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Optimization of producing baguette bread containing acorn flour and evaluating its characteristics

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ABSTRACT

In addition to the nutrients, acorn fruits contain a large amount of Polyphenolic compounds. For this reason, acorn can be considered as a suitable raw material for making bread and sweets. The use of acorn flour in food products leads to enhancing their nutritional value, creating added value for this forest fruit and then, helps to preserve oak lands and forests. Therefore, the purpose of this research was to enrich bread using acorn flour. So, the effect of replacing 10-30% acorn flour with wheat flour along with 1-4% gluten on the quality characteristics of the produced bread was investigated. Optimization of bread formula was done based on response surface method. The results showed that the use of acorn flour leads to an increase in hardness in bread and the addition of gluten moderates part of this effect. The initial hardness and specific volume of the samples were obtained in the range of 7.31 to 9.1 N and 2.94 to 3.7 cm3/g corresponding to the samples with the lowest and highest amount of acorn flour. The results of image processing of bread crumb showed that with the increase in the percentage of acorn flour usage, the percentage of porosity decreased significantly, although the porosity value was increased by the addition of gluten ($p<0.05$). It was also found that the addition of acorn flour caused a decrease in the brightness of the crumb and crust of the bread. Finally, the optimized formula with 10% acorn flour and 4% gluten was more accepted by the panel taste, with a score of 4.83, compared to the sample without acorn flour, which scored 4.08. Therefore, it is possible to remove the disadvantages of bread containing oak flour by adding gluten and even achieve bread with a more favorable overall acceptance than wheat bread.

1- Introduction

Bread is a significant part of many populations' diets. This segment of the food pyramid provides a substantial portion of calories and vitamin B and is also essential in terms of other nutrients. However, enriching flour with beneficial compounds increases the nutritional value of bread and ultimately improves individuals' dietary regimens [1]. Therefore, considering the high consumption of bread, enriching this product can be an accessible option for the general public to enhance public health.

Oak comprises about 600 species and has attracted attention in many countries, including Spain, Turkey, Asia, Central, Eastern, and Northern America [2, 3]. Acorn is consumed either raw or after thermal processing. However, acorns have become an important food source and additive in developing organic and functional foods. Accordingly, some Mediterranean countries use Acorn in ice cream and other dessert products. In Algeria, Morocco, and the eastern United States, Acorn oil is produced [4, 5], while in North Africa, Acorn is used in products such as traditional bread and beverages [6-8]. Acorn is a rich source of carbohydrates, mainly starch (31 to 51 percent), and also contains 2 to 8 percent protein and 1 to 9 percent fat. For this reason, Acorn can be considered a suitable raw material for preparing bread and pastries [9-12]. Acorn also contains polyphenol compounds, which impart bitterness to the product [13]. The health benefits of acorn flour are typically preserved during production, allowing its use in food products.

Shishehbar and colleagues (2020) demonstrated that consuming bread enriched with acorn leads to increased satiety in consumers compared to regular bread [14]. Beltra et al. (2020) examined the nutritional aspects of the final product using chestnut flour in bread. They showed that the levels of potassium (K), calcium (Ca), and manganese (Mn) significantly increased in the acorn flour-enriched sample compared to the control sample. This result indicates the health benefits potential of using acorn flour in food products such as bread [15]. Acorn contains a significant amount of tannins, which impart a bitter taste to the fruit and can pose challenges for its use in food products. However, it has been shown that the thermal processing of acorn reduced the tannin content and, consequently, the bitter taste was reduced while simultaneously increasing the content of antioxidant compounds due to the breakdown of compounds such as Gallic acid. This makes it possible to use acorn in bread production [10].

Over half of the vegetation cover in the Zagros forests consists of oak trees. Unfortunately, today the use of Acorn is mainly limited to animal feed. Additionally, oak wood and charcoal have become the primary focus, leading to excessive and illegal cutting of oak trees. Therefore, using acorn fruit in food products creates added value for the acorn fruit and helps preserve oak forests (by shifting employment from tree cutting and charcoal production to collecting and selling acorn fruit). Given that adding Acorn flour to bread formulations declines the textural properties of the resulting bread, gluten was used to improve these properties. Therefore, considering the lack of simultaneous studies on using Acorn flour and gluten to optimize bread formulations in previous research, this study employed different percentages of gluten and Acorn flour to optimize the formulation of baguette bread enriched with acorn. The quality characteristics of the product were also examined to determine a formulation that yields bread with desirable properties.

