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DEVELOPMENT AND CHARACTERIZATION OF FLAT BREAD INCORPORATED WITH MORINGA POWDER FOR NUTRITIONAL, BIOFUNCTIONAL, AND SENSORY EVALUATION

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Abstract

The global prevalence of type 2 diabetes mellitus (T2DM) is rapidly increasing, particularly in developing countries, highlighting the need for functional foods with anti-hyperglycemic potential. This study aimed to develop nutritionally enhanced wheat flatbread by incorporating Moringa oleifera leaf powder (MoLP) and evaluating its nutritional, antioxidant, physicochemical, textural, color, and sensory properties. MoLP was added at levels of 0%, 2%, 4%, 6%, and 8%. Results showed significant improvement in nutritional composition with increasing MoLP levels. Moisture content ranged from 30.50–32.10%, ash 1.20–2.20%, protein 9.80–12.80%, fat 1.50–1.95%, and fiber 1.10–2.75%. Antioxidant properties also increased, with total phenolic content (TPC) ranging from 1.85–6.25 mg GAE/g, total flavonoid content (TFC) from 0.95–3.80 mg QE/g, and DPPH activity from 18.2–67.3%. Texture analysis indicated increased hardness (8.20–13.60 N) and moderate changes in springiness, cohesiveness, gumminess, and chewiness. Color parameters showed darker, greener flatbreads with higher MoLP levels, as reflected by increased change in color and chroma, and decreased whiteness index (56.0–72.8). Sensory evaluation indicated a slight decline in acceptability with higher MoLP incorporation. Overall, MoLP-enriched flatbread demonstrates strong potential as a functional food for managing T2DM.

INTRODUCTION

The pace of life in the modern world has greatly increased, which affect diet and lifestyle in developing countries and contributing to lifestyle diseases such as diabetes. Diabetes mellitus (DM), a chronic metabolic disorder, which is classified into Type 1, Type 2, gestational diabetes. It is caused by specific conditions mainly occurs due to hyperglycemia caused by defects in insulin secretion, action, or both (Adnan & Aasim, 2020; Moucheraud et al., 2019). Hyperglycemia impairs insulin signaling in target tissues, worsening glucose uptake, and must be controlled to manage Type 2 diabetes mellitus (T2DM). T2DM is a serious public health concern globally and is predicted to rise in developing countries over the next two decades (Garia-Roves, 2011; Sruthi, 2017). Lifestyle and genetic factors are strongly associated with T2DM include sedentary behavior, smoking, physical inactivity, alcohol consumption, and obesity, which responsible for 55% of cases (Olokoba et al., 2012).

Untreated T2DM increases short- and long-term complications, including dyslipidemia, cardiovascular disease (CVD), and early mortality (Galicia-Garcia et al., 2020). Controlling hyperglycemia and dyslipidemia is critical to minimizing complications. Adults aged 45-65 are at the highest risk (Ohiagu et al., 2021). Globally, diabetes prevalence was 4% in 1995 and is projected to reach 5.4% by 2025. In 2011, 366 million individuals were diabetic, rising to 552 million by 2030 (Patodiya et al., 2017; Taher et al., 2017). Pakistan ranks 10th globally with 7.5 million cases (International Diabetes Federation, 2019), and a national survey in 2017 reported a prevalence of 26.3%, indicating a continuing epidemic (Muhammad and Aasim, 2020; Gebremedhin et al., 2019). Clinicians face challenges managing diabetes with minimal side effects, highlighting the need for natural-source alternatives to synthetic treatments (Anwer et al., 2021).

