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Formulation and quality assessment of wheat germ and date powder-enriched biscuits: Rheological, textural, and microstructural properties

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ORIGINAL ARTICLE

Abstract

This study examines the incorporation of wheat germ (WG) and date powder (DP) into biscuit formulations to enhance their nutritional, rheological, and sensory properties. WG partially replaced wheat flour, while DP substituted sugar at different levels. Rheological analyses showed that WG increased dough strength and water absorption but lowered extensibility, whereas DP improved moisture retention and moderated the structural effects of WG. Both ingredients enhanced the nutritional profile by increasing dietary fiber, protein, and mineral contents. Texture and color analyses indicated that DP led to darker coloration due to Maillard reactions, while WG contributed to greater hardness. Moderate levels of both ingredients improved the biscuit's internal structure and sensory acceptability. The optimized formulation provided a desirable balance of texture, flavor, and nutritional improvement. Overall, this study presents an approach to developing functional bakery products by combining cereal by-products with natural sweeteners, supporting sustainable and health-focused food design.

Keywords: biscuit; date powder; functional food; rheology; texture; wheat germ

Introduction

The rising global interest in foods that support health and well-being has driven the development of functional bakery products enriched with new ingredients (Dossa & Rivis, 2024). Functional foods, which offer physiological benefits beyond their basic nutritional value, are becoming increasingly incorporated into everyday diets. Among bakery products, biscuits are particularly well suited for functional reformulation due to their long shelf life, affordability, and broad consumer acceptance (Al-Marazeeq & Angor, 2017; Wang *et al*., 2025).

According to the Turkish Standard TS 2383, biscuits are defined as cereal-based products produced by kneading flour with permitted additives such as salt, sugar, fat, and leavening agents, followed by shaping and baking (Anonymus, 1991). Their low moisture content (1–5%) supports microbial stability and contributes to their crisp texture (Wade, 1988). However, conventional biscuits are often low in fiber, antioxidants, and essential micronutrients, which has encouraged researchers to explore formulations that enhance both nutritional and technological quality.

Various enrichment strategies have been documented in the literature, focusing on replacing wheat flour or sugar with ingredients rich in protein or fiber. For example, common bean flour enhances protein and mineral composition (Giuberti *et al.*, 2016), while cricket flour increases protein levels with acceptable sensory properties (Baş & El Nehir, 2022). Likewise, soy, millet, and sprouted grain flours improve nutritional quality and influence dough rheology (Serrem *et al.*, 2011; Adebiyi *et al.*, 2016; Adebiyi *et al.*, 2017; Hidalgo *et al.*, 2019). These findings emphasize the role of ingredient functionality in producing nutritionally enhanced biscuits without diminishing texture or consumer acceptability.

Two promising yet underutilized ingredients in biscuit fortification are wheat germ (WG) and date powder (DP). Wheat germ, a by-product of the milling industry, makes up about 2–3% of the wheat grain and is a rich source of protein, essential fatty acids, vitamins, minerals, and bioactive compounds (Boukid *et al.*, 2018; Weng *et al.*, 2023). Previous research has shown that WG enhances dough elasticity and viscosity, although its inclusion needs to be properly optimized to avoid excessive firmness or flavor imbalance (Petrović *et al.*, 2015; Hou & Srinivasan, 2011). Date powder, produced from Phoenix dactylifera L., supplies natural sugars, dietary fiber, and phenolic compounds with antioxidant activity (Hamza *et al.*, 2023; Barakat & Alfheeaid, 2023). The use of date fiber has also been associated with improved hydration and viscoelastic behavior (Aider & Barbana, 2013).

The combined use of WG and DP in biscuits has not been systematically examined. The interaction between a protein- and lipid-rich ingredient (WG) and a fiber- and sugar-rich ingredient (DP) may influence dough rheology, microstructure, and final texture in ways that differ from their individual applications. This research gap represents the scientific novelty of the present study.

Therefore, this study aims to investigate the combined use of wheat germ and date powder in biscuit doughs from a rheological and structural standpoint. By examining viscoelastic, textural, and microstructural changes, the study seeks to offer new insights into how these two functional ingredients interact in low-moisture bakery systems. The findings are expected to support the development of health-oriented bakery products with improved nutritional profiles and acceptable sensory attributes, helping to bridge the gap between nutritional enhancement and technological feasibility.

Materials and Methods

Materials

The wheat flour and wheat germ used in the biscuit samples were kindly supplied by Ulusoy Un. A.Ş. (Samsun, Turkey). Date powder (Hurma Aşkı, Bilgetürk Gıda, Lüleburgaz, Turkey), table salt (Billur Tuz, Çiğli, İzmir), sodium bicarbonate (Dr. Oetker, Torbalı, İzmir, Türkiye), powdered sugar (Dr. Oetker, Torbalı, İzmir, Türkiye), and vegetable shortening (Unipro, İstanbul, Turkey) were obtained from local markets. The wheat flour and wheat germ used in the formulations were analyzed for their proximate composition prior to use. The moisture, protein, ash, and total dietary fiber contents of the wheat flour were 6.43%, 9.64%, 0.57%, and 1.05%, respectively, whereas those of the wheat germ were 6.82%, 26.64%, 1.80%, and 14.44%, respectively.

Proximate analysis and water activity

The moisture (AACC Method No 44.01), protein (Kjeldahl Method, Velp Scientifica, Italy), and ash content (AACC Method No 08.01) of the wheat flour were determined using standard AACC methods (AACC, 2000). The water activity of the flour sample was measured using a water activity instrument (Aqualab 4TE (Meter Group, Inc., USA) (Demiray, 2015).

Total dietary fiber

The total dietary fiber content of wheat germ, date powder, and baked biscuits was determined using the Total Dietary Fiber Test Kit (TDF 100A; Sigma-Aldrich, Steinheim, Germany) in accordance with Method 32-07.01 (Ade-Omowaye *et al.*, 2008). The results were expressed as the mean value of two replicates.

Preparation of biscuit dough

The biscuit formulation was based on 100 g wheat flour, and to examine the effects of wheat germ and date powder, flour was replaced with wheat germ and sugar was replaced with date powder in varying proportions (Table 1). These substitution levels (10%, 15%, and 20% for wheat germ; 6%, 8%, and 10% for date powder) were selected based on preliminary rheological and sensory pre-trials, as well as previous reports indicating acceptable dough handling and product quality within these ranges (e.g., Ade-Omowaye *et al.*, 2008; Manohar & Rao, 1999).

In dough preparation, sugar and/or date powder, sodium bicarbonate, salt, and shortening were blended using a household mixer (Kitchen Aid, Elkgrove, USA) at 135 rpm for 3 minutes, with 1-minute intervals, until a creamy consistency was achieved. Water was then added, and mixing continued for 1 min at 135 rpm. Finally, flour containing varying wheat germ ratios was incorporated and mixed at 95 rpm for 30 seconds until homogeneous, after which the dough was sheeted and molded to 60 mm diameter × 3 mm thickness before baking (Figure 1).

Rheological properties of dough samples

Empirical rheological measurements

The empirical rheological properties of the biscuit dough samples were determined using Brabender Farinograph, Extensograph, and Amylograph instruments (Brabender SEW, Duisburg, Germany). Amylograph, Farinograph, and Extensograph analyses were carried out according to AACC Methods 22-10, 54-21.02, and 54-10.01, respectively (AACC, 2000). Dough development time (DDT, min), water absorption (WA, %), stability time (S, min), and degree of softening (BU) were measured using the Farinograph. Resistance to extension (RE, BU), extensibility (E, mm), ratio number, and energy (cm^2) were obtained from the Extensograph. Gelatinization onset temperature (°C), peak temperature (°C), and maximum viscosity (BU) were determined using the Amylograph.