[DOI: 10.22034/FSCT.21.154.1]

2. Materials and Methods

2.1. Materials Used and Preparation of Acorn Flour

The primary materials included wheat flour with an 82% extraction rate from Harand factory, instant dry yeast from Dormaye Company, a commercial bread improver named S500 (which provides flour, emulsifier, oxidizing enzymes, and sourdough powder), salt, and sugar purchased from local markets in Isfahan. Additionally, acorn fruit was obtained from the local market in the Chaharmahal and Bakhtiari provinces. Initially, the Acorn fruits were peeled and then milled. The milled sample was passed through a 20-mesh sieve.

2.2. Determination of Water Retention Capacity of Wheat Flour and Acorn flour

This test was conducted based on the method by Hong et al. (2021) with slight modifications. For this purpose, 0.5 grams of the sample was mixed with 10 milliliters of water for 1 minute and then kept at room temperature for 1 hour. It was subsequently centrifuged at 3000 rpm for 10 minutes, and the weight of the wet sample was calculated. Finally, the water retention capacity was determined as the weight of water per weight of the sample using formula (1) [16]:

$$WAC = \frac{W_{S1} - W_{s0}}{w_{s0}} \quad (1)$$

2.3. Bread Preparation

Bread dough was prepared using 2% yeast, 1% sugar, 1% salt, 1% improver (S500), approximately 62% water, wheat flour, and acorn flour in 11 treatments (according to the statistical design shown in Table 1). Considering the different water absorption capacities of acorn flour, gluten, and wheat flour, the amount of water was adjusted to achieve the desired dough consistency. The amount of wheat flour (70% to 100%, including the control sample) was determined based on the substitution percentage with acorn flour (0% to 30%, including the control sample), as specified in Table 1. After the dough was prepared, 150-gram dough pieces were produced. Following an initial rest period, the dough pieces were shaped and subjected to a fermentation step lasting 40 minutes. Baking was performed using an Alton oven (made in Iran) at 160 degrees Celsius for 50 minutes. After cooling the bread at room temperature (25 degrees Celsius) for 1 hour, the loaves were transferred into plastic bags for subsequent testing.

Table 1. Variables and levels used in the Central Composite method to evaluate and optimize bread enriched with acorn flour

Independent variable	the symbol in the final model	Levels of variables used		
		1	0	-1
Gluten percentage	A	4	2.5	1
Acorn flour percentage	B	30	20	10

[DOI: 10.22034/FSCT.21.154.1]

2.4. Color Analysis of Samples

The Color of the samples was analyzed using image processing techniques with Photoshop software (version CS5). For this purpose, images of the surface and center of the samples were taken with a 20-megapixel Samsung camera at a 45-degree angle inside a photography chamber (40 cm length, 20 cm width, and 30 cm height). For each sample, several points were randomly selected, and color indices, including L* (lightness), a* (red-green difference), and b* (yellow-blue difference), were calculated. Finally, the actual color indices were evaluated by calibration using standard color cards (RAL company) [17]. The Chroma or saturation index (C*) was calculated using formula (2) to examine the color intensity of the samples.

$$c^* = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

2.5. Measurement of Specific Volume and Porosity of Bread

The specific volume of the samples was evaluated after cooling based on the seed displacement method and the standard AACC (2000) method [18].

The samples were sliced into 1 cm thick cross-sections for porosity measurement and imaged at 300 dpi resolution. The desired characteristics in each image were analyzed using Image J 1.4 software [19].

2.6. Measurement of Texture Firmness

Texture analysis was performed based on the method used by Mazoubi et al. (2013) with slight modifications. The texture of the samples was examined after cooling on days one and 4. A Santam texture analyzer model STM 20 (made in Iran) equipped with a 50 kg load cell was used. A probe with a 10 mm diameter and a movement speed of 2 mm/s was employed. The penetration depth for measuring the firmness of the samples was set at 15 mm. This test was conducted at two points on each sample [20].

