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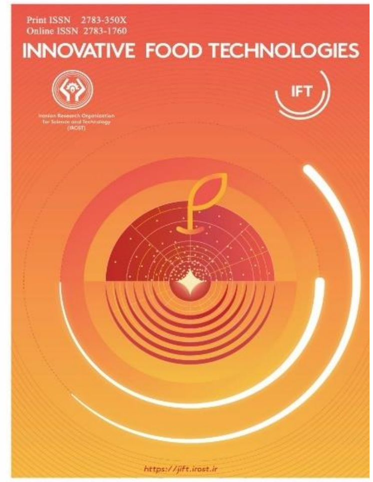

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Impact of mung bean powder as a wheat flour substitute on the quality attributes of waffle

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Abstract

Waffles are a popular wheat-based baked product that can be nutritionally enhanced through partial or complete substitution with legume flours such as mung bean powder, which is rich in protein and bioactive compounds. This study investigated the effects of substituting wheat flour with mung bean powder (0%, 50%, and 100%) on the physicochemical, textural, and sensory properties of waffles. Results showed a significant decrease in batter lightness from 89.58 (0%) to 69.10 (100%), accompanied by a shift in redness from –6.35 to –10.97 and an increase in yellowness from 38.50 to 44.69. The apparent viscosity of batter exhibited shear-thinning behavior across all formulations; however, viscosity increased significantly at 100% substitution (67.34 Pa·s) compared to the control (37.93 Pa·s). The ash content of waffles increased, reaching 2.57% at full substitution. pH decreased from 7.10 to 6.43, whereas acidity rose from 0.25% to 0.48% with higher mung bean incorporation. Total phenolic content (TPC) and antioxidant capacity (AC) were significantly enhanced, increasing from 1160.9 μg GAE/g and 67.4% in control samples to 1635.1 μg GAE/g and 81.2%, respectively, at 100% substitution. Color of baked waffles also changed, with lightness decreasing from 82.81 to 65.73, while yellowness increased from 54.73 to 60.71. Hardness increased from 0.47 to 1.15 N. Sensory evaluations revealed reduced scores for appearance, aroma, and texture at higher substitution levels, while flavor acceptance remained stable. Of course, the overall acceptance score for all samples remained above 8, indicating good consumer acceptability.

Keywords: Antioxidant capacity, Batter, Overall acceptance, Phenolic content, Viscosity.

1. Introduction

Legumes are an important component of the human diet due to their high protein content, complex carbohydrates, dietary fiber, and essential micronutrients [1-3]. Among legumes, mung bean (*Vigna radiata* L.) is particularly valued for its rich nutritional profile, including high-quality plant proteins (22–24%), minerals, vitamins, and bioactive compounds with antioxidant properties [4-6]. Koohi et al. [7] reported that mung bean powder contained 9.48% moisture, 23.16% protein, 0.41% fat, and 3.24% ash. Its low glycemic index and digestibility make it suitable for health-conscious diets and functional food development. Incorporating mung bean powder into bakery products such as bread and cakes offers a promising approach to improving their nutritional value, enhancing protein and mineral content, and introducing functional benefits without significantly compromising sensory attributes [4, 7-10]. Kaur et al. [4] developed a snack formulation incorporating a blend of sorghum and mung bean and evaluated its sensory and functional properties. The findings revealed that the sorghum–mung bean-based snack received high acceptability scores from the sensory panel, indicating favorable consumer perception and strong market potential for this composite product. Balighi et al. [9] examined the effect of substituting rice flour with raw and sprouted mung bean powder on the physicochemical properties of gluten-free batter and cake. Their results confirmed that the incorporation of sprouted mung bean powder can positively influence the quality characteristics of gluten-free cakes. Notably, the highest moisture content in the cake was observed when 20% of the sprouted mung bean flour was used in the formulation, indicating its potential to enhance moisture retention in gluten-free baked products.

Waffles, traditionally prepared from wheat flour and characterized by a cake-like texture, are widely consumed as a versatile food item, serving as bread, dessert, or a cake substitute in fast-food outlets and restaurants. The formulation can be modified by incorporating alternative flours, which not only reduces gluten content but also influences the textural and nutritional properties of the final product [11-14]. Zohry et al. [14] explored the incorporation of pineapple peel powder into waffle formulations and evaluated its impact on the functional, chemical, and nutritional attributes of the final product. Based on the favorable outcomes, the authors suggested the inclusion of pineapple peel powder as a viable strategy to enhance the sensory and functional properties of waffles, as well as to fortify similar bakery products with added nutritional value. Oliveira et al. [15] conducted a study to evaluate the qualitative attributes of waffles formulated with almond skins incorporation. Their findings revealed that waffles enriched with 10% almond skins exhibited the highest concentration of phenolic compounds and demonstrated superior antioxidant activity compared to other formulations.

Due to their convenience, ready-to-eat foods are widely consumed by younger populations; however, they are typically calorie-dense and deficient in essential nutrients and dietary fiber, highlighting the need to improve their nutritional quality to support healthier eating habits [14]. Therefore, the objective of this study was to evaluate the effects of substituting wheat flour with mung bean powder (0%, 50%, and 100%) on the color and flow behavior (viscosity) of waffle batter and the physicochemical (moisture, ash, pH, acidity), TPC, AC, color, texture, and sensory properties of baked waffles.

2. Materials and Methods

2.1. Materials

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

2.2. Preparation of waffle samples

Waffles were prepared using a basic formulation consisting of 100 g of wheat flour, 50 g sugar, 25 g sunflower oil, 50 g full-fat milk, 5 g baking powder, 2 g vanilla, and 1 egg. In this study, wheat flour was partially replaced with mung bean powder at substitution levels of 0% (control, 100% wheat flour), 50%, and 100% (complete replacement of wheat flour).