Table 1. Formulation of biscuit dough.

Ingredients	Amount
Flour (g) (Wheat flour/germ)	100.0
Shortening (g)	30.0
Sugar/date powder (g)	20.0
Water (ml)	40
$NaHCO_3$ (g)	2.1
NaCl (g)	0.5

Fundamental rheological measurements – dynamic oscillatory testing

Rheological measurements were carried out using a rotational parallel-plate rheometer (Malvern Kinexus Lab+, UK). Approximately 2.0 g of biscuit dough was placed between the plates with a 3-mm gap and a plate diameter of 20 mm. Any excess dough overflowing from the plates was trimmed with a spatula to prevent moisture loss during the 10-minute resting period prior to measurement. A protective lid was closed to minimize evaporation, and all measurements were conducted at 25 °C.

Before the dynamic oscillatory tests, strain sweep measurements were performed at 1 Hz with a strain range of 0.1–100% to determine the linear viscoelastic region (LVR) for the control dough and the samples containing different wheat germ and date powder ratios. Based on these results, a constant strain of 0.5%, within the LVR of all formulations, was selected for subsequent tests. Frequency sweep tests were then conducted over the frequency range of 0.1–10 Hz to obtain the storage modulus (G′), loss modulus (G″), complex viscosity (η*), and tan δ values. All

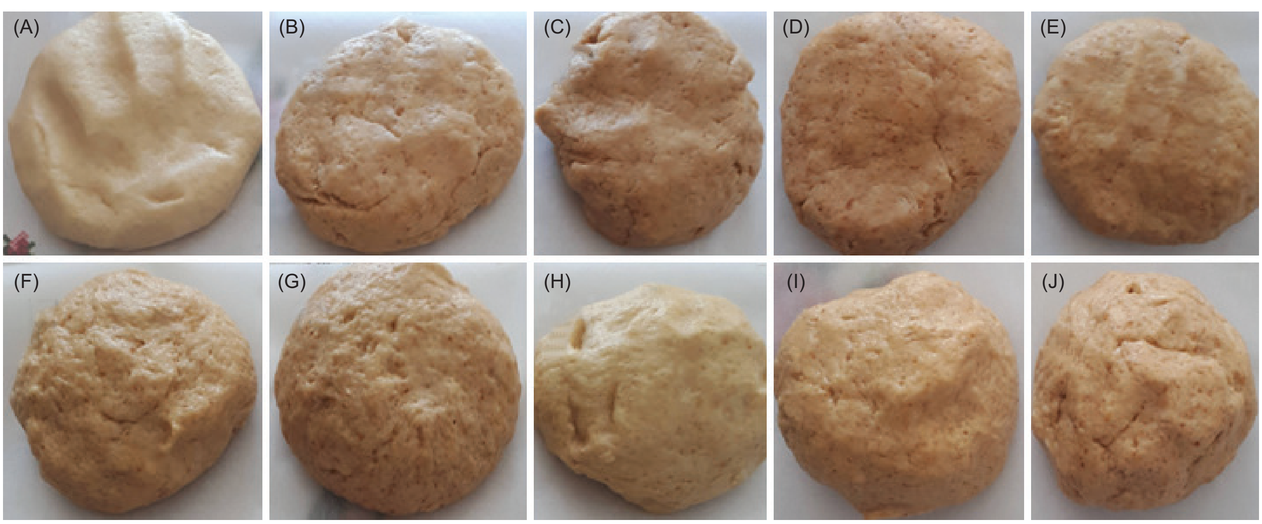

Figure 1. Biscuit dough samples before baking. Panel (A) shows the control biscuit; Panels (B–D) represent 10% WG with 6%, 8%, and 10% DP, respectively; Panels (E–G) represent 15% WG with 6%, 8%, and 10% DP, respectively; and Panels (H–J) represent 20% WG with 6%, 8%, and 10% DP, respectively.

dynamic oscillatory measurements were performed in duplicate, and the results were expressed as mean values.

Baking of biscuits

All biscuit samples were baked in a conventional household oven (Arçelik AFC 470B) using top–bottom heating at 150°C for 10 minutes (Figure 2).

Quality parameters of the biscuits

Weight loss

Weight loss was calculated as the difference between the weight of the shaped biscuit dough and the weight of the same dough after baking. The results were expressed as the mean value of three replicates.

Dimensional properties

The physical measurements of the baked biscuits were carried out following the method of Manohar and Rao (1999). Thickness was measured using four biscuits stacked one on top of another. The diameters were measured using four biscuits placed side by side with no gaps between them, using a laboratory ruler. The biscuits were then rotated 90° on a horizontal axis and the measurements were repeated. The spread ratio was calculated as the ratio of width to thickness. The results were expressed as the mean value of three replicates.

Texture profile analysis

Texture analysis of the biscuits was performed using a Texture Analyzer (TAPlus, Lloyd Instruments, England) based on the method of Keskin *et al.* (2005). Measurements were carried out with a 3-point bending jig. The bottom plate was set at 30 mm intervals, and the probe travel distance and test speed were set at 20 cm and 2 mm/s, respectively. Hardness measurements were conducted in three replicates, and the results were reported in N as mean values.

Color analysis

Color analyses were performed at two different points on the biscuits using a Minolta CR-10 Color Analyzer (Osaka, Japan), with Barium Chloride ($BaCl_2$) used as the reference. The CIE L*, a*, b* color scale was applied, where L* represents the change from 0 (black) to 100 (white), a* represents the change from −100 (green) to +100 (red), and b* represents the change from −100 (blue) to +100 (yellow). Measurements were carried out in three replicates, and the ΔE value was calculated using the equation given below.

$$\Delta E = [(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2]^{1/2}$$

Microstructure of the biscuit samples

Baked biscuit samples were examined morphologically using a scanning electron microscope (SEM) (Tescan, Gaia3, TriglavTM, Czech Republic). Images of the samples at 1000× magnification were recorded for each sample.

