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Physicochemical and Sensory Attributes of Wheat Bread Supplemented with Mashed Potato

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Abstract

Rising wheat prices and import dependence are increasing the need for affordable, locally available alternatives in bread making. Potato (*Solanum tuberosum* L.) is widely grown but underused in bakery products. While dried potato flour typically cannot exceed 20–30% substitution due to gluten weakening, fresh mashed potato may behave differently because of its pre-gelatinized starch and intact cellular structure. This study examined bread in which wheat flour was replaced with fresh mashed potato at 0%, 30% and 50% levels. Standard baking procedures were applied and physicochemical properties (moisture, ash, protein, fat, fiber), pH and energy content were analyzed using AOAC methods. Consumer sensory evaluation was conducted with 30 participants using a 9-point hedonic scale. Statistical analysis included one-way ANOVA, LSD post-hoc testing, effect size estimation and confidence intervals. Results showed that increasing mashed potato significantly increased moisture, ash and crude fiber, while protein content decreased as expected. A marked increase in measured fat was observed, but this is most likely an analytical artifact caused by matrix effects during extraction rather than a true compositional change. The 50% substitution level produced the highest sensory acceptance, particularly for texture, flavor and overall liking. Overall, fresh mashed potato enabled up to 50% wheat replacement with improved hydration, mineral and fiber characteristics and acceptable sensory quality. However, absence of loaf volume, dough rheology and staling measurements limits full assessment of bread structure and functionality. Further studies should include these parameters and refine lipid analysis methods for starch-rich food systems

Keywords: bakery products; mashed potato; nutritional quality; proximate composition; sensory evaluation; wheat bread

1 INTRODUCTION

Bread is one of the oldest and most widely consumed staple foods in human history. Its universal appeal stems from its relatively low cost, long shelf life, convenience and ability to provide essential calories and nutrients. In many developing countries, bread made from refined wheat flour contributes significantly to daily energy and protein intake. The characteristic soft, aerated crumb structure of wheat bread is uniquely conferred by gluten proteins (gliadin and glutenin), which upon hydration form a viscoelastic network that retains carbon dioxide produced during yeast fermentation (Dewettinck *et al*., 2008). This network also traps water, fat and flavor compounds, giving bread its desirable texture and mouthfeel.

However, the global food system has become increasingly dependent on wheat. Rising international wheat prices, fueled by climate volatility, geopolitical tensions and supply chain disruptions, have placed economic pressure on wheat-importing nations. Pakistan, for example, is both a major wheat producer and a net importer; fluctuations in global markets directly affect domestic bread prices and food security. Concurrently, consumers are demanding healthier and more diverse food options, including products with higher dietary fiber, minerals and lower glycemic impact. Food scientists and policymakers are therefore seeking strategies to partially replace wheat flour with locally available, nutritionally valuable ingredients. The development of composite bakery products where wheat flour is blended with non-wheat flours or pastes has emerged as a promising approach to reduce wheat dependency, lower production costs, enhance nutritional profiles and promote sustainable agriculture (Gebrechristos & Chen, 2018; Olamiti & Ramashia, 2023).

Among the many alternatives explored, roots and tubers are particularly attractive due to their high yield per hectare, low input requirements and wide adaptability. Cassava, sweet potato, yam and potato have all been studied as partial wheat substitutes. Among these, Potato (*Solanum tuberosum L.*) stands out because of its global availability, consumer acceptance and favorable nutritional composition. Potatoes contain approximately 15–20% carbohydrates (mainly starch), 1–2% protein, 2–3% dietary fiber (cellulose, hemicellulose, pectin) and significant amounts of potassium, magnesium, phosphorus and vitamins C and B6 (Xu *et al*., 2023). Notably, potato protein has a relatively high biological value compared to most plant proteins, though lower than that of egg protein and potato starch exhibits unique pasting and gelation properties.