2.7. Sensory Evaluation

The sensory evaluation panel consisted of 12 trained individuals over 30. They assessed the bread samples based on color, texture, aroma, taste, and overall acceptance. This evaluation used a 5-point hedonic scale, where 1 indicated the lowest score and 5 the highest. The results were then statistically analyzed [21].

2.8. Statistical Analysis and Optimization

This study utilized response surface methodology (RSM), central composite design (CCD), and nonlinear regression analysis to analyze and optimize the impact of variables. The significance of the models was assessed using Design-Expert software version 7.0.0. Additionally, comparisons between control and optimized samples and validation of the proposed properties by the software were carried out based on analysis of variance (ANOVA) and t-test comparisons using SPSS software version 16.

3. Results and Discussion

3.1. Water Absorption Capacity

Flour with a high water absorption capacity will likely contain many hydrophilic compounds, such as polysaccharides [22]. However, other researchers have indicated that the water absorption capacity of flour is influenced by its protein content and the level of hemicellulose. In this case, the polar amino acids in proteins attract more water molecules. Nonetheless, the complexity of food matrices and interactions among starch, fiber, protein, fat, and water prevents the attribution of a single direct cause

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for increases or decreases in water absorption capacity [23].

Wheat flour's water absorption capacity index was 1.82 ± 0.07 (g/g), and the water absorption capacity for acorn flour was 2.33 ± 0.09 (g/g). This difference in water absorption is likely due to the variation in acorn flour's starch, protein, and fiber content compared to wheat flour. The water absorption percentage of food product components influences specific textural and sensory properties. Based on the results, acorn flour's water absorption percentage is 27.5 ± 3.0% higher than wheat flour's. Measuring this index in wheat and acorn flour is crucial because it affects the water required for proper dough formation. The amount of water is a fundamental parameter in bread formulation, as the quantity of water that flour can absorb plays a significant role in dough development and, consequently, in the quality of the final product.

3.2. Bread Texture Firmness

Bread staling, as perceived by consumers, is predominantly associated with the firming of the bread, which can occur with or without moisture loss. Changes in the bread's moisture content, moisture migration from the crumb to the crust, alterations in gluten structure, and the formation of bonds between gluten and other compounds can all contribute to the staling phenomenon [8, 24]. Gluten is responsible for the viscoelastic properties of dough. Therefore, a reduction in gluten presents a technological challenge for bread production. In this study, the addition of external gluten to the wheat flour-Acorn flour-water system was examined to compensate for the reduced gluten content in the dough.

The results of the bread firmness assessment on days 1 and 4 of production are presented in Table 2 and Figure 1. As shown, the polynomial model effectively describes this characteristic. Table 2 highlights the significant effects of acorn flour, gluten, and their quadratic terms. Acorn flour increased bread firmness, while gluten had the opposite effect. This suggests that the primary impact of acorn flour is due to its reduction of gluten content, resulting in a firmer bread texture. Conversely, adding gluten counteracts this effect, leading to a softer texture. The gluten network, along with amylose released from the starch granules, forms the continuous phase of the bread, and proper hydration of this system results in the desirable characteristics of fresh bread [25]. After four days, changes in firmness were observed based on the variables of acorn flour and added gluten percentage, as shown in Figure 2.

Furthermore, according to Table 2, the effect of acorn flour on the firmness trend of bread after storage is significant with 95% confidence, resulting in a firmer texture. During storage, the gluten network undergoes physical and chemical changes, such as reduced elasticity and flexibility and alterations in starch reactivity, which may contribute to bread staling [25]. Gluten forms hydrogen bonds with starch, partially inhibiting its recrystallization. This interaction likely explains the positive effect of added gluten on reducing bread firmness. Similarly, Corti et al. (2014) reported that adding gluten is essential for reducing the firmness and staling of bread, recommending a 15% gluten addition to achieve an appropriate reduction in these characteristics [25].

The lack of fit error regarding bread firmness is not significant, indicating the adequacy of the model. The results of this section are consistent with the results of subsequent sections, such as volume and porosity, as structural density significantly influences the sample texture. Yazdani et al. (1399) demonstrated that adding 12% acorn flour leads to a firmer texture of bread [26]. According to Table 2,

[DOI: 10.22034/FSCT.21.154.1]

the effect of adding gluten on the firmness of bread samples after storage, with 95% confidence, is insignificant. This indicates that over time, retrogradation changes in starch and the connections between starch and protein under the influence of added acorn flour have occurred, where even the addition of external gluten has not created a significant effect. This observation indicates that the thinning of gluten alone has not been the cause of a firmer bread texture and possibly the interactions formed. The prevention of uniform gluten network formation after adding acorn flour has been a factor in this observation.

