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Original research

Effects of mung bean powder substitution on the physicochemical, antioxidant, and sensory properties of pancakes

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ABSTRACT

Pancakes are popular cereal-based foods, and incorporating mung bean powder is a promising approach to enhance their nutritional quality. The effects of replacing wheat flour with mung bean powder (0, 25, 50, 75, and 100%) on the physicochemical, rheological, and sensory properties of pancake batter and the baked pancakes were investigated. Increasing mung bean substitution significantly increased batter viscosity across all tested spindle speeds, indicating enhanced water-binding capacity and structural stability. Batter color shifted toward darker, greener, and more yellow tones with higher substitution levels. Pancakes formulated with greater amounts of mung bean powder exhibited higher weight, volume, moisture, and ash contents, along with reduced baking loss and density. pH decreased while acidity increased significantly with increased substitution. Nutritional analyses showed a substantial improvement in total phenolic content (TPC) and antioxidant capacity (AC). The TPC increased from 516.5 µg GAE/g in the control to 1323.1 µg GAE/g at 100% substitution. Similarly, AC increased from 36.37% in the control to 77.01% at 100% substitution, representing a 112% enhancement. Texture analysis indicated a progressive reduction in crust hardness with higher mung bean levels, reflecting a softer structure. Sensory evaluation revealed decreased appearance scores at higher substitution levels but improved aroma, flavor, and texture acceptability, with the 75% substitution level achieving the highest overall acceptance. These findings highlight the potential of mung bean powder to create nutritionally enriched, functionally improved pancakes with favorable consumer acceptance.

Keywords: Apparent viscosity; Color attributes; Density; Hardness; Total phenolic content.

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1. Introduction

Pancakes are widely consumed cereal-based bakery products valued for their soft texture, mild flavor, and ease of preparation. Traditionally made from refined wheat flour, pancakes offer desirable sensory qualities but limited nutritional and functional value (Chen et al., 2022; Obinna-Echem et al., 2024). As consumer interest grows in food products with enhanced health attributes, the substitution of wheat flour with nutrient-dense plant ingredients has emerged as an effective strategy to improve the quality of baked goods (Samary et al., 2025b; Vejdanivahid & Salehi, 2025). In particular, legume-based flours have received considerable attention because of their high protein content, dietary fiber, minerals, and bioactive compounds that contribute to antioxidant activity and improved metabolic health (Aydogdu et al., 2017; Shafiei et al., 2022; Baligh et al., 2024; Cacak-Pietrzak et al., 2024).

Legumes such as broad bean, lentils, alfalfa, bean, chickpea, pea, and mung beans are increasingly used to enhance the functional and technological properties of bakery products (Aydogdu et al., 2017; Perri et al., 2021; Shafiei et al., 2022; Sarmasti et al., 2023; Baligh et al., 2024; Cacak-Pietrzak et al., 2024). Among them, mung bean (*Vigna radiata*) powder stands out due to its favorable nutritional profile, containing high-quality proteins, resistant starch, digestible carbohydrates, and significant amounts of phenolic compounds (Elobuike et al., 2021; Salehi, 2023; Salehi & Vejdanivahid, 2025b). These components contribute not only to improved nutritional value but also to desirable functional properties such as water absorption, gelation, and emulsification. As a result, mung bean powder has been

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successfully incorporated into products such as breads, noodles, and cakes (Liu et al., 2018; Ruan et al., 2019; Nazari & Gharekhani, 2021; Ataei nukabadi et al., 2022; Balighi et al., 2024); however, its application in pancake formulation remains poorly explored.

The physical and functional performance of pancakes is largely influenced by batter viscosity, which affects gas retention, spread during cooking, heat transfer, and final texture (Salehi & Vejdanivahid, 2025a; Vejdanivahid & Salehi, 2025). Incorporation of legume flour may significantly modify batter rheology due to increased water-binding capacity and higher levels of proteins and fibers (Aydogdu et al., 2017; Bojňanská et al., 2021). Color attributes, both in batter and in the baked product, are also essential sensory indicators for consumer acceptance. Legume flours often introduce darker pigmentation and alter redness and yellowness values, which may influence perceived quality (Bojňanská et al., 2021; Cacak-Pietrzak et al., 2024). Additionally, their natural bioactive components can increase the total phenolic content (TPC) and antioxidant capacity (AC), contributing to the development of functional bakery products with potential health benefits (Cacak-Pietrzak et al., 2024).

Despite these advantages, the sensory properties of legume-enriched products must be carefully considered, as modifications in flavor, texture, or appearance can negatively affect consumer acceptance (Balighi et al., 2024; Cacak-Pietrzak et al., 2024; Mohamad et al., 2024). Achieving an optimal balance between improved physicochemical quality and desirable sensory characteristics remains a key challenge when developing functional foods based on non-wheat flours (Samary et al., 2025b; Vejdanivahid & Salehi, 2025). Although studies have examined legume incorporation in various baked products, comprehensive investigations on the effects of mung bean powder substitution in pancakes particularly across a wide range of substitution levels are limited.

This study investigated the effects of substituting wheat flour with mung bean powder (0-100%) on the physicochemical, antioxidant, and sensory properties of pancake batter and the final product. The impacts on batter viscosity, key quality attributes, TPC, AC, and sensory acceptance were evaluated to determine the potential of mung bean powder to improve pancake functionality and consumer acceptability.

2. Materials and Methods

2.1. Materials and pancake preparation

2.1.1. Materials

Mung beans (Sabz bahar, Iran), wheat flour (Zar macaron, Iran), vanilla (Hamishak, Iran), baking powder (Golestan, Iran), sugar (Zamen, Iran), pasteurized full-fat milk (3.4% fat, Damdaran, Iran), fresh eggs (Telavang, Iran), and sunflower oil (Famila, Iran) used in pancakes preparation were procured from local markets in Hamedan, Iran. The mung beans were milled using an industrial grinder produced by Best Company (China).

The chemical reagents used in this study included Folin–Ciocalteu reagent (Sigma-Aldrich, USA), sodium carbonate (Merck, Germany), gallic acid (Merck, Germany), 2,2-diphenyl-1-picrylhydrazyl (DPPH, Sigma-Aldrich, USA), and ethanol (Kimia Alcohol Zanjan Co., Iran).

