

Textural and Sensorial Properties of Bread Formulated with Aronia (*Aronia melanocarpa* L.) Fruit Juice

Aronya (*Aronia melanocarpa* L.) Meyve Suyu ile Üretilen Ekmeğin Dokusal ve Duyusal Özellikleri

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ABSTRACT

The effect of incorporating aronia (*Aronia melanocarpa* L.) fruit juice (AFJ) into bread formulations at three levels (0%, 50%, 100%) as a partial substitute for water was determined in this study. Texture Profile Analysis (TPA) was used to determine the textural profiles of bread samples while their sensory attributes were evaluated using a hedonic scale. The addition of 50% AFJ significantly increased the hardness value (from 1839.07 g to 3293.64 g) by 79% and nearly doubled the gumminess value (from 1225.24 g to 2389.26 g) of bread samples while resilience values decreased from 0.30 to 0.23. Sensory results indicated that bread samples with 50% AFJ received the highest scores in loaf volume (4.1), crust appearance (3.9), crumb color (3.9), and taste/aroma (4.1), showing improved consumer acceptance. However, the addition of 100% AFJ negatively influenced the loaf volume and crust properties of bread samples. Results indicated that bread with 50% AFJ exhibited improvements in both nutritional and sensory properties, and that this level of inclusion could be regarded as technologically sustainable. This study showed potential use of AFJ as a functional ingredient in bakery products, emphasizing the importance of its concentration in balancing quality and acceptability.

Keywords: Bakery, Texture profile analysis, Functional food, Sensory evaluation

ÖZ

Bu çalışmada, aronya (*Aronia melanocarpa* L.) meyve suyunun (AMS), ekmeğin üretiminde suyun kısmen ikamesi amacıyla %0, %50 ve %100 oranlarında kullanımının, ekmeğin kalitesi üzerindeki etkileri araştırılmıştır. Doku profili analizi (TPA) ekmeğin dokusal profilini belirlemek için kullanılırken ekmeğin duyu özellikleri ise 5 puanlı hedonik skalayla değerlendirilmiştir. Ekmeğe %50 AMS ilavesi, sertlik değerini anlamlı şekilde %79 artırmıştır (1839,07 g'dan 3293,64 g'a) ve sakızimsılık değerini neredeyse iki katına yükseltmiştir (1225,24 g'dan 2389,26 g'a). Buna karşılık ekmeğin esneklik değeri 0,30'dan 0,23'e azalmıştır. Duyusal değerlendirme bulgularına göre %50 AMS ilave edilen ekmeğin ekmeğin hacmi (4,1), kabuk görünümü (3,9), iç yapı rengi (3,9) ve tat/aroma (4,1) bakımından en yüksek puanları alarak tüketici beğenisinin arttığı gözlemlenmiştir. Ancak, %100 AMS ilavesi, ekmeğin hacmi ve kabuk özelliklerini olumsuz etkilemiştir. Araştırma bulguları, %50 oranında AMS ile formüle edilen ekmeğin hem besinsel hem de duyu özellikleri bakımından iyileşme gösterdiğini ve bu oranın teknolojik açıdan sürdürülebilir olabileceğini göstermektedir. Kalite ile tüketici kabulü arasındaki dengenin sağlanmasında kullanılan AMS konsantrasyonunun belirleyici rolüne dikkat çekilen bu çalışmada, AMS'nin fırıncılık ürünlerinde fonksiyonel bir bileşen olarak kullanım potansiyeli ortaya konulmuştur.

Anahtar Kelimeler: Fırıncılık, Doku profil analizi, Fonksiyonel gıda, Duyusal değerlendirme

INTRODUCTION

In recent years, the growing awareness of healthy living and nutrition has significantly influenced consumer food preferences, making the development of functional food products a key focus area in the food industry [1]. In this context, the incorporation of fruits and vegetables, which are rich in phenolic compounds and antioxidants, into food formulations has gained importance, both to enhance nutritional value and to impart functional properties [2]. Among such functional ingredients, aronia has emerged as a fruit of particular interest due to its exceptionally high anthocyanin content, diverse phenolic compound profile, and strong antioxidant capacity [3].

