oil at day 0 to 0.47 at day 15 and 0.55 at day 30. T_2 increased from 0.48 to 0.56 and 0.65 meq O_2 kg^{-1} oil over the same period.

Peroxide value is an indicator of primary lipid oxidation. The AOAC 965.33 titration method determines peroxide value through iodine liberation followed by titration with sodium thiosulfate and reports the result on an oil/fat basis. The increasing values observed during storage therefore indicate progressive accumulation of primary oxidation products.

T_2 consistently exhibited slightly higher peroxide values than T_0. This difference may be associated with compositional differences introduced by the greater contribution of millet flour. However, peroxide value alone should not be interpreted as a complete measure of rancidity or definitive shelf life because secondary oxidation products and sensory deterioration may develop independently of the peroxide concentration.

The sensory scores declined gradually during storage. T_0 decreased from 8.40 at day 0 to 8.12 at day 15 and 7.85 at day 30. T_2 declined from 8.30 to 8.00 and 7.70, respectively.

The simultaneous increase in moisture and peroxide value with declining sensory scores suggests that storage-induced physicochemical changes were accompanied by measurable sensory deterioration. Such relationships have been reported in stored bakery products, where moisture redistribution and lipid oxidation can influence texture, flavour and overall acceptability (Patel et al., 2025; Sharma et al., 2025).

Despite these changes, both formulations retained relatively high sensory scores after 30 days. T_0 remained at 7.85 and T_2 at 7.70, indicating that the products remained sensorially acceptable under the specific storage conditions investigated.

3.6 Comparative interpretation of T_0 and T_2 during storage

T_2 differed from T_0 in both initial composition and subsequent storage behaviour. At day 0, T_2 had higher moisture and peroxide values but retained an overall sensory score close to that of the control. During storage, these differences became somewhat more pronounced.

At day 30, T_2 contained 0.55 percentage points more moisture than T_0 and had a peroxide value 0.10 meq O_2 kg^{-1} oil higher. Its overall sensory score was 0.15 points lower than that of T_0. These differences indicate that the higher millet-containing formulation experienced somewhat greater changes in the selected storage indicators.

Nevertheless, T_2 retained an overall sensory score of 7.70 after 30 days. Thus, the storage results do not negate the sensory suitability of the formulation; rather, they indicate that formulation composition influences the rate and magnitude of quality changes during storage.

The observed behaviour emphasizes the importance of evaluating reformulated bakery products using a combination of nutritional, physical, instrumental and sensory indicators. A formulation that provides improved compositional characteristics should also be assessed for its ability to maintain desirable quality during storage.

4. Conclusion

The present study demonstrated that graded incorporation of an equal-proportion composite flour containing sorghum, pearl millet, finger millet and foxtail millet substantially influenced the nutritional, physical, textural and sensory characteristics of wheat-based cookies. Increasing millet substitution from 0 to 64% resulted in progressive increases in moisture, protein, ash and crude fibre, accompanied by reductions in fat and calculated carbohydrate.

The physical characteristics changed systematically with increasing millet incorporation. Spread ratio decreased from 7.80 ± 0.12 in T_0 to 6.40 ± 0.16 in T_3, whereas instrumental hardness increased from 2.10 ± 0.09 to 3.15 ± 0.06 N. These changes indicate that the composite millet flour influenced dough spreading and the fracture behaviour of the finished cookies.

Sensory evaluation showed that T_2, containing 44% composite millet flour, retained a high overall acceptability score of 8.30 compared with 8.40 for the control. Although T_3 showed lower sensory scores, the intermediate formulation maintained good acceptance while providing substantial modification of the measured nutritional characteristics.

During 30 days of ambient storage, moisture and peroxide values increased progressively in both T_0 and T_2, whereas overall sensory acceptability declined gradually. At the end of storage, T_0 recorded 3.85% moisture, 0.55 meq O_2 kg^{-1} oil peroxide value and 7.85 overall sensory score, while T_2 recorded 4.40%, 0.65 meq O_2 kg^{-1} oil and 7.70, respectively.

Taken together, the findings indicate that the four-millet composite flour can be effectively incorporated into wheat-based cookies and can substantially alter their nutritional and technological characteristics while maintaining good sensory quality at an intermediate substitution level. T_2 may therefore be considered a promising formulation within the experimental range evaluated. However, this interpretation is specific to the present formulation and processing conditions and should not be generalized as a universal optimum.

Further work involving extended storage, controlled temperature and relative humidity, detailed mineral and dietary-fibre profiling, secondary lipid-oxidation products, instrumental colour measurements and consumer-level sensory testing would provide additional evidence for product optimization and commercial application.

Declarations

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Conflict of interest

The authors declare that they have no competing interests.

Ethical statement

Informed consent was obtained from all participants involved in the sensory evaluation.

Data availability

The data generated and/or analysed during the present study are available from the corresponding author upon reasonable request, subject to applicable institutional requirements.

Author contributions

Happy Narang: Conceptualization, methodology, investigation and writing—original draft.
Sunil Kumar: Supervision, project administration and validation.
Thumati Mahesh Babu: Methodology, software and validation.
Gargi Shekhar: Investigation and writing—review and editing.
Dipankar Saikia: Visualization and writing—review and editing.
Abhijit Das: Writing—review and editing.
Deeksha Gautam: Formal analysis, visualization and writing—review and editing.

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