2.1.2. Pancake preparation

The pancake batter was prepared using the following ingredients: 70 g wheat flour, 1 g vanilla, 4 g baking powder, 25 g sugar, 100 g pasteurized whole milk, 57 g fresh egg, and 6 g oil. First, the egg whites were beaten with an electric mixer for 2 min until stable foam was formed. In a separate bowl, the egg yolks and vegetable oil were mixed for 1 min to obtain a uniform emulsion. After adding 50 g of milk and mixing again, the dry ingredients (including wheat flour or mung bean powder, sugar, vanilla, and baking powder), which had been previously sifted, were added and mixed for 2 min. Then, the remaining 50 g of milk was added, and mixing continued for 3 min. In the next step, the foamed egg whites were gently folded into the batter and mixed for 1 min. The batter was left to rest at ambient temperature for 10 min before further processing. For baking, a pan preheated to 170-180°C was used, and portions of 25 g of batter were cooked for 2 min on one side and 1 min on the other. Finally, after cooling to room temperature, the baked pancakes were packaged in polyethylene containers with low oxygen and moisture permeability. Following this, flour was incorporated gradually, with varying substitution levels of mung beans powder at 0% (100% wheat flour), 25%, 50%, 75%, and 100% (0% wheat flour).

2.2. Rheological and physical properties

2.2.1. Evaluation of pancake batter viscosity

The apparent viscosity of the pancake batter was evaluated using a rotational viscometer (Brookfield DV2T, RV model, USA) with spindle RV-03. Measurements were taken at spindle speeds of 5, 10, and 15 RPM over a 0-120 s period, with all tests conducted at a controlled temperature of 25 °C (Salehi & Vejdanivahid, 2025b).

2.2.2. Baking loss determination

Baking loss of the baked pancakes was determined according to the method described by Salehi and Vejdanivahid (2025c).

2.2.3. Volume and density determination

Pancake volume was measured using the canola seed displacement method, and density was determined following Amin Ekhlas et al. (2023).

2.2.4. Color parameters determination

Color analysis of the pancake batter, crust, and crumb was performed using image processing. Photos were captured under consistent lighting with a 48-megapixel camera (iPhone 15 Pro Max, Apple, China) and analyzed in ImageJ (version 1.42e, USA) by converting RGB values to L* (lightness), a* (green–red), and b* (blue–yellow) indices using a color analysis plugin (Pourghasemian et al., 2025).

2.3. Chemical properties

2.3.1. Moisture and ash contents determination

Moisture content of pancakes was measured using a digital moisture analyzer (DBS60-3, Kern, Germany), with results reported as the percentage of weight loss after heating (Salehi & Vejdanivahid, 2025b). Ash content was determined by weighing 3 g of each sample, initially combusting it over a gas flame, and then incinerating in a muffle furnace (Pars-Azma-Co., Iran) at 600 °C until constant weight (Samary et al., 2025a).

2.3.2. pH and acidity determination

The pH and acidity of the samples were assessed following the protocol described by Vejdanivahid and Salehi (2025).

2.4. TPC and AC determination

The TPC of pancakes was assessed following the method described by Samary et al. (2025a). Sample extract was prepared by mixing 2 g of sample with 20 mL of 80% methanol and stirring for 30 min, followed by centrifugation at 4000 rpm for 5 min. The supernatant was collected for analysis. TPC was determined using the Folin–Ciocalteu method. Briefly, 0.5 mL of extract was mixed with 0.5 mL of Folin–Ciocalteu reagent and, after 5 min, 2 mL of 20% sodium carbonate was added. The mixture was kept at 25°C for 15 min, then diluted with distilled water and centrifuged again at 4000 rpm for 5 min. Absorbance was measured at 725 nm using a spectrophotometer (XD-7500, Lovibond, Germany), and results were expressed as micrograms of gallic acid equivalents per gram (µg GAE/g) of dry sample, based on a standard calibration curve prepared with gallic acid.

The AC of pancakes was evaluated using the DPPH radical scavenging method described by Vejdanivahid and Salehi (2025). Briefly, 2 g of sample was extracted with 20 mL of 80% methanol, stirred for 30 min, and centrifuged at 4000 rpm for 5 min. Then, 2 mL of the extract was mixed with 2 mL of 0.1 mM DPPH solution and incubated at 25°C for 30 min in the dark. The absorbance was measured at 517 nm using a spectrophotometer (XD-7500, Lovibond, Germany).

2.5. Puncture test

The crust hardness of the pancakes was measured using a puncture test conducted with a texture analyzer (Santam, STM-5, Iran). A cylindrical probe with a diameter of 5 mm was employed, operating at a constant speed of 0.1 cm/s to a penetration depth of 1 cm.

2.6. Sensorial evaluation of pancake

The sensory analysis was conducted in the Laboratory of New Technologies at Bu-Ali Sina University. In this study, 20 panelists (10 men and 10 women) from various age groups including children, adolescents and young adults, adults, and older adults were recruited to evaluate the pancakes. A nine-point hedonic scale was used to evaluate the sensory attributes of the pancakes, where 1 indicated "dislike extremely", 5 indicated "neither like nor dislike" (moderate), and 9 indicated "like extremely". The evaluation criteria included appearance, aroma, flavor, texture, and overall acceptability.

2.7. Statistical analysis

All measurements were carried out in triplicate, and the results are expressed as the mean ± standard deviation. Statistical analysis was performed using one-way ANOVA in SPSS software (version 21, USA). When significant differences were detected, Duncan's multiple range test was applied for post hoc comparisons, and differences were considered significant at $p < 0.05$.

3. Results and Discussion

3.1. Viscosity of pancake batter

Fig. 1 illustrates the changes in the apparent viscosity of pancake batter over a 120-second period at a constant spindle speed of 10 RPM for different levels of mung bean powder substitution. As shown, increasing the percentage of mung bean powder leads to a clear rise in apparent viscosity. The control sample (0%) exhibits the lowest viscosity, while viscosity increases progressively at 25%, 50%, 75%, and reaches its highest value at 100% substitution. This trend suggests that mung bean powder enhances the batter's water-holding capacity and contributes to a thicker, more structured matrix (Mohamad et al., 2024).