In traditional Chinese medicine, various parts of the plant are used as a natural remedy to manage hypertension, hyperlipidemia, diabetes, arthritis, and rheumatism (Iqbal et al., 2012; Katsube et al., 2010). A key bioactive compound, 1-deoxynojirimycin (DNJ), and its derivatives, including α-glucosidase inhibitors, help control hyperglycemia by inhibiting intestinal enzymes (Rohela et al., 2020; Nouman et al., 2016). Leaves are also rich in antioxidants, supporting overall health (Yu et al., 2018). Today, moringa-derived products, powders, extracts, capsules, and teas are marketed as functional foods and supplements for blood glucose and weight management (Oyeyinka & Oyeyinka, 2018; Sarkhel and Manvi, 2020). Leaves serve as feed for silkworms in sericulture and as a supplement in dairy feed, while the fruits are consumed in juices, jams, and jellies. Individuals increasingly search foods enriched with nutrients from plant or animal sources to improve health (Islam et al., 2021; Thaipitakwong et al., 2018).

Moringa (*Moringa oleifera*), often called a "miracle or drumstick tree," belonging to a family Moringaceae,is highly valued for its nutritional and medicinal properties (Alemayehu & Deeyno, 2014; Matic et al., 2018). Its dried leaves are rich in protein, fiber, minerals (calcium, iron, phosphorus, potassium), beta-carotene, and vitamin C, with nutrient levels exceeding those of common foods (Kolawole et al., 2013). Seven times more vitamin C than oranges, 17 times more calcium than milk, 9 times more protein than yogurt, 25 times more iron than spinach, and 15 times more potassium than bananas (Srinivasamurthy et al., 2017; Mishra et al., 2012).

A popular variety contains energy (329 kcal/100 g), protein (29.4 g), fat (5.2 g), carbohydrates (41.2 g), fiber (12.5 g), vitamins A, C, D, E, amino acids, flavonoids (quercetin and phenolics), and other antioxidants (Chinchilla et al., 2020; Kumari, 2010). Leaves' high fiber content contributes to glucose-lowering effects by suppressing intestinal glucose uptake, enhancing insulin secretion, reducing insulin resistance, and delaying gastric emptying, making it beneficial against diabetes, inflammation, and oxidative stress (Busani et al., 2011; Gopalakrishnan et al., 2016). Biologically active compounds from Moringa can be used to develop functional foods, acting as antioxidants, antibacterial agents, and food fortifiers by preventing lipid oxidation and controlling bacterial and fungal growth (Moyo et al., 2011; Saucedo-Pompa et al., 2018).

In Pakistan, chapatti/flatbread is a staple food for meeting daily nutritional and energy needs, with wheat being predominantly used for its preparation. Chapatti is also consumed in other traditional forms such as tandoori naan, poori, and paratha (Riaz & Wahab, 2021). Wheat is low in certain micronutrients; fortifying chapatti with natural, nutrient-rich ingredients can enhance its nutritional and medicinal value (Inamdar et al, 2015; Ma et al., 2020). Various legumes, leafy vegetables, and plant leaves have been incorporated to increase protein, mineral, vitamin, fiber, and complex carbohydrate content. However, fortification may affect the quality of flatbread, which should be considered during formulation (Oyeyinka and Oyeyinka, 2018). For example, amaranth leaves increase iron and beta-carotene in biscuits, pakora, and cake, while amla and moringa leaf extracts enhance antioxidant content in biscuits. Moringa leaves, rich in 1-Deoxynojirimycin (DNJ) and antioxidants, respectively, have potential in the prevention and management of diabetes (Mouminah, 2015; Luqman et al., 2012). Incorporating these leaves into whole wheat flatbread, a commonly consumed food in Pakistan, may offer a functional dietary approach for diabetes management (Sharma & Arora, 2020). The aim of this study was the development of flat bread with the incorporation of moringa powder. Subsequently, study the effect of moringa powder on the chemical composition, biofunctional properties, and sensory evaluation of flat bread.

Materials and Methods

Procurement of raw material

Raw materials were purchased from the local market of Faisalabad. All chemicals and reagents were procured of analytical grade (Merck, Germany).

Powder preparation

Moringa leaves were collected and washed with running water to remove contaminants. After that, they were dried in a hot air dryer (POL-EKD APARATURA, Pakistan) at 70 °C for 48 hours and ground to obtain fine powder. Then, fine powders were passed through 60 mesh sieves to obtain a uniform particle size. The powders were stored in sealed polythene bags for further analysis as described by Arshid et al. (2018) and Urooj et al. (2026a).

