Hindawi
Journal of Food Quality
Volume 2024, Article ID 3091944, 10 pages
https://doi.org/10.1155/2024/3091944

Research Article

Effect of Semolina Replacement with Amaranth Flour on Quality Characteristics of Functional Pasta

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Received 27 November 2023; Revised 23 February 2024; Accepted 9 March 2024; Published 15 March 2024

Academic Editor: Sneh Punia Bangar

Amaranth is one of the gluten-free pseudocereals and is suitable for celiac disease. This research aimed to investigate the effect of amaranth flour in concentrations of 0 (C), 10 (A_{10}), 15 (A_{15}), and 20% (A_{20}) on the rheological, physicochemical, and sensory characteristics of functional pasta during 3 months. The prepared pasta was analyzed for its quality characteristics such as chemical composition, cooking loss, texture, color, and amylose leach out and was subjected to farinograph and extensograph tests and scanning electron microscopy (SEM). The results showed that the addition of amaranth flour weakens the rheological characteristics of pasta dough. Amaranth flour had a significant effect on the physicochemical properties of pasta ($p < 0.05$). The lowest moisture content, fat, protein, and fiber were observed in the control sample, and the highest amounts were observed in the A_{20} sample. The moisture content decreased during storage. The control and A_{20} samples recorded the lowest and highest cooking loss, respectively. The addition of amaranth decreased the hardness, lightness (L), and yellowness (b^*) and increased the redness (a^*) of pasta. The amylose leach out in the cooking water of all amaranth pasta ranged from 2.03 g to 3.38 g/100 g which was lower than that of the control (4.95 g/100 g). The structure of control pasta is an interwoven network of gluten with many holes and swollen starch granules. A more uniform structure with fewer holes and a looser gluten network was observed in the microstructure of amaranth pasta. A_{10} treatment obtained the highest score of sensory evaluation. In conclusion, the amaranth flour has a good potential to be used in functional foods and gluten-free pasta. A_{20} was favorable in terms of physicochemical characteristics, and A_{10} was the best in terms of sensory characteristics.

1. Introduction

Functional foods have nutritional value and beneficial effects on human health and reduce the risk of various diseases [1]. They include probiotics, prebiotics, polyunsaturated fatty acids, omega-3, conjugated linoleic acid, antioxidants, vitamins, minerals, some proteins, peptides, and amino acids [1].

Today, the consumer demand for cereal-based functional foods, i.e., pasta is increasing. Pasta is made from semolina or durum wheat and is known as a cheap food due to its simple formulation and production process [2]. Semolina is the starting material for pasta manufacture and is high in protein and fiber, both of which slow digestion. It contains various vitamins such as B complex and minerals such as iron [3]. Considering that most cereal products are made from wheat flour and wheat protein is deficient in some amino acids such as lysine, so in recent years, many studies related to the enrichment of these products have been undertaken [2].

Moreover, gluten enteropathy or celiac is caused by an inappropriate immune response to wheat gluten. Patients are unable to consume some of the most common products including breads, baked goods, and other food products made from wheat flour. The gluten-free diet is highly effective in alleviating the symptoms of the disease, i.e., small bowel villous atrophy and crypt hyperplasia. In recent years, there has been an increase in consumer interest in gluten-free foods, and researchers have been working more on the development of gluten-free products, prepared with non-wheat flours such as rice, maize, soya, guar, and amaranth [4].

Amaranth belongs to pseudocereals and does not contain gluten and with a high glycemic index, and it is suitable for celiac disease. It is a good source of carbohydrates (73–77%), protein (15.5–12.5%), lipids (7–8.1%), dietary fiber (19.5–49.3), and minerals (3.5–3%). The bran fraction is proportionally higher in amaranth seeds than in common grains such as corn and wheat, which explains the higher levels of protein and fat content in these seeds. Starch (62–65%) is the most abundant carbohydrate in amaranth. Moreover, unlike cereal grains, there is a high content of lysine in the amino acid profile of amaranth. Amaranth starch generally produces more stable pastes than cereals and legumes, due to its small size and low amylose content. Amaranth contains various minerals such as calcium (134–370 mg/100 g), magnesium (230–387 mg/100 g), phosphorus, iron, potassium, and zinc and E and B vitamins, riboflavin, ascorbic acid, polyphenols, and flavonoids. Caffeic, p-hydroxybenzoic, and ferulic acids are the main phenolic compounds in amaranth. Its oxalate content is between 178 and 278 mg/100 g. Although oxalates are a potential risk factor for kidney stone formation and reduce the availability of calcium and magnesium, most of the oxalates in amaranth seeds are in insoluble form, and their absorption may be low. Amaranth contains higher lipids than most cereals, and its oil composition is quite similar to other cereals with high unsaturated fatty acids (approximately 77%) such as linoleic acid. Amaranth oil mainly contains tocotrienols, which are associated with cholesterol-lowering activity, and squalene, which exhibits anticancer and hypocholesterolemic effects [5].