The eggs and oil were mixed for 5 min, milk was added and mixing continued for 2 min, followed by gradual incorporation of dry ingredients and flours. Portions of 30 g batter were baked in a waffle maker at 190 ± 1 °C, first for 10 min and then for 4 min after flipping, to achieve uniform texture and color. Baking time was controlled using a digital timer, and cooled waffles were packaged in moisture- and oxygen-resistant polypropylene pouches for analysis.

2.3. Color parameters determination

Color analysis of both waffle batter and baked waffles was performed using digital image processing techniques (Figure 1). High-resolution photographs of the samples were captured with a 48-megapixel camera (iPhone 15 Pro Max, Apple Co., China) under uniform lighting conditions to minimize variability. The images were subsequently processed using ImageJ software (version 1.42e, USA), where the RGB color data were converted into L*, a*, and b* values using a dedicated plugin [13]. All measurements were performed in triplicate, and care was taken to select representative areas of the samples to ensure accurate and consistent color evaluation [16].

Figure 1

2.4. Flow behavior of waffle batter

The flow behavior and apparent viscosity of the waffle batter was measured as a function of spindle rotation speed (5, 10, and 15 RPM) and time (0–120 s) using a rotational viscometer (Brookfield DV2T, RV model, USA) equipped with spindle RV-07 [17]. All measurements were conducted at a temperature of 25°C.

2.5. Moisture and ash contents determination

Moisture content of waffles was measured using a digital moisture analyzer (DBS60-3, Kern, Germany), which automatically calculated the percentage of moisture based on weight loss during heating. Ash content was determined by incinerating 3 g of sample in a muffle furnace (Pars-Azma-Co., Iran) at 600 °C until a constant weight was obtained, and the results were expressed as a percentage of the original sample weight [18].

2.6. pH and acidity determination

The pH and titratable acidity of the waffles were determined according to the method outlined by Vejdanivahid and Salehi [19], with slight modifications. Measurements were performed on homogenized waffle samples, and all analyses were conducted in triplicate to ensure reliability and reproducibility of the results.

2.7. TPC and AC determination

The TPC of waffles was assessed following the method described by Samary et al. [18]. The results were expressed as micrograms of gallic acid equivalents per gram of sample (µg GAE/g), based on a standard calibration curve prepared using gallic acid. The AC of waffles was assessed following the protocol described by Vejdanivahid and Salehi [19].

2.8. Puncture test

The textural hardness of the waffles was evaluated using a puncture test with a texture analyzer (Santam, STM-5, Iran). A cylindrical probe with a 0.5 cm diameter was used, moving at a constant speed of 0.1 cm/s until a penetration depth of 1 cm was reached. Each measurement was repeated in triplicate on different points of the waffle surface to ensure accuracy, and the maximum force recorded during penetration was considered as the hardness value.

2.9. Sensorial evaluation of waffle

The sensory evaluation procedures performed in this study were reviewed and approved by the Biomedical Research Ethics Committee of Bu-Ali Sina University, Iran (the ethical approval code 7382). All participants were informed about the purpose and procedures of the study and

gave their informed consent prior to participation. The study was carried out in compliance with the ethical standards for research involving human subjects.
The sensory analysis was conducted in the Laboratory of New Technologies at Bu-Ali Sina University. A panel of 40 individuals from diverse age groups was selected to assess the sensory attributes of the waffle samples. The evaluation criteria included appearance, aroma, flavor, texture, and overall acceptability.

2.10. Statistical analysis

All experiments were performed in triplicate, and the data are presented as mean ± standard deviation. Statistical analyses were conducted using one-way analysis of variance (ANOVA) in SPSS software (version 21, SPSS Inc., Chicago, IL, USA). Post hoc comparisons were carried out using Duncan's multiple range test, with differences considered statistically significant at $p < 0.05$.

3. Results and Discussion

3.1. Color attributes of waffle batter

Table 1 presents the influence of mung bean powder substitution on the color parameters of waffle batter, including lightness (L^*), redness (a^*), and yellowness (b^*). The results demonstrated a significant decrease in lightness ($p<0.05$) with increasing levels of mung bean powder. Specifically, the L* value declined from 89.58 at 0% substitution to 73.23 at 50% substitution and further to 69.10 at 100% substitution, indicating progressive darkening of the batter with higher proportions of mung bean powder.

Table 1

In terms of redness, a similar significant trend ($p<0.05$) was observed. The a* value shifted from -6.35 at 0% substitution to -8.80 at 50% substitution, followed by a slight decrease to -10.97 at 100% substitution. This suggests that higher proportions of mung bean powder contribute to a more pronounced greenish coloration of the batter.
Regarding yellowness, the b* value showed an increasing trend with higher substitution levels. The b* index rose from 38.50 at 0% substitution to 41.89 at 50% substitution, reaching its maximum at 44.69 at 100% substitution. This enhancement in yellowness is likely attributable to the intrinsic pigment composition of mung bean powder.
Overall, these findings indicate that the incorporation of mung bean powder significantly alters the visual properties of waffle batter, leading to reduced lightness and redness indices, and increased yellowness index, which collectively impact the color quality and potential consumer perception of the final product.

3.2. Viscosity of waffle batter

Tan et al. [20] reported that mung bean starch paste exhibits shear-thinning behavior, characterized by a reduction in viscosity as the shear rate increases. This property is typical of non-Newtonian, pseudoplastic systems commonly observed in starch-based dispersions. Figure 2a illustrates the effect of spindle rotation speed (ranging from 5 to 15 RPM) and time (in seconds) on the apparent viscosity of waffles batter. As the spindle speed increased, corresponding to a higher shear rate, a noticeable decrease in apparent viscosity was observed. This shear-thinning behavior is indicative of the batter's pseudoplastic nature, a common characteristic in non-Newtonian food systems. A similar trend was consistently observed across all levels of mung bean powder substitution. Furthermore, during the duration of spindle rotation, the viscosity of the batter remained relatively stable, with minimal reduction over time. This indicates that the viscosity was not significantly affected by prolonged shear, and thus, the batter did not exhibit time-dependent rheological behavior such as thixotropy.

