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ORIGINAL PAPER

Evaluation of the effects of *Triticum spelta* flour and Ahlat pear flour on the physical, chemical, textural, and sensory properties of bread

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Abstract

This study examined the effects of substituting spelt (*Triticum spelta*) flour (0–100%) and Ahlat pear (*Pyrus elaeagnifolia*) flour (0–10%) on the technological, chemical, textural, and sensory properties of bread. Spelt flour addition significantly increased protein, ash, and fat contents, as well as total phenolic content and antioxidant capacity compared to common wheat flour ($p<0.05$). However, the weaker gluten quality of spelt flour led to significant reductions in dough stability and bread volume, with decreases of up to 54.3% and 35.8%, respectively, compared to the control sample. Additionally, higher levels of spelt flour increased crumb hardness and chewiness. In contrast, Ahlat pear flour (APF), characterized by high ash, fat, and phenolic contents but low protein contents, exhibited improved antioxidant capacity and moisture retention. Its inclusion decreased bread hardness and chewiness and mitigated staling, resulting in a softer texture. Color analysis of bread showed that substitution from 100% T. aestivum to 90% T. spelta + 10% APF darkened the crust, with L* decreasing from 67.79 to 34.24 (≈49.5%) and a* increasing from 4.29 to 10.80 (≈151.7%), with a stronger effect in APF-containing samples due to higher pigment content. From a sensory perspective, breads no. 5 (25% spelt + 5% APF) and no. 7 (50% wheat–50% spelt) showed the highest overall acceptability with comparable scores, indicating that moderate substitution levels provide the most balanced sensory profile. However, higher levels of spelt and APF, while less preferred sensorially, enhanced functional properties such as phenolic content and antioxidant activity, revealing a trade-off between sensory quality and functional value. Overall, the combination of spelt and APF shows strong potential for developing value-added functional sweet bread.

Keywords Spelt flour · Ahlat pear flour · Composite bread · Antioxidant capacity · Color properties

Introduction

Wheat (*Triticum* spp.) is one of the most important cereal crops worldwide and serves as a staple food for a large proportion of the global population [1]. Its composition and quality characteristics vary depending on genotype and significantly influence technological performance [2]. Wheat varieties are generally classified as ancient and modern types. While ancient wheats are still cultivated in certain regions, modern breeding has primarily focused on high-yielding varieties. Ancient species such as spelt (*Triticum spelta*), emmer (*T. dicoccum*), and einkorn (*T. monococcum*) are valued for their superior nutritional profiles compared to modern wheats, including bread wheat (*T. aestivum*), durum wheat (*T. durum*), and club wheat (*T. compactum*) [3].

Among ancient species, spelt wheat (*Triticum spelta) has garnered increasing* attention due to its high levels of protein, dietary fiber, and bioactive compounds [4]. It contains higher levels of unsaturated fatty acids, minerals, and vitamins than common bread wheat, and its cultivation requires less fertilization and pesticide use [5, 6]. Spelt flour is composed of 7.1 ± 0.1% dietary fiber, 13.0 ± 0.3% protein, 74.9 ± 0.6% carbohydrates, and 3.3 ± 0.1% fat, with an energy content of 396.4 ± 2.0 Kcal per 100 g, along with various vitamins and minerals [7]. Its gluten has lower elasticity compared to modern wheat, leading to less structural integrity in dough [8]. Studies have shown that spelt

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bread exhibits a similar crumb structure and loaf volume to wheat bread, while sensory evaluations in composite and enriched breads have demonstrated that consumer acceptability can be maintained or improved depending on formulation [9, 10]. Studies show that spelt bread has a similar crumb structure and volume to wheat bread, but consumers generally prefer its sensory qualities [10]. Furthermore, while total flavonoid and phenolic compound levels are comparable between spelt and wheat bread, previous studies have reported that tocopherol and tocotrienol contents in spelt may be lower than in common wheat, depending on genotype and processing conditions [11]. Despite these technological limitations, spelt flour offers improved nutritional quality and a distinct sensory profile that appeals to consumers seeking functional bakery products.

The wild pear (*Pyrus elaeagnifolia* subsp. *elaeagnifolia*), commonly known as Ahlat, is a member of the Rosaceae family and grows naturally in several regions of Turkey, including Konya, Ankara, and Mersin [12]. This fruit blossoms from April to May and ripens between October and November. When dried and ground into flour, it is commonly incorporated into baked goods to enhance their nutritional content. The fruit is abundant in dietary fiber, phenolic compounds, and antioxidants, making it an excellent addition to bakery products [13]. Incorporating pear-derived powders or pomace into cereal-based formulations has been shown to enhance antioxidant capacity, mineral content, and moisture retention, while influencing textural properties such as hardness and crumb structure [14, 15]. Therefore, Ahlat pear flour (APF) represents a promising ingredient for improving the nutritional and functional characteristics of wheat-based products.

In recent years, blending different types of flours—known as composite flour technology—has gained considerable attention as a strategy to enhance the nutritional value, technological quality, and shelf life of bakery products [14–16]. In particular, the incorporation of alternative plant-based ingredients into wheat flour has been widely investigated to improve functionality and nutritional properties [17]. The combination of nutrient-rich ancient grains with antioxidant-rich fruit flours may provide synergistic effects, improving both the technological performance and nutritional quality of bread.

Therefore, the present study aimed to investigate the individual and combined effects of spelt wheat flour (0%, 25%, 50%, 75%, and 100%) and APF (0%, 5%, and 10%) on the technological, chemical, textural, and sensory properties of bread. These substitution levels were selected based on preliminary trials.

Materials and methods

Materials

Common wheat flour (*Triticum aestivum*), spelt wheat flour (*Triticum spelta*), table salt, and bakery yeast were purchased from local markets in Karaman (Türkiye). The chemical composition of both wheat flours was determined according to AACC methods and is presented in Table 1. The *T. aestivum* flour contained 8.65% moisture, 9.24% protein, 0.61% ash, 0.95% fat, and 80.55% total carbohydrate content, while the spelt flour contained 8.31% moisture, 14.30% protein, 2.28% fat, and 72.96% total carbohydrate content.