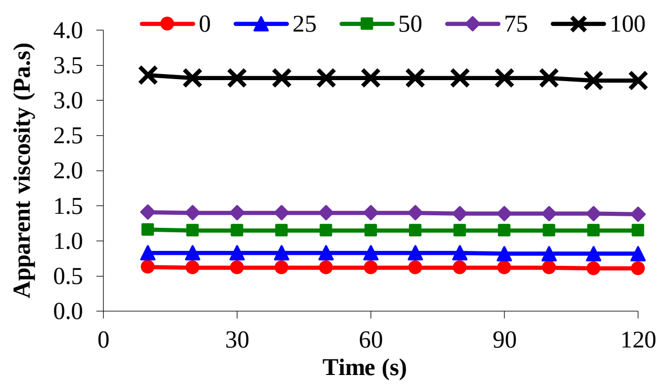

Fig. 1. Changes in apparent viscosity of pancake batter over time at different mung bean powder substitution levels (10 RPM).

Across all substitution levels, the viscosity remains nearly constant over time, with only minimal fluctuations during the 120-second measurement interval. This indicates that the batter exhibits stable rheological behavior under the low shear rate applied (10 RPM). The absence of significant shear-thinning, structural breakdown, or time-dependent thickening implies that the internal network of the batter is resistant to deformation under these conditions. The sample containing 100% mung bean powder not only shows the highest viscosity but also the greatest temporal stability. Lower substitution levels display correspondingly lower viscosities but maintain a similarly stable profile.

A similar viscosity–time behavior was also observed at the other applied spindle speeds (5 and 15 RPM), indicating that the stability trend is consistent across different shear conditions. Baligh et al. (2024) investigated the effect of replacing rice flour with raw and sprouted mung bean flour on the physicochemical properties of gluten-free batter and cake. Their findings indicated that incorporating sprouted mung bean flour significantly ($P<0.05$)

increased the dough consistency compared to the control sample made with 100% rice flour.

Fig. 2 shows the apparent viscosity of pancake batter formulated with different levels of mung bean powder substitution and measured at three spindle rotation speeds (5, 10, and 15 RPM). As illustrated, increasing the substitution level consistently leads to a marked rise in viscosity across all spindle speeds. The control batter (0%) exhibits the lowest viscosity, while the highest viscosity values are observed at 100% substitution. This steady upward trend indicates that mung bean powder substantially enhances the batter's structural consistency, likely due to its higher water-binding capacity and the presence of protein and fiber components that contribute to thicker matrix formation (Balighi et al., 2024). A clear effect of spindle rotation speed is also evident. At each substitution level, the viscosity measured at 5 RPM is the highest, followed by 10 RPM, while measurements at 15 RPM yield the lowest viscosity. This pattern reflects the shear-thinning behavior of the batter where increased shear leads to reduced apparent viscosity indicating that the batter's internal network is sensitive to shear rate and undergoes partial structural alignment or breakdown under higher rotational speeds.

The statistical groupings (as indicated by different letters above the bars) confirm significant differences ($p < 0.05$) both among substitution levels and between spindle speeds. Notably, at higher substitution levels (75% and 100%), the viscosity differences between spindle speeds become more pronounced, suggesting that mung bean–enriched formulations may be more susceptible to shear effects compared to the control.

Overall, Fig. 2 demonstrates that both mung bean powder substitution and spindle rotation speed strongly influence the rheological behavior of pancake batter, with higher substitution levels producing thicker, more viscous batters and higher spindle speeds reducing viscosity through shear-induced thinning. These findings highlight the combined roles of formulation and mechanical mixing conditions in shaping batter flow properties.

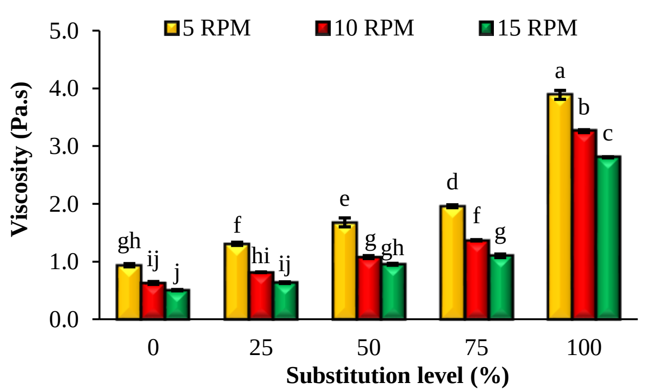

Fig. 2. Apparent viscosity of pancake batter as influenced by mung bean powder substitution and spindle rotation speed. Different letters displayed above the columns indicate statistically significant differences among samples (p<0.05).

3.2. Color parameters of pancake batter

Fig. 3 shows the effects of increasing mung bean powder substitution on the color parameters of pancake batter, including lightness (L*) (a), redness (a*) (b), and yellowness (b*) (c). All three panels demonstrate significant ($p < 0.05$) changes in batter color as substitution levels increase. In Fig. 3a, batter lightness decreases progressively with higher substitution levels. The control sample exhibits the highest L* value, while the 100% substitution sample is the darkest. This steady decline (indicated by statistical groupings a–e) suggests that mung bean powder reduces the brightness of the batter, likely due to its naturally darker pigments and higher content of colored compounds such as phenolics.

In Fig. 3b, redness (a*) becomes increasingly negative as mung bean substitution increases, indicating a shift toward greener tones. The control has the least negative a* value, while the 100% substitution sample shows the most negative value. This pattern suggests that mung bean powder introduces greenish hues into the batter, consistent with the natural coloration of mung beans. The significance letters (c–a) confirm that each substitution level results in a distinct color shift. Fig. 3c reveals the opposite trend for yellowness (b*), which increases steadily with increasing substitution. The 100% substitution sample exhibits the highest b* value, indicating a strong yellow tone. This increase may be attributed to the presence of carotenoid-like pigments or Maillard-reactive components in mung bean powder that intensify yellowness. Overall, Fig. 3 demonstrates that mung bean powder significantly alters all major color attributes of pancake batter, making it darker, less red (more green), and more yellow as substitution levels increase. These changes reflect the inherent pigmentation of mung bean powder and may influence consumer perception of batter appearance.