Flatbread formation

Flatbread was prepared using different concentrations of moringa leaf powder in combination in wheat flour as mentioned in the table given below. Preparation was done using a standard method (Khan *et al.,* 2022; Rwubatse *et al.*, 2021).

Table 1: Treatment plan for preparation of flatbread with varying concentrations (Nagarajaiah et al., 2021)

Treatments	Wheat flour (%)	Moringa leaf powder (%)
T_0	100	0
T_1	98	2
T_2	96	4
T_3	94	6
T_4	92	8

Proximate composition

Proximate composition (moisture, fat, protein, carbohydrates, fiber, and ash content) of supplemented flatbread was carried out through the prescribed method (AOAC, 2016).

Total phenolic content (TPC)

TPC of supplemented flatbread samples were measured with the help of the Folin-Ciocalteu method (Asif et al., 2025a). In this method, Folin-Ciocalteu reagent was diluted with distilled water to prepare tenfold dilutions. Aliquot of 0.5ml of the extract was added to 0.5ml of the Folin-Ciocalteu reagent, followed by the addition of an aqueous 2.5 ml of 7.5% solution of sodium bicarbonate. The mixture was stirred and allowed to stand for 30 minutes in dark place. The absorbance was measured at 765nm by using Spectrophotometer 752D (UV Visible, China). The standard curve of Gallic acid was taken as reference sample values were expressed in terms of GAE/100g.

Total flavonoid content (TFC)

TFC of the supplemented flatbread was measured using the AlCl3 colorimetric procedure as described (Asif et al., 2025b). In this method, 1mL of extract of the flatbread sample was mixed in 3mL solution of methanol containing aluminum chloride and potassium acetate. This solution was further diluted by adding 5.6mL of distilled water and placed at room temperature for half an hour. Then, sample absorbance was determined using a spectrophotometer 752D (UV Visible, China) at 415 nm wavelength. The standard curve of quercetin was taken as reference and sample values were expressed in terms of quercetin equivalents.

Anti-oxidative potential (DPPH)

The antioxidant potential of supplemented flatbread was determined according to the suggested protocol (Fatima et al., 2025). The samples were centrifuged (Eppendorf, Hamurg, Germany) at 15 °C and 6000 rpm for 5 min. The supernatant layer (0.1 mL) diluted up to 0.5 mL by adding ethanol (80%). Furthermore, 0.5 mL of DPPH (2,2-diphenyl-2-picrylhydrazyl) in a concentration of 0.2 mM was added and mixed using vortex mixer (IKA-Werke GmbH & Co. KG, Staufen, Germany). The final mixture was incubated for 15 min at room temperature in the dark. The absorbance of supplemented flatbread was determined using spectrophotometer 752D (UV Visible, China) at 517nm. Following equation was used to calculate the scavenging activity.

$$\text{Scavenging activity} = 1 - \frac{A_f}{A_0} \times 100$$

Where, A_o and A_f are absorbance values of blank and sample, respectively.

Texture analysis

Texture of flatbread was calculated according to the methods of Walde *et al. (2021)* using a Texture Analyzer (TA-XT Plus, Stable Microsystem, UK) equipped with a 5.00 kg load cell and 35 mm diameter cylindrical probe. Other parameters used in this study were: pre-test speed, 1.00 mm/s; test speed, 1 mm/s; post-test speed, 2 mm/s; data acquisition rate, 200 points per second. Hardness was determined as the maximum peak force operated with Exponent 6.1.4.0 software (Stable Micro Systems, Surrey, UK). In this method, the flatbread sample was horizontally placed, and compression force was applied with the help of a load cell. The hardness of flatbread was measured through software, and a graph was obtained. The following equations were used to calculate cohesiveness, springiness, gumminess, and chewiness.

$$Cohesiveness = \frac{Area\ of\ work\ in\ 2nd\ compression}{Area\ of\ work\ in\ 1st\ compression}$$

$$Springiness = \frac{Probe\ travel\ distance\ in\ 2nd\ compresson}{Probe\ travel\ distance\ in\ 1st\ compression}$$