Some studies evaluated the enrichment of cereal products with amaranth, such as bread [6–12], cake [13], and pasta [3, 14]. So far, very few studies have reported on the technological evaluation of pasta [3, 14]. The purpose of this research was to investigate the possibility of amaranth flour as a food supplement to replace semolina in pasta making and improve the quality properties of pasta with enriched protein content and determine the highest proportion of the amaranth flour that provides the required functionality to produce acceptable pasta.

2. Materials and Methods

2.1. Materials. Amaranth (*Amaranthus hypochondriacus* L.) grains were obtained from Jam Noor Co. (Tehran, Iran), manually cleaned, and milled separately into flour using a blender (Philips Mexicana, Mexico, D.F.). Semolina was purchased from Zar Macaron Industrial Co. (Tehran, Iran). All chemicals (hexane, potassium sulfate, copper sulfate, and sulfuric acid) were obtained from Merck (Germany).

2.2. Chemical Composition of Semolina, Amaranth Flour, and Pasta. Moisture content (AACC, 16–44), fiber (AACC, 32–10), fat (AACC, 10–30), and protein (AACC, 46–12) were measured according to AACC methods (2005) [15].

The pasta was characterized for moisture content (AACC, 16–44) during 3 months, protein (AACC-10-30), fat (AACC-46-13), and fiber (AACC-32-10) after cooking [15].

2.3. Pasta Production. Pasta was prepared in a pasta machine (Zar Macaron, Iran) with amaranth flour to semolina ratios of 0 : 100, 10 : 90, 15 : 85, and 20 : 80. Semolina pasta was also prepared as a control. All batches (280 g each, 14 g of water/100 g) were mixed at room temperature with 1.5 g of distilled monoglycerides/100 g and 10 g of egg white powder/100 g in a mixer (Moulinex, France) at a low speed for 2 min, and 50 g of warm distilled water/100 g was slowly added and mixed for 10–15 min. Afterward, the dough was allowed to rest for 35 min in a proofing chamber at 30°C and 95% RH. First, the proofed dough was laminated in the pasta machine at setting 1 and finally at setting 3. The pasta was hand-cut into strips of approximately 25 cm long (fresh pasta) using a scissor and dried at 75°C and 91% RH for 3 h (dried pasta) in an oven (Behdad, Iran). The four pasta samples were allowed to cool, placed in individual sealed containers to avoid moisture exchange, and stored at room temperature for 3 months [3].

2.4. Dough's Rheological Properties. The water absorption, dough development (DT), dough stability (DS), consistency, degree of dough softening (DOS), and the farinograph quality number (FQN) were evaluated using the Farinograph analyzer (Brabender, Version 1.1.8), according to the AACC-54-21 method [15].

The dough resistance to constant deformation (stretching) after 50 mm (R_{50}), extensibility (E), maximum resistance (R_{max}), the ratio of these parameters (R_{50}/E) and (R_{max}/E), and test area (A) were determined using the extensograph (Brabender, Version 1.1.8), according to the AACC-54-10 method [15].

2.5. Physical Characteristics of Pasta. The cooking loss was measured after 10, 20, and 30 min according to the Iranian National Standard No. 213 (2010). The hardness of the pasta was analyzed by using a texture analyzer (Brookfield, USA). The color was checked using HunterLab (FMS Jansen GmbH and Co.KG, USA), and L, a^*, and b^* values were determined [3].

2.6. Amylose Leach Out in the Cooking Water. Pasta (6 g) was cooked in 120 ml of water until optimum cooking time. Cooked water was drained thoroughly into a 100 ml volumetric flask and made up to 100 ml. After mixing, this was filtered using suction. 1 ml of the filtrate was mixed with 1 ml of iodine solution and made up to 25 ml. The color developed was read at 650 nm. The amylose content was estimated by linear regression analysis [4].

2.7. Microstructure Analysis. The morphology of the pasta after coating with gold and immersion in liquid nitrogen was analyzed using the scanning electron microscope (SEM, LEO 435VP, UK) at a voltage of 5–15 kV.

2.8. Sensory Characteristics of Pasta. The samples were coded before the test, and sensory characteristics of cooked pasta such as flavor, odor, color, texture, and overall acceptability were evaluated by 12 trained panelists from the Food Science and Technology Department, using the 5-point hedonic method. Samples were evaluated after cooking and served in porcelain cups coded with random numbers. Panelists were asked to rinse the mouth with water between each sample. Three samples were assessed per session according to a completely randomized design [4].