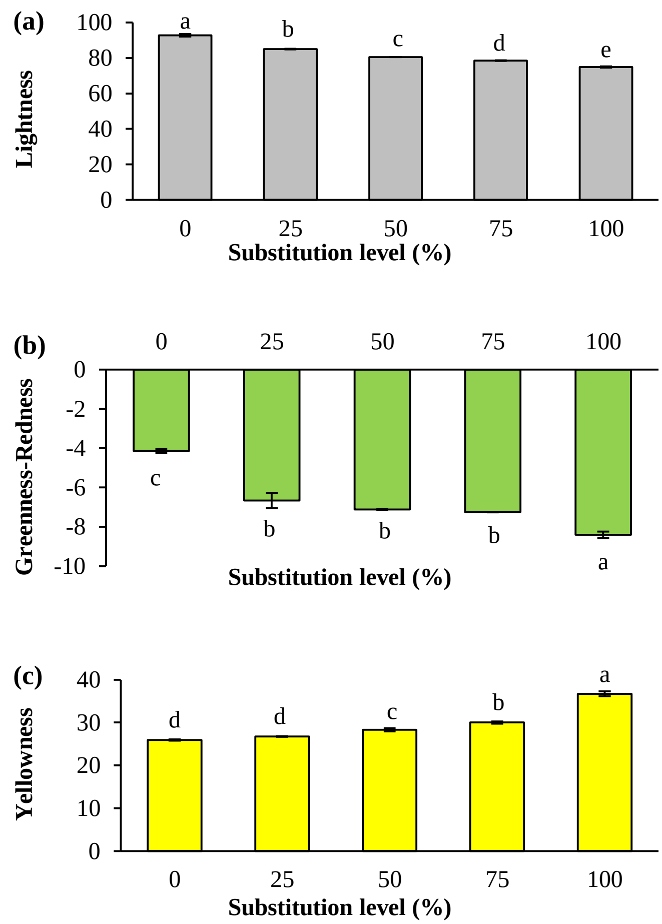

Fig. 3. Variation in pancake batter lightness (a), redness (b), and yellowness (c) with increasing mung bean powder levels. Different letters displayed above the columns indicate statistically significant differences among samples (p<0.05).

3.3. Baked pancakes weight and baking loss

Fig. 4 illustrates the effect of increasing mung bean powder substitution on the weight (a) and baking loss (b) of pancakes. The batter for each pancake was carefully measured, with a sample weight of approximately 25 grams used to ensure consistency in size and baking conditions. Both panels show strong and statistically significant ($p<0.05$) changes in these parameters as substitution levels increase. In Fig. 4a, pancake weight increases steadily with higher levels of mung bean powder. The control sample shows the lowest weight, while the 100% substitution sample has the highest weight, with statistical groups ranging from e to a. This gradual rise in weight suggests that mung bean powder enhances water absorption and retention in the batter, likely due to its higher fiber and protein content compared to wheat flour. As a result, pancakes formulated with higher levels of mung bean powder retain more moisture and develop greater mass after cooking.

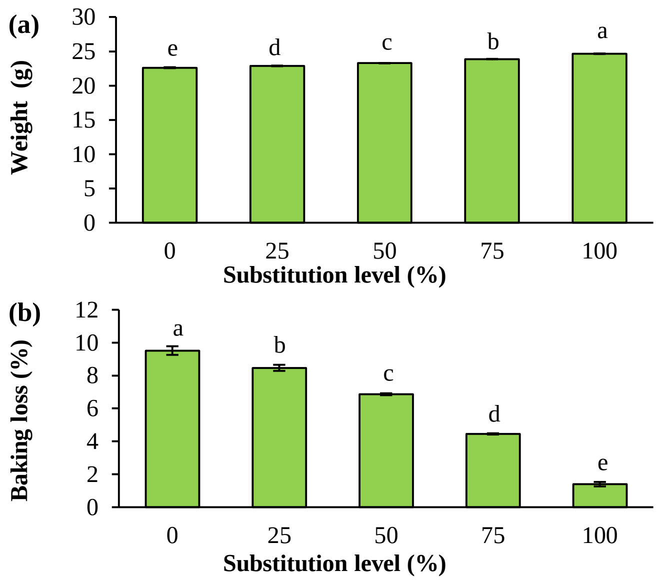

Fig. 4. Changes in pancake weight (a) and baking loss (b) as affected by mung bean powder substitution. Different letters displayed above the columns indicate statistically significant differences among samples ($p<0.05$).

Conversely, Fig. 4b shows a clear reduction in baking loss as substitution levels increase. The control sample exhibits the greatest baking loss, while the 100% substitution sample displays the lowest loss, indicating improved moisture retention during baking. The progressive shift in statistical groups (a–e) confirms that each increase in substitution level results in a significant decrease in moisture evaporation. This reduction in baking loss is consistent with the enhanced water-holding capacity of mung bean powder (Mohamad et al., 2024), which helps to minimize weight loss during thermal processing. Overall, Fig. 4 demonstrates that mung bean powder incorporation leads to heavier pancakes with reduced baking loss, reflecting the superior moisture-binding properties of mung bean components. These findings indicate that mung bean substitution not only modifies batter characteristics but also positively influences the yield and quality of the final baked product. Aydogdu et al. (2017) reported that substituting wheat flour with legume flours such as lentil, chickpea, and pea (at levels of 20–30%) noticeably altered batter behavior and improved certain quality attributes of the final baked product. They observed that cakes formulated with legume flours exhibited reduced baking weight loss compared with the control samples, a finding attributed to the higher water-binding capacity of legume-based ingredients. This trend is consistent with the results of the present study, where the incorporation of mung bean powder similarly enhanced moisture retention and influenced the rheological and physical characteristics of the pancakes.

