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IMPACT OF WHOLE OAT FLOUR ON DOUGH PROPERTIES AND QUALITY OF FRESH AND STORED PART-BAKED BREAD

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ABSTRACT

Whole oat flour (WOF) is known for high β-glucan and antioxidant content. The main purpose of this study was to replace white wheat flour with WOF at different levels of 0, 10, 20 and 30% in production of bread using part-baking technology. Dough properties (using farinograph) and physical characteristics of full-baked breads stored for 1 h and 72 h at 20C were studied. Increases in water absorption, dough development time and dough softening, while a reduction in dough stability time with addition of WOF were obsereved. The specific volume of fresh breads containing WOF reduced further after storage. The crumb hardness, chewiness, elasticity and cohesiveness reduced and crust color became lighter with addition of WOF and storage time. The effects of bread storage were more obvious for samples containing WOF. The bread containing 10% WOF received the highest sensory scores and had similar sensory characteristics to the control.

PRACTICAL APPLICATIONS

Costumer demand for breads with health benefits and superior sensory properties is increasing rapidly. This study showed the effects of substitution white wheat flour with whole oat flour (WOF) which is well-known for its health benefits owing to considerable amount of β-glucan and antioxidants. The results of this study are applicable in bakery industry and specifically in production of bread using part-baked technology and can be useful for the producers of functional and healthy products. Some of the effects of flour replacement with 0, 10, 20 and 30% WOF were undesirable and had negative effects on sensory attibutes of the full-baked breads. The adverse effects of storage (72 h at ambient temparature) were more obvious for breads containing WOF. However, inclusion of 10% WOF resulted in a bread with similar sensory properties to the control and hence it can be used succesfully for production of a healthier part-baked bread.

INTRODUCTION

Part-baking, par-baking or baked-off technology is one of the common methods of bread making. In this method, the dough is prepared in the same manner as conventional dough, then it is baked in an oven until a fully cooked crumb is formed (Almeida *et al.* 2013). The baking is interrupted just before development of any crust color. Therefore, part-baked breads have very thin and pale crust. The product can be either sold as fresh or frozen to increase the shelf-life of the product. Before consumption, the product requires the final step of baking called re-baking or full-baking which can be completed before consumption in restaurants, takeaways, and schools or at home. Full-baking takes about 5–10% of the time of bread making if the process starts from the beginning. Maillard and caramelization reactions take place at this stage leading to a golden crust color and bread aroma. The heating also increases bread freshness by enhancing bread aroma and crumb softness. Therefore, the technology of part-baking offers bread of higher quality and longer shelf-life compared to the classical method (Farahnaky and Majzoobi 2008; Altamirano-Fortoul and Rosell 2011; Majzoobi *et al.* 2011).

Regarding the high consumption of part-baked breads, they can be enriched with different nutrients and dietary fiber to improve the nutritional value. This will not only have positive effects on human health but also attract more customers.

With this aim, part-baked bread has been enriched with dietary fiber from different sources including pectin, inulin, oat fiber (Rosell and Santos 2010; Kopeć *et al.* 2011; Borczak *et al.* 2012; Škara *et al.* 2013), resistant starch and locust bean gum (Almeida *et al.* 2013), wheat bran (Almeida *et al.* 2013; Ronda *et al.* 2014) and whole grain wheat flour (Almeida and Chang 2013; Bae *et al.* 2014). These studies have revealed that various dietary fibers have different impact on physicochemical properties of the part-baked bread depending on their chemical characteristics (e.g., molecular structure and water solubility) and concentration. Some fibers can enhance the shelf-life and overall quality of the bread while others may suppress the volume and mouth-feel of the product.