Table 2. Examining the coefficients of the bread texture measurement model enriched with acorn flour and gluten

	Firmness (N)	
Independent variable	**First day**	**Fourth day**
Fixed model	8.40***	20.54**
Gluten-percentage (A)	–0.38***	–2.19
Acorn flour - percentage (B)	0.540***	8.53**
AB	–	–
A^2	0.19	3.22
B^2	–0.34**	4.76*
Lack of Fit error	n.s	n.s
Model significance	***	***
R^2	0.97	0.95

* (P < 0.05), ** (P < 0.01), and *** (P < 0.001) indicate the significant effect Of the model components on the investigated feature and the significance of the model.
n.s means non-significance. The model's coefficients are given as coefficients of coded variables (-1 to 1).

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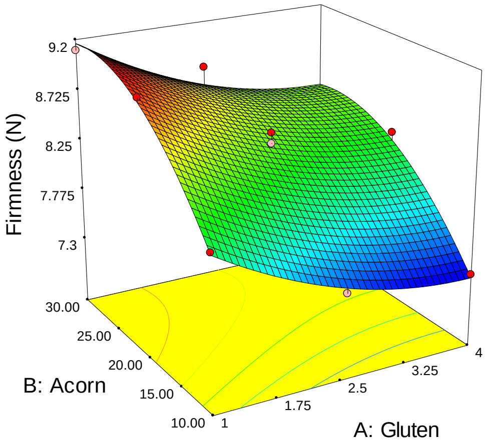

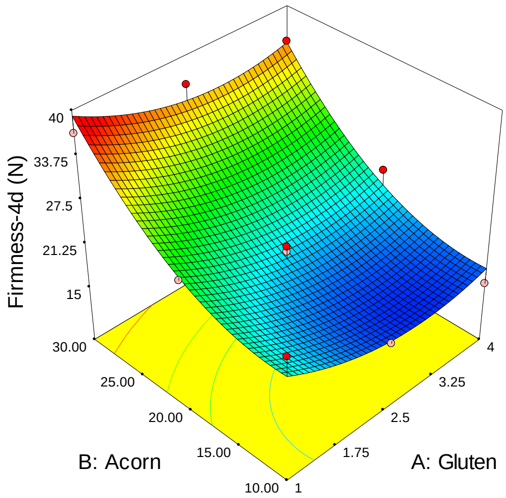

Fig. 1. The effect of gluten and acorn flour on bread firmness

3.3. Bread specific volume

Based on Figure 2 (a), it was evident that the use of acorn flour in bread resulted in a significant reduction in the specific volume of the bread, while adding gluten had a positive and significant effect in increasing the volume, essentially compensating for the impact of acorn flour. However, statistical analysis showed that acorn flour's negative effect outweighs gluten's positive impact. Possibly, the physical damage to the air bubble walls due to the presence of insoluble fiber in acorn flour and the reduction in gluten content in the air bubble walls collectively led to a decrease in the volume of dough during and after the fermentation stage, ultimately resulting in a reduction of the specific volume of bread.

Pilaki et al. (2010), upon observing electron microscopy images of the crumb of bread enriched with oat flour, reported that the added components mechanically affect the gluten structure [27]. The fracturing of the gluten matrix leads to a weaker dough structure and final texture. This effect could result in a reduction in dough volume during fermentation and the volume of the final product. The effect of insoluble fiber was also reported by Corti et al. (2002) [25]. Robula et al. (2012), using 12% chia flour in bread, observed smaller air cells and a denser bread structure [19]. Additionally, the results of this section were similar to the findings of Codina et al. (2008), who demonstrated that adding gluten improved bread volume and sensory attributes [28].