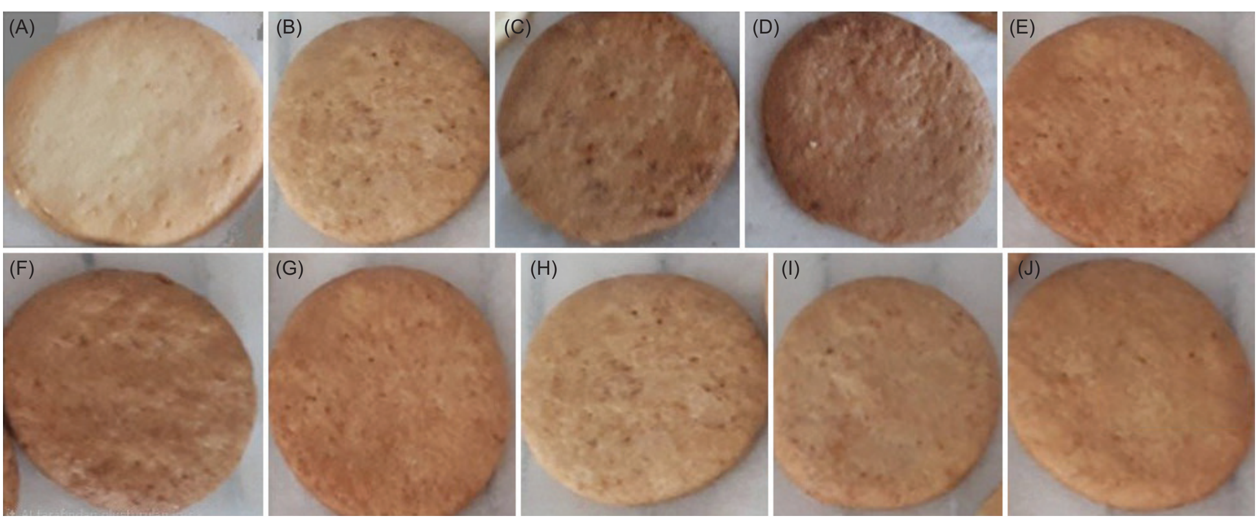

Figure 2. Biscuit samples after baking. Panel (A) shows the control biscuit; Panels (B–D) represent 10% WG with 6%, 8%, and 10% DP, respectively; Panels (E–G) represent 15% WG with 6%, 8%, and 10% DP, respectively; and Panels (H–J) represent 20% WG with 6%, 8%, and 10% DP, respectively.

Sensory analysis

Biscuit samples prepared according to the formulations were subjected to sensory analysis after baking by a panel of 10 individuals, who were asked to rate the appearance, color, texture, crispiness, sweetness, saltiness, mouthfeel, flavor, aroma, and overall acceptability (liking) using a 5-point hedonic scale: 5 = strongly liked, 4 = liked, 3 = slightly liked, 2 = disliked, and 1 = strongly disliked.

Statistical analysis

One-way and two-way ANOVA were performed using the MINITAB software (Minitab 18, State College, PA, USA). When significant differences ($p \leq 0.05$) were identified, Tukey's multiple comparison test was applied. All measurements were conducted in triplicate (n = 3) and reported as mean ± standard deviation, including both biological and analytical replicates.

Results and Discussion

Empirical rheology of biscuit dough samples

Farinograph analysis showed distinct effects of wheat germ (WG) and date powder (DP) on dough mixing behavior. Dough development time (DDT, min) ranged from 4.0 to 4.9 min, with a general increase as the WG level increased. This indicates that wheat germ supplementation prolongs the gluten network formation process, likely due to its high fiber and lipid content, which can interfere with gluten development (Vidosavljević *et al.*, 2022; Deshmukh *et al.*, 2023). In particular, the lipids in wheat germ may coat gluten proteins, reducing their hydration and cross-linking ability, while insoluble fibers compete for water, thereby slowing network alignment and extending dough development time. In contrast, variation in DP did not show a consistent pattern in DDT, suggesting that date powder had a minimal effect on dough formation time (Table 2).

Water absorption (WA, %) values ranged from 51.4 to 55.1%, showing a clear upward trend as the WG content increased. This can be attributed to the hydrophilic nature of wheat germ components, such as fiber and protein, which enhance water-binding capacity (Vidosavljević *et al.*, 2022; Deshmukh *et al.*, 2024). In contrast, DP incorporation showed a counteractive effect because its high sugar concentration competes for free water molecules through hydrogen bonding, thereby limiting overall dough hydration. Stability time (S, min) varied between 3.6 and 4.7 min, generally decreasing with higher WG levels, indicating weakened dough strength. This reduction may be due to the dilution of gluten-forming proteins and the interference of germ-derived lipids with gluten network stability. However, DP addition showed a stabilizing influence, particularly at higher concentrations, suggesting that the sugars and binding compounds in date powder may reinforce dough structure to some degree.

Degree of softening (DS, BU) values ranged from 78 to 152 BU, with WG-enriched samples exhibiting higher softening degrees, indicating reduced dough stability and weaker gluten networks. The increase in DS at higher WG ratios reflects decreased network elasticity due to disruption of the gluten–starch matrix and reduced cohesiveness of the hydrated phase. In contrast, increasing DP levels tended to reduce softening, especially at 10% DP, highlighting its potential to improve dough resistance to overmixing. The humectant

Table 2. Farinograph parameters of biscuit mixes containing varying amounts of wheat germ and date powder.

WG (%)	DP (%)	DDT (min)	WA (%)	S (min)	DS (BU)
	6	4.0	53.9	4.1	116
10	8	4.2	52.7	4.3	95
	10	4.5	51.4	4.6	80
	6	3.7	54.9	3.6	152
15	8	4.2	52.9	4.1	103
	10	4.8	51.4	4.7	78
	6	4.5	55.1	3.8	128
20	8	4.9	53.5	4.5	107
	10	4.4	54.9	4.3	136

WG, wheat germ; DP, date powder; DDT, dough development time; WA, water absorption; S, stability; DS, degree of softening; BU, Brabender units.

properties of date powder allow partial compensation for the water absorbed by fiber, maintaining internal plasticity and limiting excessive softening. The higher DS value (136 BU) observed in the sample containing 20% wheat germ may be attributed to the effect of the additional gluten fraction present in the base flour, which can contribute to greater elasticity and stability by reinforcing the protein network.

Overall, the incorporation of wheat germ increased WA and reduced dough stability, as indicated by shorter S and higher DS values, while date powder acted as a structural stabilizer, improving resistance to softening and enhancing stability. These findings are consistent with earlier research showing that wheat germ tends to weaken dough properties, whereas fiber- and sugar-rich ingredients such as date powder can enhance stability and structural integrity (Vidosavljević *et al*., 2022; Ismail *et al*., 2024; Deshmukh *et al*., 2024; Nogueira *et al*., 2020; Jukič *et al*., 2019).

Samples containing WG and DP exhibited higher resistance to extension (RE) compared to the control, particularly at higher WG levels. For example, RE increased from 129 BU in the 10% WG + 6% DP sample to 163 BU in the 20% WG + 6% DP sample. This upward trend indicates that WG incorporation strengthens the dough matrix, likely due to its protein and fiber content, which enhances dough resistance (Amr *et al*., 2023; Voinea *et al*., 2020). The strengthening effect may be attributed to gluten–fiber interactions within the composite matrix, where wheat germ proteins reinforce the gluten network while the fiber fraction increases the density of the continuous phase. This results in greater resistance to deformation under stress. However, variations in DP showed no distinct trend in RE, suggesting a limited direct influence on dough strength (Ismail *et al*., 2024**).**

Extensibility (E) values ranged from 122 mm to 172 mm. Dough extensibility decreased as WG level increased, particularly at 20% WG, where E values dropped to 122 mm. This reduction indicates that higher WG levels reduce elasticity and flexibility, likely due to gluten dilution and the disruptive effects of wheat germ fiber and lipids (Amr *et al*., 2023; Deshmukh *et al*., 2023). WG fiber fragments can interfere with the continuity of the gluten–starch matrix, while lipids compete for interfacial binding sites, producing a weaker and less extensible structure. Conversely, samples with moderate WG levels (10–15%) exhibited higher extensibility, with a peak of 172 mm in the 15% WG + 8% DP formulation, indicating that moderate WG and DP addition maintains or slightly enhances dough extensibility (Ismail *et al*., 2024). DP's sugar–fiber complex increases moisture retention and plasticity, mitigating the stiffening effect of WG and contributing to higher E values at intermediate ratios.