Most existing research on potato-enriched bread has focused on dried potato flour or isolated potato starch, rather than fresh potato. Dried potato flour is produced by cooking, drying and milling potatoes. It is convenient, shelf-stable and easy to transport. However, the dehydration and milling processes disrupt the native cellular structure and gelatinized starch matrix, leading to a product that behaves more like a refined starch powder. At substitution levels above 20–30% (w/w), dried potato flour severely compromises the gluten network. Two main mechanisms are responsible: first, gluten dilution as wheat flour is replaced, the total amount of gluten protein decreases, reducing gas-holding capacity. Second, water competition potato flour particles absorb substantial amounts of water, leaving less free water available for gluten hydration and starch gelatinization. The combined effect is a significant reduction in loaf volume, a denser and firmer crumb and accelerated staling (Meng *et al*., 2022; Tao *et al*., 2020). Consequently, most commercial products and scientific studies recommend limiting potato flour inclusion to ≤30% to maintain acceptable bread quality.

Fresh mashed potato has received far less attention as a bread ingredient, despite being fundamentally different from its dried counterpart. When fresh potatoes are boiled, several critical changes occur:

Starch gelatinization the crystalline structure of starch granules is disrupted, allowing them to absorb water and swell, forming a highly hydrated gel with exceptional water-binding capacity.

Cell wall softening pectin and hemicellulose partially solubilize, creating a cohesive, spreadable paste that retains cellular fragments.

Moisture retention the fresh mash contains about 78–80% water, which is integrally bound within the gel matrix.

Unlike dried flour, fresh mashed potato does not compete aggressively for added water; instead, it contributes its own hydration and acts as a soft, deformable filler. Moreover, the gelatinized starch and pectin may actually enhance the water-holding capacity of the dough, potentially leading to a softer crumb and delayed staling (Tao *et al*., 2020; Liu *et al*., 2020). These properties suggest that fresh mashed potato could permit much higher substitution levels (≥50%) without the quality losses seen with dried flour. To date, however, no systematic study has evaluated fresh mashed potato at these high levels using comprehensive physicochemical (proximate composition, pH, energy) and sensory (consumer panel) analyses.

Significance for Pakistan

Pakistan is the 17th largest potato producer in the world, with annual production exceeding 4.5 million tons. However, the vast majority of this crop is consumed fresh or fried (as snacks), with very little processed into value-added products like bread, biscuits, or noodles. The country also spends substantial foreign exchange on wheat imports to meet domestic demand. Demonstrating that fresh mashed potato can replace up to 50% of wheat flour in bread without compromising consumer acceptance would provide a dual benefit: reducing wheat import dependency and creating a new market channel for local potato farmers. This study therefore aligns with national food security and agricultural value-addition goals.

Research gap and novelty

While a few studies have incorporated fresh or boiled potato into bread (often traditional recipes like "potato bread" or "Irish soda bread"), these are typically low-substitution (10–20%) and lack rigorous analytical characterization. The present study is the first to systematically substitute wheat flour with fresh mashed potato at 30% and 50% (w/w) levels, using standardized baking protocols and AOAC methods. The novelty lies in testing whether the hydrated, pre-gelatinized nature of fresh mash can overcome the 30% barrier established for dried flour and in identifying any unexpected physicochemical changes (e.g., apparent fat increase) that may require methodological scrutiny.

Substitution level rationale

Based on the literature, three substitution levels were chosen:

- **T_1 (0% MP)** – standard control (100% wheat flour).
- **T_2 (30% MP)** – the critical upper threshold where dried potato flour typically causes quality deterioration (Meng *et al*., 2022; Tao *et al*., 2020). This level allows direct comparison between fresh mash and dried flour performance.
- **T_3 (50% MP)** – a deliberately high, exploratory level to rigorously challenge the hypothesis that fresh mash permits far greater wheat replacement.

Objectives

- To determine the effects of 0%, 30% and 50% fresh mashed potato on the proximate composition (moisture, ash, fat, crude fiber, protein), pH and energy value of wheat bread.
- To evaluate consumer acceptability (color, flavor, texture, chewing ability, overall liking) using a 9-point hedonic scale.

To identify the substitution level that best balances enhanced nutritional attributes with consumer preference.