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Thanks to its bioactive components, aronia fruits have demonstrated remarkable biological activities in various studies aimed at the prevention of common health issues such as cardiovascular diseases, diabetes, obesity, and certain types of cancer [4, 5, 6]. These activities are largely attributed to the health-beneficial roles of anthocyanins, flavonoids, and other phenolic compounds in reducing oxidative stress, suppressing inflammation, and modulating metabolic processes [7]. Furthermore, these compounds are frequently reported in the literature as playing a protective role against the pathogenesis of chronic diseases by supporting cellular defense mechanisms [8-10]. Considering the protective effects of such compounds, enriching/formulating foods with functional ingredients has become increasingly significant [11, 12]. In this regard, bakery products represent one of the most suitable carrier systems for the incorporation of functional components [12, 13].

The enrichment or formulation of staple foods such as bread with functional components not only improves nutritional value but also offers an effective means of promoting public health [14, 15]. However, the inclusion of functional compounds in bread formulations can influence physical, textural, and sensory properties, which may in turn directly impact consumer acceptance [15]. Bread is considered a highly suitable vehicle for the dissemination of functional content due to its widespread consumption and central role in consumer dietary habits worldwide [16]. Although the addition of bioactive compounds to bread improves its nutritional quality, it may also cause significant changes in key physical quality parameters such as volume, texture, and sensory attributes [17]. Therefore, the inclusion of functional ingredients in staple foods like bread should consider not only health benefits but also technological compatibility and consumer acceptability [18]. In this regard, optimizing nutritional contributions while preserving technological properties is essential when using functional components in bread production. Particularly, the integration of plant-based extracts or fruit juices into dough systems can affect the total water content, thus altering gluten development, dough rheology, and gas retention capacity during baking [19]. These factors can subsequently influence the physical properties of the final product, such as volume, crust, and crumb structure, thereby shaping consumer perception [20]. In addition, the sensory effects of functional ingredients are critical for consumer acceptance. Adverse changes in sensory parameters such as color, aroma, flavor, and texture may hinder market acceptance despite the product's functional value [21]. Therefore, in developing functional bakery products, it is crucial to strike a balance between health benefits, product quality, consumer expectations, and industrial feasibility [22].

A review of the literature reveals that most studies on the use of aronia fruits and their derivatives in food products have primarily focused on their phenolic profile, especially anthocyanin content and antioxidant capacity [23, 24]. Moreover, the functional use of AFJ in various food matrices such as fermented dairy products, beverages, and desserts has been evaluated in terms of phenolic

content, shelf life, and color stability [25-27]. However, studies investigating the impact of AFJ on the physical, textural, and especially sensory properties of baked goods such as bread are relatively limited [28, 29]. Current research primarily addresses phenolic inclusion and antioxidant potential, while technological parameters such as consumer acceptance, structural analysis, and post-baking quality characteristics are often considered secondary. This gap makes it challenging to comprehensively evaluate the potential use of AMJ in the bakery sector. Therefore, it is essential to assess both the functional benefits and the quality impacts of incorporating AFJ into widely consumed staple foods such as bread. Accordingly, this study aims to comprehensively evaluate the effect of incorporating AFJ into bread formulations at substitution levels of 0% (control), 50% (50-AMJ), and 100% (100-AMJ) for water on the physical, textural and sensory characteristics of bread samples.

MATERIALS and METHODS

Materials

Nero aronia (*Aronia melanocarpa* L.) fruits were used as a plant material in this study. Aronia fruits were obtained from a grape fruit production plot in Akşehir (Konya, Türkiye). The coordinates of the experimental plot with 3.0 m row spacing and 1.0 m planting distance established in 2020 are 38.3571° N and 31.4167° E, and the altitude above sea level is about 1000 m [30]. Fruit harvesting was achieved in September 2024 when fruits were fully ripe. Harvested fruits were immediately transported to a laboratory in refrigerated trucks and juices were extracted using a solid juice extractor. AFJ was stored at 4°C and used in bread production on the same day it was extracted. Pasteurization step was skipped because heat treatment could alter the natural sensory and bioactive characteristics of fresh aronia juice.