The ratio number (RE/E) ranged from 0.8 to 1.3, with higher WG levels increasing this parameter, reflecting stiffer dough and reduced extensibility. Notably, 20% WG samples displayed the highest ratio (1.3), consistent with the observed decline in E and increase in RE at high WG (Voinea *et al*., 2020). Energy values, representing the total work required to stretch the dough, ranged from 24 cm^2 to 34 cm^2. Energy increased with WG up to 15%, peaking at 34 cm^2 in the 15% WG + 10% DP sample, indicating an optimal balance between strength and extensibility. This balance suggests a cooperative interaction between WG proteins and DP's hydrophilic sugars, where partial network disruption is compensated by improved moisture distribution and viscoelastic recovery. However, energy declined slightly at 20% WG, suggesting that excessive WG

Table 3. Extensograph parameters of biscuit mixes containing varying amounts of wheat germ and date powder.

WG (%)	DP (%)	RE (BU)	E (mm)	Ratio number	Energy (cm^2)
	6	129	149	1,0	26
10	8	125	154	0,8	26
	10	136	163	0,8	30
	6	128	140	0,9	24
15	8	141	172	0,8	30
	10	156	168	0,9	34
	6	163	131	1,2	28
20	8	160	122	1,3	27
	10	158	122	1,3	26

WG, wheat germ; DP, date powder; RE, resistance to extension; E, extensibility; BU, Brabender units.

compromises extensibility, thereby lowering the total deformation energy (Deshmukh *et al.*, 2024; Paucar-Menacho *et al.*, 2024).

The Amylograph parameters of biscuit doughs containing different WG and DP ratios are presented in Table 4. The control dough exhibited a gelatinization onset temperature of 60.9 °C, a peak temperature of 89.0 °C, and a maximum viscosity of 1718 BU. These values serve as a baseline to evaluate the impact of WG and DP incorporation on starch pasting behavior in the formulations.

The gelatinization onset temperature (61.0–61.8 °C) and peak gelatinization temperature (88.8–89.5 °C) did not show significant deviations from the control, indicating that the incorporation of wheat germ and date powder exerted only a minor influence on the initial gelatinization behavior (Hedayati & Niakousari, 2018). However, a slight upward trend was observed, where higher wheat germ and date powder levels corresponded to marginally increased onset temperatures. This may suggest that the added components modified water availability for starch swelling and gelatinization (Li *et al.*, 2020).

The maximum viscosity values varied considerably among the formulations, ranging from 1226 BU to 1668 BU. Compared with the control sample (1718 BU), most formulations exhibited reduced peak viscosity, except for the sample containing 10% wheat germ and 8% date powder (1668 BU), which was close to the control. The decrease in viscosity can be attributed to the dilution effect of non-starch components derived from wheat germ and date powder, which may hinder starch pasting and weaken the overall viscosity (Jukič *et al.*, 2019). The lowest viscosity (1226 BU) was recorded for the sample containing 6% wheat germ, indicating a more pronounced disruption of the starch gel network (Izhevska, 2019). Overall, these findings indicate that the addition of wheat germ and date powder to biscuit formulations alters pasting characteristics, particularly by lowering the peak viscosity, which may in turn affect dough handling and final biscuit texture (Nadian *et al.*, 2022).

Dynamic oscillatory testing

Biscuit doughs containing 10% wheat germ and varying levels of date powder (6%, 8%, and 10%) exhibited viscoelastic behavior characterized by storage modulus (G′) values consistently exceeding loss modulus (G″) across the tested frequency range, as shown in Figure 3. This indicates an overall elastic-dominant response, typical of structured viscoelastic systems (Aider & Barbana, 2013; Zhou *et al.*, 2018). Both moduli increased progressively with frequency, confirming the formation of a weak gel-like network within the dough matrix. The formulation with 8% date powder displayed the highest G′ values, suggesting improved structural strength and elasticity. The 6% date powder sample showed the lowest moduli among the enriched groups, while the control dough (without wheat germ and date powder) consistently demonstrated the weakest rheological behavior. These results confirm that even a moderate addition of wheat germ combined with date powder can significantly enhance dough elasticity and structural integrity (Petrović *et al.*, 2015).

Figure 4 demonstrates that increasing the wheat germ content to 15% further improves the viscoelastic properties of biscuit doughs. For all samples, G′ values remained higher than G″ across the tested frequency range, maintaining the dominance of elastic characteristics. Compared with the 10% wheat germ samples, the increase in both moduli suggests enhanced network formation, likely due to the additional protein and fiber content derived from wheat germ (Haque & Moore, 2011;

Table 4. Amylograph parameters of biscuit mixes containing varying amounts of wheat germ and date powder.

WG (%)	DP (%)	Gelatinization onset T (°C)	Gelatinization peak T (°C)	Max. Viscosity (BU)
	6	61.1	89.3	1489
10	8	61.4	89.0	1668
	10	61.8	89.5	1300
	6	61.6	89.1	1385
15	8	61.4	89.3	1530
	10	61.6	89.1	1289
	6	61.8	88.9	1226
20	8	61.3	88.8	1516
	10	61.0	88.8	1575

T, temperature; Max, maximum; BU, Brabender units.

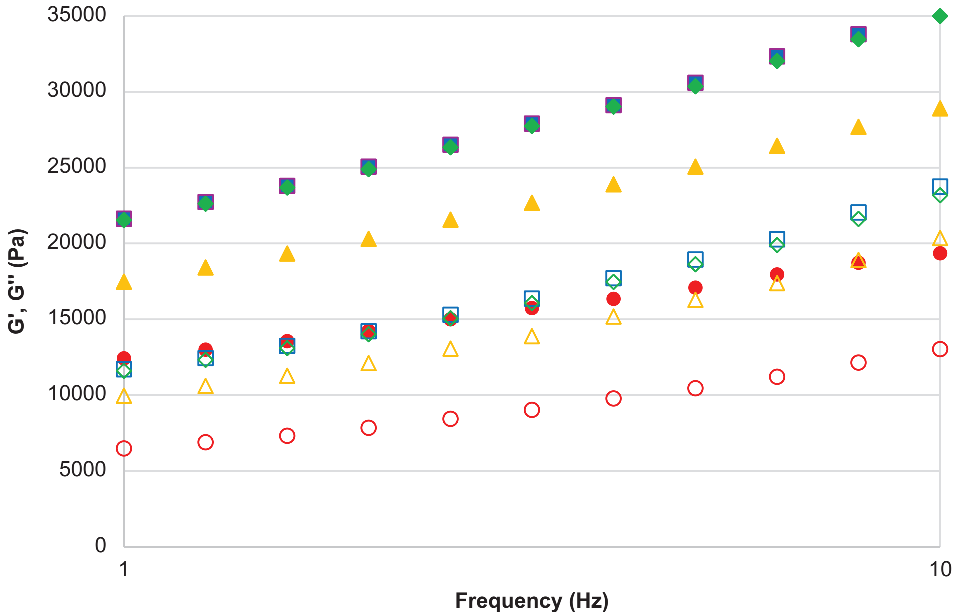

Figure 3. **Storage modulus (G´) (closed symbols) and loss modulus (G´) (open symbols) values of biscuit doughs containing 10% wheat germ and varying ratios of date powder (DP), along with the control biscuit dough sample, each represented by different symbols (●: control sample, ▲: 6% DP, ■: 8% DP, ♦: 10 % DP).**