2.9. Statistical Analysis. All experiments were conducted in a completely randomized design and with three replications. The results were expressed as the mean ± standard deviation (SD). Analysis of variance (ANOVA) was performed by SPSS software (ver. 21) at a significance level of 0.05 ($p < 0.05$) [13].

3. Results and Discussion

3.1. Chemical Characteristics of Flour. Amaranth flour has a significantly higher moisture content, fat, protein, and fiber than the semolina flour ($p < 0.05$) (Table 1).

The chemical composition of amaranth flour was consistent with other researchers [9, 13, 16].

3.2. Dough's Rheological Properties. Farinograph and extensograph results are summarized in Tables 2 and 3.

Amaranth increased water absorption, dough consistency, and development time. The water absorption increase is probably related to the hydrophilic compounds (fibers) that reacted with water. Amaranth reduced the dough's stability. The highest and the lowest DS were related to the control and A_{20} samples, respectively, because of the dilution effect of amaranth on the gluten network formation [17]. On the other hand, amaranth contains polysaccharides (insoluble fiber) with a weakening effect on gluten [7].

The degree of softening (DOS) increased with the increase in the concentration of amaranth, which is due to the dilution of the gluten network and the reaction between fiber and gluten, which causes the softening of dough [17].

The farinograph quality number (FQN) is a standard that describes the overall quality of the flour. Weak flours show low FQN, and strong flours show high FQN. As can be seen from Table 2, the control treatment showed the highest FQN and the increase in the amaranth concentration decreased FQN.

Table 1: Chemical characteristics of raw materials (dwb).

%	Semolina	Amaranth
Moisture	11.72 ± 0.01^b	14.98 ± 0.08^a
Fat	0.86 ± 0.29^b	6.58 ± 0.04^a
Protein	12.72 ± 0.04^b	15.79 ± 0.08^a
Crude fiber	1.07 ± 0.4^b	13.32 ± 0.05^a

The mean ± SD (standard deviation) within rows with different small letters differs significantly ($p < 0.05$).

With the increase of the amaranth substitution, the elastic behavior (R_m: maximum resistance) is strengthened and the viscous behavior (E: extensibility) is weakened. During the dough rest, these components are recovered and form a uniform gluten network due to glutenin changes. Therefore, R_m and E improve. The elastic properties are related to the presence of glutenins, and the viscous properties are related to gliadins. The dilution of gluten changes the ratio of gliadin to glutenin [18]. Amaranth treatments had lower R_m and E and higher R_{50} than the control sample. This is probably related to the coarser size of the amaranth particles compared to wheat particles, which causes the rupture of gluten during stretching [11].

Considering the different effects of amaranth on R_{50} (resistance), R_m (maximum resistance), and E (extensibility), the evaluation of energy required for dough stretching (A: energy) can be a better explanation for the rheological behavior. A larger value indicates high dough strength. Amaranth decreased A in comparison with the control sample.

3.3. Chemical Characteristics of Pasta. The moisture content of pasta samples decreased during 3 months of storage (Figure 1(a)). The lowest and the highest moisture contents were observed in the control and A_{20} samples, respectively, with a significant difference ($p < 0.05$). The ANOVA results showed that amaranth had a significant effect on the contents of fat, protein, and fiber ($p < 0.05$). The semolina pasta (control) showed the lowest amount of fat, protein, and fiber, and the highest amounts of these parameters belong to the A_{20} sample (Figures 1(b)–1(d)).

The presence of hygroscopic compounds such as soluble and insoluble fibers, cellulose, hemicellulose, and lignin in amaranth preserves the moisture content after cooking and increases water absorption [7]. The results of moisture content confirmed the results of water absorption in farinograph tests.

The higher fat and protein content of pasta samples containing amaranth can be attributed to the difference between fat and protein contents of amaranth and semolina (Table 1).

Sanz-Penella et al. [7] showed that replacing wheat flour with amaranth increases the amounts of protein, fat, ash, dietary fiber, and minerals. According to the findings of Hamzehpour and Dastgerdi [13], the addition of amaranth flour significantly increases the fiber and protein content of the cake.

According to the national standard of Iran (no. 213; 2010), the permissible limit of moisture content, protein, and fiber is maximum 12%, 10%, and 2-3%, respectively, in regard to moisture, all pasta samples were within the standard range, and in regard to protein and fiber, A_{20} treatment was in the standard range [19].

Table 2: Farinography characteristics of pasta dough.