3.4. Baked pancakes volume and density

Fig. 5 presents the effects of mung bean powder substitution on pancake volume (a) and density (b). The results indicate that substitution level significantly influences both parameters. In Fig. 5a, pancake volume increases progressively as substitution levels rise from 0% to 100%. The control sample exhibits the lowest volume, while the 100% substitution sample shows the highest volume. Statistical groupings (d–a) confirm that each increase in mung bean proportion leads to a significant increase in volume. This enhancement in volume may be attributed to the improved water-binding capacity and structural integrity imparted by mung bean components, which may support better gas retention during cooking. The study by Baligh et al. (2024) showed that the addition of both whole and sprouted mung bean flour significantly ($P<0.05$) increased the cake volume index compared to the control. The lowest specific volume was observed in the control sample, while the cake containing 20% sprouted mung bean flour exhibited the highest specific volume among all treatments.

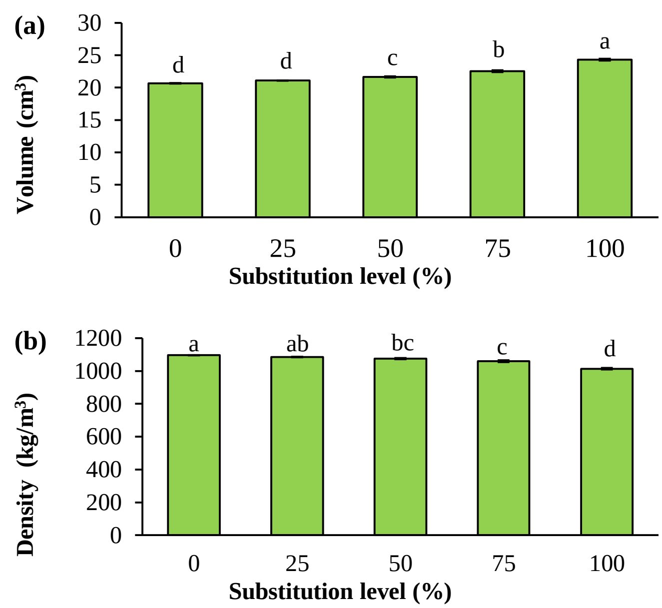

Fig. 5. Changes in pancake volume (a) and density (b) as affected by mung bean powder substitution. Different letters displayed above the columns indicate statistically significant differences among samples ($p<0.05$).

In contrast, Fig. 5b shows a gradual decrease in pancake density with increasing substitution levels. Although the differences among some intermediate treatments (0%, 25%, and 50%) are not statistically distinct (a–bc), the overall trend indicates that pancakes become less dense at higher substitution levels. The 100% substitution sample has the lowest density, corresponding to its highest observed volume. This inverse relationship between volume

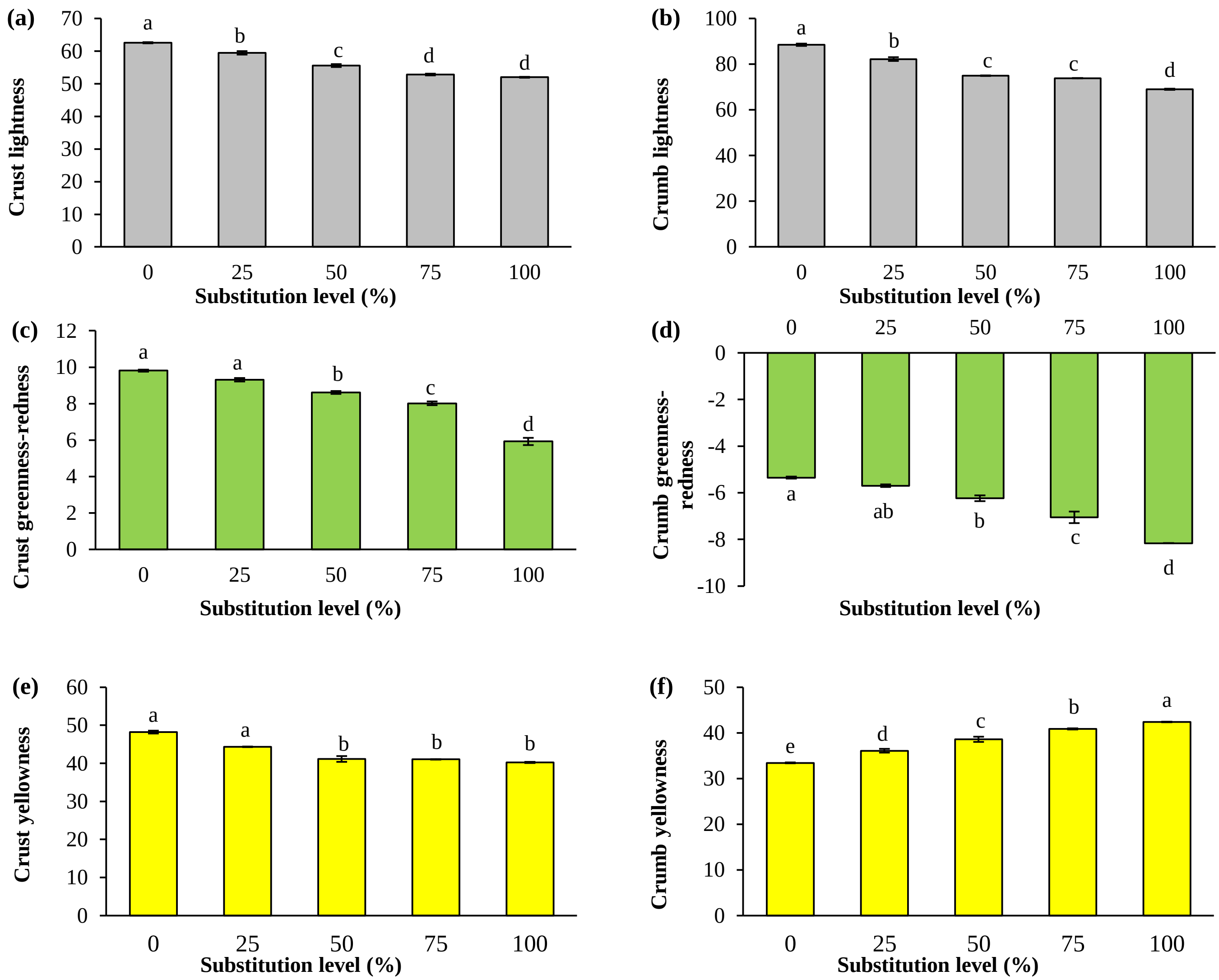

Fig. 6. Changes in crust and crumb color attributes of pancakes (lightness, redness–greenness, and yellowness) as influenced by mung bean powder substitution levels. Different letters displayed above the columns indicate statistically significant differences among samples ($p<0.05$).

and density is consistent with a more aerated structure being formed when mung bean powder is incorporated.