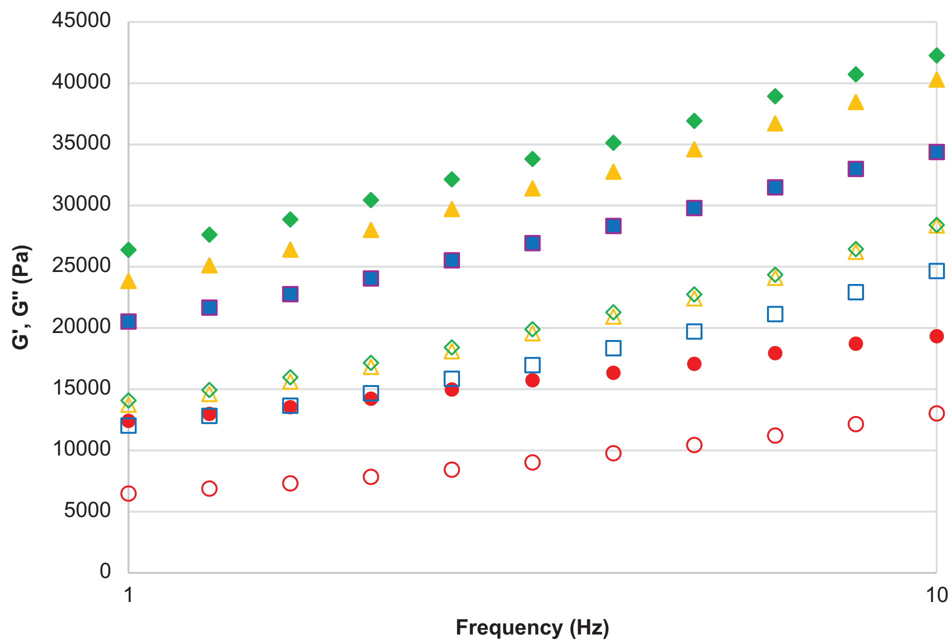

Figure 4. **Storage modulus (G´) (closed symbols) and loss modulus (G´) (open symbols) values of biscuit doughs containing 15% wheat germ and varying ratios of date powder (DP), along with the control biscuit dough sample, each represented by different symbols (●: control sample, ▲: 6% DP, ■: 8% DP, ♦: 10 % DP).**

Hou & Srinivasan, 2011). The dough sample containing 10% date powder exhibited the highest G′ values, followed by 8% and 6% additions. The control sample again presented the lowest moduli, confirming its structurally weaker nature. These results support that higher wheat germ content, particularly in combination with increased levels of date powder, contributes to stronger viscoelastic networks in biscuit doughs (Haque & Moore, 2011).

According to the frequency sweep results (Figure 5), samples containing 20% wheat germ displayed the most evident viscoelastic responses among all tested groups. All formulations containing date powder showed substantial increases in both G′ and G″, with the 10% date powder sample exhibiting the highest elasticity throughout the tested frequency range. These results indicate a well-developed internal structure resulting from the combined effects of wheat germ and date powder. The gap between G′ and G″ widened notably at higher frequencies, especially for the sample with 10% date powder, reinforcing its elastic-dominant behavior (Zhou *et al.*, 2018). The control sample maintained the lowest moduli across all frequencies, emphasizing the critical role of functional ingredients in rheological enhancement. The data suggest that increasing both wheat germ and date powder contents contributes synergistically to the development of a firmer and more elastic dough matrix.

As presented in Table 5, the viscoelastic parameters of biscuit doughs were significantly influenced by wheat germ (WG) and date powder (DP) levels ($p < 0.05$), as determined by two-way ANOVA applied to all parameters. The storage modulus (G′), representing the elastic component, increased with higher levels of ingredient incorporation. The formulation containing 20% WG and 10% DP exhibited the highest G′ value (34 177 Pa), while the 10% WG + 6% DP dough showed the lowest (15 820 Pa). Similar trends were observed for the loss modulus (G″), which also increased in enriched formulations, indicating an improved viscous response. The maximum G″ was recorded in the same 20% WG + 10% DP sample, while the lowest value was found in the least enriched dough (Petrović *et al.***,** 2015).

Tan δ values across all samples were below 1, suggesting elastic-dominant behavior characteristic of weak gel-like systems. The highest tan δ value (0.59) was found in the 15% WG + 8% DP sample, implying a slightly more viscous character. In contrast, lower tan δ values in other samples, particularly those with 10–20% WG and 10% DP, confirmed stronger elastic structures. These findings highlight the synergistic effect of wheat germ and date powder in enhancing the viscoelastic strength and stability of biscuit dough formulations.

Chemical properties of the biscuits

Various chemical property analyses were conducted for flour, wheat germ, date powder, and baked biscuit samples. The moisture, ash, water activity (a_W), protein, and total dietary fiber content were determined in biscuits containing different ratios of wheat germ and date powder. The same analyses were also performed on flour, wheat germ, date powder, and control biscuits (without wheat germ and date powder). The chemical analysis results of biscuits containing wheat germ and date powder are presented in Table 6.

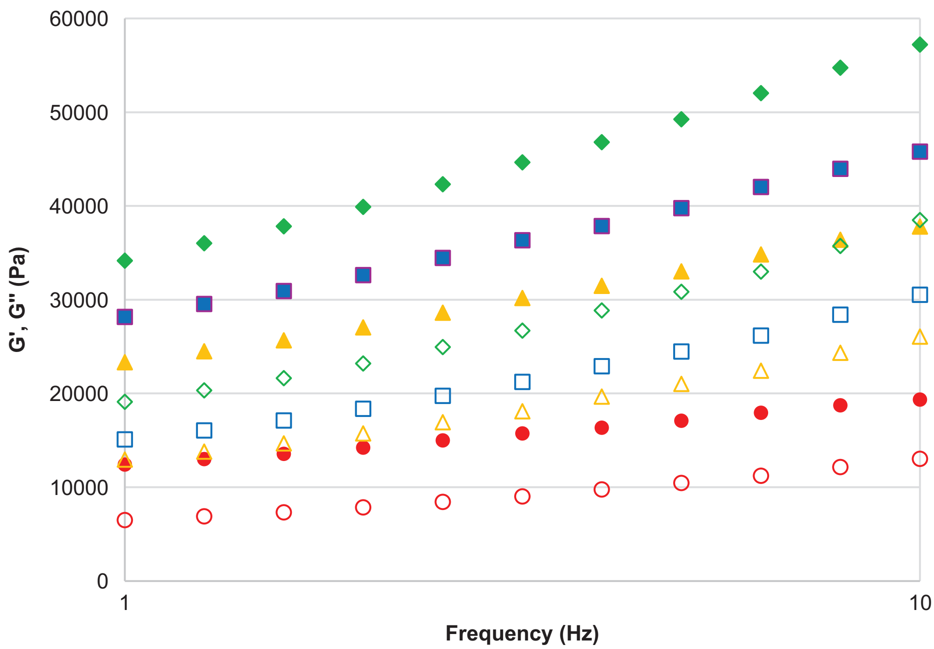

Figure 5. Storage modulus (G´) (closed symbols) and loss modulus (G´) (open symbols) values of biscuit doughs containing 20% wheat germ and varying ratios of date powder (DP), along with the control biscuit dough sample, each represented by different symbols (●: control sample, : 6% DP, ■: 8% DP, ♦: 10 % DP).

Table 5. Dynamic rheological properties of the biscuit doughs containing different ratios of wheat germ and date powder.