Sample	Water absorption (%)	Dough consistency (BU)	Dough development time (min)	Dough stability (min)	Degree of softening after 10 min (BU)	Degree of softening after 12 min (BU)	Farinograph quality number
C	58.4 ± 0.01^{d}	495 ± 0.12^{d}	1.48 ± 0.15^{d}	14.50 ± 0.11^{a}	13 ± 1.1^{d}	19 ± 1.05^{d}	174 ± 1.78^{a}
A_{10}	59.7 ± 0.14^{c}	503 ± 0.12^{c}	6.04 ± 0.16^{a}	8.35 ± 0.16^{b}	19 ± 1.12^{c}	51 ± 1.09^{c}	120 ± 1.56^{b}
A_{15}	62.4 ± 0.11^{a}	517 ± 0.22^{a}	5.10 ± 0.15^{c}	8.52 ± 0.17^{b}	23 ± 1.14^{b}	60 ± 1.11^{b}	114 ± 1.44^{c}
A_{20}	61.4 ± 0.01^{b}	514 ± 0.15^{b}	5.55 ± 0.21^{b}	6.54 ± 0.16^{c}	25 ± 1.16^{a}	75 ± 1.08^{a}	106 ± 1.23^{d}

The mean ± SD (standard deviation) within rows with different small letters differs significantly ($p < 0.05$). C, control (without amaranth); A_{10}, pasta with 10% amaranth; A_{15}, pasta with 15% amaranth; A_{20}, pasta with 20% amaranth.

Table 3: Extensograph characteristics of pasta dough.

Sample	Resistance (BU)	Maximum resistance (BU)	Extensibility (mm)	Resistance/extensibility	Maximum resistance/extensibility	Energy (cm^2)
C	476 ± 1.32^d	636 ± 2.05^a	138 ± 1.17^a	3.61 ± 0.02^d	3.91 ± 0.08^d	114 ± 1.07^a
A_{10}	498 ± 1.11^c	476 ± 2.09^d	122 ± 1.12^b	3.91 ± 0.01^c	4.41 ± 0.03^c	84 ± 0.95^b
A_{15}	521 ± 1.19^b	528 ± 2.03^c	120 ± 1.16^c	4.35 ± 0.15^b	4.61 ± 0.06^b	81 ± 1.01^c
A_{20}	571 ± 1.16^a	602 ± 2.06^b	104 ± 1.15^d	5.50 ± 0.13^a	5.79 ± 0.03^a	80 ± 0.91^c

The mean ± SD (standard deviation) within rows with different small letters differs significantly ($p < 0.05$). C, control (without amaranth); A_{10}, pasta with 10% amaranth; A_{15}, pasta with 15% amaranth; A_{20}, pasta with 20% amaranth.