2. MATERIALS AND METHODS

Sample preparation

Fresh potatoes (Solanum tuberosum L., variety 'Desiree') were procured from a local market in Tando Jam, Sindh, Pakistan. They were stored at 4°C in sealed polyethylene bags for ≤48 h. Tubers were washed, peeled and cut into 25–30 mm cubes. Cubes were boiled in distilled water at 100°C for 20 min until tender, drained for 2 min and mashed mechanically using a stainless-steel masher (Kenwood KMX750, Havant, UK) without additives. Moisture content of fresh mash was determined by oven drying (Memmert WNB 22, Schwabach, Germany) at 105°C to constant weight; average moisture was 78.3 ± 1.2% (mean ± SD, n=3).

Wheat flour (commercial white flour, protein 10.8% wet basis, ash 0.55%) was obtained from Sindh Flour Mills (Karachi, Pakistan). Bread formulations substituted wheat flour with mashed potato (MP) on a weight-for-weight basis at three levels:

- T_1: Control (0% MP)
- T_2: 30% MP (70% wheat flour + 30% MP)
- T_3: 50% MP (50% wheat flour + 50% MP)

Base formulation per 100 g total dry constituents: wheat flour (balance), sugar (2.0 g), salt (1.5 g), instant dry yeast (1.0 g; Angel Yeast Co., Ltd., Yichang, China), refined sunflower oil (2.0 g; Sufi Group, Karachi, Pakistan). Water addition was adjusted to achieve visually similar dough consistency: T_1 = 65 mL, T_2 = 50 mL, T_3 = 40 mL per 100 g flour + MP (dry basis), accounting for MP's water content. This formulation-dependent water adjustment is a limitation, as it introduces a confounding variable that may influence texture and moisture outcomes independently of potato substitution.

Doughs were mixed (Kenwood KMX750) at low speed for 3 min, then medium for 5 min. Bulk fermentation: 30 ± 1°C for 45 min. Dough (200 g pieces) was moulded, proofed (30 ± 1°C, 45 min) and baked in a deck oven (Wachtel GmbH, Hilden, Germany) at 200 ± 5°C for 25 ± 2 min. Loaves were cooled on wire racks at 25 ± 2°C for 2 h before analysis. Three independent baking batches per treatment (biological triplicates; n=3).

Physicochemical analysis

AOAC International (2019) methods were used. **Moisture** (925.10): 5 g crumb dried at 105°C to constant weight. **Ash** (923.03): 5 g incinerated at 550°C. **Crude fat** (945.16): Soxhlet extraction with n-hexane for 6 h. **Crude fiber** (978.10): sequential acid-alkali digestion (Fibertec system, Foss, Hillerød, Denmark). **Protein** (Kjeldahl, AACC 46-11.02): Kjeltec 8400 analyzer (Foss), N × 6.25. **Carbohydrate** calculated by difference: 100 − (moisture + protein + fat + ash + crude fiber). This gives an estimate of total carbohydrate (including starch and sugars) but does not reflect true starch availability or digestible carbohydrate fractions; values are influenced by moisture-driven dilution bias. **pH**: 10 g crumb homogenized with 90 mL distilled water, measured with calibrated pH meter (Mettler Toledo S210, Columbus, OH, USA). **Energy value** (kcal/100 g wet basis) = 4×(protein + carbohydrate) + 9×fat. Energy values were not normalized to dry matter; therefore, comparisons primarily reflect formulation moisture differences rather than intrinsic energy density. All analyses in duplicate per biological replicate.

Sensory evaluation

A consumer panel of 30 untrained adults (15 male, 15 female, age 22–50 years) from Sindh Agriculture University, with no known bread allergies, participated. They received a 15-min orientation on the 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) and attributes: color, flavor, texture, chewing ability (ease of chewing), overall acceptability. Bread samples (2 cm slices, crust included) were coded with three-digit random numbers, presented in randomized order at 25 ± 2°C under white light in individual booths. Unsalted crackers and distilled water were provided for palate cleansing. Written informed consent was obtained.