WG (%)	DP (%)	G´ (Pa)	G˝ (Pa)	Tan δ
	6	15820[d*]	8984[c]	0.57[ab]
10	8	21640[cd]	11703[bc]	0.54[bc]
	10	21527[cd]	11610[bc]	0.54[bc]
	6	23857[bc]	13740[b]	0.58[a]
15	8	20530[cd]	12037[bc]	0.59[a]
	10	26400[bc]	14090[b]	0.53[c]
	6	21250[cd]	11628[bc]	0.55[bc]
20	8	28170[ab]	15093[b]	0.54[c]
	10	34177[a]	19107[a]	0.56[abc]

WG, wheat germ; DP, date powder.
*Mean values within a column followed by the different letter are significantly different.

Table 6. Chemical properties of biscuits containing different ratios of wheat germ and date powder.

WG (%)	DP (%)	Moisture (%)	Aw	Protein (%)	Ash (%)	TDF (%)
	6	5.73[c*]	0.49[c]	8.12[f]	1.65[e]	5.34[a]
10	8	5.87[b]	0.53[b]	8.05[fg]	1.72[d]	5.07[a]
	10	6.51[a]	0.53[b]	7.97[g]	1.78[c]	5.46[a]
	6	4.09[g]	0.41[d]	8.58[d]	1.78[c]	4.64[a]
15	8	4.75[e]	0.55[a]	8.28[e]	1.79[c]	5.43[a]
	10	5.55[d]	0.55[a]	8.25[e]	1.79[c]	4.92[a]
	6	3.83[h]	0.33[g]	9.81[a]	1.87[b]	5.65[a]
20	8	4.13[g]	0.35[f]	9.64[b]	1.89[b]	5.68[a]
	10	4.55[f]	0.37[e]	9.34[c]	1.95[a]	5.89[a]

WG, wheat germ; DP, date powder, A_w, water activity; TDF, total dietary fiber.
*Mean values within a column followed by the different letter are significantly different.

Examining the chemical results of flour, wheat germ, and control biscuit samples, the moisture content (%) was found to be 6.43 in wheat flour, 6.82 in wheat germ, and 6.58 in the control biscuit. As seen in Table 2, the moisture values of all biscuits containing wheat germ and date powder were observed to be lower than those of the control sample. It was determined that both wheat germ and date powder ratios had a statistically significant effect on the moisture content in biscuit samples. In general, an increase in wheat germ ratio resulted in a decrease in moisture content, which is in line with earlier findings showing that wheat germ's high oil content reduces water retention capacity in baked products (Petrović *et al.*, 2015) and contributes to a drier texture (Srivastava *et al.*, 2006). On the other hand, increasing the ratio of date powder led to a rise in moisture content. This can be attributed to its hygroscopic nature, as reported in previous studies, which found that date powder binds water effectively during baking processes and that this property results in softer and more moist baked products (Jahan *et al.*, 2023; Amin *et al.*, 2019). Similarly, both protein and ash contents were significantly affected by wheat germ and date powder ratios ($p < 0.05$). The increase in protein content was mainly associated with the high protein level of wheat germ, while the rise in ash content reflected the mineral contribution of both ingredients. These findings were statistically verified through ANOVA and Tukey's multiple comparison tests, as indicated in Table 6.

The water activity (a_W) values were found to be 0.53, 0.57, and 0.55 for flour, wheat germ, and the control biscuit, respectively. As seen in Table 2, the water activity values of all biscuits containing wheat germ and date powder were observed to be lower than those of the control sample. It was determined that both wheat germ and date powder ratios had a statistically significant effect on water activity in biscuit samples. The changes in water activity values paralleled those of moisture content. An increase in wheat germ ratio led to a decrease in water activity values, likely due to the oil-rich structure and low water retention of wheat germ, which was also observed in rheological studies of wheat germ-based doughs (Petrović *et al.*, 2015). However, this trend did not hold consistently for the 15% wheat germ samples, suggesting a potential threshold beyond which texture or formulation properties may interfere with expected patterns. On the other hand, an increase in date powder ratio resulted in an increase in water activity values. This can be explained by the natural sugars and fiber compounds in date powder, which are known to be hygroscopic and enhance water retention (Jahan *et al.*, 2023). The same pattern was observed for water activities as moisture content, with wheat germ contributing to lower water activity and date powder increasing it. These findings suggest that the inclusion of wheat germ and date powder in biscuits can be strategically utilized to modulate moisture content and water activity, thereby influencing both texture and shelf stability. Nonetheless, excessive inclusion of wheat germ may lead to undesirably dry and brittle textures, a phenomenon previously noted in biscuit and cookie formulations enriched with wheat germ (Srivastava *et al.*, 2006).

When analyzing protein content (%), the protein values for flour, wheat germ, date powder, and the control biscuit were found to be 9.64%, 26.64%, 1.93%, and 7.20%, respectively. As seen in Table 6, the protein content of all biscuits containing wheat germ and date powder was observed to be higher than that of the control sample. This is due to the presence of wheat germ, which contains a high amount of protein, in the biscuits. It was determined that both wheat germ and date powder ratios had a statistically significant effect on protein content in biscuit samples. As the wheat germ ratio increased, a corresponding increase in protein content was observed, consistent with findings from wheat germ-enriched baked product formulations (Srivastava *et al.*, 2006). The use of wheat germ as an additive in food products can be considered an alternative to increase protein content. Additionally, due to the low protein content of date powder, an increase in the date powder ratio generally led to a decrease in protein content in biscuits with the same wheat germ ratio (Amin *et al.*, 2019).

Regarding ash content, the ash content of the control biscuit sample was found to be 1.34%. As seen in Table 6, the ash content of all biscuits containing wheat germ and date powder was observed to be higher than that of the control sample. The ash content is directly proportional to the amount of mineral substances. Accordingly, it can be stated that both wheat germ and date powder contain high amounts of minerals, as supported by prior analyses showing significant increases in ash content with these ingredients (Amin *et al.*, 2019; Tahir *et al.*, 2023). The use of wheat germ and date powder as additives in food products can increase the mineral content in the products. It was determined that both wheat germ and date powder ratios had a statistically significant effect on ash content in biscuit samples. Except for samples containing 15% wheat germ, an increase in date powder ratio resulted in an increase in ash content in samples with the same wheat germ ratio.

Finally, examining the total dietary fiber content, the dietary fiber values for flour, wheat germ, date powder, and the control biscuit were found to be 1.05%, 14.44%, 8.40%, and 3.35%, respectively. As seen in Table 6, the total dietary fiber content of all biscuits containing wheat germ and date powder was observed to be higher than that of the control sample. Both wheat germ and date powder have higher total dietary fiber content compared to flour or sugar (Jahan *et al.*, 2023; Elkatry *et al.*, 2024). Accordingly, the presence of wheat germ and date powder in biscuits increased the total dietary fiber content. Statistically, it was observed that changes in the proportions of wheat germ and date powder in the biscuits did not significantly affect total dietary fiber content (Table 6); however, there was a significant increase compared to the control sample.

Physical characterization of the biscuits

The results of the color and textural analysis of biscuits enriched with different ratios of wheat germ (WG) and date powder (DP) reveal significant changes in quality characteristics. In terms of lightness (L*), a decrease was observed with increasing DP content (Table 7). This suggests that DP, due to its high sugar content and darker natural pigments, intensifies browning reactions during baking, leading to a darker surface color (Latif Ma, 2023; Elkatry *et al.*, 2024). Simultaneously, the a* value, which indicates redness, increased with higher DP concentrations, indicating enhanced Maillard and caramelization reactions (Abdelmegiud, 2024). However, the observed color differences originate from two distinct mechanisms: (i) chemical browning reactions, mainly Maillard and caramelization processes that occur during baking and contribute to decreased L* and increased a* values, and (ii) compositional effects arising from the intrinsic color of the ingredients. Specifically, DP contains naturally dark pigments, phenolic compounds, and caramel-colored constituents, whereas WG has a lighter yellowish hue. Therefore, the overall darkening and redness enhancement are jointly influenced by both Maillard-type color chemistry and compositional color contributions. These changes in L* and a* values are consistent with previous findings that associate DP incorporation with color intensification in baked goods.