Whole oat flour (WOF) is a well-known source of dietary fiber and other nutrients such as antioxidants, minerals and vitamins. The most important dietary fiber of the oat grains is β-glucan (2.3–8.5%) which is a water-soluble fiber and is known for numerous health benefits. It is proven that β-glucan can reduce the risk of coronary heart disease, cholesterol and type 2 diabetes (Brown *et al.* 1999). The required dose for such effects is 0.75 g β-glucan per serving (FDA, 1997). Mandala *et al.* (2009) added WOF in bread formulation to determine the frozen storage stability of part-baked bread. Polaki *et al.* (2010) compared the effects of dietary fibers as opposed to hydrocolloids on frozen storage stability of part-baked frozen bread. However, in these studies the optimum level of WOF was not determined.

The main purpose of this study was to improve the nutrition quality of part-baked bread by replacing white wheat flour with different levels of WOF. The effects of flour replacement on dough and bread characteristics (fresh and stored for 72 h) were determined and the suitable level of WOF resulted in an acceptable part-baked bread was reported.

MATERIAL AND METHODS

Materials

WOF with an average particle size of 475 μm was purchased from store of Isfahan University of Technology, Isfahan, Iran. White wheat flour with extraction rate of 73% and an average particle size of 250 μm was supplied by Sepidan milling factory, Zarghan, Fars, Iran. Active dry yeast (*Saccharomyces cerevisiae*) with commercial name "Dez Mayeh," salt (NaCl) and bread improver with commercial name "Sahar 01" (containing malt extract, guar gum, ascorbic acid, corn starch and tartaric acid) were purchased from local market. Gluten powder was obtained from Fars-Glucosin, wheat starch producing company, Marvdasht, Iran. Other chemicals were purchased from Merck, Schuchardt OHG, Hohenbrunn, Germany.

Methods

Chemical Analysis. Moisture content, ash, fat, crude fiber, protein and wet gluten content of wheat flour and WOF were determined according to the Approved Methods of the AACC (2000), methods 44-15A, 08-01, 30-25, 32-07, 46-12 and 38-12, respectively.

Farinograph Test. Wheat flour was replaced with 0, 10, 20 and 30% (w/w) WOF and mixed well. The water absorption and mixing behavior of the samples were determined using a Brabender farinograph (Model FE022N, Germany) according to the Approved method of AACC (2000) method 54-21, using a 50 g dry weight of the sample (14%, moisture basis). The farinograph parameters including water absorption, dough development time, dough stability time and dough softening 12 min after peak were obtained from the farinograph curves.

Preparation of Part-Baked Bread. Wheat flour was replaced with 0, 10, 20 and 30% (w/w) WOF and mixed with bakery yeast (2%, w/w), NaCl (1.5%, w/w), bread improver (1.5%, w/w) and gluten powder (3%, w/w). The amount of water obtained from the farinograph test was added to each recipe.

The ingredients were mixed in a spiral dough mixer (Iypto, EB12, Germany) at 140 rpm at 25C for 20 min. Then the dough was proofed in a proofing cabinet (Mashhad baking Industries, Mashhad, Iran) at relative humidity of 80% and 32C for 20 min. The dough was hand divided into pieces (100 g), rounded and returned to the proofing cabinet again and kept for 35 min. The most suitable baking time and oven temperature required for part-baking was determined by trial and error to obtain the part-baked breads with proper crumb but no crust color. Therefore, dough pieces were part-baked in an electrical baking oven (Nan-e-Razavi Company, Iran) set at 200C for 7 min at a relative humidity of 90%. The part-baked breads (in the form of buns) were then left at ambient temperature for 1 h to cool down and then packed and sealed in polyethylene bags and stored in an incubator set at 20C for 24 h before full-baking.

Full-Baking of the Part-Baked Breads. The samples were full-baked in an electrical baking oven at 230C until a golden crust and bread flavor were formed (took about 8.5 min for all samples). The fully baked samples were left for 1 h at ambient temperature to cool down. The samples at this stage are called "fresh" samples and used for physical tests. Some of the samples were packed and sealed in polyethylene bags and stored at 20C for 72 h for to determine the effect of storage on physical properties of the breads. These samples are called "stored" samples.

