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Using Alternative Flours as Partial Replacement in Barbari Bread (Traditional Iranian Bread) Formulation

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Abstract. *Since cereals and cereal-based products are a cheap source of energy, they are highly consumed in all of countries. Wheat is the major cereal, consumed in different food products, especially bread. Today, whole wheat flour is being consumed in most of the breads because of its nutrient components but still different problems are associated with this flour, such as allergies and loss of nutrient components due to milling and refining. Thus, to find different sources to fortify products made with wheat flour as their major ingredient, especially bread is important. In this study, five different flours (20% of each flour plus 80% of wheat flour) were used as alternatives to wheat flour in production of Iranian traditional bread, Barbari. These flours were amaranth, barley, DDGS, rye and oat. Proximate analyses were conducted in order to find out the moisture, fat, fiber, protein and ash content of each product. Also rheological tests were done to understand the change in the color, thickness and texture of final products. The results showed that the gluten content of each flour had significant effect on the texture and thickness of the bread. As for the color, it was shown that the bread made with rye flour had the highest L* value and the one made with oat flour had the highest a* value. As for the b* value, the highest was for the bread made with DDGS. As for the chemical properties of the breads, it was determined that bread made with 20% DDGS and 80% of wheat flour had the highest fiber and moisture content. The bread made with amaranth had the highest ash content, while the one made with rye had the highest protein and fat content. Overall, adding different flours to wheat flour can change the physical and chemical attributes of final product significantly.*

Keywords. Amaranth, Barbari bread, barley, DDGS, oat, rye.

Introduction

Cereals are one of the most widely consumed foods in the world because they are inexpensive and readily available. Cereals are the edible seeds or grains of the grass family, Gramineae. Cereals and cereal products are an important source of energy, protein and fiber (Mckevith, 2004). Though wheat is the most important highly consumed cereal, the exact location where ancient wheat cultivation began remains a mystery. Some sources point to either Syria-Palestine or southern parts of Anatolia. Wheat cultivation spread from Palestine to Egypt and from northern Mesopotamia to Iran, where bread wheat was first developed. From Persian, the growth of wheat bread in all directions (Qarooni, 1996). Although whole wheat has many nutritional benefit as a food components for humans, most of its nutrients are lost due to the milling processes. Thus, to add value to those products made by all-purpose flour or other wheat flours gains importance. Since bread is the most consumed cereal product, fortification can help prevent certain diseases and problems, such as malnutrition.

One way to fortify bread products is to use alternative flours (Pourafshar et al, 2010a). Different flours have different nutritional characteristics; thus, they can be added to bread products. For example, oat and barley can enhance the β-glucan content of bread, which can have a significant impact on human health (Marrioti et al, 2006). Barley and oat can contain 3-11% and 3-7% of β-glucan, respectively (Sidhu and Kabir, 2007). Consumption of barley has increased during the past few years because of its association with lowering cholesterol levels and moderating blood glucose (Skendi et al, 2010). The β-glucan in barley flour can increase the quality of bread by modifying the glycemic and insulin response (Gujral and Gaur, 2005). The high value of fiber in barley flour can lower the blood cholesterol and glucose. Studies also show that bread made with blend of wheat and barley flour has acceptable sensory properties (Skendi et al, 2010). Amaranth has twice the lysine content of wheat protein. It also has

cholesterol-lowering properties attributable to its nutrient components; its fiber content is three times higher than that of wheat (Ayo, 2001). In Europe, rye is the most common cereal grown after wheat. Production of this grain is about 15.7 million tons per year (Horszwald et al, 2009). Rye is a healthy cereal with high amounts of dietary fiber; whole grain rye contains 13% to 17% of DF (Rakha et al, 2010). Another positive nutritional effect of rye flour is the existence of lignin, phytosterols, and phenolic compounds which are biologically active components which have antioxidant properties (Horszwald et al, 2009). Oat also offers health benefits because it is high in dietary fiber and protein content. Besides the dietary fiber, oat is rich in essential amino acids, unsaturated fatty acids, minerals and antioxidants (Huttner and Arendt, 2010).