Gumminess = Hardness × Cohesiveness
Chewiness = Hardness × Cohesiveness × springiness

Color analysis

The color characteristics of supplemented flatbread samples were determined using the CIE L*a*b* color system with a colorimeter (Color Tec-PCM, NY, USA), following the procedure described by Ravishankar Pandiselvam et al. (2023) and Iqbal et al. (2026). The CIE L*a*b* color space expresses color in terms of L* (lightness), a* (redness-greenness), and b* (yellowness-blueness). Color measurements were taken at different positions of each flatbread sample, and each measurement was performed in triplicate. The mean values of L*, a*, and b* were used to calculate additional color parameters including chroma (C*), whiteness index (WI), and total color difference (ΔE) according to the following equations:

Chroma (color intensity) was calculated as:

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

Whiteness index was determined using:

$$WI = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2}$$

Total color difference between the sample and the control (standard) was calculated as:

$$\Delta E = \sqrt{\left(L^* - L^*_{std}\right)^2 + \left(a^* - a^*_{std}\right)^2 + (b^* - b^*_{std})^2}$$

Sensory evaluation

Sensory evaluation of the flatbread was performed for color, taste, aroma, texture; flavor and overall acceptability through panelists using the 9-Point Hedonic scale as mentioned by Abdel & Abdull (2014) and Urooj *et al.* (2026b). Flatbread samples were placed in the randomly coded plates. The plates were presented to panelists to give their non-biased opinion by giving scores about the likeness and dislike of the product. To enhance the accuracy, panelists were provided with water in between the samples to rinse their mouths.

Statistical analysis

The statistics gained for respective factor remained exposed towards statistical examinations to observe the level of significance as described by Urooj *et al.* (2026c) and Zahid *et al.* (2025) using statsitix 8.1. Data was performed in the form triplicates and comparison of means using One-way ANOVA (Analysis of Variance). Further Tukey HSD test all-Pairwise comparisons, the significance of the means of the analyzed parameters was determined using the test.

3. Results and Discussions

Proximate composition of flatbread

The chemical composition of leaf powders derived from plants can differ based on several aspects such as harvest time, geographical location, and processing conditions. Nutrient composition of Moringa oleifera leaf powder (MoLP) and flatbreads enriched with 0-8% MLP as presented in Table 1. The moisture content for the flatbreads varied from 32.10 ± 0.45% in T0 to 30.50 ± 0.40% in T4. T0 had the highest moisture value was recorded prepared with 100% wheat flour, while the lowest value was observed in T4, which containing 8% MoLP. A gradual decrease in moisture content was reported by Zula et al. (2021), who observed a reduction in moisture content of noodles from 10.83% to 7.72% when MoLP levels were increased up to 20%.

Fat content in the flatbreads showed a slightly increase as the concentration of MoLP was increased, ranging from 1.50 ± 0.04% in T0 to 1.95 ± 0.03% in T4. This could be due to the presence of fats in moringa leaves, which contain approximately 6.91% fat content according to Getachew & Admassu (2022). Similar results were observed by Zula et al. (2021), who found an increase in fat content in noodles from 0.49% to 1.24%. Fiber content in the flatbreads was also found to be significantly higher, varying between 1.10 ± 0.05% in T0 to 2.75 ± 0.06% in T4. As noted by Getachew and Admassu (2022), MoLP is rich in crude fiber content (5.27%), which contributes to the enhanced fiber content observed in the composite food products.

Protein level of the flatbreads was found to be progressively increasing, with values from 9.80 ± 0.32% for T0 to 12.80 ± 0.27% for T4. The outcomes are consistent to those presented by Agba et al. (2024), where they noted an increase in the protein content of wheat cookies from 8.46% to 9.69%, following enrichment with MoLP. In a study conducted by Zula et al. (2021), the protein level of noodles increased from 9.85% to 10.92% as the quantity of MoLP incorporation increased.