Bread wheat flour conforming to the criteria specified in the “Turkish Food Codex Wheat Flour Communiqué; Communiqué No: 2013/9” [31] was obtained from Hediye Flour Milling Factory (Isparta, Türkiye). Baker's yeast complying with TS 3522 [32]. “Baker's Yeast” standard and salt in accordance with TS 933 [33] edible salt standards were purchased from local markets in Isparta, Türkiye.

Methods

Bread Production Process

Bread production was carried out according to AACC Approved Method 10-10.03 [34] with some modifications. In alignment with the objectives of the present study, the impact of replacing water with AFJ in bread formulation on the textural and sensory properties of bread loaves was investigated by substituting tap water with AFJ at concentrations of 0%, 50%, and 100% during the bread-making process. Bread produced with 100% tap water was considered as control bread.

Briefly, dough ingredients; 1 kg bread wheat flour, 1.5% salt, 3% bread yeast and tap water, which quantity was determined with a farinograph were mixed to optimum development in a spiral mixer [35].

In a mixer, yeast dissolution was carried out with some water. Subsequently, flour was added and kneaded at a slow speed for 5 min. After this, salt was dissolved in remaining water and mixed at a rapid speed for 10 min. Following the weighing of dough, it was allowed to undergo bulk fermentation for 30 minutes at 65-70% humidity and $25\pm1^{\circ}\text{C}$. After bulk fermentation, dough was divided into 10 equal parts, each based on 100 g of flour and rounded, and allowed an intermediate proof period of 12-15 min at ambient temperature. After shaping, the dough pieces were panned and subjected to the final proofing for 1.5 h at 65-70% relative humidity and $25\pm1^{\circ}\text{C}$. Heat-resistant, teflon-coated, galvanized sheet metal baking pans were used for panning the doughs in accordance with AACC Method 10-10.03. Pans had an upper length of 14.3 cm, upper width of 7.9 cm, lower length of 12.9 cm, lower width of 6.4 cm and depth of 5.7 cm [34]. At the end of fermentation phase, breads were baked in a conventional, stone-based electric oven (Enkomak, Antalya, Türkiye) at 260°C for 15 min. After baking, loaves were immediately removed from pans and allowed to cool on wire racks at room temperature for at least an hour before evaluation. Optimal mixing time, mass, final fermentation time, baking temperature, and baking time were determined through a series of preliminary trials. These parameters were carefully adjusted to get the desired texture and flavour character in the final product. Bread production process incorporating AFJ is illustrated in **Figure 1**.

Bread Analysis

Texture Profile Analysis

Texture profile analysis is a widely employed instrumental technique in food science that simulates the mastication process, offering valuable insights into the hardness, cohesiveness, springiness, chewiness, and adhesiveness of food products.

This study utilised TPA to objectively assess the textural alterations in breads made with AFJ and compare them with breads containing no AFJ. TPA was applied by using a TA-XT Plus Texture Analyzer (Stable Micro Systems Ltd., Surrey, UK). TPA was carried out on all bread samples using a 36 mm cylindrical probe (36 mm radial cylinder probe Stable Micro Systems Ltd., Surrey, UK) and a 50 kg load cell with test parameters of 1 mm/s pre-test speed, 5 mm/s test speed and 1.7 mm/s post-test speed; 10 mm test distance; penetration depth Strain: 40%. All tests were performed in triplicate. Hardness, tackiness, springability, springiness, gumminess, elasticity and chewability were determined, and data obtained were statistically analyzed using one-way ANOVA and multiple post-hoc Duncan test [36]. The textural and sensory characteristics of breads formulated with varying concentrations of AFJ are presented in **Figure 2**.

Sensory Analysis

Sensory analysis was carried out by the quantitative descriptive analysis (QDA). Ten faculty staff members (2 male and 8 female), aged 20-50 years, served as panelists and were presented with randomly coded samples. All panelists were identified as regular bread consumers. Criteria used in sensory evaluation and “Bread Evaluation Table” were prepared by using Hayıt and Gül[37]. Before sensory evaluation, panelists were informed about the criteria for bread evaluation [37]. Breads were randomly served to panelists at room temperature and cold drinking water was offered to panelists to cleanse their palate between bread samples. Data were performed in groups of three and evaluated by averaging data. A 5-point hedonic scale, which is the average of a 5-point structured scale ranging from 1 (very poor ‘bad’), 2 (poor ‘not good enough’), 3 (medium ‘acceptable’), 4 (good) to 5 (extremely high), was used for the descriptors of volume, shape symmetry, crust color, crust structure, loaf color, texture, mouthfeel, smell, aroma, taste/flavor, overall liking and affordability.