Distillers dried grains with soluble (DDGS) can also be a good source for fortification of cereal-based products. DDGS is a product resulting from the fermentation of cereal grains, mostly corn, for the production of ethanol. DDGS is a valuable source of protein, fiber, minerals and vitamins. Different methods can be used in production of DDGS and the method chosen then affects the physiochemical properties of the final product (Cromwell et al, 1993). The process used can affect the appearance and the protein content of final product. The protein content of DDGS can range from 27% to 35%. Furthermore, variation in the composition of corn can affect the composition of the final DDGS (Belyea et al, 2004). Many works have been reported on incorporation of DDGS into food products. Finely and Hanamoto,(1980), used brewer's spent grain in bread, Tsen et al (1983, 1982), used DDG in bread and cookies and evaluated their qualities; and Wu et al (1987) supplemented spaghetti using corn distiller's grains. The use of DDGS in food products helps produce a healthier baked product with a higher amounts of fiber and protein. Different types of bread in Middle Eastern countries are made with various types of flours. For example, Baladi and Aish Meharha from Egypt; round shaped as are Bazlama, Pide and Yufca from Turkey, and both are mainly made with wheat flour. Morocco has pan fried bread made with semolina flour. Afghanistan and Tajikistan have

Bolani, flat bread stuffed with different vegetable. Each of these breads has their own physical and chemical characteristics. Because they are made mainly with wheat and other milled flours, they have deficiencies in certain nutrient components that can be minimized through fortification.

In Iran, four major types of breads are consumed: Barbari, Lavash, Sangak and Taftoon. Of these, Barbari is the most popular bread, especially in northern part of Iran, where it originated. Historically, Barbari was brought to Iran during the revolution in Russia. It became popular among Iranians in the north part of Iran, but today is consumed in all parts of Iran. Barbari crust has a thickness of 1-2 mm, length of 67-75 cm, and width of 13.5-20 cm. Barbari is thick and oval shaped and is topped with poppy seeds. Barbari gets its golden color from the use of Romal. Romal is made from flour, baking soda, mixed in the boiling water, which then turns the starch of the flour into dextrin, which makes the golden color. The Romal is then brushed on the shaped dough. Barbari has a unique smell and the taste depending on the amount of sour dough and baking time (Pourafshar et al, 2010b).

In this study, five different flours were used as alternatives flours for the production of Barbari. The flours used were amaranth, barley, DDGS, oat and rye. Proximate analysis was done on the produced breads to find the nutritional changes in the altered breads. In addition to this, rheological tests were conducted to understand the physical behavior of each bread using different flour formulas. The hypothesis in this study was that adding alternative flours to traditional Barbari bread will enhance the nutrients in the final products. Thus, the objective of this study was to understand the chemical and physical changes in the Barbari bread made with different types of flours.

Materials and Methods

Experimental Design

Distillers dried grains with solubles (DDGS) was obtained from a commercial ethanol plant in South Dakota. All-purpose wheat flour, amaranth, barley, oat and rye flours were purchased from local markets. Barbari bread was baked as a control sample at 550°C for 10 min, only using wheat flour. All in all, there was one type of bread with six different flour mixes; thus, a one factor experimental design with 6 levels was used (table 1). So, beside the control, 5 types of Barbari bread were baked each with two replications. The dependent variables in each sample were the physical and chemical attributes, since with the change in flour these parameters were changed in the final products.

Preparation

For making the sour dough, 1 g of salt, 9 g of active dry yeast, 400 g of flour, with 650 g of water were used. In order to prepare the Romal as the topping for the bread, and 4.2 g of flour, and 4.2 g of baking soda, and 85 g of water were used.

For the bread made with only wheat flour (the control), 880 g of all-purpose flour was used; the rest of ingredients were 4.2 g of sugar, 4.2 g of salt, 689.76 g of water. For the other breads, the same ingredients were used, except for the amount of flour. Barley grains were ground in a Restch Mill (GmbH & Co. KG, 5657 HAAN1, and Germany) operated at 20,000 rpm using a 0.5 mm sieve. The same procedure was followed for grinding the grain in bread made with DDGS. 704 g of all-purpose flour was used substituted with 176 g of alternative flours which were: amaranth, barley, DDGS, oat, rye. To obtain a fine, well-distributed flour for each treatment, wheat flour was mixed with each of the other flours using a blender (Blend Master, Patterson-Kelley, Harsco, East Stroudsburg, PA, USA). Turbofan 32 convection oven was used to bake the breads.