Table 1 The chemical analysis results for the raw materials used in bread making

	Triticum spelta flour (%)	*Triticum aestivum* flour (%)	Ahlat pear flour (%)
Color properties of raw material			
L*	79.30 ± 0.01	87.76 ± 0.01	23.54 ± 0.04
a*	6.95 ± 0.03	1.52 ± 0.04	42.04 ± 0.06
b*	9.99 ± 0.04	10.59 ± 0.00	40.38 ± 0.00
Chemical properties of raw material			
Moisture (%)	8.31 ± 0.20	8.65 ± 0.11	11.81 ± 0.43
Ash (%)*	2.15 ± 0.02	0.61 ± 0.02	2.52 ± 0.00
Fat (%)*	2.28 ± 0.03	0.95 ± 0.03	3.61 ± 0.31
Protein (%)*	14.30 ± 0.16	9.24 ± 0.34	3.85 ± 0.02
Total Carbohydrate (%)*	72.96 ± 0.50	80.55 ± 0.44	78.21 ± 0.11
Total phenolic content (mg GAE/100 g, dm)*	174.63 ± 0.55	88.88 ± 0.74	1613.80 ± 0.57
Trolox equivalent antioxidant capacity (mMol Trolox/g sample)*	6.60 ± 0.82	4.33 ± 0.16	12.99 ± 0.12
Antioxidant capacity (% inhibition)	7.16 ± 0.63	4.33 ± 0.13	34.38 ± 0.57

All analyses were performed in duplicate, and results are presented as the mean of two independent determinations

*Results are presented on a dry matter basis

Ahlat pears (*Pyrus elaeagnifolia* subsp. *elaeagnifolia*) were harvested in Konya (Türkiye) between October 10 and 20 during the 2024 season. The fruits were cleaned, sliced, and crushed with their seeds using a mortar, then sun-dried for seven days under ambient conditions (average temperature 28–30 °C). The dried material was ground in a traditional stone mill and sieved through a 600 µm mesh to obtain Ahlat pear flour (APF).

The APF contained 11.81% moisture. 3.85% protein, 2.52% ash, 3.61% fat, and 78.21% total carbohydrate. All flour samples were stored in airtight polyethylene bags at 4 °C until use.

Methods

Experimental design

In this study, spelt flour was incorporated at five different levels (0%, 25%, 50%, 75%, and 100%). In comparison, Ahlat pear flour was used at three levels (0%, 5%, and 10%) to produce composite flour blends with wheat flour based on the displacement principle. Bread production followed a 5 (spelt ratio) ×3 (APF ratio) × 2 (duplicate production) factorial experimental design, resulting in 30 bread samples.

Composite flour rheology

The dough kneading and thermo-rheological properties of the 15 formulated flour mixtures were analyzed using the "Chopin+" protocol (ICC Method 173) with an ICC-approved Mixolab (Chopin Technologies, France) [18].

Bread production

In this study, various combinations of spelt flour (*Triticum spelta*), bread wheat flour, and Ahlat pear flour (APF) were used for bread production. Flour formulations consisted of spelt flour (0–100%) and wheat flour (0–100%), while APF was incorporated at levels of 0–10%, with total flour content adjusted to 100% in all formulations. Salt (1.5%) and baker's yeast (*Saccharomyces cerevisiae*, 3%) were kept constant across all samples. Water addition (56.0–62.4%) for each formulation was determined based on Mixolab (Chopin+ protocol, ICC Method 173) rheological analysis of the 15 composite flour blends, in order to standardize dough consistency and ensure comparable processing behavior across formulations with differing fiber and protein contents. Fifteen different bread formulations were prepared in total.

The bread was prepared in accordance with the Turkish Food Codex Communiqué No. 2012/2 [19]. The direct dough-making method was employed, with preliminary trials determining an optimal kneading time of 10 min using a laboratory-type kneader (KitchenAid, USA). The dough underwent primary fermentation at 30 °C for 30 min, followed by hand rolling and an intermediate fermentation at the same temperature for another 30 min. After rolling and shaping, the dough was placed in metal pans for final fermentation at 30 °C for 55 min. Baking took place in a preheated oven at 250 °C for 30 min. The bread was then cooled at room temperature for 1 h before analysis.

Bread physicochemical analyses

Bread weight was recorded one hour after baking, and baking loss was calculated by subtracting the final bread weight from the initial dough weight. Bread volume was determined using the displacement method with rapeseed after a 1-hour rest [20].

The color parameters (L*, a*, b*) of the bread were measured using a Hunter colorimeter (Color Flex, USA) [21].

The moisture content of the raw materials was analyzed gravimetrically according to AACC Method 44–15 A [22]. Ash content was measured by incinerating the samples at 900 °C in a muffle furnace (Nüve, MF106, Ankara) until a constant weight was achieved (AACC Method 08 − 01). Fat content was determined using the Soxhlet extraction method (AACC Method 30 − 25) with an automatic Gerhardt Extraction System (Soxtherm, Germany). Protein content was assessed using the Kjeldahl method (AACC Method 46 − 12) with a Kjeldahl Semi-Automatic System (S2, Behr Labor-Technik, Germany). Total carbohydrate content was calculated using the following formula:

$$Total\ Carbohydrate\ (\%) = 100 - (\%\ Moisture + \%\ Ash + \%\ Fat + \%\ Protein)$$

Bread samples were freeze-dried, ground, and sieved (355 µm). For extraction, 1 g of sieved sample was mixed with 10 mL acidified methanol (HCl/methanol/water, 1/80/10, v/v) and shaken (200 rpm, two h, room temperature). The obtained extract was used for both total phenolic content and DPPH antioxidant capacity analyses.

The total phenolic content was determined using the Folin-Ciocalteu method [23]. For extraction, 1 g of sample was mixed with 10 mL acidified methanol (HCl/methanol/water, 1/80/10, v/v) and shaken (200 rpm, two h, room temperature). A 250 µL extract was mixed with 250 µL Folin-Ciocalteu reagent, followed by 5.75 mL of water (8 min). Then, 2.5 mL of sodium carbonate and 5 mL of water were added. After two hours at room temperature, absorbance was measured at 750 nm. Results were expressed as mg Gallic Acid Equivalent /100 g using a gallic acid standard curve.

Antioxidant capacity was measured using two different methods.

Antioxidant capacity was measured using the DPPH radical inhibition assay [24]. For analysis, 100 µL of the sample extract was mixed with 3.9 mL of DPPH solution (6×10^{-5} mol/L), shaken, and incubated in the dark at room temperature for 30 min. Absorbance was recorded at 515 nm using a spectrophotometer. A DPPH solution served as the control, and acidified methanol was used as the blank.

DPPH inhibition (%) was calculated as:

$$(Control_abs - Sample_abs) / Control_abs \times 100$$

The TEAC assay, based on $ABTS^+$ radical cation decolorization [25], was used with slight modifications. $ABTS^+$ solution was prepared by dissolving 96 mg ABTS in 25 mL of water, adding 12.5 mL of 2.45 mM potassium persulfate, and incubating in the dark (12–16 h). Before analysis, it was diluted with 0.1 M phosphate buffer (pH 7.4) to an absorbance of 0.700 ± 0.020 at 734 nm. For extraction, 2 g of the sample was mixed with 5 mL of 80% ethanol, shaken (150 rpm, 30 min), and centrifuged (1500 × g, 10 min). Then, 10–30 µL extract was mixed with 3 mL diluted $ABTS^+$, incubated (6 min, dark), and absorbance was measured at 734 nm. TEAC values were calculated using a Trolox standard curve.