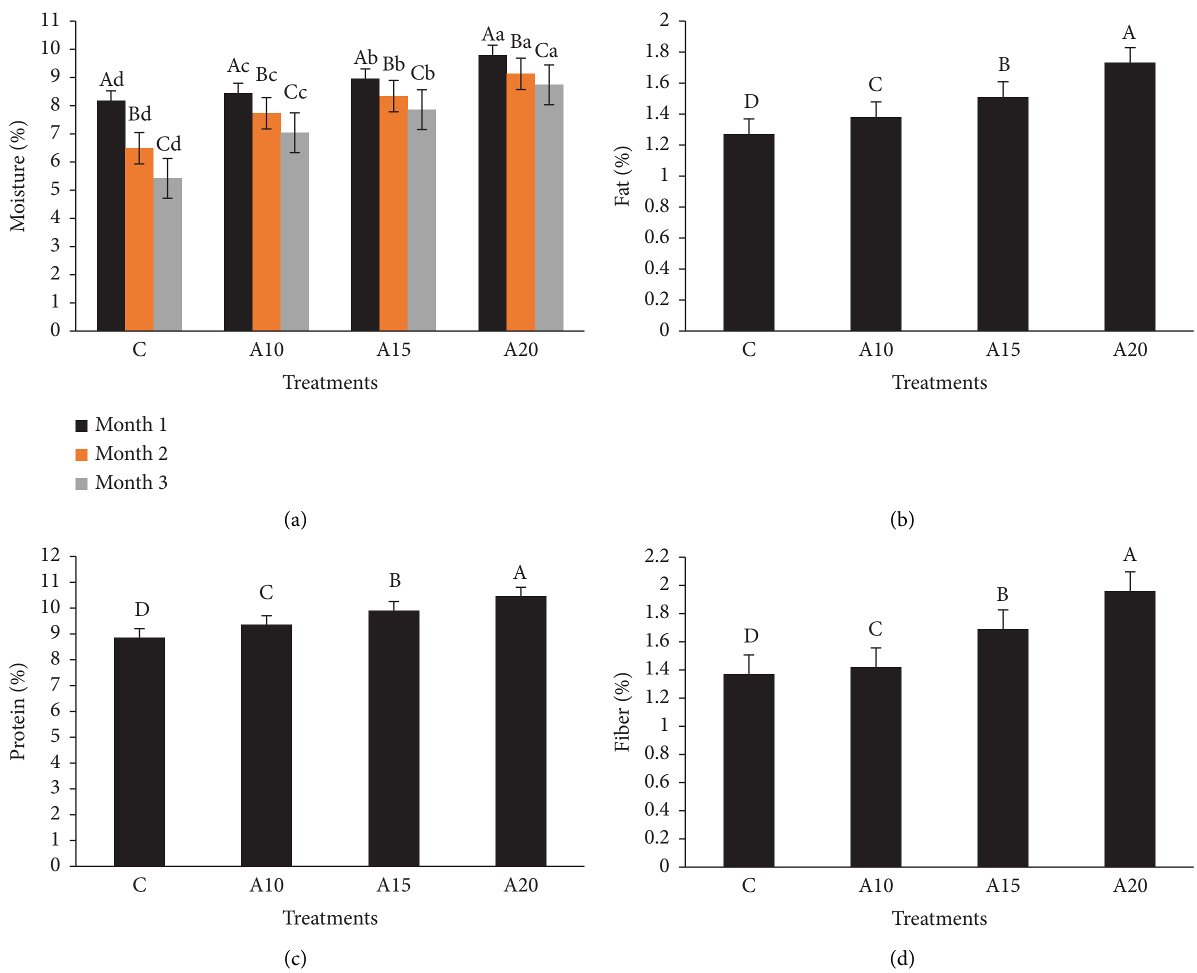


Figure 1: Moisture content of pasta during 3 months (a). Fat, protein, and fiber contents of pasta (b–d). Different letters indicate a significant difference ($p < 0.05$). C: control (without amaranth), A_{10}: pasta with 10% amaranth, A_{15}: pasta with 15% amaranth, and A_{20}: pasta with 20% amaranth.

The microbial growth, chemical reactions, and enzyme activities that can affect the stability of products are influenced by the moisture content and water activity. The lower the water activity, the more the stability increases. A lower moisture content is essential for safe storage. However, a very low moisture content leads to dry and brittle pasta [3].

3.4. Cooking Loss. The results of ANOVA revealed that amaranth had a significant effect on the cooking loss of different pasta types during 30 min ($p < 0.05$). The lowest and highest cooking loss was observed in the control (semolina pasta) and A_{20} samples, respectively (Figure 2). As the time increased from 10 to 30 min, the cooking loss increased ($p < 0.05$).

The amounts of cooking loss (4.14–5.37%) in all samples are in accordance with the national standard of Iran (no. 213; 2010), in which the cooking loss has been determined at a maximum of 11% [19].

3.5. Texture. Amaranth reduced the hardness of pasta. The lowest hardness was observed in the A_{20} sample, and the highest hardness belonged to the semolina pasta (Figure 3).

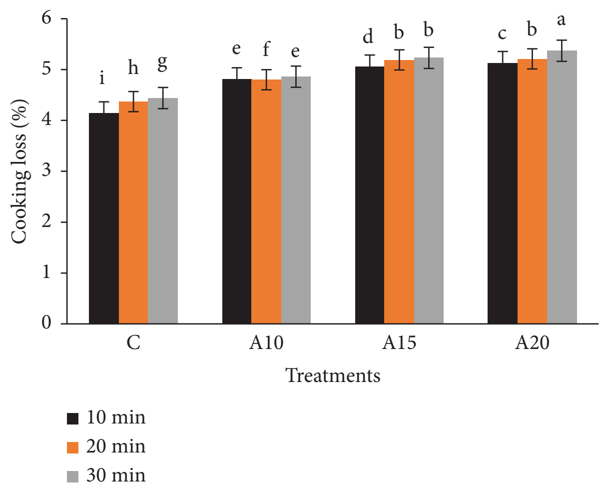


Figure 2: Cooking loss of pasta. Different letters indicate a significant difference ($p < 0.05$). C: control (without amaranth), A_{10}: pasta with 10% amaranth, A_{15}: pasta with 15% amaranth, and A_{20}: pasta with 20% amaranth.