Bread Production

Sour dough was prepared the night before in each bread preparation. To make the sour dough, 9 g of active dry yeast, 1 g of salt and 650 g of water were mixed together very well, and then the bowl of sour dough was covered and left for 18 h at room temperature. To prepare the bread, first the yeast was dissolved in warm water and sugar was added and the mixture put aside for 10 min. Next it was mixed with salt, water and the flour was added gradually mixing well. Finally, the sour dough from the previous day was added as well. The mixture was mixed well enough until it was not sticky. The next step was proofing, where the dough was put in the proofing machine for hour and half for the yeast to act. After proofing, the air was punched out of the dough. Then 400 g of the dough was weighted and punched down to form a 20” by 20” (figure 1) square so that all the dimensions become the same for all the breads. The thickness of the dough was measured in three different areas of the edges. Then the Romal was made and brushed on top of the dough. The dough was put aside for 10 minutes, and then it was ready to be baked. The temperature used for each bread was 500 ˚C for 10 min.

The other breads were made the same way, except for the flour used. In the breads other than control 80% all-purpose flour was used with 20% alternative flour. The rest of the ingredients were the same. Two loaves of breads were prepared and baked on stone, to make the baking condition close to that of the traditional ovens used for Barbari in Iran.

Physical and Chemical Properties

After the bread was baked and cooled, the thickness of the edges and of the center of the bread was measured using digital Vernier calipers. For the center measurement, the thickness was measured three times, since it was not the same in the center because of the existence of bubbles in the middle of the bread. A texture analyzer was used to study the firmness and extensibility of the bread samples using two different probes: SMS/Chen-Hoseney

Dough stickiness RIG and Pizza Tensile RIG (TX.XT- plus texture analyzer, Texture Technologies Corp., Scarsdale, New York). For measurement of each of these variables, duplications were done for each loaf, so four samples for each type of bread were evaluated for a total of 24 samples.

After that, the breads were ground and moisture content and water activity were determined. The particles were dried at room temperature, for one day and then ground into fine particles. In order to determine water activity, a water activity meter was used (Aqua lab CX-2, Decagon Devices, Inc, Pullman, Washington).

Color was measured by Spectrophotometer (Minolta CM-508d, Ramsey, New Jersey, U.S.A) in which L* is the measure of lightness, a* is the measure of greenness to redness and b* is the measure of blueness to yellowness. The color was determined for the baked products just like was done for the dough, and L*, a* and b* were measured to get the color value.

Moisture content was determined using method 44-19 (AACC, 1999), oven drying at 135°C (Model Labline, Inc, Chicago, IL, U.S.A). Protein was measured using the AACC method for combustion method 46-30 (AACC, 2000) with a CE Elantech (Flash EA 1112, ThermoFinnigan Italia S.p.A., Rodano (MI) Italy). Nitrogen then was converted into percentage protein using a conversion factor of 5.7. Fat content was determined using AOAC method 920.39 (AOAC, 1990) on automated Soxhlet extractor using petroleum ether (CH-9230, Buchi laborotechnik AG, Flawil, Switzerland). For the determination of neutral detergent fiber (NDF), method 30-25 (AOAC) was used. Ash content was measured by method 08-03 (AACC, 1999) using a muffle furnace (Lindberg/Blue 1100°C Box furnace BF 51800 series Ashville, NC), at 525 °C.

Data Analysis

All collected data were analyzed with Microsoft Excel v.2007 and SAS v.9.0 software (SAS Institute, Cary, NC) using Type I error rate (α) of 0.05, by analysis of variance (ANOVA) to find if there were significant differences between treatments. Then, post-hoc LSD tests were used to determine where the differences occurred.