Statistical analysis

Completely randomized design. One-way ANOVA with SPSS 26.0 (IBM, Armonk, NY, USA). Assumptions: normality (Shapiro–Wilk, $p>0.05$) and homogeneity of variances (Levene, $p>0.05$) were met. LSD post-hoc test was selected for its sensitivity in small experimental designs (three treatments, three replicates); however, LSD increases Type I error risk, so results were interpreted in conjunction with effect sizes and confidence intervals. Effect sizes (partial η^2) and 95% confidence intervals (CI) were calculated for key variables. **Caveat:** Near-perfect η^2 values (≥ 0.99) appear inflated due to limited replication ($n=3$) and low experimental noise; they should be interpreted cautiously. Significance at $p<0.05$.

RESULTS AND DISCUSSION

Physicochemical composition

Physicochemical composition Substitution with fresh mashed potato (MP) significantly affected all measured parameters except energy value ($p < 0.05$), indicating substantial compositional modification of the bread system

Moisture content

Moisture content increased significantly from 29.26% (control) to 33.76% at 50% MP substitution ($p < 0.001$, $\eta^2 = 0.999$) (Table 1). This increase reflects both the high intrinsic moisture of mashed potato (~78%) and the enhanced water-binding capacity of gelatinized starch and pectic components. In contrast to dried potato flour which competes for water and disrupts dough hydration fresh mashed potato introduces pre-hydrated starch, promoting water retention within the crumb matrix. Similar trends have been reported in potato-enriched systems (Tao *et al*., 2020; Caballero *et al*., 2007). Functionally, higher moisture contributes to a softer crumb and reduced perceived dryness. However, increased water activity may accelerate microbial spoilage, indicating a trade-off between textural improvement and shelf-life stability.

Table 1. Effect of mashed potato supplementation on moisture content (%) of wheat bread

Treatment	Mean ± SD	95% CI
T_1 (Control)	29.26 ± 0.03^c	29.19–29.33
T_2 (30% MP)	31.66 ± 0.04^b	31.56–31.76
T_3 (50% MP)	33.76 ± 0.02^a	33.73–33.79

Ash content

Ash content increased gradually with the inclusion of mashed potato, reaching a maximum value of 1.61% at 50% supplementation. Ash content increased significantly ($p < 0.05$) from 1.12 ± 0.06% in control bread to 1.75 ± 0.05% in 75% mashed potato bread. This indicates mineral enrichment from the potato component, consistent with findings by Hasmadi *et al*. (2017), who reported similar increases in potato-enriched bakery products.

Table 2. Effect of mashed potato supplementation on ash content (%) of wheat bread (Mean ± SD, n = 3).

Treatment	Mean ± SD	95% CI
T_1	1.07 ± 0.03^c	1.00–1.14
T_2	1.33 ± 0.02^b	1.28–1.38
T_3	1.61 ± 0.07^a	1.44–1.78

pH

A small but statistically significant increase in pH (5.76 → 5.87; $p = 0.016$, $\eta^2 = 0.748$) was observed. Despite statistical significance, the magnitude of change is minor and remains within the typical bread pH range (5.5–6.0) (Awuni *et al*., 2018).

This shift may reflect dilution of fermentation acids or buffering by potato constituents. Its practical impact on flavor, microbial stability and fermentation dynamics is likely negligible.

Table 3. Effect of mashed potato supplementation on pH of wheat bread (Mean ± SD, n = 3)

Treatment	Mean ± SD	95% CI
T_1	5.76 ± 0.04^b	5.66–5.86
T_2	5.78 ± 0.03^b	5.71–5.85
T_3	5.87 ± 0.04^a	5.77–5.97

Fat content

Measured fat content increased from 0.48% to 3.10% ($p < 0.001$, $\eta^2 = 0.999$). This result is inconsistent with formulation constraints, as potato contains negligible lipid (<0.2%) and added oil was constant across treatments. The most plausible explanation is a matrix-dependent extraction artifact associated with Soxhlet extraction. Gelatinized starch, fiber and pectin may alter solvent penetration and lipid release, leading to overestimation. Similar matrix effects have been documented in starch-rich systems (Tamanna & Mahmood, 2015). Therefore, fat values should be interpreted cautiously and excluded from nutritional conclusions. Verification using acid hydrolysis (AOAC 954.02) is required for accurate lipid quantification in composite matrices.