Specific Volume of the Breads. To measure specific volume of the breads, each sample was first weighed and then the volume was determined by rapeseed displacement method according to the AACC (2000) method 10-05.01. Then the specific volume was measured by dividing volume into weight.

Bread Texture. A texture Analyzer (TA-XT2, Stable Micro Systems Ltd., Surrey, UK) was used to determine the textural properties of bread crumb after full-baking using Texture Profile Analysis (TPA) test. The experiment was performed with a compression test. A piece of bread crumb (1.0 × 1.0 × 0.5 cm) was cut and removed from the centre of each sample using a sharp knife and used for the test. The TPA was conducted at pretest speed of 5 mm/s, test speed of 0.25 mm/s and strain deformation of 25% by an aluminum cylindrical probe with diameter of 75 mm. From each force-time curve, the maximum peak force during the first compression cycle was determined as bread hardness. Cohesiveness was calculated as the ratio of the positive force area during the second compression cycle to the area during the first compression. Elasticity (springiness) was obtained from the ratio of the time elapsed during positive force at the second compression, to that of the first compression. Chewiness was calculated as the product of hardness×cohesiveness×springiness (Steff 1996).

Color Evaluation. The color parameters of bread crust including lightness (*L*-value), redness (*a*-value) and yellowness (*b*-value) were determined using the method illustrated by Afshari-Jouybari and Farahnaky (2011). Samples were placed in a wooden box (50 × 50 × 60 cm) with interior white color with a fixed distance (50 cm) from the above lid. A white light lamp was fixed inside the box on the top of the sample. A digital camera (Canon, Model IXUS 230 HS, 14.0 Megapixels, Japan) was placed at 25 cm distance from the sample making an angel of 45° between the lens and the sample. The resolution, contrast and lightness of all images were set on 300 dots per inch (dpi), 62 (%) and 62 (%), respectively. Pictures from at least five different points of each sample, were saved in JPEG format and analyzed using "Lab mode" of Adobe Photoshop 11 to obtain color parameters.

Preliminary Sensory Evaluation. The full-baked samples were coded with random three-digit numbers and presented to a panel of 12 in-house panelists. The test was conducted in a sensory booth where a day light illumination was used for color evaluation and a red light was applied for evaluation of other sensory characteristics. Only fresh breads were used for sensory analysis. The whole breads were presented on clear plastic plate to the panelists and they were asked to score them using a 5-point hedonic test from 0–1 (strongly disliked), 1–2 (moderately disliked), 2–3 (neither disliked nor liked), 3–4 (moderately liked) and 4–5 (strongly liked).

Statistical Analysis. The variables of this study were WOF levels (0, 10, 20 and 30%) and storage time (1 h and 72 h) after full-baking. The experiments were performed in a completely randomized design. All experiments were conducted in triplicate and the average and standard deviations were calculated. Analysis of variance (ANOVA) was performed and the results were separated using the Multiple Ranges Duncan's test ($P < 0.05$) using statistical software of Statistical Package for the Social Sciences (SPSS), Version 16; (SPSS, Inc. New Jersey).

RESULTS AND DISCUSSION

Chemical Composition of White Wheat Flour and WOF

The results showed that the WOF had significantly ($P < 0.05$) higher protein (12.50 versus 10.30%), fat (8.01 versus 1.51%), crude fiber (4.13 versus 1.89%) and ash (3.90 versus 1.20%) content compared to the white wheat flour. Therefore, substitution of white wheat flour with WOF can enhance the nutrition value of the bread. The chemical composition of the samples are close to the values reported previously (Salehifar and Shahedi 2007; Wang *et al.* 2007; Koletta *et al.* 2014).