Results and Discussion

The results of the measurements are summarized in the following tables, table 1 shows the ingredients used in production of each bread and the amount of wheat flour substituted with other flours. Tables 2 and 3 show the physical and chemical attributes of the final products, respectively.

Physical attributes

Thickness of Bread

Thickness, in general is related to the gluten content of the flour. In this experiment, the thickness of both center and edges of breads were measured.

The thickness of center results show that the lowest measurement was observed for the bread made with 20% barley, while the highest value was for the bread made with amaranth flour. Figure 4.1 shows cross section pictures of the resulted bread.

A study done by Morita et al (1999) showed that although amaranth flour has been used to improve the quality of wheat bread, but substitution with 10% or more amaranth flour gave lower loaf volume and lower taste score. But wheat bread substituted with 5% of amaranth flour produced an increase in loaf volume; this study concluded that this was due to a disulfide exchange reaction of amaranth proteins with wheat gluten during mixing (Morita et al, 1999).

Significant differences occurred in the thickness of breads made with amaranth, rye flour and that made with DDGS.

The highest value of thickness at edge was for the bread made with rye flour, with the control bread the next highest. The lowest value was for bread made with DDGS. This was because of the attributes of DDGS itself, which can't help in the development of gluten network in the bread as compare to control and rye. There were no significant differences between the thickness of edges in bread made with rye flour and bread made with 100% of wheat flour, but there were significant differences between bread made with DDGS and the other ones. Tsen et al (1983) reported that adding up to 10% DDGS flour to non-flat breads made with white wheat flour didn't change the volume and quality of the bread; however, replacement at 20% greatly reduced the loaf volume (Tsen et al, 1983).

Texture

Texture has direct impact on consumer acceptability, and in addition, it also affects modulation of flavor release and influences appearance. Texture and food structure are tightly linked; any change in the structure can also change the texture, which may eventually lead to changes in consumer acceptance (Zeppa et al, 2007). In this experiment, two different textural attributes were studied, the extensibility and the firmness of the bread.

As for extensibility, the results showed that the highest value was for the bread made with oat, while the lowest value was for amaranth bread. Significant differences were determined between the extensibility of control bread and that of the oat and rye breads, but there were no significant differences between the control bread and those made with DDGS, barley or amaranth.

Table 2 illustrates that for firmness, the highest value was for the bread made with rye flour, while the lowest value was for that made with oat flour. Furthermore there were significant

differences between the control bread and the other breads made with all-purpose flour substituted with alternatives. Also, significant differences were found between firmness of the bread made with oat compared to all other samples.

These changes in the texture can occur due to the different amounts of gluten, which play an important role in the texture of final products. To further illustrate, amaranth had the lowest amount of extensibility because of the absence of gluten in this type of flour. Ayo (2001) concluded that increasing the amount of amaranth flour would lead to a significant decrease of texture score, which was also due to the poor rising of the dough prior to baking and the high amount of fiber. Gujral and Pathak (2002) found that incorporation of barley flour in wheat flour at the level of 20% increased chapathi's extensibility; however, addition of higher levels of barley flour decreased extensibility. In the texture profile of bread, two components play an important role; fiber can absorb water more than other particles and can prevent them from being fully integrated into the starch/gluten matrix and will also lead to a harder texture (Gould et al, 1989). On the other hand, gluten also plays more important role. Better texture was obtained in bread made with a wheat cultivar with better in gluten quality which leads to a higher level of gas during baking, thus causing an increase in the bread volume and porosity (Golmohammadi et al, 2005).

Density

No significant differences were determined between the densities of each of the breads. The gluten matrix in the dough can play an important role in the final volume of the breads and therefore, the density. Esteller and Lannes (2008) concluded that addition of rye flour can increase the distribution of gluten matrix, thus changing gas retention and finally increasing the volume. Another important factor affecting the volume and density is the amount of fiber in the flour. Chen et al (1988) determined that as the fiber content of the flour increases, the loaf

volume decreases and the loaf weight increases. This can be due to the increase in water absorption caused by the strong water-binding ability of the fiber in the flour.