3.5. Crust and crumb color indices of pancakes

Fig. 6 illustrates the significant impact of mung bean powder substitution on the crust and crumb color attributes (Lightness - L, Redness-Greenness - a, and Yellowness-Blueness - b*) of pancakes. The results demonstrate that the incorporation of mung bean powder induces statistically significant and visually perceptible changes in the color profile of both the crust and crumb.

The most pronounced effect is observed on the lightness (L*) values. For both the crust and crumb, there is a clear and significant dose-dependent decrease in L* as the substitution level increases. For instance, the crumb lightness likely decreases from approximately 88.58 at 0% substitution to around 69.05 at 100% substitution. This darkening effect is a common phenomenon when refined wheat flour is replaced with legume or whole-grain flours, due to the higher content of melanoidins and other colored compounds formed during Maillard reaction, as well as the inherent pigments and dietary fiber in mung bean powder. Regarding redness-greenness (a*), a significant shift towards more negative values (indicating decreased redness or brownness) is evident, particularly in the crumb. The crust a* value declined from 9.81 at 0% substitution to 5.93 at 100% substitution. Similarly, the yellowness-blueness (b*) parameter shows a substantial and significant increase with higher substitution levels for crumb. The crumb b value, for example, may rise from approximately 33.43 to 42.38. This dramatic enhancement in yellowness can be primarily attributed to the natural yellow pigments (such as flavonoids and carotenoids) present in mung bean powder. These color changes are critical as color is a primary sensory attribute that directly influences consumer perception and acceptance. Cacak-Pietrzak et al. (2024) investigated the effects of incorporating organically grown wheat and legumes (field bean, chickpea, lentil, and pea) on the physicochemical properties and quality of bread. Their results showed that the addition of legume flours led to increased redness and yellowness and a reduction in lightness of the crumb, indicating noticeable changes in the appearance and color of the enriched bread.

3.6. Baked pancakes moisture and ash contents

Fig. 7 displays the changes in moisture content (a) and ash content (b) of pancakes prepared with increasing levels of mung bean powder. In Fig. 7a, moisture content shows a slight but consistent increase across substitution levels. Although some treatments (25%, 50%, and 75%) fall into overlapping statistical groups (ab), the 100% substitution sample is significantly higher (group a), indicating that pancakes become progressively more moist with greater mung bean incorporation. The increased moisture of the baked pancakes can be attributed to the high water-holding capacity of mung bean powder, due to its protein and dietary fiber content. Similar effects have been reported by Mohamad et al. (2024), where water-holding capacity of waffle premix flour increased from 17.71% to 68.88% with mung bean addition. Also, Nazari and Gharekhani (2021) reported that increasing the level of sprouted mung bean flour in bread dough up to 15% resulted in a non-significant reduction in baking loss, indicating that moderate substitution levels may slightly improve moisture retention during baking without significantly altering water loss dynamics.

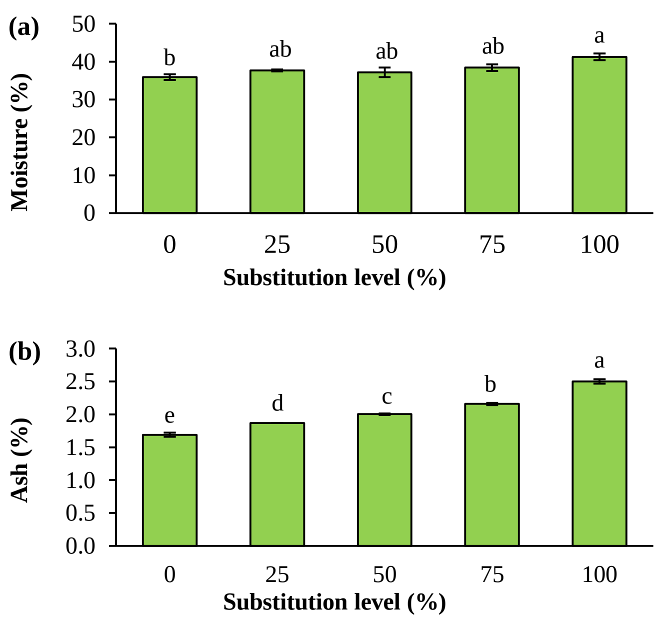

Fig. 7. Changes in pancake moisture (a) and ash (b) contents as affected by mung bean powder substitution. Different letters displayed above the columns indicate statistically significant differences among samples ($p<0.05$).

Fig. 7b shows a clear, linear increase in ash content as substitution levels rise. Each substitution level belongs to a distinct statistical group (e–a), demonstrating a significant rise in mineral content with increasing mung bean powder. This outcome is expected, as mung bean powder contains higher intrinsic mineral content than wheat flour, thereby contributing to higher ash levels in the final product. The results of the present study are in agreement with those reported by Ataei nukabadi et al. (2022), who investigated the substitution of wheat flour with mung bean powder in sponge cake and observed a significant increase in ash content with increasing levels of mung bean powder.

Overall, Fig. 7 confirms that mung bean powder substitution increases both moisture and ash contents in pancakes, improving their nutritional value while contributing to moisture retention during cooking. Balighi et al. (2024) reported that on the day of baking, the moisture content of the cake crumb increased significantly ($p<0.05$) when sprouted mung bean flour was added at levels of 5-20% and whole mung bean flour at levels of 15-20%, compared to the cake prepared with 100% rice flour.