Figure 2

Figure 2b illustrates the impact of mung bean powder substitution level (0%, 50%, and 100%) on the apparent viscosity (in Pa·s) of waffle batter across three spindle rotation speeds: 5 RPM, 10 RPM, and 15 RPM. The data reveals the following trends:

At 0% substitution, the viscosity values are 37.93 Pa·s (5 RPM), 31.2 Pa·s (10 RPM), and 27.12 Pa·s (15 RPM), indicating a decrease in viscosity with increasing spindle speed, with statistically significant differences ($p < 0.05$). At 50% substitution, the viscosity decreases to 24.91 Pa·s (5 RPM), 22.40 Pa·s (10 RPM), and 20.05 Pa·s (15 RPM), showing a consistent reduction with higher speeds, with significant differences ($p<0.05$). At 100% substitution, the viscosity increases to 67.34 Pa·s (5 RPM), 61.51 Pa·s (10 RPM), and 57.32 Pa·s (15 RPM), reflecting a higher viscosity compared to lower substitution levels, with significant differences ($p<0.05$) indicated by letters a and b.

These results suggest that increasing the mung bean powder substitution level from 0% to 100% significantly elevates the apparent viscosity of waffle batter, particularly at lower spindle speeds. Conversely, higher spindle speeds (10–15 RPM) consistently reduce viscosity across all substitution levels, likely due to increased shear thinning. The statistical significance ($p<0.05$) underscores the robustness of these observations, highlighting the interplay between substitution level and spindle speed in modulating batter viscosity.

3.3. Moisture and ash contents of waffles

The effects of mung bean powder substitution on the moisture content of waffles are illustrated in Figure 3a. As shown in this figure, no significant differences ($p > 0.05$) were observed in the moisture content of waffles across the substitution levels (0%, 50%, and 100%).

Figure 3

In contrast, ash content was significantly affected by mung bean substitution (Figure 3b). Waffles prepared with 50% and 100% mung bean powder exhibited notably higher ash values compared to the control ($p < 0.05$), with the maximum observed in the 100% substitution sample (2.57%). Since ash content is a direct indicator of mineral composition, this increase can be attributed to the inherently higher mineral content of mung bean relative to wheat. Consistent with the current findings, Koohi et al. [7] demonstrated that incorporating 30% mung bean powder into brotchen bread formulations led to an increase in the ash content of the final product.

3.4. pH and acidity of waffles

Figure 4a illustrates the influence of mung bean powder substitution level on the pH of waffles. As the proportion of mung bean powder increased, the pH of the baked waffles decreased, while the acidity values showed a corresponding increase (Figure 4b). The highest pH (7.10) and lowest acidity (0.25%) were observed in the sample containing 100% wheat flour. In contrast, the lowest pH (6.43) and highest acidity (0.48%) were recorded in the sample made with 100% mung bean powder. These differences were statistically significant ($p<0.05$). The significant decrease in pH and corresponding increase in acidity with higher levels of mung bean powder can be explained by the intrinsic chemical composition of mung bean powder. Mung bean powder contains naturally occurring organic acids, phenolic compounds, and enzymatically active components that can lower the pH of the final product [21]. As the proportion of mung bean powder increases, these acidic constituents become more dominant in the formulation, resulting in a measurable reduction in pH. At the same time, acidity increases because titratable acidity reflects the total amount of acid present, not just free hydrogen ions. Therefore, as more acidic compounds are introduced through mung bean substitution, titratable acidity rises accordingly. This inverse relationship is expected and consistent with the chemical behavior of plant-based ingredients rich in bioactive and phenolic compounds.

Figure 4

3.5. Total phenolic content and antioxidant capacity of waffles

Figures 5a and 5b illustrate the influence of mung bean powder substitution on the TPC and AC of waffles, respectively. As the substitution level of mung bean powder increased, both the TPC and AC of the waffles rose correspondingly. The lowest TPC (1160.87 µg galic acid/g) and AC (67.40%) values were observed in the sample containing 100% wheat flour. In contrast, the highest TPC (1635.08 µg galic acid/g) and AC (81.17%) values were recorded in the sample made with 100% mung bean powder. The differences between these two extremes were statistically significant ($p < 0.05$). Supporting the outcomes of this study, Koohi et al. [7] found that partial substitution of corn starch with 30% mung bean powder significantly enhanced the antioxidant capacity of brotchen breads. Oliveira et al. [15] reported that waffles enriched with 10% almond skins contained a TPC of 415 µg GAE/g. Also, Zohry et al. [14] reported that waffles enriched with 15% pineapple peel powder contained a TPC of 630 mg GAE/100 g DW.

Figure 5

3.6. Color attributes of baked waffles

The color characteristics of baked waffles were significantly influenced by the substitution level of mung bean powder (Table 1). Lightness exhibited a notable decline with increasing substitution levels, decreasing from 82.81 in the control (0% substitution) to 70.82 at 50% substitution and further to 65.73 at 100% substitution. This reduction in lightness can be attributed to the natural pigments present in mung bean powder, which impart a darker appearance compared to wheat flour. Consistent with the findings of the present study, Oliveira et al. [15] and Zohry et al. [14] reported that the incorporation of almond skin and pineapple peel powder into waffle formulations resulted in a reduction in lightness index.