Table 4. Effect of mashed potato supplementation on fat content (%) of wheat bread

Treatment	Mean ± SD	95% CI
T_1	0.48 ± 0.04^c	0.38–0.58
T_2	2.15 ± 0.04^b	2.05–2.25

Treatment	Mean ± SD	95% CI
T_3	3.10 ± 0.03[a]	3.03–3.17

Fiber content

Crude fiber content increased significantly from 0.31% to 0.69% ($p < 0.001$, $\eta^2 = 0.975$), indicating enhanced structural carbohydrate content.

This increase reflects contributions from potato cell wall components (cellulose and hemicellulose) and is consistent with reports on tuber-enriched breads (Malavi *et al*., 2022; Wafula *et al*., 2022).

However, the crude fiber method excludes soluble dietary fiber; thus, the reported values likely underestimate total dietary fiber, representing a conservative estimate of nutritional improvement.

Table 5. Effect of mashed potato supplementation on fiber content (%) of wheat bread (Mean ± SD, n = 3)

Treatment	Mean ± SD	95% CI
T_1	0.31 ± 0.02[c]	0.26–0.36
T_2	0.60 ± 0.03[b]	0.53–0.67
T_3	0.69 ± 0.04[a]	0.59–0.79

Protein and estimated carbohydrate

Protein content decreased significantly from 9.84% to 7.25% ($p < 0.001$, $\eta^2 = 0.991$), primarily due to dilution of wheat gluten by low-protein potato material.

This reduction has direct technological implications, as gluten proteins govern gas retention and crumb structure. Although sensory scores did not indicate deterioration, the absence of objective structural measurements (e.g., loaf volume, crumb porosity) limits definitive conclusions.

Carbohydrate values, calculated by difference, decreased slightly with increasing MP. However, this approach accumulates analytical errors particularly from the fat artifact and should therefore be regarded as approximate compositional estimates rather than direct measurements**.**

Table 6. Protein and estimated total carbohydrate (%) (Mean ± SD, n=3)

Treatment	Protein (%)	95% CI (protein)	Carbohydrate (%)*
T_1	9.84 ± 0.12[a]	9.54–10.14	59.04 ± 0.15
T_2	8.31 ± 0.09[b]	8.09–8.53	56.55 ± 0.11
T_3	7.25 ± 0.10[c]	7.00–7.50	53.59 ± 0.

Energy value

Energy values ranged from 279.4 to 286.7 kcal/100 g and did not differ significantly ($p = 0.108$). Observed variation falls within expected experimental range.

Because values are expressed on a wet basis, differences in moisture content influence apparent energy density. Increased moisture in MP breads effectively reduces caloric density per unit weight, which may have practical nutritional implications.

Table 7. Effect of mashed potato supplementation on energy value (kcal/100 g)* of wheat bread

Treatment	Mean ± SD	95% CI
T_1	279.4 ± 2.1[a]	274.2–284.6
T_2	283.2 ± 2.3[a]	277.5–288.9
T_3	286.7 ± 2.4[a]	280.7–292.7