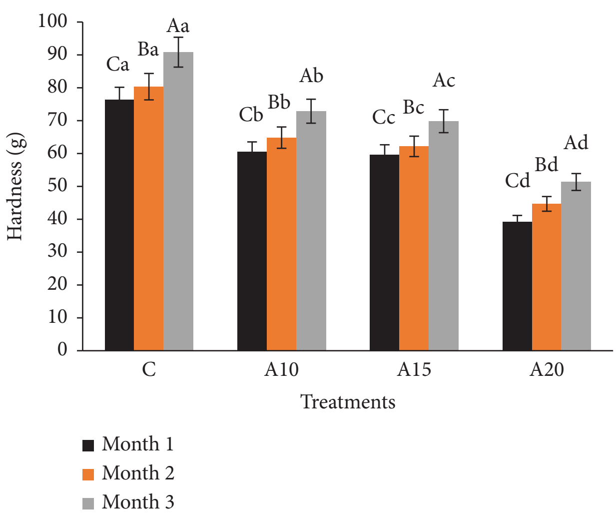


Figure 3: Hardness of pasta during 3 months. Different uppercase and lowercase letters indicate a significant difference between the storage time and treatments, respectively ($p < 0.05$). C: control (without amaranth), A_{10}: pasta with 10% amaranth, A_{15}: pasta with 15% amaranth, and A_{20}: pasta with 20% amaranth.

Regarding the reduction of hardness of some samples, it can be said that the preservation of moisture due to the high amount of fiber is one of the important factors [20]. It seems that fat and hydrocolloids in amaranth flour were also effective in reducing hardness (Table 1). The hardness reduction of cereal products as a result of adding dietary fibers has been reported in other studies [21]. Islas-Rabio et al. [3] showed that replacing semolina with amaranth reduces the hardness of pasta.

The hardness of pasta samples increased during storage ($p < 0.05$). Staling or hardening of the baked products during storage is a complex process that involves several factors including the recrystallization of gelatinized starch, especially amylopectins, retrogradation of amylose, binding of amylose and amylopectin to each other, moisture migration after crystallization of starch, and reduction of moisture content or distribution of moisture between amorphous and crystalline regions. The staling of bakery products is related to the moisture content, so there is an inverse relationship between the moisture content and its staling. Water can be effective in reducing hardness by playing the role of a plasticizer. Also, the tendency of fibrous compounds to absorb water causes less gelatinization and recrystallization during storage, which ultimately leads to a reduction in hardness [13].

3.6. Color. By adding amaranth flour to pasta, the L and b^* values decreased and the a^* value increased (Figure 4). During storage, the L^* value of all samples decreased and $a^*$and b^* values increased ($p < 0.05$).

The difference in color parameters can be due to the natural pigments of the amaranth and the hydrophilic role of fibers, which decreased the L and b^* values and increased the a^* values in the amaranth pasta [7]. The color values in the present study are similar to those found for other gluten-free products containing amaranth [13, 22–24].

The color can be attributed to the interaction of fibers with amylose. Sugar and protein compounds can affect the color parameters. During the cooking process, fiber compounds cause a migration of moisture from the crumb to the crust. Another cause of color change is the browning reactions [13].

3.7. Amylose Content in Cooking Water. The amylose content of all amaranth pasta ranged from 2.03 g to 3.38 g/100 g, which was lower than that of the semolina pasta (4.95 g/100 g), as shown in Figure 5.

A higher amylose content is associated with higher hardness and less surface stickiness. Pasta surface stickiness is influenced by both the surface structure of the strand and starch exuded onto the strand surface during cooking. Amylose decrease increases the stickiness of the pasta. The higher protein content and lower amylose leach out into cooking water may be the reason for the less stickiness of gluten-free pasta [14].

These results are in agreement with the results of Martinez et al. [25]. They reported that 2–5 g/100 g of amylose leach out in cooking water of commercial spaghetti.

3.8. SEM Analyses. The microstructure of the functional pasta is shown in Figure 6. The structure of control pasta is an interwoven network of gluten with many holes and swollen starch granules (Figure 6(a)). The microstructures of pasta-containing amaranth are slightly different (Figure 6(b)). A more uniform structure with fewer holes and a looser gluten network can be seen.

SEM images of gluten-free pasta showed a protein matrix distinct from the gluten network. This may be due to the high protein content, fiber, and starch of the flour used in pasta. The microstructure showed a fibrous and protein