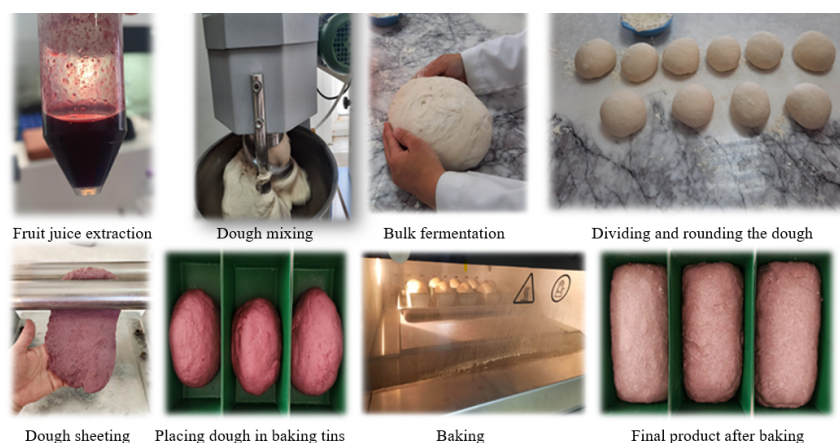


Figure 1. Production stages of bread prepared with aronia fruit juice

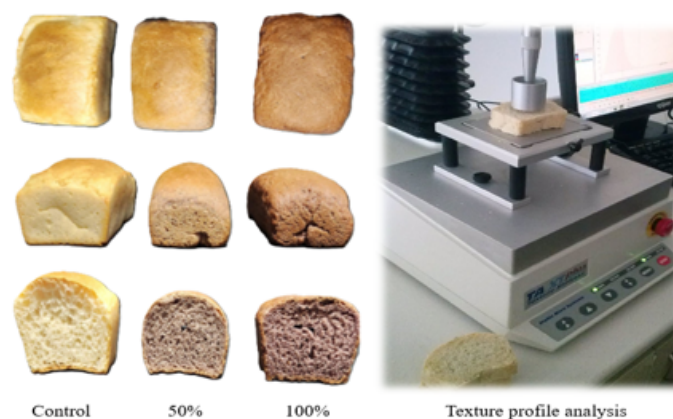


Figure 2. Images of breads prepared with aronia fruit juice and determination of their texture profile analysis

Statistical Analysis

This study was designed according to a completely randomized design with three replicates. For each replicate, three loaves of bread were prepared, resulting in a total of nine samples per treatment. Data obtained were analyzed using SPSS 22.0 statistical software. Differences among treatment groups were determined by one-way analysis of variance (ANOVA), and means showing significant differences were compared using Duncan's multiple range test. Means were considered statistically significant at $p < 0.05$ [38].

RESULTS and DISCUSSION

Effect of Aronia Fruit Juice Addition on Texture Profiles of Bread

The incorporation of AFJ into bread formulations significantly influenced several TPA parameters, and results are presented in **Table 1**. Particularly, hardness increased dramatically with AFJ addition from 1839.07 g (control) to 3293.64 at 50% AFJ, representing a 79% increase ($p < 0.05$). This suggests that the phenolic compounds and acidity of AFJ likely strengthened the crumb structure of bread samples, potentially through enhanced crosslinking or water retention within the starch-protein matrix in agreement with [39, 40, 41]. However, 100% AFJ addition resulted in a significant decrease in hardness (2706.90 g) compared to 50% AFJ addition. These results may be attributed to the complex interaction between the chemical constituents of AFJ and the flour matrix. At 100% replacement, the increased concentration of organic acids like malic acid and natural sugars in the juice might have a plasticizing effect on the gluten network, or potentially alter the pH of the dough to a point that affects yeast activity and crumb pore distribution differently than at the 50% level.