Texture analysis

Texture analysis was performed two hours after baking using the AACC 79-09.01 method with a TA.TX2 texture analyzer (Stable Micro Systems, England). Bread samples (25 mm thick) were analyzed with a 36 mm probe, a 50 kg load cell, and a 25% compression ratio.

Sensory analysis

A panel of seven trained evaluators, aged between 25 and 45, with prior experience in sensory assessments, conducted a hedonic sensory evaluation of the bread samples. They assessed key characteristics, including color, taste, odor-aroma, volume, internal pore homogeneity, hardness, and overall liking, using a 5-point hedonic scale: 1 (I would not say I liked it), 2 (I liked it a little), 3 (I neither liked it nor disliked it), 4 (I liked it), and 5 (I liked it a lot).

Statistical analysis

The data were evaluated across different formulations, and statistical comparisons were performed using SPSS statistical software (SPSS Inc., version 16.0, Chicago, IL, USA). Differences among groups were analyzed by one-way ANOVA, followed by Duncan's multiple range test ($p < 0.05$).

Results and discussion

Proximate composition of the raw materials

Table 1 summarizes the color analyses and chemical composition of the raw materials used in bread making. *T. aestivum* flour showed the highest lightness (L* value of 87.76), while APF had the lowest (23.54), indicating a darker color. The a* value (redness) was highest in APF (42.04), followed by spelt (6.95) and *T. aestivum* (1.52). Similarly, the b* value (yellowness) was also highest in APF (40.38), compared to spelt (9.99) and *T. aestivum* (10.59).

In terms of chemical composition, APF had the highest moisture (11.81%) and fat content (3.61%), as well as notable ash content (2.52%). While spelt showed the highest protein level (14.30%), *T. aestivum* contained the most total carbohydrates (80.55%). Compared to Biel et al. [26], who reported protein contents of 11.0% (*T. aestivum*) and 12.8% (*T. spelta*) and ash contents of 1.52% and 1.86%, respectively, the present study found slightly lower protein and ash values for *T. aestivum* and slightly higher for *T. spelta*. These differences may result from variations in wheat varieties, environmental conditions, and analytical methods. Additionally, Bozdogan et al. [14] reported lower protein (2.89%), fat (1.88%), and ash (1.20%) contents in pear pomace powder compared to APF. Similarly, the higher ash and fat contents in APF likely come from its inclusion of both pulp and seed fractions, which are rich in minerals and lipids. Furthermore, the drying method (sun-drying at 28–30 °C) and grinding technique (stone milling) may have influenced moisture retention and nutrient levels.

APF showed a notably high total phenolic content (1613.80 mg GAE/100 g dm), significantly higher than that of spelt (174.63 mg) and *T. aestivum* (88.88 mg). Its antioxidant capacity was also the highest, with 12.99 mMol Trolox/g and 34.38% inhibition. These values indicate strong bioactive potential, supporting its use as a functional ingredient in bread formulations. The phenolic content of *T. aestivum* is consistent with previously reported values [27]. The TEAC value of *T. spelta* was slightly lower than that reported by [28]. The higher values observed in this study may be due to the use of wild pear species (*Pyrus elaeagnifolia*) and differences in extraction methods or fruit parts, as discussed by [29].

Dough rheology properties

The thermo-rheological properties of the dough were assessed using the Mixolab device, with detailed results shown in Table 2. These evaluations determined the target torque required to achieve the desired dough consistency to be 1.1 Nm (± 0.05 Nm), following the "Chopin+" protocol [18]. The water absorption capacity of spelt flour was found to be 60%, based on a moisture content of 14%. Previous studies suggest that water absorption values for spelt flour generally range from 57.7% to 60% [8, 30, 31]. Additionally, the water absorption capacity of bread flour is reported to range from 57% to 60% [32].

The addition of spelt flour extended the dough development time while also reducing its stability. The optimal dough in terms of speed and stability was achieved using only bread flour. The decline in C2 torque with increasing spelt flour content can be attributed not only to the weaker gluten network of spelt proteins but also to changes in starch–protein interactions. The higher fiber and ash content in spelt flours and APF alters water distribution within the dough, leading to lower protein hydration and partial denaturation during heating. This interaction between the onset of starch gelatinization and protein weakening collectively contributes to the lower C2 torque values. Additionally, since pear flour is gluten-free, its inclusion dilutes the gluten in the mixture, further reducing C2 torque. C3 torque, which indicates starch gelatinization at 90 °C, decreased with the addition of pear flour; however, an increase was observed with the inclusion of spelt flour at 25%. Higher levels of spelt flour, on the other hand, caused a decline. C4 torque, reflecting the stability of starch gel and amylase activity, also decreased with the addition of both spelt and APF. C5 torque measures starch retrogradation during cooling from 90 °C to 50 °C; a decrease indicates delayed staling [32]. Consistent with the patterns seen in C2 and C4, C5 torque was reduced with the addition of spelt and APF. Notably, the lowest C5 torque was recorded for the 15th bread formulation, which contained 0% *Triticum aestivum*, 90% *Triticum spelta*, and 10% APF. The complex interactions among flour components can explain the lack of a clear linear trend in Mixolab parameters. Variations in gluten quality, starch gelatinization capacity, and fiber–phenolic content of APF likely influenced the dough's viscoelastic response in a nonlinear way. These combined effects resulted in irregular changes in torque and stability values rather than a consistent pattern.

The results of the Chopin protocol (+) index type analysis for flour mixtures with varying ratios of spelt and APF are summarized in Table 3. The key parameters evaluated include water absorption, kneading, gluten content, viscosity, amylase activity, and retrogradation, all of which are scored on a scale of 0 to 9. As the proportion of spelt and APF increased, the values for water absorption, kneading, gluten content, and viscosity also increased, indicating that the incorporation of these flours enhanced dough hydration and structural development. Conversely, the values for amylase activity and retrogradation decreased with higher proportions of these flours [19], suggesting that enzymatic activity and staling tendency were reduced due to the compositional changes introduced by spelt and APF. For instance, the water absorption value for the control bread (designated as bread number 1) was 3, which rose significantly to 8 with the addition of spelt flour and