Ash content, which represents the total mineral composition of the food product, was highly increased from 1.20 ± 0.06% in T0 to 2.20 ± 0.05% in T4. The increase in ash content is attributed to the presence of minerals in moringa leaves. As mentioned by Zula et al. (2021), the ash content of noodles was found to increase from 0.99% to 1.38% as the concentration of MoLP increased. Likewise, Sibanda et al. (2024) noted an increased in ash content to 2.93 g/100 g in pearl millet and moringa composite powders in comparison 1.67 g/100 g in the control formulation.

Table 1 composition of wheat flatbread enriched with MoLP (mean ± SD)

Treatments	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)
T_0	32.10 ± 0.45^a	1.20 ± 0.06^e	9.80 ± 0.32^e	1.50 ± 0.04^c	1.10 ± 0.05^e
T_1	31.85 ± 0.38^a	1.45 ± 0.05^d	10.60 ± 0.28^d	1.60 ± 0.03^c	1.45 ± 0.06^d
T_2	31.40 ± 0.42^b	1.70 ± 0.04^c	11.30 ± 0.35^c	1.72 ± 0.05^b	1.85 ± 0.07^c
T_3	30.95 ± 0.36^c	1.95 ± 0.06^b	12.10 ± 0.30^b	1.85 ± 0.04^{ab}	2.30 ± 0.05^b
T_4	30.50 ± 0.40^c	2.20 ± 0.05^a	12.80 ± 0.27^a	1.95 ± 0.03^a	2.75 ± 0.06^a

Biofunctional Chracterization

Total phenolic content (TPC)

Total phenolic content (TPC) of flatbread increased significantly ($p < 0.05$) with the incorporation of MoLP, as shown in Table 2. TPC values progressively increased from 1.85 ± 0.06 mg GAE/g in the control sample (T_0) to 6.25 ± 0.09 mg GAE/g in treatment T_4 (8% moringa supplementation). These increases may be attributed to the naturally high concentration of phenolic compounds present in the leaves of *Moringa oleifera*. These results were corroborated studies by Osagie Mary Aishat et al. (2021) who observed an increase in the TPC from 0.50 to 1.24 mg GAE/g extract while assessing the impact of moringa leaves on the quality of bread. Likewise, Fazia Ghaffar et al. (2024) highlighted that the increase in the TPC of bread was due to the bioactive compounds such as phenolic acids and polyphenols in moringa leaves. In a similar study conducted by Luis K. Sánchez-Ortiz et al. (2024) in moringa-enriched oat bread, a significant increase in phenolic compounds was also noted with increase in MoLP level. Therefore, the results of the present study are aligned with other previous research where the inclusion of MoLP significantly enhances phytochemicals such as rutin, epicatechin, and dihydroxybenzoic acid present in moringa leaves and nutritional value of bakery products.

Total flavonoid content (TFC)

The total flavonoid content (TFC) in the flatbread significantly ($p < 0.05$) improved with the fortification of MoLP as shown in Table 2. The TFC values varied from 0.95 ± 0.04 mg QE/g in the control sample (T_0) to 3.80 ± 0.08 mg QE/g in treatment T_4, indicating that a high level of MoLP enhanced the levels of flavonoids in the fortified flatbread. Flavonoids are considered important secondary metabolites in plants that are involved in antioxidant activities by scavenging free radicals and chelating metal ions. A comparable finding was demonstrated by Osagie Mary Aishat et al. (2021) that found out an increase in the content of flavonoids in moringa-fortified bread from 1.55 to 9.01 mg QE/g extract by increasing the concentration of MoLP. Similarly, S. Khalid et al. (2023) studied that moringa leaf extracts contain abundant flavonoids and polyphenols responsible for their strong antioxidant and therapeutic potential. Furthermore, Luis K. Sánchez-Ortiz et al. (2024) presented that the presence of high levels of flavonoids in fortified oat bread with MoLP, contributed to enhanced antioxidant capacity.