Farinograph Properties of the Flours

Changes in the farinograph properties of the flour mixture are presented in Table 1. Replacement of wheat flour with WOF, reduces the gluten content of the mixture, while increases the non-gluten proteins, fiber, fat and ash content. The proteins and fibers from WOF contain a large number of hydroxyl groups and hence have positive effects on water absorption (Rosell *et al.* 2001). However, reduction of the gluten content and the increase in the fat content can have negative effect on dough hydration. The outcome of these

TABLE 1. FARINOGRAPH PROPERTIES OF WHEAT FLOUR MIXTURE CONTAINING DIFFERENT LEVELS OF WHOLE OAT FLOUR (WOF)

WOF (%)	Water absorption (%)	Dough development (min)	Dough stability (min)	Softening (BU)
0	66.03 ± 0.25^c	1.4 ± 0.1^b	3.3 ± 0.3^a	106.7 ± 11.5^d
10	66.26 ± 0.25^c	1.5 ± 0.1^b	2.6 ± 0.4^b	141.6 ± 2.8^c
20	67.13 ± 0.32^b	2.1 ± 0.1^a	1.7 ± 0.2^c	158.3 ± 2.8^b
30	68.30 ± 0.62^a	2.2 ± 0.1^a	1.3 ± 0.1^d	239.0 ± 1.6^a

Averages with different superscripts in each column are significantly different ($P < 0.05$).

changes was an increase in water absorption from 66.03% to 68.30% which is in agreement with Rosell *et al.* (2010), Collar *et al.* (2007) and Miś *et al.* (2012).

With inclusion of different levels of WOF, dough development time increased from 1.4 min to 2.2 min indicating that a longer time was required for gluten hydration and network formation. The fiber and proteins of the WOF have high affinity for water and compete with gluten for the available water. The interactions between gluten proteins and WOF components can postpone gluten network development. The increase in fat content of the dough with addition of WOF can delay water uptake of the flour components and increase dough development time.

Increment of the WOF concentration, reduced dough mixing stability from 3.3 min to 1.3 min and increased dough softening from 106.7 BU to 239.0 BU. These changes indicate that the dough became softer rapidly and reached to a lower consistency during mixing. The dilution of gluten content and disruption of gluten network as a result of interactions between gluten and WOF components can reduce dough stability during mixing. The higher fat content of the dough containing WOF can also soften the dough as it acts as a lubricant. Similar changes in the farinograph parameters of the dough have been reported with inclusion of WOF by Salehifar and Shahedi (2007), Peressini and Sensidoni (2009), Miś *et al.* (2012) and Koletta *et al.* (2014).

Specific Volume of the Bread

Table Specific volume is an indication of the internal bread crumb structure. The higher specific volume is related to more porous crumb and softer texture. As Fig. 1 shows, the specific volume of the samples declined significantly ($P < 0.05$) with increasing the WOF and storage for 72 h. The specific value of the fresh samples was in the range of 3.75 to 2.96 cm^3/g while the specific volume of the stored samples was between 3.70 to 2.80 cm^3/g. This could be a result of the lower gas retention capacity of the substituted flour dough because of the dilution of the gluten content and interruption of gluten-starch matrix and subsequent loss of gas during baking (Rubel *et al.* 2015). Determination of the pasting properties has shown higher gelatinization temperature and lower peak viscosity for the mixture of wheat flour and WOF (Raess Jalali 2013). Therefore, it is possible that some water and CO_2 (responsible for dough expansion and bread volume) were evaporated before starch gelatinization and crumb formation resulting in lower bread volume. The dough with lower viscosity can be expanded rapidly but it may easily collapse after expansion leading to a lower bread volume. Reduced bread volume is an important consequence of bread staling over storage time which occurs mainly due to the shrinkage of internal structure of the bread (Gray and Bemiller 2003). Similar results were found when whole grain wheat flour and WOF were added to part-baked bread (Mandala *et al.* 2009; Bae *et al.* 2014).