Similarly, the gumminess value of bread samples rose from 1225.24 g (control) to 2389.26 g at 50% AFJ addition, which corresponds to a 95% increase while their chewiness value followed with a rise from 1147.85 g to 1771.01 g, indicating that the addition of AFJ significantly altered the mechanical resistance and mastication properties of breads.

These changes in texture profiles due to AFJ incorporation can be closely linked to underlying microstructural changes within the bread matrix [29, 42]. Polyphenols and organic acids present in AFJ are known to interact with gluten proteins through hydrogen bonding and hydrophobic interactions [43, 44]. These interactions can disrupt the continuous gluten network, resulting in denser and more compact crumb structures, as reflected by the significant increase in hardness and gumminess, particularly at 50% AFJ addition.

Studies by Nikolić et al. [39] and Zhang et al. [40] demonstrated that adding natural compounds like fruit juice can increase the hardness and adhesiveness of bread. This increase could be attributed to interactions between phenolic compounds and gluten networks, which may tighten the dough structure and result in a denser texture. These results suggest that phenolic compounds in fruit juice exert similar effects and lead to notable changes in the metric properties of bread. Petković et al. [29] and Cacak-Pietrzak et al. [42] also reported that fruit-based compounds, including fruit juice, significantly alter the microstructure of bread, contributing to increased product density.

In particular, these compounds are thought to affect the gluten network, leading to a more compact and dense bread structure [29, 42]. In this context, polyphenols and organic acids in fruit juice emerge as key contributors to these microstructural changes. Girard and Awika [43], and Wróblewska et al. [44], further indicated that phenolic compounds can interact with gluten via hydrophobic interactions and hydrogen bonding, thereby strengthening the bread matrix. These interactions may contribute to a firmer and more resilient bread structure. Moreover, increases in mechanical resistance parameters such as hardness, adhesiveness, and chewiness are consistent with these microstructural alterations. The increase in hardness and other textural changes observed with the incorporation of AFJ up to 50% corroborate the structural role of such compounds in modifying bread texture.

Resilience showed a significant decrease from 0.30 (control) to 0.23 at 50% AFJ addition ($p < 0.05$), followed by a slight increase to 0.26 at the 100% AFJ level.

Table 1. Texture profiles of bread samples prepared with aronia fruit juice at different levels (Experiments were designed in a completely randomized design with three replications, each comprising three samples.) (n=3×3=9)

Addition level of AFJ (%) [*]	Hardness (g)	Springiness	Stickiness	Gumminess	Chewiness	Resilience
0	1839.07±1.38 ^{C**}	0.95±0.01 ^A	0.53±0.01 ^A	1225.24±1.80 ^C	1147.85±0.09 ^B	0.30±0.30 ^A
50	3293.64±0.55 ^A	0.93±0.01 ^A	0.58±0.08 ^A	2389.26±3.16 ^A	1771.01±1.41 ^A	0.23±0.23 ^B
100	2706.90±1.87 ^B	0.93±0.03 ^A	0.61±0.03 ^A	1745.68±1.95 ^B	1731.24±0.05 ^A	0.26±0.26 ^{AB}

^{*}AFJ: *Aronia melanocarpa* fruit juice. ^{**}The mean values in the same column of the table with differing superscripts are significantly different at p<0.05.

This suggests that while AFJ initially reduces the ability of breads to recover from deformation, structural changes occurring at full juice replacement partially mitigate this loss in resilience compared to partial replacement. This could be linked to disruptions in the gluten network caused by acidic and polyphenolic interactions, reducing elasticity [20, 45, 46]. Anthocyanin rich profile of AFJ may contribute to lower pH values during dough development, which could partially hydrolyze gluten and weaken its viscoelastic properties. This phenomenon may explain the decrease in resilience and the slightly lower springiness, although not statistically significant. Such structural weakening may also reduce gas retention capacity, influencing loaf volume and crumb texture factors directly perceived during sensory evaluation [47, 48]. Springiness and stickiness values (ranging from 0.93 to 0.95 and from 0.53 to 0.61, respectively) did not differ significantly among treatments (p>0.05), suggesting that AFJ incorporation did not notably influence the elasticity or adhesiveness of the bread within the tested concentration range.