DPPH radical scavenging activity

There was an observable significant ($p < 0.05$) increase in DPPH radical scavenging activity with increase in the levels of MoLP, as indicated in Table 2. A considerable increase in DPPH inhibition values from 18.2±0.75% in the control sample (T_0) to 67.3±0.95% in T_4 treatment. The substantial improvement could be explained by the presence of various bioactive phytochemicals like phenolic compounds and flavonoids in moringa leaves. In the same manner, Osagie Mary Aishat et al. (2021) found out that there was an increase in DPPH radical scavenging activity of moringa leaf flour-enriched bread from 45.13% to 77.65%. Likewise, Fazia Ghaffar et al. (2024) reported an improved level of antioxidant activity in bread enriched with MoLP because of the presence of phenolic acids and flavonoids in moringa leaves. Similarly, Luis K. Sánchez-Ortiz et al. (2024) showed that moringa leaves had contributed to the increase in DPPH radical scavenging of bread, especially at 5% MoLP concentration.

Table 2. Biofunctional Characterization of flat bread supplemented with moringa powder

Treatments	TPC (mg GAE/g)	TFC (mg QE/g)	DPPH Inhibition (%)
T_0	1.85 ± 0.06^{e}	0.95 ± 0.04^{e}	18.2 ± 0.75^{e}
T_1	2.90 ± 0.08^{d}	1.60 ± 0.05^{d}	29.5 ± 0.82^{d}
T_2	3.95 ± 0.10^{c}	2.30 ± 0.06^{c}	41.8 ± 0.90^{c}
T_3	5.10 ± 0.12^{b}	3.05 ± 0.07^{b}	54.6 ± 0.88^{b}
T_4	6.25 ± 0.09^{a}	3.80 ± 0.08^{a}	67.3 ± 0.95^{a}

Texture profile analysis (TPA) of flatbread

Texture profile analysis of flatbread incorporated with MoLP is provided in Table 3. Hardness of the flatbread was found to gradually increase with the inclusion of MoLP, from 8.20±0.35 N in T_0 to 13.60±0.45 N in T_4. The increase hardness may have been due to gluten dilution and high amount of fibers present in the moringa leaves which would interfere with gluten formation thus leading to the development of the dense texture in baking products. This is consistent with the results obtained by J. Agrawal et al. (2022) when hardness of cookie dough was tested for increasing amounts of incorporation of moringa flour, which found a significant difference in hardness value from 89.2 N in control sample to 284.7 N at higher flour inclusion level.

Springiness of the flatbread showed a gradual decreasing trend with increasing fortification of MoLP, with the value from 0.92 ± 0.02 N in T_0 to 0.82 ± 0.02 N in T_4. Similar reduction in springiness was observed by J. Agrawal et al. (2022), who reported that cookie dough decreased as more moringa flour fortification. The reduction in elasticity indicates that the dough becomes less flexible due to structural changes within the protein-starch matrix. The cohesiveness values were also decreased gradually from 0.68 ± 0.03 N in T_0 to 0.57 ± 0.03 N in T_4, which means that the internal bonding of the bread structure was affected slightly as MoLP content increased. These results are in line with J. Agrawal et al. (2022), who found that cohesiveness decreased with increasing levels of moringa-derived flour due to reduced gluten interactions within the dough structure.

The gumminess and chewiness of the flatbread increased significantly ($p < 0.05$) with rising concentrations of the MoLP. In particular, the gumminess index rose from 5.58 ± 0.28 N in T_0 to 7.75±0.36 N in T_4, whereas the chewiness index rose from 5.13±0.25 N in T_0 to 6.35±0.33 N in T_4. Such changes were mainly associated with the enhanced hardness index and dietary fiber content in moringa leaves leading to a more compact and dense bread crumb structure. According to Pamisetty et al. (2020), the inclusion of plant-derived powders in wheat flour negatively affects the properties of gluten and bread dough. Yi Liu et al. (2025) adding moringa seed flour to noodle recipes led to improved viscoelasticity of the dough, producing a chewier and firmer product. This was due to the presence of moringa protein-fiber-starch interaction which imparted rigidity to the dough structure (Getachew & Admassu, 2022).