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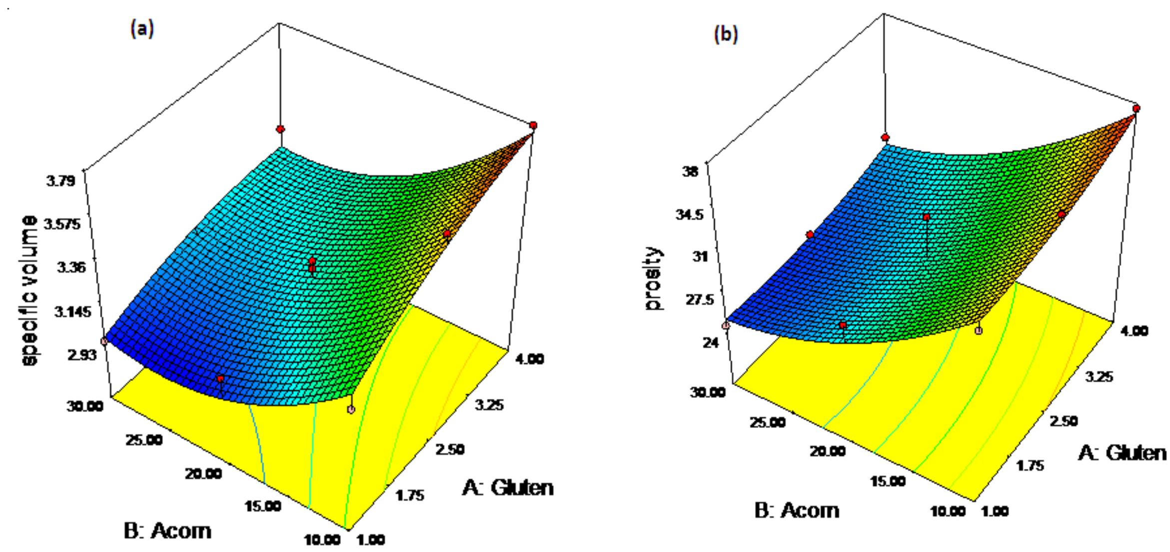

Fig. 2. The effect of acorn flour and gluten on the volume and porosity of bread

3.4. Bread porosity

Porosity is an essential indicator of bread quality. It generally refers to the structure of pores in bread crumb. Porous materials like bread crumb have a complex and irregular structure that cannot be easily quantified in terms of their physical structure. Image processing is an efficient tool for evaluating the properties of bread crumb.

Examining the results presented in Figure 2 (b), it was evident that adding acorn flour significantly reduces the porosity of the bread, which was also observed in the specific volume of the bread. Furthermore, the effect of acorn flour was greater than that of gluten. However, gluten was able to compensate for the negative impact of acorn flour to some extent. According to Figure 2 (b), the trend of changes in specific volume and porosity of bread is similar, which confirms the accuracy of measuring these indicators. As mentioned in the previous section, the reduced bread porosity due to adding acorn flour is likely attributed to the physical effect on the bubble wall formed during fermentation. Acorn flour has less elasticity than gluten, and due to the detrimental impact of insoluble fibers present in acorn flour, the bubbles do not expand well, and their rupture during baking may also be accelerated. Angeloni et al. (2009) reported a reduction in porosity and an increase in the thickness of air cell walls due to carboxymethyl cellulose and fructo-oligosaccharides in bread [31].

3.5. Bread color

Color is an essential characteristic of food products and can play a significant role in consumers' acceptance of them. Nowadays, image processing science is expanding, and its applications have been found in various fields of science. One of its applications is color analysis, which has been used by Afshari Jouybari et al. (2011), Angeloni et al. (2009), and Yam et al. (2004) in the assessment of bread and pizza crust [17, 30, 31].

According to Figure 3 (a, b), the brightness of the bread crumb and crust decreased with an increase in the percentage of acorn flour. Statistical analysis showed that different gluten percentages did not result in a significant change in this indicator. This observation indicates that the initial color of the ingredients plays a dominant role in the color of the breadcrumb. However, caramelization and Millard reactions may also affect this bread characteristic.

[DOI: 10.22034/FSCT.21.154.1]

However, due to the difference in temperature between the bread crumb and the crust during baking, color in this part is more dependent on the color of the dough components [32]. Therefore, the creation of such a change is interpreted based on the initial difference in the color of these two mixtures. Cross et al. (2015) also reported the darkening of the bread crumb due to the darker color of acorn flour compared to wheat flour [10]. Saturation (C) is one of the critical indicators in assessing the color of bread, which determines the intensity of color in the sample.