Table 2 The thermo-rheological properties of the dough

Bread no	Triticum aestivum flour (%)	Triticum spelta flour (%)	Ahlat pears flour (%)	Water absorption (%)	Development time (min)	Stability time (min)	C2 Torque (Nm)	C3 Torque (Nm)	C4 Torque (Nm)	C5 Torque (Nm)
1	100	0	0	57.00	1.92	9.40	0.45	1.73	1.85	2.61
2	95	0	5	57.00	1.23	7.40	0.39	1.59	1.55	2.17
3	90	0	10	57.30	1.28	7.47	0.35	1.52	1.41	2.05
4	75	25	0	58.00	2.32	7.87	0.36	2.52	1.53	2.38
5	70	25	5	57.90	4.17	7.40	0.38	1.54	1.47	2.27
6	65	25	10	56.00	3.62	7.58	0.31	1.51	1.33	2.03
7	50	50	0	57.50	2.98	6.57	0.36	1.59	1.50	2.49
8	45	50	5	56.50	2.98	7.05	0.32	1.52	1.35	2.21
9	40	50	10	57.00	3.37	7.27	0.29	1.54	1.25	2.00
10	25	75	0	58.00	2.73	6.03	0.32	1.56	1.39	2.45
11	20	75	5	56.70	2.37	6.02	0.33	1.56	1.33	2.26
12	15	75	10	58.00	2.22	6.85	0.30	1.59	1.16	2.03
13	0	100	0	59.10	3.18	4.30	0.33	1.62	1.25	2.40
14	0	95	5	60.40	2.92	4.73	0.33	1.57	0.92	2.22
15	0	90	10	62.40	3.32	6.52	0.33	1.49	1.11	1.78

Note: The variations and lack of a clear trend among thermo-rheological parameters may be attributed to the combined effects of gluten dilution, differences in protein quality between *T. aestivum* and*T. spelta*, and the fiber- and phenolic-rich, gluten-free structure of Ahlat pear flour

Table 3 Chopin+ protocol index type results of flour blends containing different ratios of *Triticum spelta* and pear flour

Run	*Triticum aestivum* flour (%)	*Triticum spelta* flour (%)	Ahlat pears flour (%)	Water absorption	Kneading	Gluten content	Viscosity	Amylase activity	Retrogradation
1	100	0	0	3	3	3	5	8	6
2	95	0	5	3	1	3	4	7	4
3	90	0	10	4	2	2	3	6	4
4	75	25	0	5	4	2	4	6	6
5	70	25	5	5	4	1	4	6	6
6	65	25	10	2	4	1	4	4	5
7	50	50	0	4	2	2	5	7	7
8	45	50	5	3	3	1	4	5	6
9	40	50	10	3	3	1	4	4	5
10	25	75	0	5	2	2	5	6	7
11	20	75	5	3	2	1	4	5	6
12	15	75	10	5	2	1	5	1	6
13	0	100	0	6	2	2	5	3	7
14	0	95	5	7	2	2	4	1	7
15	0	90	10	8	2	2	3	1	6

APF at various ratios, reflecting the higher fiber and protein contents of these flours that bind more water. The kneading index of the control flour was 3; however, it dropped to 1 after adding 5% APF pear flour, possibly due to dilution of gluten proteins by the non-gluten components of APF. The most stable dough was observed in formulations 4, 5, and 6 during kneading, likely because of the balanced ratio of spelt to APF, which provided both elasticity and extensibility. While the gluten index for the control flour stood at 3, the addition of spelt and APF resulted in a reduction in both the quantity and quality of gluten, leading to lower index values of 1 to 2 compared to the control. This reduction can be attributed to the weaker gluten network formed by spelt proteins and the absence of gluten in APF. The viscosity evaluation revealed that flour mixtures numbered 1, 7, 10, 12, and 13 achieved the highest score of 5, indicating better dough consistency, while other formulations scored between 3 and 4. The amylase index for the control flour was 8, whereas bread made with spelt and APF exhibited values ranging from 1 to 7, suggesting that both flours contributed to lower enzyme activity, which could influence starch degradation during baking. Regarding retrogradation, the control bread scored 6, and bread containing spelt flour scored between 6 and 7. In contrast, adding pear flour to the control flour decreased the retrogradation index value to 4, indicating a beneficial effect on staling, which may be attributed to the presence of phenolic compounds and fibers that retard starch recrystallization.

Bread physicochemical results

Baking loss, volume, and color properties of bread samples containing *Triticum aestivum.* spelt and APF are presented in Table 4. The baking loss values of the bread samples ranged between 11.09% and 13.82%. Moisture loss is a critical phenomenon during the transformation of dough into bread. Loss of moisture during baking reduces the final product weight, a phenomenon known as baking loss [33]. Baking loss in bread samples containing 10% APF was slightly lower than in the control (13.74%), with a value of 13.08% observed in the wheat-based formulation. However, the effect was not linear with increasing spelt substitution. While a slight increase was observed at lower spelt levels (13.39%), higher spelt incorporation (50–90%) resulted in a notable reduction in baking loss (11.09–12.07%). This behavior may be attributed not only to the water-binding capacity of pectin present in APF, but also to structural changes in the dough matrix induced by spelt flour, which can influence moisture retention and evaporation during baking [34]. Jinxin et al. [34] investigated the effects of high methoxyl apple pectin (HMAP), low methoxyl apple pectin (LMAP), and amidated apple pectin (ALMAP) on the rheological properties of wheat dough and the quality of Chinese steamed bread (CSB). They found that pectin addition at appropriate concentrations improved dough fermentation performance, increased gas retention capacity, and enhanced dough structural stability. In terms of product quality, pectins improved CSB texture, increased specific volume and water-holding capacity, and reduced moisture loss during storage. Overall, HMAP was identified as the most effective pectin type in improving dough fermentation behavior and overall CSB quality.

Loaf volume is a key indicator of bread quality [35]. Analysis shows that increasing the proportion of spelt and APF reduces bread volume, with the lowest volumes observed in bread made with 0% *Triticum aestivum* flour. This is due to

Table 4 Baking loss, volume and color properties of bread samples containing *Triticum aestivum. Triticum spelta* and Ahlat pear flour[1]