Table 3. Texture profile analysis (TPA) of flatbread enriched with moringa powder

Treatments	Hardness (N)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N)
T_0	8.20 ± 0.35^{e}	0.92 ± 0.02^{a}	0.68 ± 0.03^{a}	5.58 ± 0.28^{e}	5.13 ± 0.25^{e}
T_1	9.45 ± 0.40^{d}	0.90 ±0.03^{ab}	0.66 ± 0.02^{ab}	6.24 ± 0.30^{d}	5.62 ± 0.27^{d}
T_2	10.80 ± 0.38^{c}	0.88 ± 0.02^{b}	0.63 ± 0.03^{b}	6.80 ± 0.32^{c}	5.98 ± 0.29^{c}
T_3	12.15 ± 0.42^{b}	0.85 ± 0.03^{c}	0.60 ± 0.02^{c}	7.29 ± 0.34^{b}	6.20 ± 0.31^{b}

T_4	13.60 ± 0.45^{a}	0.82 ± 0.02^{c}	0.57 ± 0.03^{c}	7.75 ± 0.36^{a}	6.35 ± 0.33^{a}

Color analysis

One of the critical quality parameters for bakery items is the color of the product, which has a considerable effect on consumers' perceptions and acceptance of the baked product. With the enhancement in moringa, from 0% (T_0) to 8% (T_4), there was a significant increase in color difference (ΔE), as well as a decrease in chroma (C^*) and whiteness index (WI) were observed. The control sample (T_0) had no difference in color and the highest value of C^* (18.5 ± 0.45) and WI (72.8 ± 0.90), which indicated the typical light appearance of the bread made from wheat flour. However, with the increase in the substitution of moringa, a noticeable change was observed, where the values of ΔE increased from 4.25 ± 0.15 at T_1 to 11.10 ± 0.22 at T_4. At the same time, C^* decreased from 18.5 ± 0.45 in T_0 to 13.2 ± 0.40 in T_4, while the WI declined from 72.8 ± 0.90 to 56.0 ± 0.88, indicating that higher levels of moringa powder produced darker and less vivid flatbread.

The progressive rise in ΔE values (0.00 ± 0.00 to 11.10 ± 0.22) shows that there was an increased difference in the coloration between the moringa-supplemented flatbread and the control sample because of the increased levels of MoLP used. This phenomenon is mainly associated with the chlorophyll and polyphenolic content of moringa leaves that give the bread its distinctive green-brown color. There was a reduction in chroma values from 18.5 ± 0.45 at T_0 to 13.2 ± 0.40 at T_4, indicating reduced color saturation intensity. The progressive reduction in whiteness index from 72.8 ± 0.90 to 56.0 ± 0.88 indicated the progressive darkening of the bread (Govender & Siwela, 2020). A similar trend was also reported by Koriyama (2025) in their study published in Foods, where the color properties of wheat flour, MoLP, and steam-treated moringa powder were evaluated.

Table 4. Color parameters (ΔE, C^*, and WI) of flatbread enriched with MoLP

Treatments	Color Change (ΔE)	Chroma (C^*)	Whiteness Index (WI)
T_0	0.00 ± 0.00^{e}	18.5 ± 0.45^{a}	72.8 ± 0.90^{a}
T_1	4.25 ± 0.15^{d}	17.2 ± 0.38^{b}	68.5 ± 0.85^{b}
T_2	6.40 ± 0.18^{c}	16.0 ± 0.42^{c}	64.3 ± 0.78^{c}
T_3	8.75 ± 0.20^{b}	14.6 ± 0.36^{d}	60.2 ± 0.82^{d}
T_4	11.10 ± 0.22^{a}	13.2 ± 0.40^{e}	56.0 ± 0.88^{e}

Sensory evaluation of flatbread

The sensory scores for all attributes, such as color, taste, texture, aroma, and overall acceptability, are tabulated in Table 5. Control samples (T_0) consisting of 100% wheat flour had the highest sensory scores, which were 8.20±0.35 for color, 8.10±0.30 for taste, 8.00±0.28 for texture, 8.15±0.32 for aroma, and 8.12 ± 0.30 for overall acceptability. T_4 (92% wheat flour + 8% MoLP) had the lowest acceptability scores of 6.20 ± 0.40 (color), 6.30 ± 0.37 (taste), 6.10 ± 0.35 (texture), 6.15±0.38 (aroma), and 6.18±0.36 (overall acceptability).