Table 7. Color and textural analysis of the biscuits containing different ratios of wheat germ and date powder.

WG (%)	DP (%)	L*	a*	b*	Hardness (N)
	6	$62.61^{a\dagger}$	12.87^{f}	33.95^{e}	44.82^{c}
10	8	61.61^{b}	13.58^{de}	33.88^{e}	36.21^{d}
	10	57.59^{e}	14.77^{b}	34.19^{de}	47.26^{b}
	6	62.83^{a}	13.47^{e}	36.88^{a}	33.88^{e}
15	8	60.71^{c}	13.89^{cd}	35.73^{b}	28.15^{f}
	10	55.99^{f}	15.53^{a}	34.34^{d}	22.52^{g}
	6	59.66^{d}	14.09^{c}	34.82^{c}	43.38^{c}
20	8	55.75^{f}	15.52^{a}	33.96^{e}	35.06^{de}
	10	54.91^{g}	15.57^{a}	33.20^{f}	52.18^{a}

WG, wheat germ; DP, date powder.
†Mean values within a column followed by the different letter are significantly different.

Table 8. Dimensional properties of biscuits containing different ratios of wheat germ and date powder.

WG (%)	DP (%)	Thickness (mm)	Diameter (mm)	Spread ratio
	6	$7.3^{a\dagger}$	51.6^{abc}	7.1^{b}
10	8	6.4^{ab}	53.2^{a}	8.3^{ab}
	10	7.2^{a}	50.2^{c}	6.9^{b}
	6	7.0^{a}	51.1^{abc}	7.3^{b}
15	8	6.5^{ab}	51.8^{abc}	8.0^{b}
	10	6.6^{ab}	52.4^{ab}	8.0^{b}
	6	6.9^{a}	50.9^{bc}	7.4^{b}
20	8	6.0^{ab}	52.4^{ab}	8.7^{ab}
	10	5.1^{b}	51.8^{abc}	10.2^{a}

WG, wheat germ; DP, date powder.
†Mean values within a column followed by the different letter are significantly different.

Regarding the texture, biscuit hardness values varied significantly depending on WG and DP ratios (Table 7). The highest hardness was recorded in the formulation with 20% WG and 10% DP (52.18 N), whereas the softest biscuit appeared in the sample with 15% WG and 10% DP (22.52 N). The observed increase in hardness at higher WG levels may be attributed to the protein and fiber content of wheat germ, which can reinforce the biscuit matrix and influence dough structure and viscoelasticity (Pauly *et al.*, 2013). On the other hand, the softening effect at specific WG and DP combinations suggests complex interactions between moisture-binding components and the structural network, especially considering the hygroscopic nature of date powder (Latif Ma, 2023).

The dimensional properties of biscuits formulated with different levels of wheat germ (WG) and date powder (DP) demonstrated clear trends influenced by ingredient interactions. As seen in Table 8, the spread ratio significantly increased with higher DP inclusion, reaching the highest value (10.2) at 20% WG and 10% DP, corresponding with the lowest thickness (5.1 mm). This may be explained by the high sugar and fiber content of date powder, which weakens the structural network and increases spreadability during baking (Ranasinghe *et al.*, 2024; Kayode *et al.*, 2024). Concurrently, wheat germ, despite its protein content, can dilute gluten strength and reduce dough viscosity, further facilitating dough spread (El-Sharnouby *et al.*, 2012).

In addition, in Table 8, diameter values increased with DP at lower WG levels but remained stable or slightly decreased at higher WG levels, suggesting a complex interaction between water-holding capacity and dough matrix integrity. The inverse relation between thickness and spread ratio reinforces the hypothesis that higher sugar/fiber content contributes to increased flow during baking, resulting in thinner, wider biscuits

(Ranasinghe *et al.*, 2025). These outcomes align with prior findings where incorporation of DP or dietary fiber-rich by-products modified the viscoelastic behavior of dough and the final geometry of the biscuit.

Microstructure of the biscuits

The scanning electron microscopy (SEM) images in Figure 6 illustrate the effects of wheat germ and date powder incorporation on biscuit microstructure. The control biscuit (Figure 4A) exhibited a relatively compact and smooth surface with limited porosity, indicating a dense internal matrix. In contrast, enriched samples, particularly those with 10% wheat germ (Figures 4B–D), displayed rough textures, disrupted starch–protein networks, and more open voids, especially in the sample containing 8% date powder (Figure 4C). These observations are in line with earlier studies reporting that fiber-rich ingredients lead to increased pore formation and surface irregularities in bakery products (Blanco Canalis *et al.*, 2017; Sibian & Riar, 2020). The higher porosity and less compact morphology observed in these samples are consistent with their lower G′ and