3.7. pH and acidity of pancakes

Fig. 8 illustrates the significant impact of substituting wheat flour with mung bean powder on the pH (Fig. 8a) and acidity (Fig. 8b) of pancakes. The results demonstrate a clear and consistent trend: as the level of mung bean powder substitution increases, the pH of the pancake decreases significantly, while the acidity increases significantly. This inverse relationship is expected, as pH and acidity are chemically interdependent.

In Fig. 8a, the pH values show a statistically significant decline across the different substitution levels. Columns marked with different letters indicate that each incremental increase in mung bean powder leads to a measurably lower pH compared to the control (0% substitution) and other lower substitution levels. This can be attributed to the inherent acidic components present in mung bean powder, which are not found in the same proportion in refined wheat flour (Dahiya et al., 2015). Conversely, Fig. 8b shows a corresponding and significant increase in acidity. The statistical analysis confirms that the acidity at higher substitution levels is markedly greater than at lower levels or the control. This rise in acidity is likely due to the presence of organic acids, phosphates, and other acidulants in mung bean powder (Dahiya et al., 2015).

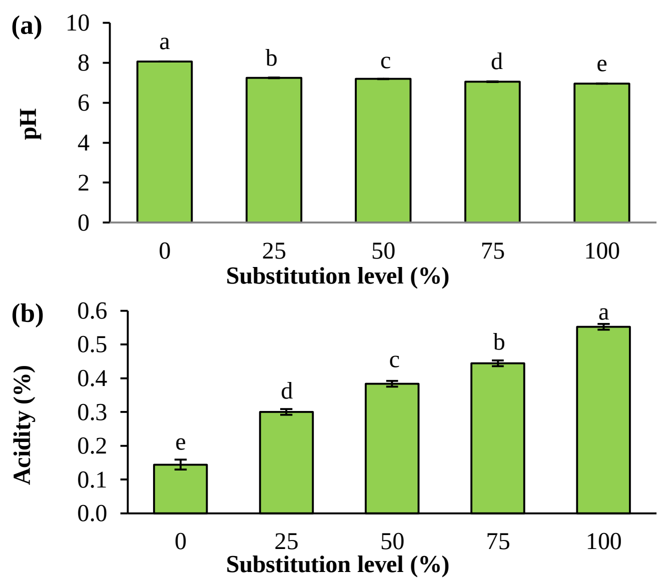

Fig. 8. Changes in pancake pH (a) and acidity (b) as affected by mung bean powder substitution. Different letters displayed above the columns indicate statistically significant differences among samples ($p<0.05$).

3.8. TPC and AC of pancakes

Fig. 9 demonstrates the profound and positive impact of mung bean powder substitution on the nutritional quality of pancakes, specifically regarding TPC (Fig. 9a) and AC (Fig. 9b). The results reveal a strong, dose-dependent relationship where increasing the substitution level leads to a significant enhancement in both parameters. In Fig. 9a, the TPC shows a remarkable and statistically significant upward trend (p<0.05). The TPC in the control sample (0% substitution) is the lowest, with each subsequent increase in mung bean powder proportion resulting in a measurably higher TPC, as indicated by the different letters above the columns. For instance, the TPC at the highest substitution level (e.g., 100%) is approximately 1323.1 µg GAE/g, which is roughly 2 times higher than the control sample (516.5 µg GAE/g). This dramatic increase is a direct contribution of the rich array of polyphenolic compounds naturally present in mung beans, which are absent in refined wheat flour. The study by Cacak-Pietrzak et al. (2024) demonstrated that the inclusion of legume flours in bread increased ash, protein, fiber, fat, and TPC, while carbohydrate content decreased.

A parallel and equally significant trend is observed in Fig. 9b for AC. The graph clearly shows that the AC strengthens progressively with higher levels of mung bean powder. The statistical analysis confirms that the antioxidant activity at the maximum substitution level is substantially greater than at all lower levels. To quantify, the AC at 100% substitution is nearly 77.01%, representing a 2.12-fold increase compared to the control (36.37%). Cacak-Pietrzak et al. (2024) reported an enhancement in the antioxidant activity of bread containing legume flours. The highest increase was observed in bread enriched with pea flour, indicating the potential of certain legumes to improve the functional properties of bakery products.

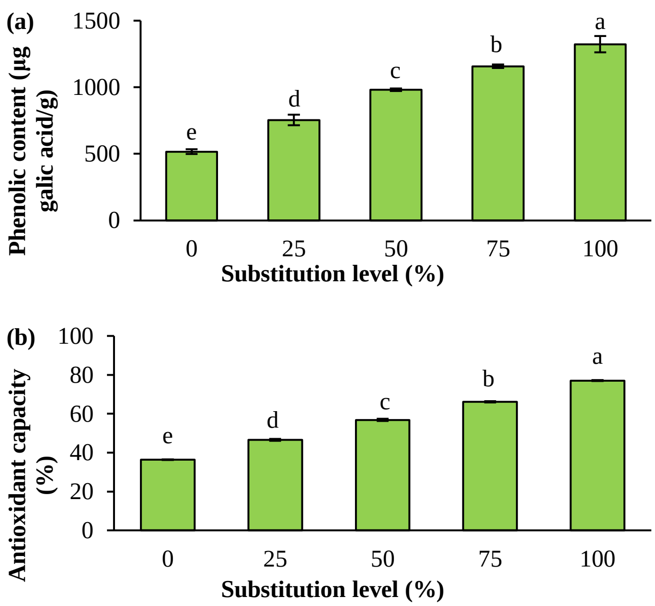

Fig. 9. Changes in pancake total phenolic content (a) and antioxidant capacity (b) as affected by mung bean powder substitution. Different letters displayed above the columns indicate statistically significant differences among samples (p<0.05).