Conversely, redness displayed a significant negative shift across the substitution levels. The control sample recorded a redness value of -2.29, which decreased to -4.16 at 50% substitution. However, at 100% substitution, redness decreased to -5.95, suggesting an enhanced greenish hue at higher levels of mung bean incorporation. This trend reflects the inherent green pigments in mung bean, which dominate at complete substitution.

For yellowness, a progressive increase was observed with higher substitution, rising from 54.73 in the control to 55.89 at 50% substitution and further to 60.71 at 100% substitution. Overall, these findings suggest that mung bean powder incorporation significantly modifies the visual quality of waffles, particularly by reducing brightness, enhancing yellowness, and altering the red-green balance toward a greenish hue at complete substitution.

3.7. Hardness of baked waffles

Figure 6 presents the impact of mung bean powder substitution level (0%, 50%, and 100%) on the hardness of waffles. The data indicates the following numerical trends:

At 0% substitution, the hardness is measured at 0.47 N, serving as the baseline. At 50% substitution, the hardness increases to 0.92 N, showing a significant rise compared to the 0%

level, with a statistically significant difference ($p < 0.05$). At 100% substitution, the hardness further increases to 1.15 N, representing the highest value observed, with a statistically significant difference ($p < 0.05$) marked by the letter a. These results demonstrate a clear positive correlation between mung bean powder substitution level and waffle hardness, with a 98% increase from 0% to 50% substitution and an additional 25% increase from 50% to 100%. The statistical significance ($p < 0.05$) confirms that these increments are robust, suggesting that higher substitution levels substantially enhance the structural firmness of waffles, likely due to the increased protein and fiber content from mung bean powder. Similarly, Koohi et al. [7] observed that introducing 30% mung bean powder in brotchen bread preparation resulted in a notable rise in textural hardness.

Figure 6

3.8. Sensory evaluation of baked waffles

The sensory evaluation results presented in Figure 7 demonstrate that mung bean powder substitution had a significant impact on the sensorial attributes of waffles ($p < 0.05$). Appearance acceptance showed a decreasing trend with increasing substitution levels. The control sample (0%) had the highest score of 9.00, which declined to 8.58 at 50% substitution and further to 7.70 at 100%, indicating reduced visual appeal with higher mung bean content. Similarly, aroma acceptance decreased progressively from 8.93 (0% substitution) to 8.68 (50%) and 7.20 (100%), suggesting that high levels of mung bean powder negatively affected the perceived aroma. For flavor acceptance, minimal variation was observed across treatments, with scores ranging from 9.00 (0%) to 8.93 (50%) and 9.00 (100%), indicating that the substitution did not significantly influence flavor perception. In contrast, texture acceptance declined noticeably from 9.00 in the control to 8.50 at 50% and 7.40 at 100% substitution, reflecting the textural changes induced by mung bean powder incorporation. Finally, overall acceptance followed a similar pattern, decreasing from 9.00 in the control to 8.63 at 50% and 8.15 at 100%, highlighting that higher substitution levels reduced overall consumer acceptability. These results suggest that partial substitution (up to 50%) maintains acceptable sensory quality, whereas complete replacement (100%) negatively impacts appearance, aroma, texture, and overall acceptability.

Figure 7

4. Conclusion

This study showed that substituting wheat flour with mung bean powder significantly affects the physicochemical, functional, and sensory properties of waffles. Increasing the substitution level from 0% to 100% darkened the batter and waffle color and increased viscosity, indicating notable changes in processing behavior. While moisture remained unchanged, ash content, total phenolic content, and antioxidant capacity increased, confirming the nutritional advantages of mung bean incorporation. However, higher substitution levels also increased hardness and negatively affected appearance, aroma, and texture, though flavor acceptance remained stable and overall acceptability stayed above 8. Based on these findings, a 50% substitution level offers the best balance between enhanced nutritional value and acceptable sensory quality. Complete replacement, despite its functional benefits, compromises texture and consumer appeal. Future work should explore formulation strategies to improve the sensory attributes of legume-enriched waffles.

Ethics statement: The study received ethical approval from the Biomedical Research Ethics Committee of Bu-Ali Sina University, Iran (Approval No. 7382).

Founding source: This work was supported by a grant from the Bu-Ali Sina University, Hamedan, Iran (Grant No. 40346 to Fakhreddin Salehi).

References

[1] Affrifah, N.S., Uebersax, M.A., & Amin, S. (2023). Nutritional significance, value-added applications, and consumer perceptions of food legumes: A review. *Legum. sci.*, 5, e192. https://doi.org/10.1002/leg3.192

[2] Sarmasti, M., Mojani-Qomi, M.S., & Zolfaghari, M.S. (2023). Preparation and quality characteristics of gluten-free sponge cake using alfalfa seed (*Medicago sativa* L.) flour. *Journal of Food and Bioprocess Engineering*, 6, 43-48. https://doi.org/10.22059/jfabe.2023.356462.1139

[3] Feyera, M. (2025). Processing techniques and nutrient retention in complementary foods for older infants and young children. *Journal of Food and Bioprocess Engineering*, 7, 93-103. https://doi.org/10.22059/jfabe.2025.386057.1190

[4] Kaur, J., Singh, B., & Singh, A. (2023). Sorghum–mung bean combination snacks: Effect of extrusion temperature and moisture on chemical, functional, and nutritional characteristics. *Legum. sci.*, 5, e186. https://doi.org/10.1002/leg3.186

[5] Bai, Y., Chang, J., Xu, Y., Cheng, D., Liu, H., Zhao, Y., & Yu, Z. (2016). Antioxidant and myocardial preservation activities of natural phytochemicals from mung bean (*Vigna radiata* L.) seeds. *J. Agric. Food Chem.*, 64, 4648-4655. https://doi.org/10.1021/acs.jafc.6b01538

[6] Salehi, F. (2024). Microwave pretreatment of sprouted mung beans before hot-air and infrared drying process. *Innov. Food Technol.*, 11, 182-197. https://doi.org/10.22104/ift.2024.6635.2164

[7] Koohi, S., Faraji, A., & Moshashaei, S.A. (2020). Study of rheological and chemical properties of gluten-free brotchen bread product by chia (*Silvia hispanica*), teff (*Eragrostis teff*) and mung bean (*Vingna radiate*). *J. Innov. Food Sci. Techno.*, 12, 79-96.