Bread no	Triticum aestivum flour (%)	Triticum spelta flour (%)	Ahlat pears flour (%)	Baking loss (%)	Volume	Crust-L*	Crust-a*	Crust-b*	Crumb- L*	Crumb-a*	Crumb-b*
1	100	0	0	13.74 ± 0.09 a	731.70 ± 2.36 a	67.79 ± 0.42 a	4.29 ± 0.53 f	19.78 ± 0.00 de	76.24 ± 0.31 a	0.94 ± 0.02 l	17.18 ± 0.07 ef
2	95	0	5	13.61 ± 0.14 a	631.70 ± 2.36 b	52.26 ± 3.06 c	4.15 ± 1.36 f	17.14 ± 0.00 f	58.53 ± 0.13 c	3.35 ± 0.00 k	14.27 ± 0.07 h
3	90	0	10	13.08 ± 0.39 ab	610.00 ± 4.71 c	48.53 ± 0.01 d	6.60 ± 0.15 e	15.73 ± 0.00 g	52.04 ± 0.46 e	5.63 ± 0.06 ı	13.56 ± 0.15 ı
4	75	25	0	13.31 ± 0.53 ab	640.00 ± 4.71 b	59.16 ± 0.11 b	10.48 ± 1.37 c	23.43 ± 0.09 bc	62.51 ± 0.42 b	3.42 ± 0.01 k	20.31 ± 0.52 b
5	70	25	5	13.36 ± 0.11 ab	601.70 ± 2.36 c	49.59 ± 3.17 d	8.94 ± 0.06 d	22.72 ± 0.34 c	51.58 ± 0.07 e	4.65 ± 0.05 j	16.79 ± 0.18 f
6	65	25	10	13.39 ± 0.18 ab	570.00 ± 0.00 d	48.16 ± 0.19 d	5.95 ± 0.04 e	19.38 ± 1.30 e	49.89 ± 0.06 fg	6.51 ± 0.18 g	15.26 ± 0.12 g
7	50	50	0	13.68 ± 0.39 a	556.70 ± 4.71 d	49.04 ± 0.21 d	12.32 ± 0.04 a	25.36 ± 0.00 a	57.41 ± 0.20 d	5.43 ± 0.21 i	21.45 ± 0.45 a
8	45	50	5	12.55 ± 0.08 bc	525.0 ± 11.79 e	46.79 ± 0.49 def	11.09 ± 0.02 bc	23.19 ± 0.18 c	51.90 ± 0.08 e	6.01 ± 0.00 h	18.46 ± 0.19 d
9	40	50	10	12.07 ± 0.23 cd	500.00 ± 14.14 f	44.80 ± 1.00 fg	8.21 ± 0.02 d	19.50 ± 0.12 e	49.37 ± 0.69 g	7.08 ± 0.01 de	17.57 ± 0.16 e
10	25	75	0	13.82 ± 1.08 a	506.70 ± 4.71 f	45.69 ± 0.23 ef	12.05 ± 0.12 ab	25.67 ± 0.21 a	50.33 ± 0.32 f	6.71 ± 0.06 f	21.56 ± 0.21 a
11	20	75	5	13.40 ± 0.48 ab	501.70 ± 2.36 f	42.39 ± 0.38 gh	11.35 ± 0.02 abc	24.19 ± 0.09 b	48.51 ± 0.26 h	6.99 ± 0.04 e	19.28 ± 0.07 c
12	15	75	10	11.09 ± 0.74 e	460.10 ± 14.19 g	41.31 ± 0.22 h	10.27 ± 0.12 c	17.33 ± 0.03 f	45.42 ± 0.73 ı	7.80 ± 0.06 b	17.49 ± 0.02 e
13	0	100	0	13.04 ± 0.00 ab	470.00 ± 9.43 g	40.45 ± 0.47 hı	11.14 ± 0.00 abc	20.60 ± 0.33 d	49.77 ± 0.25 fg	7.18 ± 0.02 d	21.26 ± 0.05 a
14	0	95	5	13.31 ± 0.09 ab	460.00 ± 9.43 g	38.37 ± 0.28 ı	10.42 ± 0.02 c	16.48 ± 0.21 fg	45.60 ± 0.09 ı	7.36 ± 0.02 c	18.55 ± 0.05 d
15	0	90	10	11.52 ± 0.01 de	475.00 ± 7.07 g	34.24 ± 0.18 i	10.80 ± 0.26 c	16.18 ± 0.68 g	42.82 ± 0.05 i	7.95 ± 0.03 a	17.34 ± 0.025 e

All analyses were performed in duplicate, and results are presented as the mean of two independent determinations

L*: lightness; a*: redness; b* denotes yellowness

[1]Different letters in the same column signify a statistically significant difference ($p < 0.05$)

the lack of gluten in fruit and vegetable flours and the low-gluten quality of *Triticum spelta*. Bojnanska & Francakova [36], noted that spelt loaves have lower volumes than those made with conventional bread flour. Although spelt flour has higher gluten content, its lower elasticity reduces bread volume [5].

The color values of the bread samples are shown in Table 4. For the crust, L*, a*, and b* values ranged from 34.24 to 67.79, 4.15 to 12.05, and 15.73 to 25.67, respectively; for the crumb, L* values ranged from 42.82 to 76.24, a* values from 0.94 to 7.95, and b* values from 13.56 to 21.56. Statistical analysis revealed significant differences ($p < 0.05$) between the crust and crumb colors. The highest L* values (67.79 for the crust and 76.24 for the crumb) were found in bread made from *Triticum aestivum* flour. The crust is darker due to Maillard and caramelization reactions [32]. Higher spelt flour and APF levels resulted in lower L* values, with the lowest values observed at 34.24 for the crust and 42.82 for the crumb, due to their rich pigments [37]. Increased spelt flour raised the a* value in both the crust and crumb, while APF also increased the a* value in the crumb. For b* (yellowness), more spelt flour raised the crumb's b* value, but this effect on the crust occurred only with less than 100% *Triticum spelta* flour. Conversely, adding APF decreased b* values in the crumb and crust.

Chemical properties, total phenolic content, and antioxidant capacity of bread samples with *Triticum aestivum. Triticum spelta* and APF are exhibited in Table 5. The protein, ash, and fat content of the bread ranged from 7.11% to 10.91%, 1.91% to 3.46%, and 0.21% to 0.61%, showing statistically significant differences ($p < 0.05$). The addition of spelt flour, which is rich in protein (14.30%), ash (2.15%), and fat (2.28%), was associated with higher protein, ash, and fat levels in the bread samples. Increasing the proportion of APF, which contains low protein (3.85%), high ash (2.52%), and fat content (3.61%), leads to bread that has lower protein and higher ash and fat contents compared to bread made only from *Triticum aestivum* (Bread no 1). Bozdoğan [38] examined the use of pear flour from Santa Maria pear pulp in cake production, along with xanthan gum, rice flour, potato starch, and quinoa flour. The protein content of the cakes ranged from 8.71% to 9.50%, decreasing with higher levels of pear pulp due to the low protein content in pear flour. The ash content ranged from 1.40% to 1.48%, and the fat content ranged from 18.07% to 21.04%, with no significant differences ($p > 0.05$). The carbohydrate content of the bread samples ranged from 66.80% to 78.56%, with statistically significant differences ($p < 0.05$). A decrease in carbohydrate content was observed with the incorporation of spelt flour and APF. However, this reduction is mainly attributed to a formulation-driven dilution effect, as these ingredients contain relatively lower carbohydrate levels compared to refined wheat flour. Similar compositional changes due to ingredient substitution in bakery formulations have been reported in the literature [39].