Water Activity

The results show that the highest value for a_w was for the bread made with 20% DDGS and 80% wheat flour; the lowest value was for the bread made with oat flour. No significant differences were identified between the water activity of bread made with DDGS and control bread, barley and rye flours. Saunders (2008) concluded that as the protein content of the flour increases, the water activity increase as well. This can occur because of the hydration of the protein, a process in which protein goes from its dry stage to the solution stage and is affected by the amino acid composition of the protein (Belgacem and Gandini, 2008). The water activity in the bread can also depend on the amount of fiber. As the amount of fiber increases, the flour-water absorption in the bread increases, as well. This also depends on the particle size of the fiber in a significant way. A minimum particle size results in increasing the water binding capacity (Sabanis et al, 2009).

Color

Color is a key quality parameter which affects consumer acceptability. As was previously described, the golden yellow color on Barbari bread comes from the Romal which is brushed on top of bread. Romal is made from baking soda and wheat flour dissolved in warm water, which leads to the formation of dextrin, and finally the golden color. In production of crust color of bread, type of flour and the browning reaction which are non-enzymatic reactions, play important roles. Since bread contains both reducing sugar and amino groups, when it is heated, caramelization and Maillard reaction may take place at the same time. Parlis and Salvadori (2009) determined that in order for browning reactions to take place, temperatures greater than 120˚ C and water activity less than 0.6 are required.

Color also depends on the physiochemical properties of the dough. These properties can be the water content, pH, reducing sugar and amino acid content of the flour which was used in the production of the dough (Sabanis et al, 2009).

As the results for the color determination show, the value of L* was significantly different in bread made partially with rye flour and the control, as well as bread made with oat compared to control. But there wasn't any significant differences in the L* value of breads made with DDGS, amaranth or barley flour. The bread made with rye had the highest value for L* and the control one had the lowest value. This was the result of the type of flour used and also the browning reaction occurred on breads during baking.

As for a* value, the breads made with amaranth, DDGS, and oat were significantly different than the control bread. For the bread made with rye flour and the one made with barley, there were not significantly different a* values from the control bread. The highest value for a* was for bread made with oat, while the lowest was for the control.

The results for b* also showed that all the breads were significantly different compared to the control, with the highest value for DDGS, and the lowest value for the control. This was due to the original color of DDGS which is more yellow in compare to the other flours used in this experiment.

Chemical Attributes

Moisture Content

The results for moisture content (MC) showed that bread made with 20% DDGS had the highest moisture content, while the one made with barley had the lowest value. There were no significant differences between bread made with amaranth and with DDGS or between the control and bread made with barley flour. Barbari bread has the highest moisture content, in

general, compared to other Iranian breads such as Sangak which has low moisture content and can be preserved up to six months (Faridi et al, 1982). In a study done by Sabanis et al (2009), the amount of fiber increased in the bread sample, and the moisture content of both crumb and crust increased. Thus is can be concluded that the amount of fiber can play an important role in binding with the water and increasing the moisture content of final products. Perhaps this is why the bread with DDGS had the highest moisture content.

Protein Content

The results showed that, highest protein content was for the bread made with DDGS flour, while the lowest, for the rye, which was significantly different from the control. The protein content of bread can be influenced by the Maillard reaction, and aggregation which can happen due to the dehydration of the surface because of the high temperature during baking. Also protein content of the final product can be related to the type of flour which is used in baking and the degree of extraction in the flour. The protein content of the bread can be a direct reflection of fermentation in the dough, because this is an important step for protein solubilization (Horszwald et al, 2009).

DDGS is a good source of protein, as results showed its protein content was relatively high compared to all other breads and the control. A similar result was obtained in the study done by Wu et al (1987), where spaghetti was supplemented with CDG; Results showed that supplementation with 10% CDG increased the amount of protein up to 12-14%. Also, incorporation of 20% DDG into muffins showed higher amount of protein in compare to the control (Reddy et al, 1986). One study determined that although amaranth flour itself is high in essential amino acids such as lysine, when it is added to bread as alternative flour, the protein content of the bread made with amaranth flour and wheat will be lower than that of bread made with wheat flour only. This can be caused by some environmental and soil factors (Ayo, 2001).