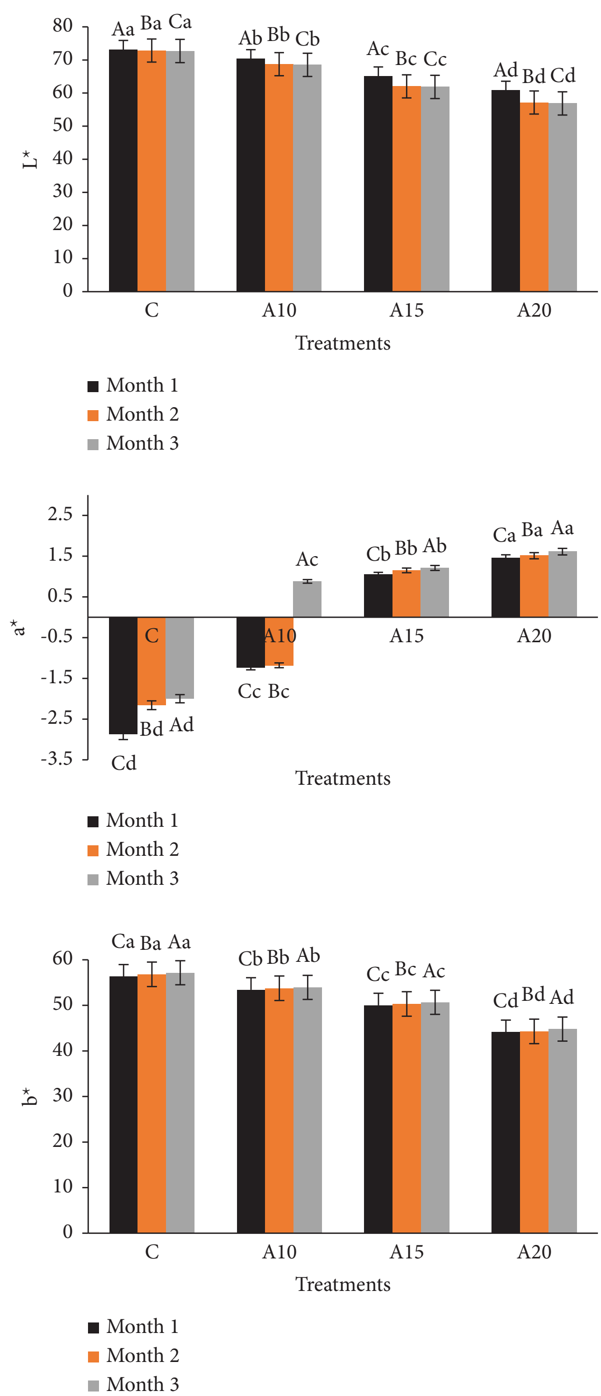


Figure 4: Color parameters of pasta during 3 months. Different uppercase and lowercase letters indicate a significant difference between the storage time and treatments, respectively ($p < 0.05$). C: control (without amaranth), A_{10}: pasta with 10% amaranth, A_{15}: pasta with 15% amaranth, and A_{20}: pasta with 20% amaranth.

network but not similar to the gluten network. Amaranth pasta showed a smooth but an intact structure when observed in cross section of the pasta which clearly showed the starch molecules that may be the reasons for less starch leaching out during cooking. The control pasta revealed the gluten protein network with wheat starch molecules embedded in it [14].

3.9. Sensory Characteristics. A_{10} obtained the highest score for flavor. The highest score of odor belonged to A10 and A15 samples and the control sample obtained the lowest score. The semolina pasta (control) and A10 samples showed the highest scores of color and texture. The highest overall acceptability belonged to the A10 sample, followed by the semolina pasta (Figure 7).

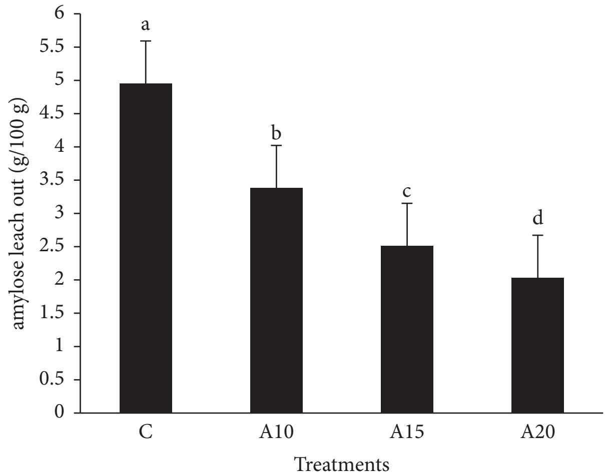
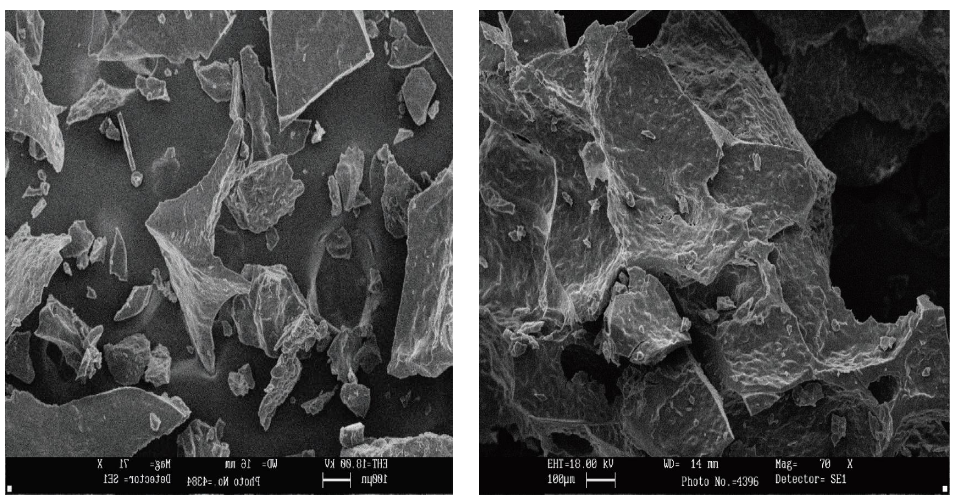