The study assessed the total phenolic content, Trolox equivalent antioxidant capacity, and DPPH antioxidant capacity in various bread formulations. The total phenolic content ranged from 70.27 to 327.24 mg GAE/100 g. Trolox equivalent antioxidant capacity ranged from 3.77 to 12.67 mM Trolox/g, while DPPH inhibition ranged from 4.79% to 14.24%, with all differences statistically significant ($p<0.05$). The control bread sample (100% *Triticum aestivum*) exhibited the lowest total phenolic content (70.27 mg GAE/100 g), as well as the lowest Trolox equivalent antioxidant capacity (3.77 mM Trolox/g) and DPPH inhibition (4.79%). In contrast, the incorporation of *Triticum spelta* and APF flour significantly increased both phenolic content and antioxidant capacity parameters. The highest total phenolic content (327.24 mg GAE/100 g) was observed in the 15th formulation (0% *Triticum aestivum*, 90% *Triticum spelta*, and 10% pear flour). This formulation also exhibited the highest Trolox equivalent antioxidant capacity (12.67 mM Trolox/g).

Despite this increase, the phenolic content in bread samples remained substantially lower than that of APF flour (1613.80 mg GAE/100 g), indicating a loss of approximately 80% during baking. This reduction can be attributed not only to thermal degradation of heat-sensitive phenolic compounds [40, 41] but also to their association with dietary fiber and other macromolecules, which may limit their extractability [42]. In addition, the presence of pectin in pear flour, acting as a hydrocolloid, may influence the retention and distribution of phenolic compounds within the food matrix [40]. Therefore, the observed decrease in phenolic content is attributable to a combination of thermal effects, matrix interactions, and reduced extractability rather than to independent absolute losses. Erdoğan [43] reported that breads enriched with fruit and vegetable flours exhibited higher total phenolic content, Trolox equivalent antioxidant capacity, and DPPH inhibition compared to control bread, supporting the findings of the present study.

Textural properties of bread samples

The textural properties of the bread samples are presented in Table 6. The results indicate that hardness values ranged from 1311.4 to 8050.0 N, springiness from 0.867 to 0.958, cohesiveness from 0.660 to 0.821, chewiness from 1029.9 to 4954.7, and resilience from 0.269 to 0.45.

Hardness refers to the maximum force required to compress bread samples, indicating the structural firmness of the product [31]. Bread made with *Triticum aestivum* flour and a slight increase in APF resulted in slightly higher hardness

Table 5 Chemical properties, total phenolic content, and antioxidant capacity of bread samples with *Triticum aestivum. Triticum spelta* and Ahlat pear flour[1]

Bread no	*Triticum aestivum* flour (%)	*Triticum spelta* flour (%)	Ahlat pears flour (%)	Moisture (%)	Protein* (%)	Ash* (%)	Fat* (%)	Total Carbonhydrate* (%)	Total phenolic content mg GAE/100 g. dm*	Trolox equivalent antioxidant capacity (mMol Trolox/g sample*)	Antioxidant capacity (% inhibition*)
1	100	0	0	11.82 ± 0.08	7.87 ± 0.00 d	1.91 ± 0.01 k	0.21 ± 0.00 ı	78.12 ± 0.06 a	70.27 ± 0.29 m	3.77 ± 0.33 f	4.79 ± 0.61 g
2	95	0	5	11.97 ± 0.18	7.16 ± 0.38 e	1.99 ± 0.01 j	0.31 ± 0.00 h	78.56 ± 0.20 a	89.66 ± 0.57 l	4.37 ± 0.19 f	13.71 ± 0.20 cde
3	90	0	10	15.91 ± 0.01	7.11 ± 0.00 e	2.14 ± 0.02 i	0.37 ± 0.03 fgh	74.48 ± 0.06 d	138.67 ± 0.30 i	7.38 ± 0.79 d	16.62 ± 0.85 a
4	75	25	0	10.94 ± 0.10	9.29 ± 0.00 c	2.16 ± 0.01 i	0.33 ± 0.05 gh	77.29 ± 0.04 b	89.83 ± 0.00 l	4.43 ± 0.00 f	15.39 ± 0.29 b
5	70	25	5	11.92 ± 0.03	8.33 ± 0.56 d	2.28 ± 0.04 ı	0.48 ± 0.00 bc	76.99 ± 0.57 bc	123.94 ± 0.57 j	6.12 ± 0.12 e	12.75 ± 0.85 ef
6	65	25	10	12.69 ± 0.15	7.94 ± 0.03 d	2.35 ± 0.01 ı	0.57 ± 0.06 a	76.45 ± 0.09 c	165.05 ± 0.87 ı	9.05 ± 0.00 c	14.02 ± 0.65 cd
7	50	50	0	14.52 ± 0.02	9.45 ± 0.15 c	2.49 ± 0.03 h	0.39 ± 0.00 efg	73.15 ± 0.21 e	117.96 ± 0.19 k	4.50 ± 0.15 f	12.17 ± 0.04 f
8	45	50	5	15.36 ± 0.17	7.92 ± 0.00 d	2.65 ± 0.04 g	0.45 ± 0.00 cde	73.63 ± 0.13 e	171.60 ± 0.39 h	8.62 ± 0.19 c	12.39 ± 0.04 f
9	40	50	10	15.97 ± 0.06	7.17 ± 0.00 e	2.81 ± 0.08 f	0.47 ± 0.04 bcd	73.59 ± 0.17 e	232.91 ± 1.20 d	10.88 ± 0.75 b	12.34 ± 0.66 f
10	25	75	0	16.54 ± 0.04	9.98 ± 0.28 b	2.94 ± 0.04 e	0.36 ± 0.03 fgh	70.19 ± 0.17 g	184.72 ± 0.61 g	5.89 ± 0.72 e	13.19 ± 0.07 cdef
11	20	75	5	12.12 ± 0.01	9.38 ± 0.04 c	3.03 ± 0.00 d	0.41 ± 0.06 def	75.06 ± 0.10 d	197.92 ± 0.19 f	8.49 ± 0.19 c	12.36 ± 0.15 f
12	15	75	10	16.14 ± 0.00	8.30 ± 0.49 d	3.18 ± 0.00 c	0.61 ± 0.05 a	71.78 ± 0.55 f	240.34 ± 0.20 c	12.20 ± 0.50 a	12.94 ± 0.07 def
13	0	100	0	17.52 ± 0.11	10.91 ± 0.00 a	3.25 ± 0.03 c	0.53 ± 0.00 ab	67.81 ± 0.08 ı	218.71 ± 1.12 e	7.36 ± 0.17 d	12.88 ± 0.42 ef
14	0	95	5	16.59 ± 0.36	10.31 ± 0.03 b	3.34 ± 0.09 b	0.59 ± 0.00 a	69.18 ± 0.42 h	256.05 ± 0.01 b	10.04 ± 0.06 b	14.24 ± 0.58 c
15	0	90	10	18.92 ± 0.46	10.26 ± 0.00 b	3.46 ± 0.00 a	0.57 ± 0.01 a	66.80 ± 0.47 i	327.24 ± 0.62 a	12.67 ± 0.40 a	13.65 ± 0.28 cde