[8] Nazari, E., & Gharekhani, M. (2021). Effect of replacement of rice flour with raw and sprouted mung bean Flour on phenolic compounds and physicochemical properties of gluten-Free Bread. *Food Res. J.*, 31, 17-33. https://doi.org/10.22034/fr.2021.34235.1677

[9] Balighi, F., Alami, M., & Sadeghi, A. (2024). Effect of replacing rice flour with raw and sprouted mung bean flour on the physico-chemical characteristics of gluten-free batter and cake. *Food Res. J.*, 34, 117-132. https://doi.org/10.22034/fr.2024.61385.1933

[10] Asadi, Z., Masoud Nia, A., & Zia Ziabari, S.F. (2022). Physicochemical and sensorial properties of non-gluten supplemented flat bread with the replacement of sprouted wheat flour, lentil, mung been. *J. Food Sci. Technol. (Iran)*, 18, 75-83. https://doi.org/10.52547/fsct.18.120.7

[11] Huber, R., & Schoenlechner, R. (2017). Waffle production: influence of batter ingredients on sticking of fresh egg waffles at baking plates—Part I: effect of starch and sugar components. *Food Sci. Nutr.*, 5, 504-512. https://doi.org/10.1002/fsn3.424

[12] Giau, T.N., Thuy, N.M., Tien, V.Q., & Tai, N.V. (2023). Quality evaluation of waffles produced from the partial replacement of wheat flour with green banana flour and potato starch. *Acta Sci. Pol. Technol. Aliment.*, 22, 13-21. https://doi.org/10.17306/J.AFS.2023.1076

[13] Aussanasuwannakul, A., Puntaburt, K., & Pantoa, T. (2024). Enhancing gluten-free crispy waffles with soybean residue (okara) flour: rheological, nutritional, and sensory impacts. *Foods*, 13, 2951. https://doi.org/10.3390/foods13182951

[14] Zohry, F.Z., Zaki, S.A., Dewidar, O.M., & Amin, W.S. (2025). Quality characteristics and nutritional attributes of waffles formulated with pineapple byproducts as a source of bioactive

compounds. *Egyptian Journal of Chemistry*, 68, 271-282. https://doi.org/10.21608/ejchem.2024.305021.10031

[15] Oliveira, I., Marinho, B., Szymanowska, U., Karas, M., & Vilela, A. (2023). Chemical and sensory properties of waffles supplemented with almond skins. *Molecules*, 28, 5674. https://doi.org/10.3390/molecules28155674

[16] Salehi, F. (2019). Color changes kinetics during deep fat frying of kohlrabi (*Brassica oleracea var. gongylodes*) slice. *Int. J. Food Prop.*, 22, 511-519. https://doi.org/10.1080/10942912.2019.1593616

[17] Salehi, F., & Vejdanivahid, S. (2025). Effect of basil seed gum concentration on the physical, textural and sensory properties of quinoa pancakes. *Innov. Food Technol.*, 13, 13-22. https://doi.org/10.22104/ift.2025.7821.2231

[18] Samary, K., Salehi, F., Aliverdi, A., & Daraei Garmakhany, A. (2025). Effect of magnetized water and magnetic field treatments on the physicochemical properties, total phenolic and antioxidant capacity of sprouted oats flour. *Innov. Food Technol.*, 12, 273-285. https://doi.org/10.22104/ift.2025.7738.2225

[19] Vejdanivahid, S., & Salehi, F. (2025). Enhancing the quality and nutritional properties of gluten-free pancakes using sprouted quinoa flour treated with magnetic fields, ultrasound, and infrared drying. *Food Sci. Nutr.*, 13, e70502. https://doi.org/10.1002/fsn3.70502

[20] Tan, H.-Z., Tan, B., Gao, H., & Gu, W.-Y. (2007). Rheological behavior of mung bean starch dough. *Food Science and Technology Research*, 13, 103-110. https://doi.org/10.3136/fstr.13.103

[21] Onwurafor, E., Onweluzo, J., & Ezeoke, A. (2014). Effect of fermentation methods on chemical and microbial properties of mung bean (*Vigna radiata*) flour. *Nigerian Food Journal*, 32, 89-96. https://doi.org/10.1016/S0189-7241(15)30100-4