The decrease in sensory acceptability was noted as the amount of MoLP increased from 2% (T_1) to 8% (T_4). When compared to the control (T_0), there was a decrease in acceptability of 3.7%, 8.5%, 16.0%, and 23.8% for T_1, T_2, T_3, and T_4, respectively, suggesting that the consumer's preference is affected by dosage. Similarly, the score for color decreased by 4.3% (T_1), 9.8% (T_2), 16.5% (T_3), and 24.4% (T_4) relative to the control. As for the taste, it showed a reduction between 2.5% and 22.2%. For the texture, there was a decrease between 3.1% and 23.8%. The aroma had a range between 4.3% and 24.2% when comparing the samples from T_1 to T_4. The current study results find strong support from studies carried out by Govender and Siwela (2020), which mentioned that the inclusion of more MoLP into white and brown breads had resulted in a significant decrease in their taste and aroma because of the formation of a unique plant odor and color difference. This is in accordance with a study carried out by Bourekoua et al. (2018), who found a significant reduction in sensory acceptability of bread with increased MoLP levels, especially at higher levels (10%).

The texture degradation noted also in line with Agba et al. (2024), who showed that inclusion of MoLP resulted in a weakened gluten matrix development, hence making the product less soft and chewy. Similarly, Sánchez-Ortiz et al. (2024) also noted that the phenolic and flavonoid contents of moringa leaves can give rise to bitter and grassy tastes in bread, especially when using higher quantities of moringa leaves. However, the most acceptable to consumers among the treatments tested were T_1 and T_2, in which T_1 had a MoLP level of 2%, followed by T_2 of 4%. As the level of MoLP incorporation increased, the sensory acceptability progressively declined due to darker coloration, stronger flavor, and structural alterations in the matrix (Bassi et al., 2021).

Table 5. Sensory evaluation scores of wheat flatbread enriched with MoLP

Treatments	Color	Taste	Texture	Aroma	Overall Acceptability
T_0	8.20 ±0.35^a	8.10 ±0.30^a	8.00 ± 0.28^a	8.15 ± 0.32^a	8.12 ± 0.30^a
T_1	7.85 ±0.33^b	7.90±0.28^{ab}	7.75±0.30^{ab}	7.80 ±0.29^{ab}	7.82 ± 0.27^{ab}
T_2	7.40 ± 0.36^c	7.50 ± 0.32^b	7.35 ± 0.31^b	7.45 ± 0.34^b	7.43 ± 0.30^b
T_3	6.85 ± 0.38^d	6.90 ± 0.35^c	6.80 ± 0.33^c	6.75 ± 0.36^c	6.82 ± 0.34^c
T_4	6.20 ± 0.40^e	6.30 ± 0.37^d	6.10 ± 0.35^d	6.15 ± 0.38^d	6.18 ± 0.36^d

Figure 1. Effect of varying concentrations of moringa powder on sensorial attributes of flat bread

Conclusion

The study assessed the impact of Moringa leaf powder (MoLP) on wheat flatbread quality. Results showed that increasing MoLP (2–8%) enhanced nutritional value, with higher ash, protein, fat, and fiber contents, while moisture slightly decreased. Functional properties improved, with increased total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity (DPPH). However, physicochemical changes were observed: hardness, gumminess, and chewiness increased, whereas springiness and cohesiveness declined, likely due to gluten dilution and high fiber content. Color analysis indicated darker, green-brown bread with increased ΔE and reduced chroma and whiteness index, attributed to chlorophyll. Sensory evaluation revealed overall acceptability, but higher MoLP levels reduced consumer preference due to herbal flavor, darker color, and texture changes. Incorporation at 2–4% provided the best balance between improved nutrition, antioxidant properties, and sensory quality, while 6–8% enhanced nutrients but negatively affected acceptability.

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