*Results are presented on a dry matter basis. All analyses were performed in duplicate, and results are presented as the mean of two independent determinations

[1]Different letters in the same column signify a statistically significant difference ($p < 0.05$)

Table 6 The textural properties of the bread samples

Bread no	*Triticum aestivum* flour (%)	*Triticum spelta* flour (%)	Ahlat pears flour (%)	Hardness (g)	Springiness	Cohesiveness	Chewiness	Resilience
1	100	0	0	1311.4 ± 27.75 h	0.958 ± 0.01 a	0.821 ± 0.011 a	1029.9 ± 48.29 f	0.45 ± 0.02 a
2	95	0	5	1472.4 ± 701.54 gh	0.94 ± 0.00 b	0.795 ± 0.000 b	1097.1 ± 527.28 f	0.42 ± 0.00 b
3	90	0	10	1827.8 ± 96.12 gh	0.934 ± 0.00 b	0.801 ± 0.001 b	1379.1 ± 55.12 f	0.43 ± 0.01 b
4	75	25	0	2069.9 ± 211.15 g	0.939 ± 0.002 b	0.795 ± 0.01 b	1542.90 ± 174.86 ef	0.41 ± 0.01 b
5	70	25	5	1839.2 ± 0.00 gh	0.927 ± 0.00 bc	0.772 ± 0.009 c	1190.5 ± 151.28 f	0.394 ± 0.005 c
6	65	25	10	2075.5 ± 30.03 g	0.912 ± 0.00 de	0.744 ± 0.002 d	1348.7 ± 59.19 f	0.343 ± 0.011 d
7	50	50	0	3473.1 ± 0.00 f	0.932 ± 0.01 b	0.739 ± 0.00 d	2218.0 ± 56.98 d	0.353 ± 0.00 d
8	45	50	5	3320.0 ± 0.00 f	0.918 ± 0.00 cd	0.728 ± 0.00 e	2074.4 ± 256.65 de	0.342 ± 0.004 d
9	40	50	10	3273.2 ± 0.00 f	0.887 ± 0.005 gh	0.714 ± 0.00 f	2415.5 ± 401.74 cd	0.339 ± 0.000 d
10	25	75	0	5860.7 ± 442.92 cd	0.901 ± 0.013 ef	0.696 ± 0.00 g	3657.8 ± 201.29 b	0.345 ± 0.00 d
11	20	75	5	5250.6 ± 0.00 d	0.873 ± 0.014 hı	0.681 ± 0.00 g	2982.0 ± 297.62 c	0.319 ± 0.00 e
12	15	75	10	4452.1 ± 96.94 e	0.844 ± 0.000 i	0.648 ± 0.00 ı	2560.8 ± 393.67 cd	0.308 ± 0.00 e
13	0	100	0	8050.0 ± 691.12 a	0.888 ± 0.006 fg	0.694 ± 0.004 g	4954.7 ± 419.74 a	0.285 ± 0.001 f
14	0	95	5	6873.5 ± 56.08 b	0.867 ± 0.000 ı	0.669 ± 0.004 h	3970.8 ± 192.65 b	0.278 ± 0.00 f
15	0	90	10	6265.3 ± 453.19 bc	0.881 ± 0.004 ghı	0.660 ± 0.00 h	3682.4 ± 215.11 b	0.269 ± 0.00 g

All analyses were performed in duplicate, and results are presented as the mean of two independent determinations

values. In contrast, adding spelt flour (*Triticum spelta*) to the formulation significantly increased hardness compared to the control bread. However, when APF was added alongside spelt flour, no significant increase in hardness was observed. In fact, in bread containing high levels of spelt flour, increasing APF led to a reduction in hardness.

Springiness reflects the ability of bread to recover its original shape after deformation. Cohesiveness refers to the material's resistance to breakdown during mechanical processing. At the same time, resilience indicates the ability of the product to return to its original form after the applied force is removed. Chewiness measures the amount of energy required to chew the product until it is ready for swallowing [31]. When evaluating springiness, cohesiveness, and resilience values, bread made entirely from *Triticum aestivum* flour exhibited the highest values. In contrast, adding *Triticum spelta* and APF to the formulation resulted in decreases in all three of these parameters. Regarding chewiness, the highest value was observed in bread made solely with *Triticum spelta* flour, while bread containing *Triticum aestivum* and APF showed lower chewiness values.

Spelt flour (*Triticum spelta*) possesses a distinct gluten composition compared to common wheat (*Triticum aestivum*), generally exhibiting lower elasticity and gas retention capacity, which may result in a denser crumb structure [8]. Its higher fiber content also contributes to increased water absorption and a more compact dough matrix. In contrast, APF, being gluten-free and containing pectin, may weaken the gluten network and promote a softer and more open crumb structure [40]. The presence of pectin, acting as a hydrocolloid, can enhance water-binding capacity and influence moisture distribution within the crumb [15]. However, these effects are formulation-dependent and based on observations at a single storage time point; therefore, no conclusions can be drawn regarding crumb firming or staling behavior during storage.

Sensory properties of bread samples

The sensory evaluation results of the bread samples are presented in Table 7. The assessments for color and odor were found to be statistically insignificant ($p > 0.05$), whereas taste, volume, crumb pore homogeneity, hardness, and overall acceptability showed significant differences ($p < 0.05$). Panelists rated the bread produced with 100% spelt flour the lowest in terms of taste, crumb pore homogeneity, hardness, and overall acceptability. Regarding volume, formulations with higher proportions of spelt and APF exhibited the lowest scores, indicating a negative effect of high substitution levels on loaf expansion.

Based on overall acceptability scores, the formulations can be ranked as follows: bread no. 7 (50% *Triticum aestivum* + 50% *Triticum spelta*) ≈ bread no. 5 (25% *Triticum spelta* + 5% APF) > bread no. 2 (95% *Triticum aestivum* + 5% APF) > other formulations with higher substitution levels. Among these, breads no. 5 and 7 exhibited the highest overall acceptability with comparable scores, suggesting that moderate inclusion of spelt and APF contributes to a more balanced sensory profile.