These findings are of paramount importance. They confirm that the functional food potential of the pancake is significantly boosted through fortification with mung bean powder. The strong correlation observed between the increase in TPC (Fig. 9a) and the enhancement in AC (Fig. 9b) is expected, as phenolic compounds are renowned for their potent antioxidant activity. These compounds donate hydrogen atoms or electrons to neutralize free radicals, thereby reducing oxidative stress in the human body (Jain et al., 2025). The incorporation of mung bean powder effectively transforms a conventional bakery product into a functional food with potential health benefits, including reduced risk of chronic diseases such as cancer, cardiovascular diseases, and diabetes, which are associated with oxidative damage (Dahiya et al., 2015; Salehi & Vejdanivahid, 2025b).

3.9. Puncture test results

Fig. 10 presents the changes in pancake crust hardness, as measured by a puncture test, resulting from the substitution of wheat flour with mung bean powder. The results indicate a clear and significant trend where the crust hardness decreases progressively with higher levels of mung bean powder substitution. The graph demonstrates a strong dose-response relationship. The control sample (0% substitution) exhibits the highest crust hardness, forming the baseline. As the substitution level increases to 25%, 50%, 75%, and 100%, a consistent and statistically significant decrease in hardness is observed, as denoted by the different letters above the columns. The Baligi et al. (2024) study found that increasing the proportion of raw or sprouted mung bean flour reduced the hardness of the cake crumb on the baking day, indicating a softer texture with higher levels of mung bean flour.

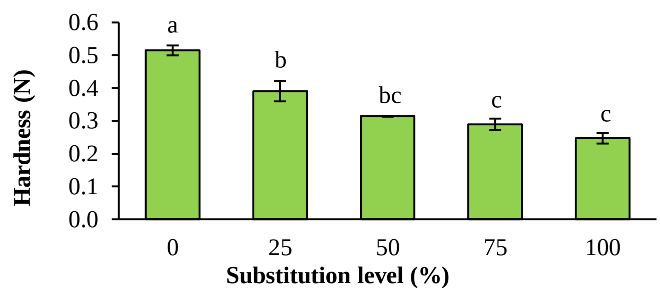

Fig. 10. Changes in pancake crust hardness (puncture test) as affected by mung bean powder substitution. Different letters displayed above the columns indicate statistically significant differences among samples (p<0.05).

3.10. Sensory evaluation of pancakes

Table 1 presents the effect of mung bean powder substitution on the sensory attributes of pancakes, providing crucial insights into consumer acceptability. The results reveal a complex and non-linear relationship between substitution level and sensory scores, with notable trends in texture and overall acceptance.

According to the data in Table 1, the appearance acceptance of the pancakes decreased consistently and significantly with increasing mung bean powder substitution levels, with the control sample (0%) receiving the highest scores (9.0) and the 100% substitution sample the lowest (5.9). In contrast, the acceptance of aroma and flavor followed a different pattern. Although a slight decrease was observed at intermediate substitution levels (25% and 50%), the scores for these two parameters improved significantly at higher substitution levels (75% and 100%), matching or even surpassing the control sample (aroma and flavor scores at 75% were 8.2 and 8.7, respectively). These results indicate that while the color and appearance changes (likely darkening) negatively influenced the visual sensory judgement, the distinct and desirable aroma and flavor profile developed at higher substitution levels were appealing and acceptable to consumers.

Table 1. Effect of mung bean powder substitution on the sensory attributes of pancakes.

Substitution level	Appearance acceptance	Aroma acceptance	Flavor acceptance	Texture acceptance	Overall acceptance
0%	9.0 ± 0.0 [a]	8.7 ± 0.9 [a]	8.8 ± 0.5 [a]	7.0 ± 1.3 [c]	8.0 ± 0.9 [b]
25%	8.5 ± 0.5 [b]	8.0 ± 1.0 [b]	7.8 ± 0.8 [b]	7.2 ± 0.8 [bc]	6.9 ± 1.0 [c]
50%	7.6 ± 0.6 [c]	7.4 ± 0.9 [c]	7.4 ± 0.5 [b]	7.6 ± 0.6 [b]	6.5 ± 1.0 [c]
75%	6.6 ± 0.6 [d]	8.2 ± 0.8 [ab]	8.7 ± 0.7 [a]	8.6 ± 0.5 [a]	8.6 ± 0.6 [a]
100%	5.9 ± 0.9 [e]	8.2 ± 0.9 [ab]	8.6 ± 0.5 [a]	8.9 ± 0.4 [a]	8.1 ± 0.5 [b]

Results are presented as mean ± standard deviation (N = 20), and different letters within columns indicate significant differences at $p < 0.05$.

A significant shift in texture preference is observed. The control pancake (0%) received the lowest texture acceptance score (7.0). Interestingly, texture acceptance improved with higher levels of substitution, peaking at the 100% level with a significantly higher score of 8.9. This suggests that the softer, potentially low dense texture resulting from mung bean incorporation (as indicated in previous texture analysis) was preferred by the sensory panel over the firm, traditional wheat texture. The overall acceptance did not follow a simple declining trend. While the 0% control had a high score (8.0), acceptance significantly dropped at the 25% (6.9) and 50% (6.5) levels. However, it recovered remarkably at the 75% substitution level, achieving the highest overall acceptance score of 8.6. This indicates that a high level of substitution is not only acceptable but potentially preferred, creating a product with a distinct and appealing sensory profile. The 75% substitution level appears to be the optimal formulation for maximizing consumer liking in this study.

4. Conclusion

The incorporation of mung bean powder as a partial or complete replacement for wheat flour significantly improved the nutritional, rheological, and functional properties of pancakes. Higher levels of substitution resulted in increased viscosity stability, improved moisture retention, reduced baking loss, and enhanced structural characteristics such as greater volume and lower density. The marked rise in both TPC and AC underscores the nutritional advantage of mung bean enrichment, effectively transforming pancakes into a functional food with potential health-promoting benefits. Although appearance scores declined due to darker coloration, sensory attributes related to aroma, flavor, and texture improved at higher substitution levels. Notably, the 75% substitution level demonstrated the most balanced performance, achieving the highest overall consumer acceptability. The reduction in crust hardness further contributed to a more desirable texture profile. Overall, the results demonstrate that mung bean powder is a promising ingredient for developing healthier pancake formulations, with 75% substitution identified as the optimal level for maximizing both quality and consumer satisfaction.

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Conflict of interest

The authors declare that there is no conflict of interest.

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