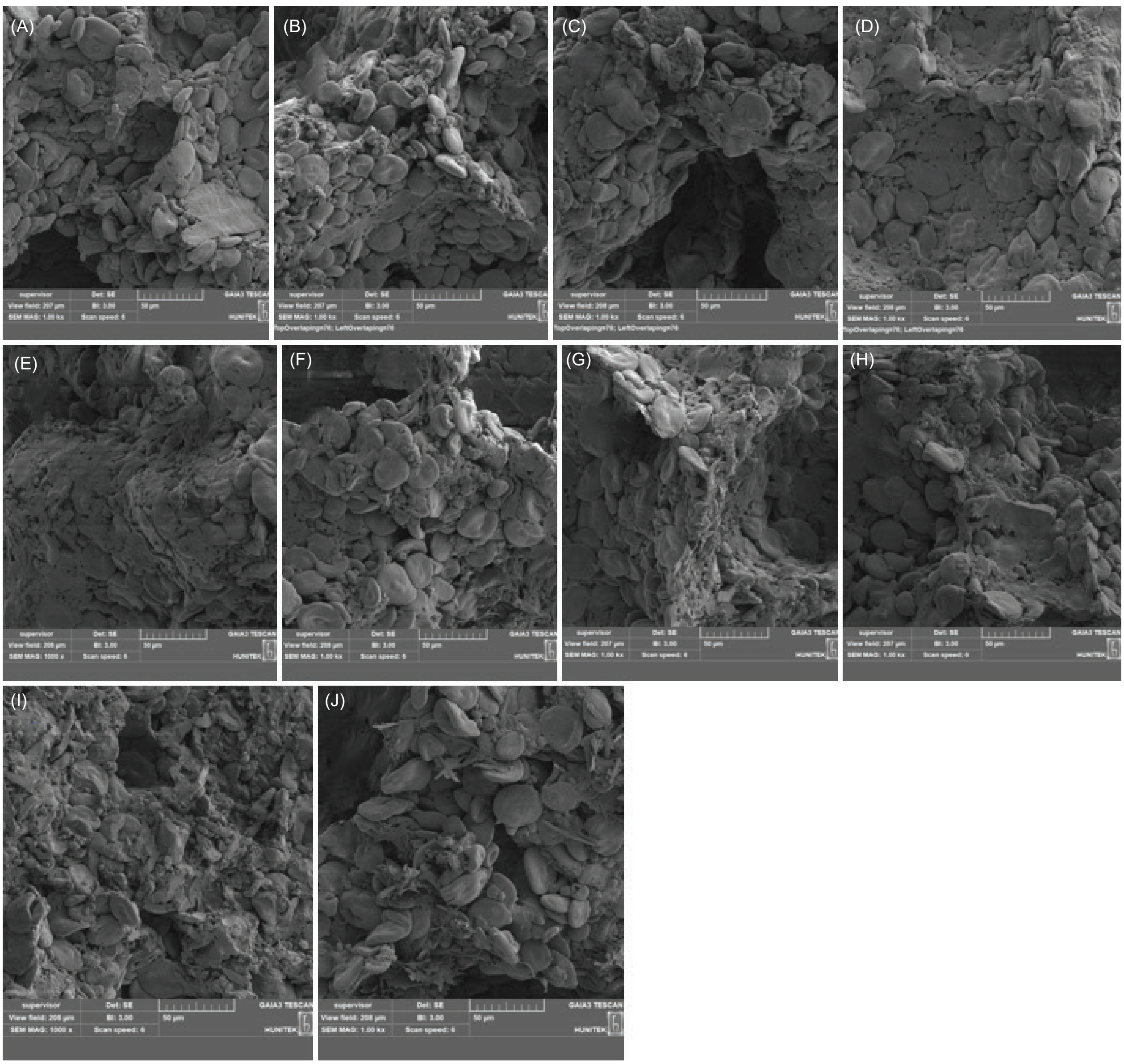

Figure 6. SEM figures for biscuits containing varying amounts of wheat germ (WG) and date powder (DP) at 1000× magnification. Panel (A) shows the control biscuit; Panels (B–D) represent 10% WG with 6%, 8%, and 10% DP, respectively; Panels (E–G) represent 15% WG with 6%, 8%, and 10% DP, respectively; Panels (H–J) represent 20% WG with 6%, 8%, and 10% DP, respectively.

G″ values, indicating weaker structural integrity and reduced elasticity compared to formulations with higher wheat germ or date powder contents.

As wheat germ concentration increased to 15% (Figures 4E–G), the samples showed slightly more cohesive but still heterogeneous microstructures. The formulation containing 10% date powder (Figure 4G) appeared more integrated, likely due to the binding effect of natural sugars and dietary fiber from the date component. This more cohesive structure parallels the increased G′ and G″ moduli observed in rheological tests, suggesting improved network connectivity and enhanced viscoelastic strength at intermediate enrichment levels. However, further increasing the wheat germ level to 20% (Figures 4H–J) resulted in denser and more compact structures, especially at lower date powder levels, where pore collapse was more evident. The 20% WG + 10% DP sample (Figure 4J) retained some porosity, suggesting a better balance between aeration and matrix firmness (Wang *et al*., 2025). This microstructural densification corresponds well with the high elastic modulus (G′) values measured for the same formulation, confirming that the compact structure contributes to stronger elastic behavior and lower tan δ values, indicative of a more solid-like matrix.

Overall, the SEM images confirm that the combined addition of wheat germ and date powder significantly alters biscuit morphology. Moderate enrichment enhanced porosity and disrupted the internal network, while higher levels of wheat germ promoted densification. These microstructural transitions directly support the rheological findings, where increased compactness and reduced pore volume were associated with higher G′/G″ ratios, reflecting the strong correlation between structural integrity and viscoelastic performance. These structural changes corroborate findings in other composite flour systems and reflect the rheological and textural shifts observed in enriched biscuit formulations (Blanco Canalis *et al*., 2017; Wang *et al*., 2025).

Sensory analysis

The biscuit samples containing different levels of wheat germ and date powder were subjected to sensory evaluation by a trained panel consisting of 10 university-graduate panelists aged 40–50 years, following baking and cooling to room temperature. The panel assessed the samples based on appearance, color, texture, crispiness, sweetness, saltiness, mouthfeel, flavor, aroma, and overall acceptability (Table 9). According to the overall acceptability scores, a decline in preference was observed in formulations containing more than 10% wheat germ and 8% date powder. Specifically, biscuits with higher levels of

Table 9. Sensory analysis scores of the biscuit samples.

WG (%)	DP (%)	Appearance	Color	Texture	Crispiness	Sweetness	Saltiness	Oral disintegration	Flavor	Aroma	General acceptance
	6	4.2	4.1	4.3	4.3	4	4.5	4.2	4.2	4.5	4.2
10	8	4.3	3.9	4.2	4.4	3.9	4.5	4.4	4.3	4.5	4.1
	10	4.3	4.3	4.3	4.5	4.4	4.7	4.6	4.5	4.5	4.5
	6	4.3	4.4	4	4.3	3.9	4.7	4	4.3	4.5	4.4
15	8	4.3	4.1	4.1	3.8	3.5	4.4	3.9	3.7	4.4	3.8
	10	4.5	4.3	4.1	4.2	3.4	4.5	3.7	3.7	4.5	3.6
	6	4.1	3.9	3.5	3.9	3.9	4.4	3.8	3.7	4.1	3.8
20	8	3.8	3.9	3.4	4.3	3.9	4.6	3.9	4.3	4.5	3.8
	10	4.2	4.2	4.2	4.4	3.8	4.5	4.4	4.2	4.8	3.9

WG, wheat germ; DP, date powder.

both wheat germ and date powder received lower scores in sweetness and mouthfeel attributes. The control biscuit sample received a score of 4.4 for general acceptance and had score values higher than 4.0 for all the other evaluation parameters.

Among all tested formulations, the biscuit sample containing 10% wheat germ and 10% date powder received the highest scores in texture, crispiness, sweetness, mouthfeel, flavor, and overall acceptability. These findings suggest that a balanced formulation using a moderate amount of wheat germ and a relatively higher amount of date powder can yield biscuits with enhanced consumer preference. Similar outcomes have been reported in previous studies, where optimal sensory scores were achieved at intermediate levels of date powder or fiber-rich additives, while excessive inclusion led to declines in sweetness, aroma, or mouthfeel due to textural or flavor imbalances (Latif Ma, 2023; Ranasinghe *et al*., 2025).

Conclusion

This study demonstrated that the combined use of wheat germ and date powder in biscuit formulations enhances both nutritional quality and processing performance. Wheat germ contributed to increased protein, mineral, and dietary fiber contents, while date powder acted as a natural sweetener that improved moisture retention and color through Maillard reactions. Rheological and microstructural analyses revealed that optimal incorporation levels, particularly 10% wheat germ and 10% date powder, improved dough elasticity, baking behavior, and final texture. These findings provide a scientific understanding of how the protein–fiber matrix of wheat germ and the sugar–fiber components of date powder interact to influence viscoelasticity and structure, supporting the development of balanced, functional dough systems. From an industrial perspective, this combination offers a practical approach to formulating clean-label, nutrient-enriched bakery products without compromising texture or consumer acceptance, aligning with current trends toward health-focused and sustainable food design.

Compliance with Ethics

This study does not contain any studies with human participants or animals performed by any of the authors.

Ethical Approval

This article does not contain any studies with human or animal subjects.

Human Ethics and Consent to Participate Declarations

Not applicable. Since the article is not a study requiring an ethical declaration, no norms or standards were applied.

Data Availability Statement

Data will be available upon request.

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Authors Contribution

All authors contributed equally to this article.

Conflict of Interest

The authors declare no conflict of interest.

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