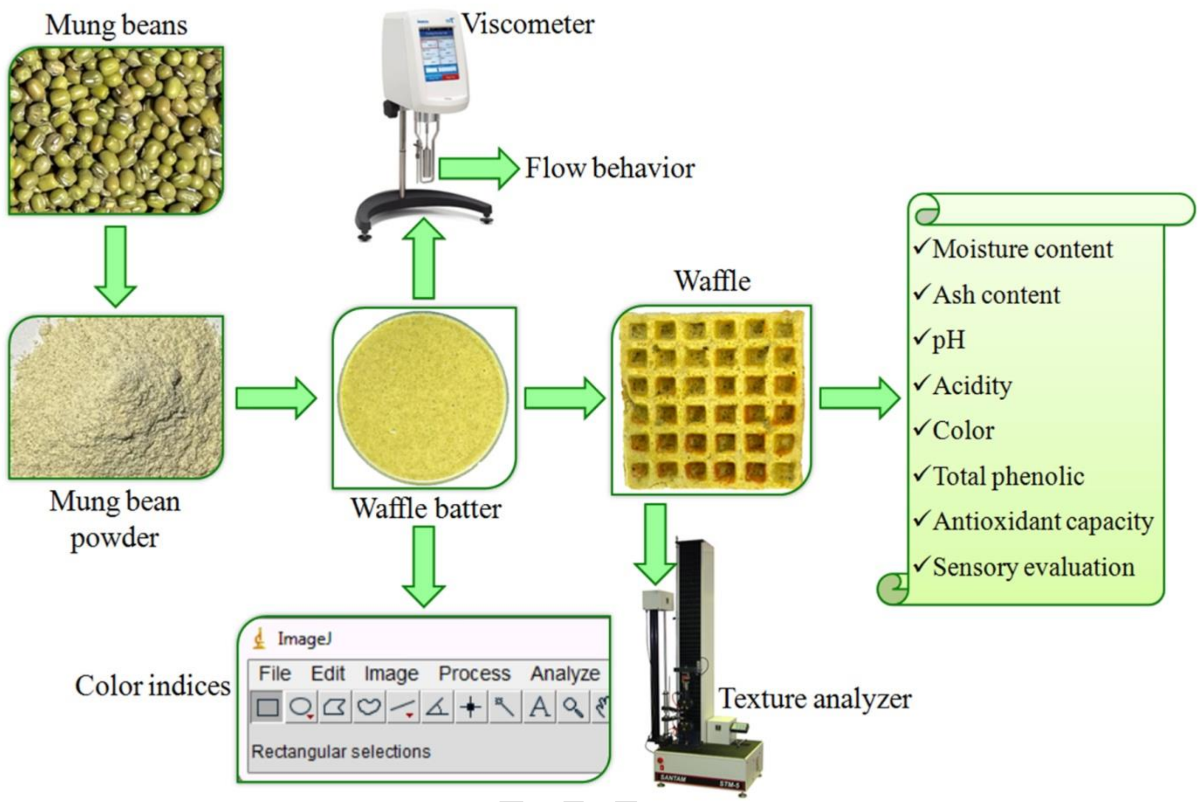

Figure 1- Schematic representation of the experimental workflow for evaluating the physicochemical, textural, and sensory properties of mung bean–based waffles

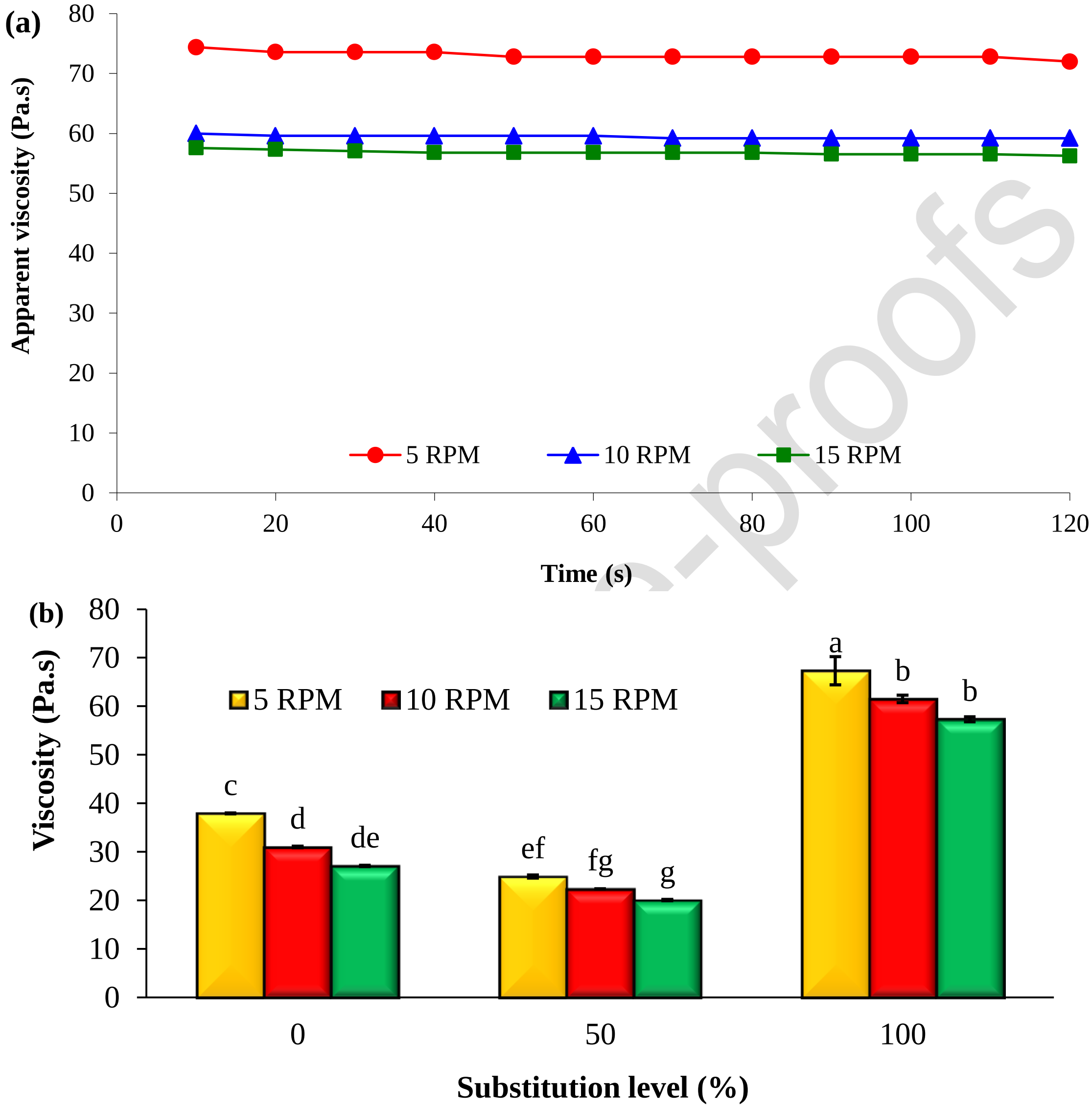

Figure 2- Impact of mung bean powder substitution on the apparent viscosity of waffle batter as a function of spindle rotation speed (5-15 RMP)

Distinct letters above the columns denote statistically significant differences at the $p<0.05$ level.