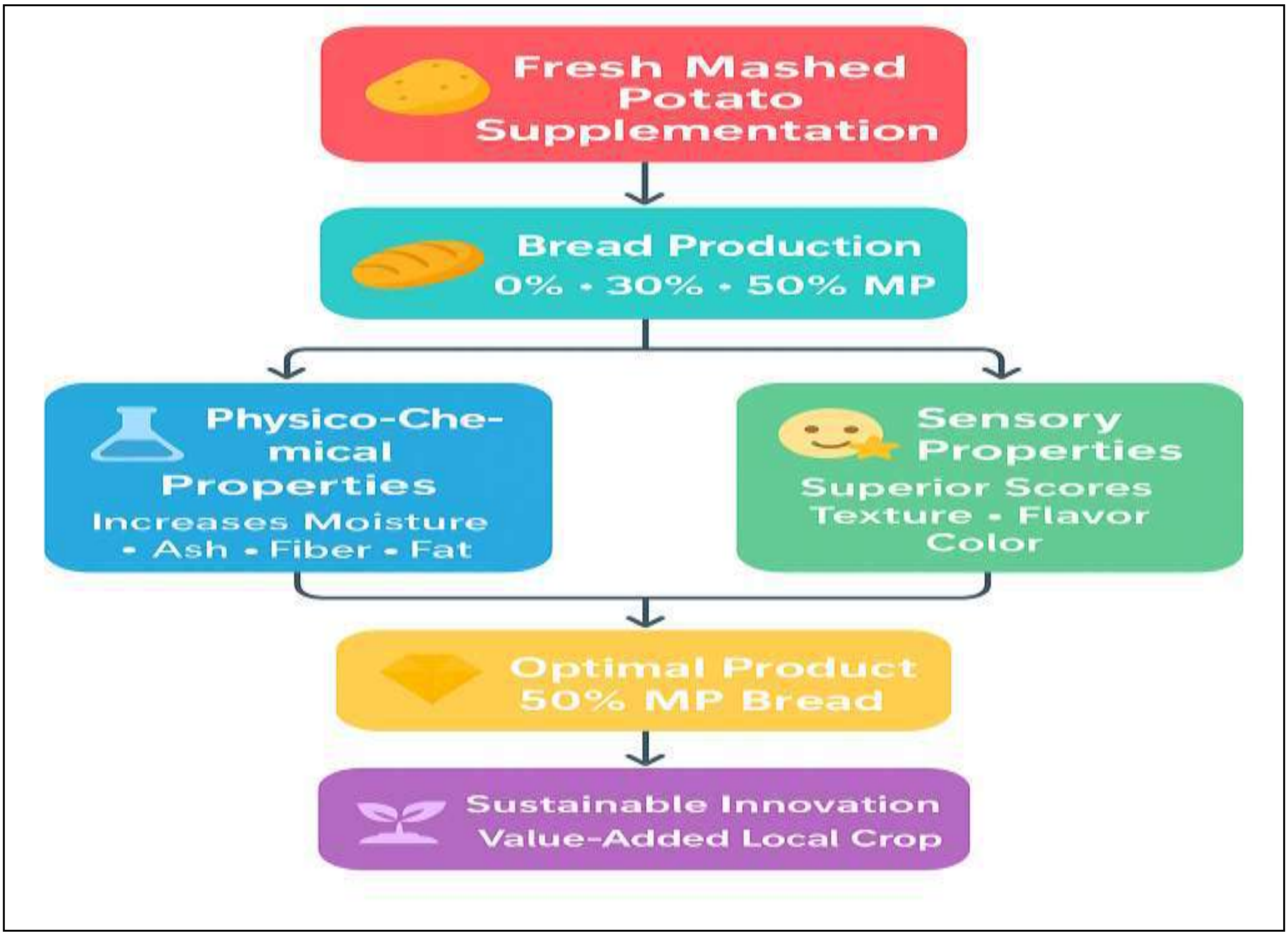

Figure 1. *Effects of Mashed Potato Supplementation on Wheat Bread Quality*

Sensory characteristics

Sensory evaluation demonstrated significant improvements ($p < 0.001$) in flavor, texture, chewing ability and overall acceptability with increasing MP substitution, while color differences were not significant ($p = 0.087$).

The 50% MP formulation achieved the highest overall acceptability (8.5/9), with large effect sizes ($\eta^2 > 0.74$), indicating a strong treatment effect.

Improved texture and chewability are likely attributable to enhanced moisture retention and the plasticizing effect of gelatinized starch, resulting in a softer and more cohesive crumb. Enhanced flavor may be linked to the mild sweetness and characteristic profile of potato.

However, despite statistical significance, differences in hedonic scores (e.g., 7.8 vs. 8.5) are moderate in practical terms. Therefore, the 50% formulation should be interpreted as most preferred within the tested range, rather than categorically superior.