Ash Content

The highest ash content was for the bread made with amaranth flour, while the lowest value was for the control bread. Amaranth grain has a high nutritional value. The nutritional composition of this grain (such as total protein, amino acid composition, mineral and vitamin content) has been shown to be higher than that of common cereal grains (Sindhuja et al, 2005). There was no significant difference between bread made with amaranth, DDGS or rye flour, but there were significant differences between the control and the other breads. Ash content is directly related to the type of flour used in the production of bread. Research shows that the amounts of elements are related to soil and fertilizer composition. Also, neither total ash nor the content of any of the mineral elements are directly related to the reported degree of refinement of the flour (Czerniejewski et al, 1964). In similar studies, supplementation of wheat flour with 10% DDGS flour can lead to a higher amount of ash in the resulted bread (Tsen et al, 1983).

Fat Content

The fat content results showed that rye, oat and barley were different in fat content, but amaranth and DDGS didn't show any differences. Also, the fat content of bread made with barley was significantly different compare to the breads made with oat and rye flour. The highest value in fat content was for the bread made with rye flour, and the lowest fat value was for the DDGS. However, in a study done on muffins, no change in fat content was found in the muffins with 10% DDG (Reddy et al, 1986).

Fiber Content

As was expected, DDGS had the highest fiber content, while control bread had the lowest value. There were significant differences between the fiber content of the bread made with DDGS and the others. There was no significant difference between the control and the bread made with oat flour. Dietary fiber is non-starchy polysaccharides and lignin. The methods used

to measure the amount of dietary fiber depend on an efficient removal of starch, because if any starch remains, it adds to the dietary fiber value (Johansson et al, 1984). Bakery products are an important source of dietary fiber. Fiber has different effects on the quality of final products. It can affect the loaf volume, increase the crumb firmness, and lead to the change in crumb color (Saiz et al, 2007). Studies show that, in general, fiber changes as a result of baking. This is due to the formation of fiber-like substances which are produced by non-enzymatic browning among peptides, free amino acids, and carbohydrates (Faridi et al, 1982). The same result was obtained by Tsen et al (1983), when addition of DDG to bread resulted in a higher amount of measured fiber compared to the control sample. Also, supplementation of corn distiller's grain into spaghettis resulted in a significantly higher amount of fiber in comparison to the control (Wu et al, 1987).

Conclusions

About 9,000 years ago, people in what is now Iran and Syria began farming wheat and learned how to make grain into bread. The consumption of bread and other cereal-based products then continued until today cereals are the most consumed food staples around the world. Alternative grains such as amaranth, DDGS, and rye can be cultivated and used in bread production. In this study, five different flours were substituted into wheat flour to understand the changes in physical and chemical attributes of the final products. The results demonstrated that the bread made with 20% rye flour and 80% all-purpose flour had the highest levels of protein and fat content, it also caused the increase in the value of L*, firmness and edge thickness. DDGS caused the bread to be high in the amount of fiber and moisture content. Also, the bread made with DDGS had the highest b* value. All in all, using different sources of flours in the production of traditional breads can lead to a better product with a higher nutrient content. However, the original taste, aroma and texture of the bread must also be considered. Overall, flour which is a combination of flours such as wheat helps to maintain the gluten content, rye to

have better protein content, and DDGS to have higher amount of fiber. Balancing all these factors will help produce healthier bread while maintaining consumer acceptability.

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Table 1. Ingredients used in the production of each experimental bread.

Bread	Wheat Flour (g)	Other Flour (g)	Water (g)	Sugar (g)	Salt (g)	Active dry yeast (g)	Total (g)
Wheat[1] (Control)	800 (100%)	0	689.76	4.2	4.2	7	1505.16
Amaranth[2]	704 (80%)	176 (20%)	689.76	4.2	4.2	7	1585.16
Barley[3]	704 (80%)	176 (20%)	689.76	4.2	4.2	7	1585.16
DDGS[4]	704 (80%)	176 (20%)	689.76	4.2	4.2	7	1585.16
Oat[5]	704 (80%)	176 (20%)	689.76	4.2	4.2	7	1585.16
Rye[6]	704 (80%)	176 (20%)	689.76	4.2	4.2	7	1585.16

1. From market source, Hy-Vee bleached all-purpose flour.
2. From market source, Bob's Red Mill.
3. From market source, Bob's Red Mill.
4. From Wentworth, South Dakota.
5. From market source, Bob's Red Mill.
6. From market source, Bob's Red Mill.