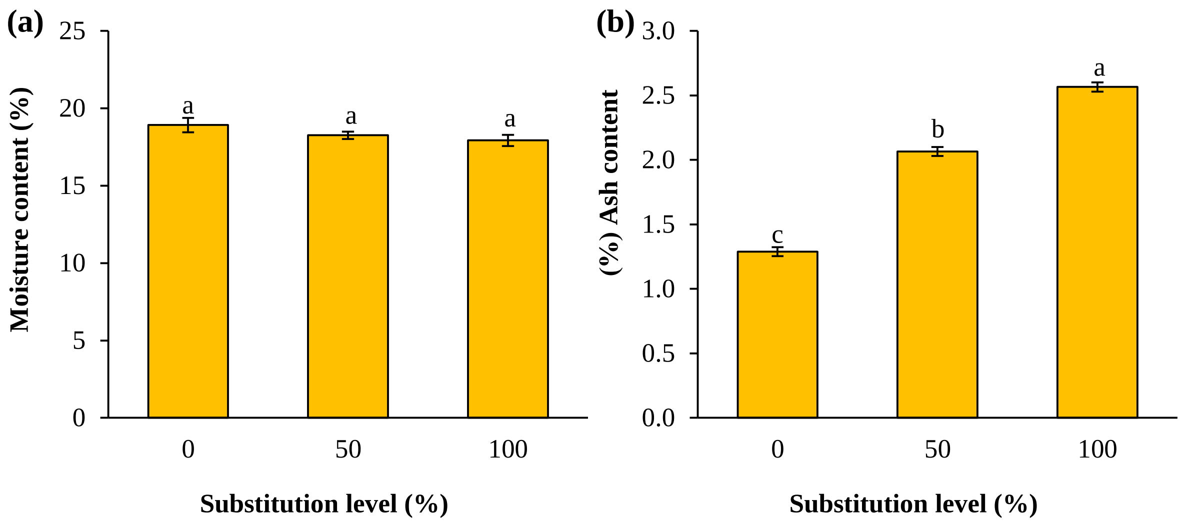

Figure 3- Impact of mung bean powder substitution on the moisture (a) and ash (b) contents of waffles

Distinct letters above the columns denote statistically significant differences at the $p<0.05$ level.

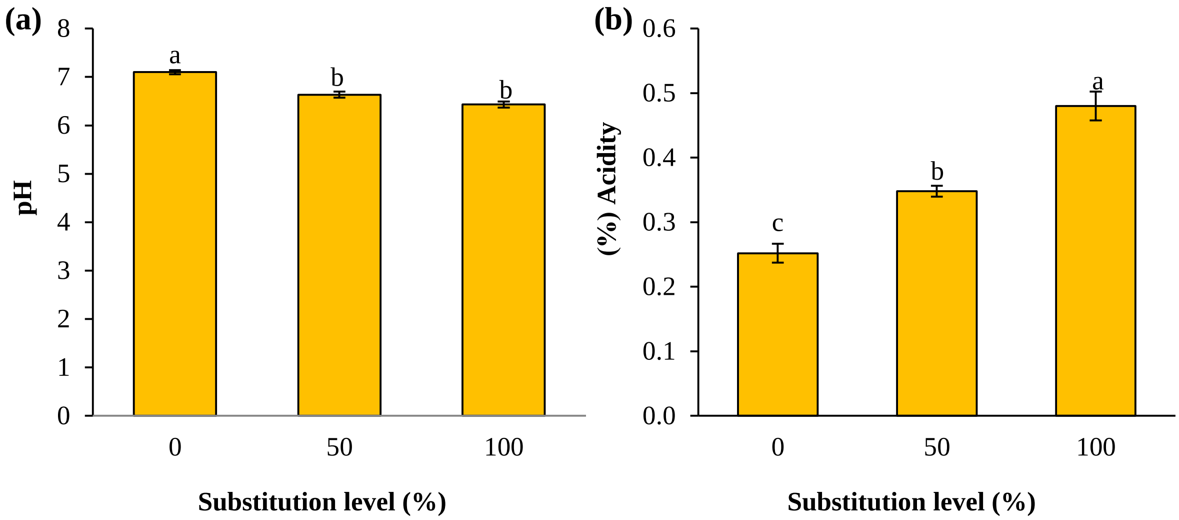

Figure 4- Impact of mung bean powder substitution on the pH (a) and acidity (b) of waffles
Distinct letters above the columns denote statistically significant differences at the $p<0.05$ level.