Although bread no. 7 showed a slightly higher numerical score, no clear superiority can be inferred, as both samples belong to the same statistical group. Their high acceptability may be associated with improved structural and textural characteristics, along with a balanced taste profile. In

Table 7 The sensory analysis results for the bread samples

Bread no	*Triticum aestivum* flour (%)	*Triticum spelta* flour (%)	Ahlat pears flour (%)	Color	Taste	Odor and aroma	Volume	Internal pore homogeneity	Hardness	Overall liking
1	100	0	0	4.30 ± 0.95 a	4.44 ± 0.50 ab	4.20 ± 0.63 a	4.80 ± 0.42 a	4.50 ± 0.53 a	4.44 ± 0.49 a	4.10 ± 0.74 abc
2	95	0	5	3.70 ± 1.16 a	4.50 ± 0.67 ab	4.00 ± 0.94 a	4.10 ± 0.88 b	4.25 ± 0.41 ab	4.25 ± 0.41 ab	4.20 ± 0.63 ab
3	90	0	10	3.70 ± 1.25 a	4.50 ± 0.47 ab	3.80 ± 1.03 a	3.60 ± 0.69 bcd	4.16 ± 0.30 ab	3.50 ± 0.41 cd	3.90 ± 0.88 abc
4	75	25	0	4.10 ± 0.57 a	3.60 ± 0.46 d	4.10 ± 0.74 a	4.00 ± 0.47 bc	4.20 ± 0.79 ab	3.13 ± 0.74 d	4.00 ± 0.67 abc
5	70	25	5	4.00 ± 1.16 a	4.00 ± 0.00 bcd	3.70 ± 0.68 a	4.00 ± 0.47 bc	4.00 ± 0.67 abc	4.25 ± 0.41 ab	4.30 ± 0.82 a
6	65	25	10	3.70 ± 1.42 a	4.43 ± 0.43 ab	3.90 ± 0.99 a	3.50 ± 0.97 cde	3.80 ± 0.42 bcd	4.10 ± 0.74 abc	4.00 ± 0.67 abc
7	50	50	0	3.80 ± 0.92 a	4.20 ± 0.63 abc	4.00 ± 0.94 a	4.00 ± 0.00 bc	3.63 ± 0.46 cd	4.00 ± 0.67 abc	4.33 ± 0.47 a
8	45	50	5	4.10 ± 0.88 a	4.25 ± 0.41 abc	3.60 ± 0.97 a	4.00 ± 0.67 bc	3.56 ± 0.49 cd	3.13 ± 0.99 d	3.63 ± 0.46 bc
9	40	50	10	4.10 ± 0.88 a	4.56 ± 0.50 a	4.10 ± 0.74 a	4.00 ± 0.00 bc	3.50 ± 0.53 cde	3.00 ± 0.82 d	4.00 ± 0.67 abc
10	25	75	0	4.00 ± 0.67 a	3.58 ± 0.43 d	4.11 ± 0.57 a	3.89 ± 0.57 bcd	3.40 ± 0.52 def	3.64 ± 0.46 bcd	4.00 ± 0.00 abc
11	20	75	5	4.11 ± 0.74 a	3.67 ± 0.82 d	4.11 ± 0.57 a	3.89 ± 0.57 bcd	3.30 ± 0.48 defg	4.00 ± 0.47 abc	4.13 ± 0.74 abc
12	15	75	10	4.11 ± 0.11 a	3.74 ± 0.34 cd	3.67 ± 1.05 a	3.44 ± 0.83 cde	3.00 ± 0.00 efg	3.33 ± 0.82 d	3.56 ± 0.49 bc
13	0	100	0	4.00 ± 0.67 a	2.38 ± 0.49 e	3.11 ± 0.88 a	3.61 ± 0.45 bcd	2.94 ± 0.87 fg	3.00 ± 0.67 d	3.48 ± 0.47 c
14	0	95	5	4.11 ± 0.88 a	3.57 ± 0.44 d	3.44 ± 0.83 a	3.36 ± 0.36 de	2.87 ± 0.48 g	3.22 ± 0.79 d	3.66 ± 0.41 bc
15	0	90	10	4.11 ± 1.12 a	3.73 ± 0.41 cd	3.78 ± 0.79 a	2.97 ± 0.48 e	2.80 ± 0.42 g	3.33 ± 0.47 d	3.60 ± 0.47 bc

All analyses were performed in duplicate, and results are presented as the mean of two independent determinations

contrast, excessive substitution levels generally resulted in reduced sensory quality, particularly affecting texture and volume. To better understand the drivers of acceptability, the relationship between individual sensory attributes (taste, texture-related parameters, and volume perception) and overall liking should be considered. In particular, taste and texture-related attributes appear to play a major role in overall acceptability.

In a study [36], bread was produced from five varieties of *Triticum spelta* and then evaluated for sensory attributes. The crust was reported to be chestnut-colored, while the crumb was creamy. The bread showed good porosity and elasticity, a pleasant aroma, and was generally well received by panelists. In another study [15], cakes were produced with varying levels of wild pear fiber (0%, 10%, 20%, and 30%). The formulation with 10% substitution received the highest scores for taste, aroma, crumb structure, and overall appearance, whereas the 30% substitution received the lowest scores. Overall, increasing levels of wild pear fiber led to a decline in sensory acceptability. Similarly, in the study by [13], cookies were formulated with 5%, 10%, and 20% pear flour substitution. Products containing 5% pear flour showed improved color and flavor, although overall preference was highest for cookies with 20% substitution.

Conclusion

This study demonstrated that the incorporation of *Triticum spelta* and Ahlat pear (*Pyrus elaeagnifolia*) flour (APF) significantly influenced the physicochemical, functional, and sensory properties of bread. Increasing levels of spelt and APF enhanced the nutritional profile, particularly by increasing protein, ash content, total phenolic content, and antioxidant capacity, while also modifying textural characteristics.

From a sensory perspective, breads no. 5 (70% *Triticum aestivum* + 25% *Triticum spelta* + 5% APF) and no. 7 (50% *Triticum aestivum* − 50% *Triticum spelta*) exhibited the highest overall acceptability with statistically comparable scores, indicating that moderate substitution levels provide

the most balanced sensory profile in terms of taste, texture, and volume. However, formulations with higher levels of spelt and APF, although less preferred sensorially, showed superior functional properties, particularly in terms of phenolic content and antioxidant activity. This reveals a trade-off between sensory quality and functional enhancement.

Therefore, the optimal formulation depends on the intended product goal: breads no. 5 and 7 are more suitable for consumer-oriented products prioritizing sensory quality, whereas formulations with higher spelt and APF levels may be preferred for functional or health-oriented applications. This dual perspective highlights the complementary (synergistic) role of spelt and APF in balancing nutritional improvement and sensory acceptability, providing a practical framework for future product development and industrial applications.

However, further studies are needed to evaluate the shelf-life stability, industrial scalability, and in vitro bioavailability of bioactive compounds in these breads. These findings provide a preliminary insight into the potential of ancient grains and functional fruit flours as local, value-added ingredients in health-oriented bakery products.

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Declarations

Competing İnterest The authors declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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