Overall, these results indicate that moderate AFJ inclusion (especially at 50%) considerably modifies bread structure enhancing firmness and chewiness while potentially compromising softness and resilience. From a product development perspective, formulation with 100% AFJ offered a softer texture (2706.90 g) compared to 50% AFJ, while still maintaining elevated gumminess and chewiness, indicating a more balanced textural profile for functional bread applications.

Sabanis et al. [49] reported that the addition of raisin juice had adverse effects on bread volume and textural properties, attributing these effects to the acidic pH levels and the interaction of polyphenols in the juice with gluten proteins, which disrupts dough structure. Similarly, Gawlik-Dziki et al. [50] observed that apple pomace powder reduced bread volume due to the deterioration of the gluten network. Such results are consistent with the hypothesis that fruit juice additives, particularly those with acidic pH, can weaken the gluten matrix and negatively affect the viscoelastic properties of the dough. According to Muñoz-Bernal et al. [51], the incorporation of grape pomace into bread increased the total phenolic and flavonoid content, thereby enhancing the antioxidant capacity of the bread. This suggests that anthocyanin-rich AFJ may contribute to improving the nutritional quality of bread. The potential of AFJ addition to enhance the nutritional quality of bread is supported by its rich anthocyanin and phenolic profile.

In our related study Acun et al. [61], we reported that incorporating 50% and 100% AFJ increased the total phenolic content by approximately 176% and 393%, respectively, and antioxidant activity by 89% and 228%. These results suggest that the incorporation of AFJ into bread formulation could provide a significant source of bioactive compounds that may offer health-promoting effects. However, the physical properties, such as hardness (which peaked at 3,293.64 g at the 50% level before decreasing at 100%) and resilience (which dropped from 0.30 to 0.23-0.26), indicate that the incorporation level must be carefully balanced to maintain structural integrity.

Anthocyanins are known for their strong antioxidant activity, which can mitigate cellular damage and provide protective effects against conditions such as cardiovascular diseases. However, the negative impacts of fruit juice addition on bread's physical properties are largely associated with the disruption of the gluten network structure.

Girard and Awika [43] reported that polyphenols and acidic compounds can interact with gluten proteins, weakening the structural integrity of the gluten matrix. These interactions may disrupt the bonding structure of gliadin and glutenin proteins, thereby reducing dough elasticity and gas retention capacity. During bread production, this may lead to insufficient entrapment of carbon dioxide during fermentation, ultimately resulting in products with reduced volume. From a physiological perspective, the gluten network is a key structural component that determines dough's viscoelastic properties, including water absorption, consistency, and gas-holding ability. Polyphenol-gluten interactions may fragment this network, reducing dough extensibility, destabilizing structure, and resulting in denser, lower-volume breads with diminished spring-back capacity [16, 21]. In this context, fruit juice additives such as anthocyanin-rich AFJ may impair the physiological functionality of the gluten matrix in bread dough, leading to microstructural deterioration [19]. These structural changes are reflected in sensory attributes, particularly texture and volume parameters, that are readily perceived by consumers [50].

Sensory Evaluation of Bread Formulated with Varying Levels of Aronia Fruit Juice

The spider-web in **Figure 3** and **Table 2** present the results of the sensory evaluation of bread incorporating different levels of AFJ. Results provided valuable insights into how the addition of AFJ at various concentrations impacts the sensory attributes of the bread.

In terms of loaf volume, the 50% AFJ bread received the highest panel score (4.1 out of 5), followed by control bread (4.0) and bread with 100% AFJ (3.8). However, control bread received the highest scores for both crust color and crust appearance (4.4), followed by bread with 50% AFJ (3.9) and bread with 100% AFJ (3.5).

Bread with 50% AFJ received a slightly higher sensory score for loaf volume than the control bread. In contrast, bread with 100% AFJ received lower sensory scores for loaf volume and crust color. These differences may be associated with the effects of AFJ components on dough hydration, yeast fermentation, and gluten network formation [52-55]. The results of sensory evaluation revealed that bread samples formulated with 50% AFJ received a slightly higher loaf-volume score than control bread. However, control bread received higher scores for crust color and crust appearance than bread with 50% AFJ (Table 2).