Bread Texture

Textural properties of the samples are given in Table 2. Hardness corresponds to the force necessary to compress a food between molars in the first bite. The results showed that the bread hardness increased with addition of WOF and storage time. Chewiness represents the energy required to masticate a solid food to a state ready for swallowing. Addition of WOF and storage time increased the chewiness of the sample. The increased crumb hardness is attributed to the dilution of gluten network which impairs gas retention resulting in a lower bread volume (see Fig. 1) and firmer texture (Flander *et al.* 2011). With increasing bread hardness, the energy required for chewing the sample increased. Bread staling is the main reason for harder crumb texture during the storage. Starch retrogradation along with the formation of some interactions between flour components (i.e., starch,

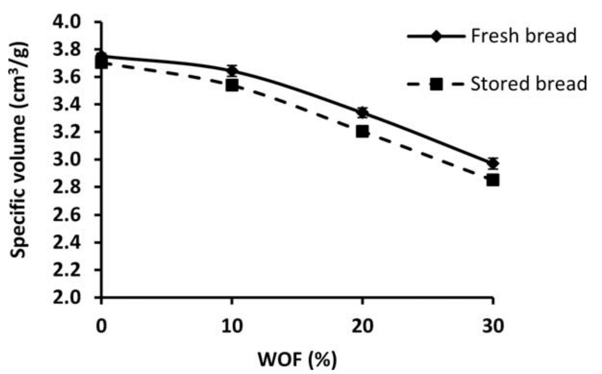

FIG. 1. EFFECT OF DIFFERENT LEVELS OF WHOLE OAT FLOUR (WOF) ON SPECIFIC VOLUME OF FRESH BREAD (1 H AT 20C AFTER FULL-BAKING) AND STORED BREAD (STORED FOR 72 H AT 20C AFTER FULL-BAKING). VALUES ARE AVERAGE ± STANDARD DEVIATION

TABLE 2. TEXTURAL PROPERTIES OF FULL-BAKED BREAD CRUMB CONTAINING DIFFERENT LEVELS OF WHOLE OAT FLOUR (WOF)

	Hardness (g)		Cohesiveness		Elasticity		Chewiness (g)	
WOF (%)	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored
0	12.33 ± 1.53^{dB}	17.33 ± 2.50^{dA}	0.85 ± 0.01^{aA}	0.86 ± 0.03^{aA}	0.96 ± 0.02^{aA}	0.97 ± 0.02^{aA}	40.25 ± 2.09^{dB}	66.86 ± 12.72^{dA}
10	21.00 ± 2.64^{cB}	26.00 ± 3.60^{cA}	0.78 ± 0.01^{bA}	0.73 ± 0.03^{bB}	0.89 ± 0.04^{bA}	0.87 ± 0.04^{bB}	45.61 ± 3.62^{cB}	75.49 ± 8.85^{cA}
20	31.00 ± 3.00^{bB}	43.70 ± 3.78^{bA}	0.75 ± 0.01^{cA}	0.72 ± 0.02^{cB}	0.85 ± 0.02^{bA}	0.82 ± 0.00^{cB}	52.28 ± 3.43^{bB}	120.50 ± 7.54^{bA}
30	52.67 ± 4.51^{aB}	88.33 ± 1.52^{aA}	0.72 ± 0.01^{dA}	0.68 ± 0.02^{dB}	0.78 ± 0.05^{cA}	0.74 ± 0.04^{dB}	94.31 ± 8.37^{aB}	191.63 ± 14.83^{aA}

Values are the average of triplicate ± standard deviation. The experiment was performed after 1 h (fresh) and 72 h storage at 20C (stored) after full-baking. Different small letters in each column show significant difference between samples containing different level of WOF ($P < 0.05$). Different capital letters show significant difference ($P < 0.05$) between fresh and stored samples.