Based on the statistical analysis and examination of Figure 3(c), it is evident that acorn flour has a significant effect on the saturation index of the bread crumb. However, gluten does not significantly affect this parameter (statistical analysis data not provided). Therefore, the primary variable determining the color of the bread crumb is the amount of acorn flour, which increases the saturation index as its concentration increases. On the other hand, the color saturation of the crust increases with higher levels of gluten (Figure 3d). The effect of acorn flour compared to the percentage of gluten is more significant, indicating the multifactorial nature of crust color control. Gianuva et al. (2016) also demonstrated in a study that adding gluten led to a considerable increase in the saturation of the crust color of bread prepared from frozen dough, and the color of the bread crumb was not affected by adding gluten [33]. Non-enzymatic browning reactions (Millard and caramelization) are the main factors in the formation of bread crust color. Despite the significant effect of added compounds on the color of the bread crust, changes in crust color are mainly due to non-enzymatic browning reactions. Therefore, the presence of prerequisites for these reactions can influence crust color formation. Amino acids and phenolic compounds are essential for non-enzymatic browning [34].

[DOI: 10.22034/FSCT.21.154.1]

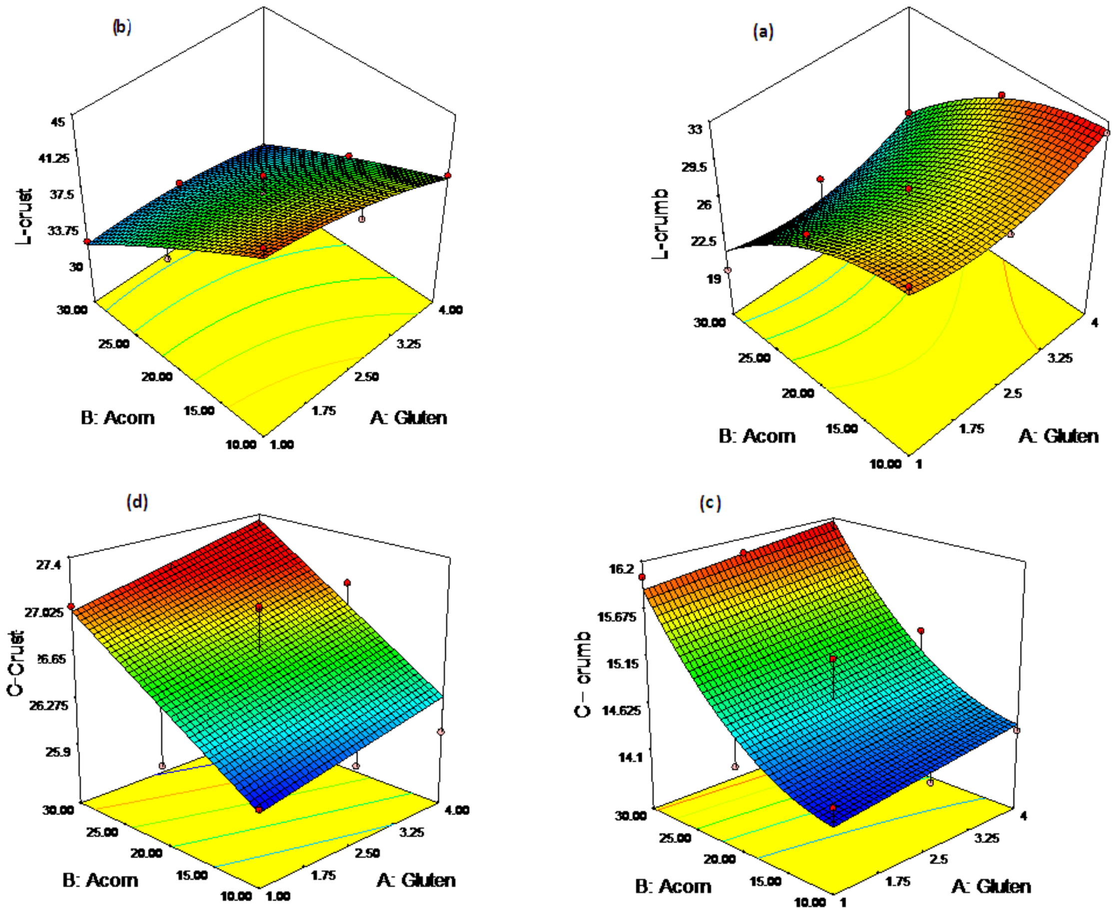

Fig. 3. Color characteristics of bread with acorn flour

3.6. Selection of optimized sample and comparison with control

Using optimization algorithms in the Design Expert software and setting parameters such as firmness, specific volume, porosity, and saturation, a sample containing 10% acorn flour and 4% added gluten was suggested as the optimal treatment for bread, with a desirability index of 92%. This desirability level indicates the suitability of the proposed software conditions. The optimal treatment was prepared to verify this suggestion, and quality assessment tests were conducted, with the results shown in Table 3. Statistical analysis using the t-test method revealed that the data from the software and the laboratory quality assessment data of the optimal sample did not significantly differ, indicating the accuracy of the variable suggestions and quality assessment tests.

Furthermore, the optimal sample was compared with the control sample (without acorn flour and added gluten). It was found that the initial firmness, firmness after storage, and specific volume of the bread in the optimal treatment and the control sample did not have a statistically significant difference. This indicates the role of added gluten in improving the properties of bread containing acorn flour. According to Table 3, the saturation index in the optimal and control samples showed a statistically significant difference ($p < 0.05$). The saturation index was higher in the control sample than in the sample containing acorn flour, indicating an increase in the yellow and red index in the control sample compared to the acorn flour sample. This difference may be related to the variation in moisture content between the two samples or the moisture retention capability of the acorn flour sample. Increased moisture can complicate the formation of color due to Millard reactions [20]. This section's results agree with the sensory analysis of the optimal and control samples.