Figure 5: Amylose content leach out in cooking water. Different letters indicate a significant difference ($p < 0.05$). C: control (without amaranth), A_{10}: pasta with 10% amaranth, A_{15}: pasta with 15% amaranth, and A_{20}: pasta with 20% amaranth.



(a) (b)

Figure 6: SEM images of pasta. (a) Semolina pasta. (b) Amaranth pasta.

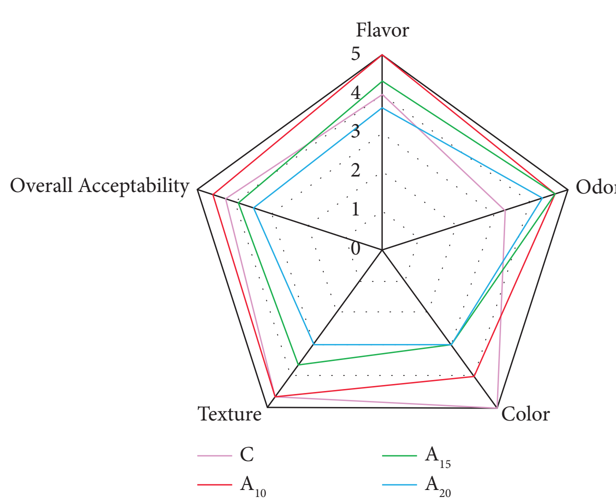


Figure 7: Sensory characteristics of pasta. C: control (without amaranth), A_{10}: pasta with 10% amaranth, A_{15}: pasta with 15% amaranth, and A_{20}: pasta with 20% amaranth.

The higher scores in the A_{10} treatment are due to the high ability of the fiber compounds in amaranth to retain moisture and its more uniform release of moisture during the cooking process [9, 10]. However, the decrease in sensory characteristics of A_{20} treatment is due to the increasing amaranth flour substitution and the insufficient cohesion of the gluten network, the reduction of the chewiness, and the aftertaste of amaranth [8].

Buresova et al. [6] showed that the overall acceptability of bread-containing amaranth was negatively influenced by the flavor of amaranth. In the research of Nasir et al. [10], the bread prepared by substituting 5% and 10% of amaranth flour is acceptable from the nutritional and sensory points. Derkanosova et al. [8] showed that amaranth bread was similar to traditional samples. Also, amaranth improved the nutritional, sensory, and technological quality of some products [9, 13].

4. Conclusion

The formulation of gluten-free bakery products presents a challenge to food technologists. The present study aims at the development of functional pasta mainly covering the evaluation of product quality.

The results showed that increasing amaranth flour weakened the rheological properties of the dough and improved the physicochemical properties of the final product. With the increase of amaranth flour, the moisture content increased and hardness decreased. Although the cooking loss of enriched pasta was higher than that of the control sample, it was in accordance with the standard limit. Amaranth also reduced amylose leach out compared to the control sample. Amaranth (even in small levels) darkened the final product. Amaranth increased the fat, protein, and fiber contents of pasta. The increase in protein and fiber can be seen as a reason for the higher nutritional value of pasta products. Thus, amaranth can be used in the formulation of functional baking goods. However, the industrialization of this product requires more studies on increasing shelf life and preventing microbial growth.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

S. Alizadeh designed the experiment and data collection. S. Tahriri analyzed the data. M. Zokaei and F.Ebrahimi Tirtashi helped in the design and contributed to the compilation of the manuscript. A. Ahmadi Dastgerdi read and approved the final version of the manuscript.

Acknowledgments

The authors would like to thank the University of Ardestan for their technical help and Miss Shiva Tahriri for the statistical analysis of this paper.

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