TABLE 3. COLOR PARAMETERS OF FULL-BAKED BREAD CRUST CONTAINING DIFFERENT LEVELS OF WHOLE OAT FLOUR

	Whole oat flour (%)							
	0		10		20		30	
Color parameters	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored
L-value	51.14^{c} ± 0.57	48.73^{d} ± 0.33	51.10^{c} ± 0.41	45.30^{f} ± 0.57	52.10^{bc} ± 0.53	44.96^{f} ± 0.43	53.70^{a} ± 0.57	46.22^{e} ± 0.45
a-value	18.77^{c} ± 0.41	20.81^{b} ± 0.57	18.66^{c} ± 0.43	22.10^{a} ± 0.57	13.51^{f} ± 0.57	18.51^{d} ± 0.43	11.81^{g} ± 0.41	17.25^{e} ± 0.43
b-value	51.47^{a} ± 0.33	40.14^{b} ± 0.33	51.40^{a} ± 0.45	38.59^{c} ± 0.57	36.59^{d} ± 0.41	36.21^{d} ± 0.57	34.88^{e} ± 0.45	34.43^{e} ± 0.41

Values are the average of triplicate. Fresh samples were left at 20C for 1 h while stored samples were incubated for 72 h at 20C after full-baking. Different superscripts in each row show significant difference ($P < 0.05$).

protein and fiber) and water migration from crumb to crust increase crumb hardness during bread staling (Gray and Bemiller 2003). These changes were enhanced by increasing wheat flour substitution level.

Cohesiveness is related to the strength of the internal bonds making up the body of the food. Addition of WOF and storage time reduced cohesiveness which can be related to the dilution of gluten network and formation of a course crumb structure. In addition, the homogeneity of the dough system is disrupted by addition of WOF resulting in less cohesive crumb. Elasticity is related to the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite. It represents the rate at which a deformed material goes back to its un-deformed condition after deforming force is removed. With increasing the flour substitution level and storage time, elasticity of the samples reduced significantly ($P < 0.05$). Similar textural changes have been reported for part-baked breads with addition of WOF and some soluble fibers (Mandala *et al.* 2009; Rosell and Santos 2010; Rubel *et al.* 2015).

Crust Color

Table 3 shows the color parameters of bread crust. The crust lightness (*L*-value) increased while redness (*b*-value) and yellowness (*a*-value) reduced with addition of WOF. This may indicate that the crust became whiter as the WOF increased (Fig. 2). It is possible that the components of WOF, including fibers, proteins and lipid make physical obstacle for Maillard reaction and caramelization, the major color producing reactions during baking, resulting in lighter crust color. These components may also affect the optimum condition required for these reactions including water activity and pH which requires further investigations. Storage of the full-baked breads for 72 h reduced crust lightness while

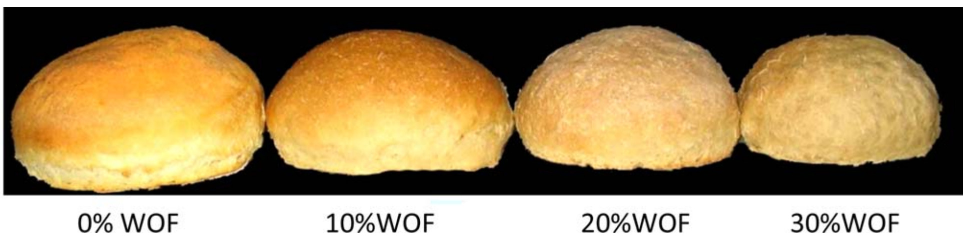

FIG. 2. THE CRUST OF THE FRESH FULL-BAKED BREADS CONTAINING DIFFERENT LEVELS OF WHOLE OAT FLOUR (WOF).
THE HEIGHT AND WIDTH OF THE 0–30% WOF BREADS WERE 4.55 × 8.94 CM, 3.98 × 8.84 CM, 2.75 × 8.60 CM AND 1/91 × 8.30 CM, RESPECTIVELY, (MEASURED BY A CALIBRATED VERNIER CALIPER).