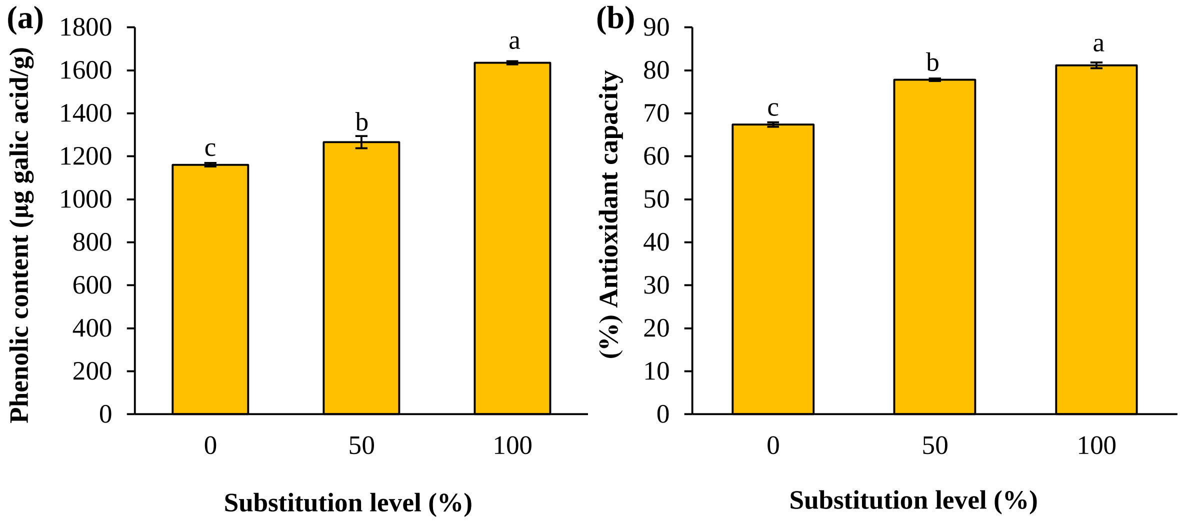

Figure 5- Impact of mung bean powder substitution on the total phenolic content (a) and antioxidant capacity (b) of waffles

Distinct letters above the columns denote statistically significant differences at the $p<0.05$ level.

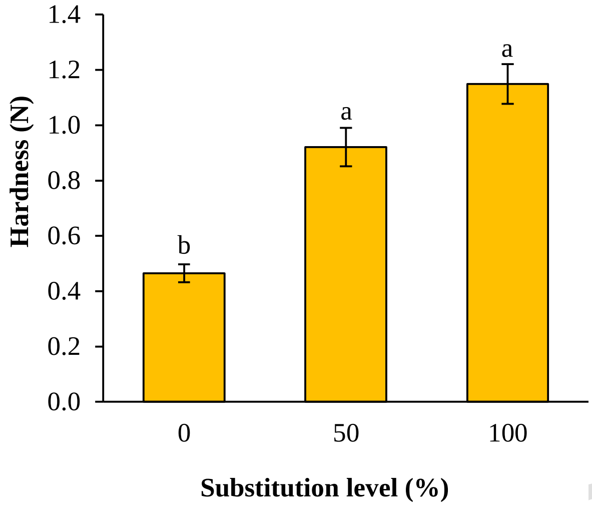

Figure 6- Impact of mung bean powder substitution on the hardness of waffles
Distinct letters above the columns denote statistically significant differences at the $p<0.05$ level.

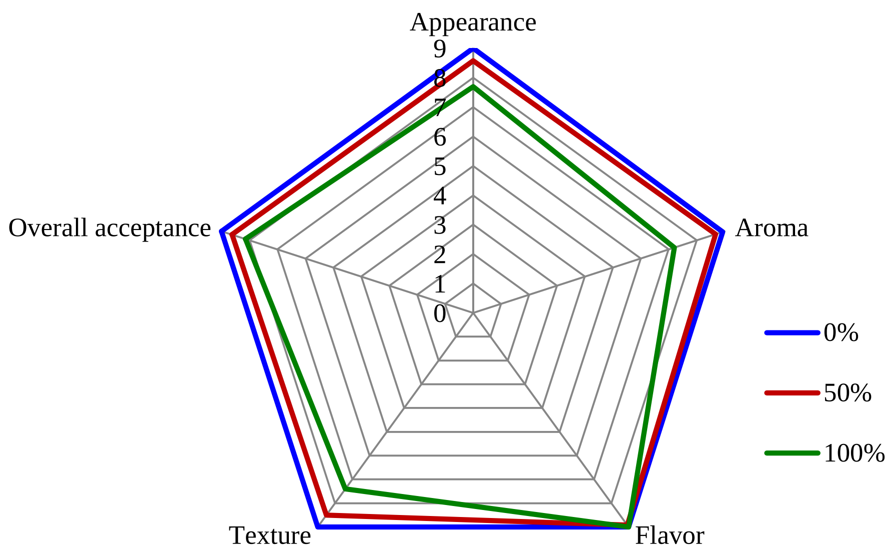

Figure 7- Impact of mung bean powder substitution on the sensorial attributes of waffles (Data are shown as mean, N = 40).

Table 1- Impact of mung bean powder substitution on the color attributes of waffle batter and baked waffles

Substitution level	Waffle batter			Baked waffle		
	Lightness	Redness	Yellowness	Lightness	Redness	Yellowness
0%	89.58±1.21 [a]	-6.35±1.16 [a]	38.50±3.25 [b]	82.81±0.69 [a]	-2.29±1.15 [a]	54.73±3.69 [a]
50%	73.23±0.32 [b]	-8.80±0.24 [b]	41.89±0.49 [ab]	70.82±2.79 [b]	-4.16±0.42 [ab]	55.89±1.78 [a]
100%	69.10±1.81 [c]	-10.46±0.92 [b]	44.69±1.00 [a]	65.73±0.77 [c]	-5.95±1.01 [b]	60.71±2.11 [a]

Data are shown as mean ± standard deviation (N = 3). Distinct letters within the columns denote statistically significant differences at the $p<0.05$ level.