Table 2. Physical properties of resulting breads[1].

	Flour Substitution					
Properties	**100% Wheat**	**20% Amaranth**	**20% Barley**	**20% DDGS**	**20% Oat**	**20% Rye**
Thickness in Center (mm)	16.36 b (0.23)	18.57 a (0.64)	12.7 d (0.80)	16.11 b (0.75)	14.60 c (0.61)	17.75 a (0.08)
Thickness of Edge (mm)	16.41 ab (0.17)	14.06 c (0.0)	13.90 c (0.95)	10.35 d (1.98)	15.11 bc (1.48)	17.70 a (0.02)
Extensibility[2]	31.10 ab (3.42)	8.87 c (1.09)	28.59 ab (13.04)	28.17 ab (6.97)	43.76 a (7.71)	25.71 bc (2.99)
Firmness[2]	31.25 c (2.28)	45.27 b (5.24)	40.98 b (28.59)	41.50 b (3.08)	22.91 d (3.45)	56.51 a (2.82)
Density (g/cm^3)	0.04 a (0.00)	0.05 a (0.00)	0.05 a (0.00)	0.05 a (0.01)	0.04 a (0.00)	0.04 a (0.00)
a_w (-)	0.89 ab (0.0)	0.87 b (0.01)	0.89 ab (0.00)	0.92 a (0.01)	0.75 c (0.05)	0.91 ab (0.00)
L* (-)	47.27 c (1.07)	56.31 ab (0.72)	55.78 ab (5.36)	56.54 ab (3.96)	54.78 b (2.55)	62.18 a (8.26)
a* (-)	3.33 c (1.85)	8.85 a (1.22)	5.76 b (2.33)	8.41 a (0.86)	9.49 a (0.50)	5.38 bc (0.61)
b* (-)	13.06 b (2.25)	19.27 a (1.04)	19.03 a (0.90)	20.16 a (2.33)	19.32 a (0.75)	19.35 a (4.16)

[1]Means followed by similar letters for a given dependent variable are not significantly different at $P<0.05$, LSD. Values in parentheses are standard deviation. a_w is water activity, L*, a* and b* are color parameters. [2]The force was measured over time for firmness and over distance for extensibility.

Table 3. Chemical properties of resulting Breads[1].

	Flour Substitution					
Properties	**100% Wheat**	**20% Amaranth**	**20% Barley**	**20% DDGS**	**20% Oat**	**20% Rye**
MC (% db)	0.33 d (0.05)	0.41 ab (0.03)	0.32 d (0.0)	0.44 a (0.03)	0.39 cb (0.02)	0.35 ad (0.0)
Protein (% db)	11.62 a (0.27)	11.17 b (0.15)	11.16 b (0.06)	12.55 c (0.10)	11.53 a (0.07)	11.12 b (0.41)
Fat (% db)	0.52 c (0.07)	0.54 c (0.06)	0.74 b (0.10)	0.46 c (0.05)	1.02 a (0.17)	1.09 a (0.11)
Fiber (% db)	0.91 d (0.19)	1.46 bc (0.34)	1.70 b (0.45)	3.57 a (0.38)	0.99 cd (0.35)	0.91 d (0.16)
Ash (% db)	1.22 c (0.39)	2.29 a (0.20)	1.74 b (0.30)	2.28 a (0.09)	1.66 b (0.01)	2.08 a (0.04)

[1]Means followed by similar letters for a given dependent variable are not significantly different at $P<0.05$, LSD. Values in parentheses are standard deviation. MC is moisture content.

Control

20% Amaranth

20% Barley

20% DDGS

20% Oat

20% Rye

Figure 1. Cross sections of resulting breads.