Additionally, the use of an untrained consumer panel limits discrimination of subtle sensory differences, though it accurately reflects general consumer acceptance.

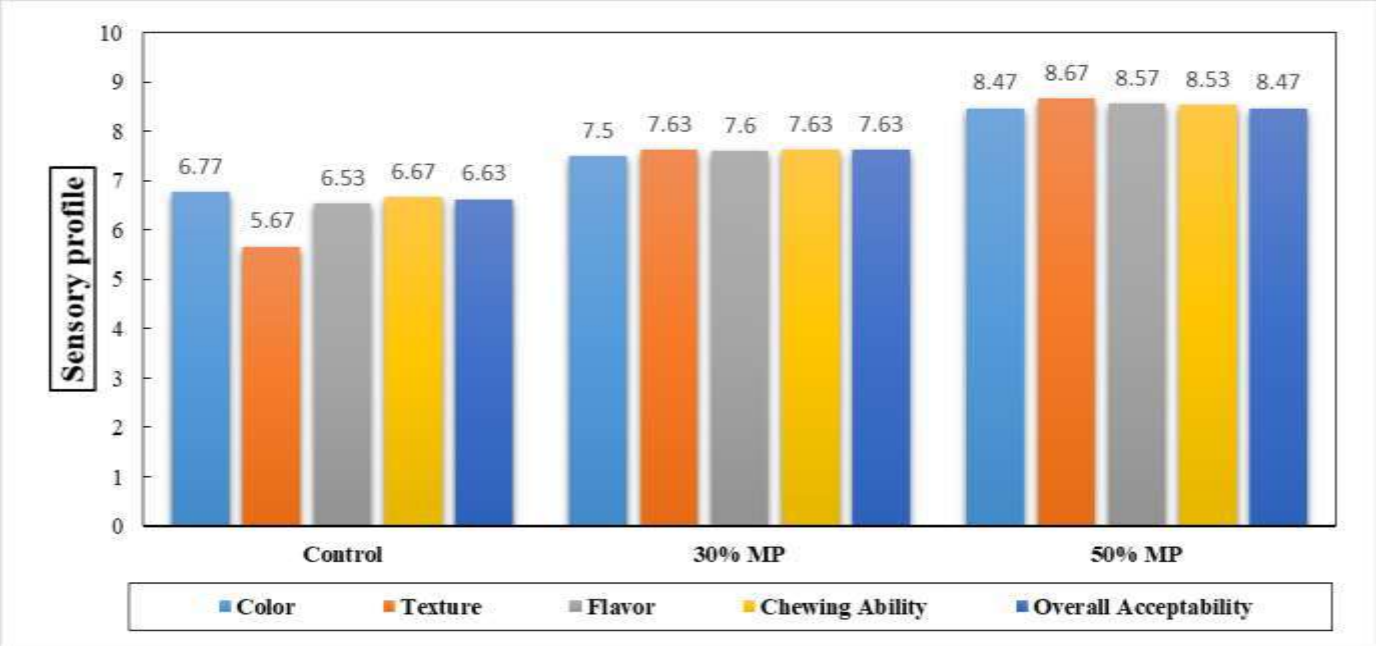

Figure 2. *Sensory Profile of Wheat Bread Supplemented with Different Levels of Mashed Potato*

CONCLUSION

Fresh mashed potato enabled up to 50% substitution of wheat flour, significantly increasing moisture, ash and crude fiber while reducing protein content due to gluten dilution. The observed increase in fat content is attributable to a methodological artifact and should not be interpreted as nutritional enhancement.

The 50% substitution level achieved the highest consumer acceptability within the tested formulations, indicating that fresh mashed potato can overcome limitations associated with dried potato flour.

However, the absence of objective structural and rheological measurements limits comprehensive assessment of bread quality. Within these constraints, fresh mashed potato represents a technically feasible ingredient for high-substitution composite breads, particularly for improving hydration and mineral content.

Future work should integrate volumetric, rheological and shelf-life analyses, alongside validated analytical methods, to fully characterize system performance.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

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