Table 3. Statistical comparison of model quality indicators with experimental data and statistical comparison of optimal and control samples

Quality measurement parameter	Optimal sample	Control sample	Sig (Anova)	Prediction results of optimization	Sig (Anova)
Stiffness (N)	7.97 ± 0.37	8.48 ± 0.56	Ns	7.32 N	Ns
Stiffness on day 4 (Ne)	18.03 ± 0.70	16.27 ± 0.81	Ns	17.79 N	Ns
Special volume	3.97 ± 0.27	4.04 ± 0.10	Ns	3.75	Ns
Chroma - crust	15.16 ± 0.71	21.11 ± 2.1	*	14.39	Ns
Porosity (%)	37.63 ± 1.03	37.09 ± 0.78	Ns	37.25	Ns

*** indicates A statistical difference at the significance level of 95%, and ns indicates no statistical difference among the samples.**

***Sig (Anova): indicates the statistical difference between the control sample (without acorn flour) and the optimal sample.**

***Sig (t-test) indicates the statistical difference between the optimal sample's software proposal and laboratory-measured characteristics.**

3.7. Sensory evaluation of optimized sample and comparison with control

Consumer evaluation of food products is an essential test in assessing product quality because this evaluation determines consumer acceptance or rejection of the produced product. This test evaluated the optimal samples (with 10% Acorn flour and 4% added gluten) and the control samples regarding aroma, taste, color, texture, and overall acceptance. According to the results in Table 4, in the consumers' opinion, the color of the crust of the sample containing acorn flour and the control sample was similar. Statistical analysis of consumer scores for texture and color of the bread crust and crumb showed that the control and optimal samples did not significantly differ in these two characteristics. This result indicates that the darkening of the bread crumb with the addition of acorn flour (at the optimized level) is not significant enough to create a noticeable difference for consumers compared to the sample without acorn flour.

From the consumers' perspective, the optimal bread's aroma and taste were preferred over the control sample. Also, the overall acceptance score of the optimal sample was significantly higher than that of the control sample. This result can indicate the proper acceptance of the optimal sample as a valuable nutritionally enhanced product. The most important aspect of sensory testing is the overall

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acceptance of the product from the consumer's point of view, which serves as a criterion for its rejection or acceptance. Mojtahedi et al. (2013) showed that adding acorn flour did not result in significant changes in the sensory characteristics of the bread. However, consumers reported changes in taste and aroma in acorn flour samples (more than 40%). Additionally, these researchers demonstrated that the color change in bread due to adding Acorn flour was desirable to consumers.