TABLE 4. SENSORY EVALUATION OF THE FULL-BAKED FRESH BREADS CONTAINING DIFFERENT LEVELS OF WHOLE OAT FLOUR (WOF)

WOF (%)	Color	Texture	Taste	Overall acceptability
0	4.83 ± 0.39^{a}	4.58 ± 0.51^{a}	5.00 ± 0.01^{a}	4.90 ± 0.27^{a}
10	4.25 ± 0.45^{a}	4.08 ± 0.67^{a}	4.50 ± 0.52^{ab}	4.33 ± 0.40^{a}
20	3.83 ± 0.72^{b}	3.41 ± 0.97^{b}	3.58 ± 0.70^{b}	3.75 ± 0.62^{ab}
30	3.83 ± 0.58^{b}	3.08 ± 0.99^{b}	3.50 ± 0.67^{b}	3.50 ± 0.52^{b}

Values are the average of triplicate ± standard deviation. Different superscripts in each column show significant difference ($P < 0.05$).

increased the redness and yellowness. Structural changes of the crust due to bread staling and water migration from crumb to crust can affect light reflection from the crust and increase crust dullness (Gray and Bemiller 2003).

Preliminary Sensory Evaluation Results

The results of sensory evaluation of the full-baked fresh breads are given in Table 4. The control received a color score of 4.83 that reduced significantly ($P < 0.05$) when more than 10% WOF was added. As shown in Fig. 3, the crust color became paler with addition of WOF which made the samples less desirable. The texture of the control and the sample containing 10% WOF received the highest scores (4.58 and 4.08) while the values reduced significantly with further addition of WOF. This can be due the increase in crumb hardness which made the sample less chewable and reversible which are in agreement with the textural analysis results (see Table 2). The panelists could recognize a bitter taste with increasing the level of WOF, therefore the samples containing 20 and 30% WOF had significantly lower scores compared with the control and 10% WOF. The increased

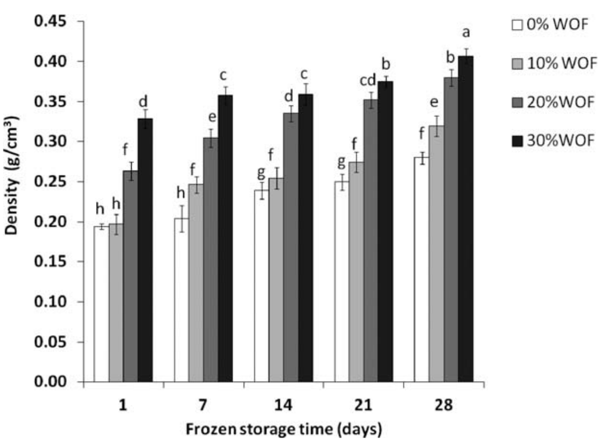

FIG. 3. DENSITY (g/cm^3) OF THE RE-BAKED BREADS OBTAINED FROM PART-BAKED BREADS CONTAINING DIFFERENT LEVELS OF WHOLE OAT FLOUR (WOF) DURING FROZEN STORAGE. DIFFERENT LETTERS ON THE BARS SHOW SIGNIFICANT DIFFERENCE ($P < 0.05$).

bitterness can be related to composition of the WOF and possible rancid taste due to the lipid oxidation or protein degradation during bread processing which needs further investigations. These changes affected overall acceptability of the samples and resulted in lower scores for the samples containing 20 and 30% WOF.

CONCLUSION

This study provides basic information for production of healthier bread as requested by the consumers using the part-baking technology. Increasing the flour substitution level affected dough water hydration, rheological and pasting properties. These changes could have some effects on bread making performance and the quality of the final product. Reduced specific volume and unpleasant taste, increased bread hardness, color changes and higher rate of staling for 72 h were the undesirable effects of WOF inclusion. Although these changes affected sensory attributes of the samples, the sample containing 10% WOF received similar scores to that of the control and can be suggested as appropriate bread which can be produced successfully using part-baked technology. Increasing the WOF level reduced the sensory scores, however, the scores given to 20 and 30% WOF samples were also in the acceptable range (3.50–3.75). Further studies are required to improve the quality of the WOF part-baked bread particularly those containing higher substitution levels.

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