These results align with previous studies suggesting that the appropriate inclusion of fruit juices or fruit-derived compounds can influence the sensory properties of bread. For instance, Alamri et al. [52] reported that moderate levels of plant extract incorporation into dough can stimulate yeast activity, resulting in improved fermentation profiles and increased loaf volume. This is consistent with the highly voluminous and porous structure observed in the samples with 50% AFJ addition in our study.

Natural sugars and bioactive compounds present in AFJ may support yeast metabolism at optimal concentrations, leading to more active carbon dioxide production. This, in turn, facilitates dough expansion and increases bread volume.

Conversely, bread samples with 100% AFJ received lower sensory scores for loaf volume (3.8), crust color (3.5), and crust appearance (3.5) than control bread and bread with 50% AFJ. These lower scores may be associated with the components of AFJ on dough properties. This can be attributed to the high levels of phenolic compounds and the low pH, which may negatively affect the structure of gluten proteins, thereby limiting the dough's gas retention capacity. Czajkowska-González et al. [54] noted that aronia and other phenolic-rich fruit compounds, particularly at high concentrations, can weaken the viscoelastic properties of dough, leading to adverse effects on physical parameters such as crust formation and volume. Similarly, Akbaş and Kılmaoğlu [55] reported that high levels of grape juice concentrate negatively affected the sensory attributes of bread, an effect attributed to the interaction between phenolic compounds and gluten proteins.

Control bread received the highest crumb-color score (4.4), followed by bread samples with 50% AFJ (3.9) and with 100% AFJ (3.5). In contrast, bread samples with 50% AFJ received the highest scores for aroma (4.1) and taste/flavor (4.0). Control bread and bread with 50% AFJ received the same smell score (4.0).

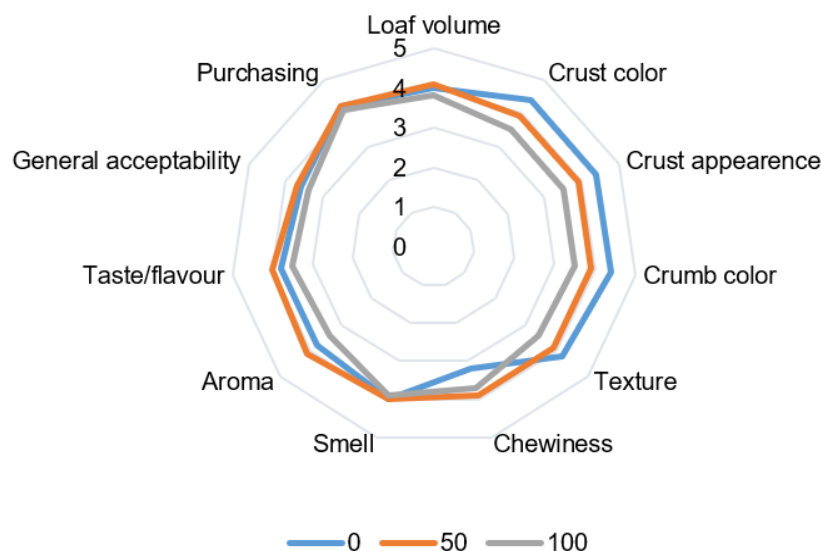


Figure 3. Effect of different aronia fruit juice levels (0, 50 and 100%) on sensory properties of bread

Table 2. Effect of addition of aronia fruit juice at different levels into bread formulation on the sensory properties of bread

AFJ Addition Level (%)*	Loaf Volume	Crust Color	Crust Appearance	Crumb color	Texture	Chewiness	Smell	Aroma	Taste/Flavour	General Acceptability
0	4.0**	4.4	4.4	4.40	4.20	3.20	4.00	3.80	3.80	3.60
50	4.1	3.9	3.9	3.90	3.90	3.90	4.00	4.10	4.00	3.70
100	3.8	3.5	3.5	3.50	3.40	3.70	3.90	3.40	3.50	3.40

*AFJ: *Aronia melanocarpa* fruit juice, **Mean sensory scores based on a 5-point hedonic scale, where 1=very poor, 2=poor, 3=acceptable, 4 = good, and 5=extremely high.