Table 4. Sensory evaluation of bread enriched with acorn

Sample	Bread crust color	Bread core color	Bread texture	The aroma of bread	Overall acceptance
Control	4.50± 0.90 [a]	4.42± 0.60 [a]	4.42± 0.66 [a]	4.17± 0.57 [a]	4.08± 0.90 [a]
Optimum (10% acorn flour)	4.41± 0.88 [a]	4.66± 0.42 [a]	4.75± 0.45 [a]	4.75± 0.45 [b]	4.83± 0.38 [b]

[*]Same letters indicate no significant difference in an index

4. Conclusion

The use of acorn flour in bread leads to a significant decrease in the specific volume of the bread, and adding gluten also has a positive and significant effect on this characteristic. Moreover, adding acorn flour results in a firmer texture of the bread, while adding gluten reduces the impact of acorn flour on the structure and firmness of the sample. Therefore, the dilution of wheat flour protein has been compensated by adding gluten, resulting in a softer bread texture. After a storage period, the effect of adding gluten on firmness was not statistically significant (with 95% confidence). Thus, acorn flour's impact on firmness is not solely attributed to the dilution of wheat flour gluten. Adding acorn flour significantly reduces the porosity of the bread, which is also observed in the specific volume of the bread. Additionally, due to its natural color difference compared to wheat flour, acorn flour reduces the brightness of the bread crust; however, consumers found this acceptable. Optimization results indicate that the optimal sample (containing 10% acorn flour and 4% gluten) and the control sample (without acorn flour) do not show statistically significant differences in terms of firmness, specific volume, and porosity, demonstrating the role of gluten in preserving bread quality after the addition of acorn flour. Sensory evaluation showed that consumers preferred the optimal sample over the control.

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بهینه سازی تولید نان باگت حاوی آرد بلوط و ارزیابی ویژگی های بافتی و حسی آن

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چکیده

بلوط دارای ترکیبات پلی‌فنولی و املاح سودمند می‌باشد که استفاده از آن در محصولات غذایی موجب افزایش ارزش غذایی محصولات تولید شده، ایجاد ارزش افزوده برای این میوه جنگلی و درنهایت، حفظ اراضی و جنگل‌های بلوط می‌شود. هدف از این تحقیق، غنی سازی نان باگت با استفاده از آرد بلوط بود. تأثیر جایگزینی ۱۰ تا ۳۰ درصد آرد بلوط با آرد گندم، به همراه ۱ تا ٤ درصد گلوتن بر خصوصیات کیفی نان تولید شده، بررسی شد. بهینه‌سازی فرمولاسیون نان بر اساس طرح سطح پاسخ انجام شد. نتایج نشان داد که استفاده از آرد بلوط منجر به افزایش سفتی در نان می‌گردد و افزودن گلوتن، بخشی از این اثر را تعدیل می‌کند. سفتی اولیه و حجم مخصوص نان‌های دارای کمترین و بیشترین میزان آرد بلوط به ترتیب در محدوده ۷/۳۱ تا ۹/۱۰ نیوتن و ۲/۹٤ تا ۳/۷۰ سانتی‌متر مکعب بر گرم به‌دست آمد. نتایج پردازش تصویر مرکز نان نشان داد که با افزایش درصد آرد بلوط، درصد تخلخل به شکل معنی‌داری کاهش یافت، هرچند که افزودن گلوتن، تخلخل را به‌طور معنی‌داری ($P<0.05$) افزایش داد. همچنین مشخص شد که افزودن آرد بلوط، باعث کاهش روشنایی (L^*) مغز و پوسته نان گردید. در نهایت از نظر مصرف‌کننده، فرمول بهینه که دارای ۱۰ درصد آرد بلوط و ٤ درصد گلوتن بود، با امتیاز ٤/۸۳ نسبت به نمونه فاقد آرد بلوط با امتیاز ٤/۰۸، دلپذیرتر تشخیص داده شد. بنابراین، می‌توان معایب نان حاوی آرد بلوط را با افزودن گلوتن برطرف نمود و حتی به نان با پذیرش کلی مطلوبتر نسبت به نان گندم دست یافت.