Chewiness score was highest in breads with 50% AFJ (3.9), followed by breads with 100% AFJ (3.7) and control (3.2) breads. These results demonstrate that the effects of AFJ varied according to the sensory attribute evaluated.

Bread with 100% AFJ exhibited comparatively lower sensory acceptability in several attributes, particularly loaf volume and crust characteristics. General acceptability scores were 3.6, 3.7, and 3.4 for control bread, bread with 50% AFJ, and bread with 100% AFJ, respectively. Thus, bread with 50% AFJ received a slightly higher general acceptability score than control, whereas bread with 100% AFJ received the lowest score. Overall, results indicate that 50% AFJ addition produced a more favorable sensory response than 100% AFJ addition in breads for some attributes; however, control bread remained preferable in terms of crumb color and crust characteristics.

Results demonstrated that bread samples with 50% AFJ received the highest panelist scores in sensory attributes such as crumb color, taste/aroma, and odor. This suggests that the controlled inclusion of AFJ into bread formulation can enhance the sensory quality of bread. These results are consistent with previous literature indicating that fruit-based additives, when used at appropriate levels, can positively influence the taste, aroma, and color profile of baked products. For instance, Luo et al. [58] highlighted that fruit extracts rich in antioxidants and anthocyanins contribute not only to nutritional value but also to more complex and appealing aroma profiles in baked goods. The distinctive flavor profile and phenolic composition of AFJ may enhance the depth of flavor and aromatic complexity of bread, leading to a more pleasant sensory experience. Additionally, Wang et al. [59] reported that moderate levels of fruit additive incorporation increased consumer acceptance, while higher concentrations could disrupt the balance of aroma and acidity, thus reducing sensory quality. This is consistent with the lower sensory scores observed in breads with 100% AFJ in our study. Chewiness results are also supported by the literature. For example, Nowicka et al. [60] noted that fruit-based ingredients rich in fiber, such as apple pomace, can enhance moisture retention, leading to a softer, moister, and more balanced crumb structure, which positively impacts mouthfeel. The natural fiber and soluble solid content of AFJ may contribute to structural integrity when used at moderate levels, delivering a more satisfying and substantial mouthfeel [60]. This characteristic is particularly valued in functional and artisanal breads, where consumer expectations emphasize both sensory appeal and nutritional quality.

CONCLUSION

This study demonstrated that the incorporation of AFJ at moderate levels, particularly at 50% substitution for water, into bread formulation influenced the textural and sensory properties of bread.

Breads with 50% AFJ received a slightly higher sensory score for loaf volume than control samples and the highest scores for aroma and taste/flavor, whereas control breads received higher scores for crust appearance and crumb color. The incorporation of 50% AFJ into bread formulation also increased the gumminess and chewiness values of breads compared with control bread. Breads with 100% AFJ received lower sensory scores for loaf volume and crust characteristics than control breads and breads with 50% AFJ. Overall, these results indicate that the level of AFJ incorporation influenced the textural and sensory properties of bread and should be carefully considered in product formulation.

Based on these results, it is recommended that future research should investigate the shelf life stability, nutritional bioavailability, and consumer acceptance of AFJ-formulated breads under commercial conditions. Exploring combinations of AFJ with dietary fibers, alternative flours, or enzyme systems may further optimize texture and functionality. Additionally, studies on the interactions between AFJ polyphenols and dough proteins at a molecular level could provide mechanistic insights into texture and volume changes. Pilot-scale trials involving broader consumer panels would be valuable for scaling up production and validating market potential. Incorporating AFJ into other bakery matrices such as rolls, crackers, or gluten-free products may also broaden its application scope in functional food development.

AUTHOR CONTRIBUTIONS

Conceptualization was done by Kerem Mertoğlu, Hülya Gül, İlknur Eskimez. Investigation, methodology, and writing-original draft were done by Hülya Gül, Şeyma Ulutürk and İlknur Eskimez. Also, data curation was done by Hülya Gül and Şeyma Ulutürk. Review and editing were done by Kerem Mertoğlu and Sultan Acun. Hülya Gül and Kerem Mertoğlu had supervised the entire research work. All authors of this research read the manuscript and agreed to publish it.

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