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Oat–buckwheat breads – technological quality, staling and sensory properties

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Abstract

The technological and sensory properties and the staling of breads made from oat flour (OF) and buckwheat flour (BF) were analysed. Significant differences in protein and ash content were found in the experimental breads due to significant differences in the composition of the BF and OF used. As the proportion of BF in the recipe increased, a deterioration in the technological properties of the dough and bread as well as an increase in the crumb hardness were observed. The presence of OF in the recipe increased the bread volume, significantly enhanced the lightness of the crust and crumb and improved the overall sensory quality. The OF used in the recipe decreased the starch retrogradation enthalpy value, which is strongly related to a delay in bread staling. The proposed bakery products can be attractive to consumers who are looking for new food products.

Keywords

Bread • buckwheat • differential scanning calorimetry • oats • sensory analysis • staling

Introduction

Buckwheat is classified as a member of the knotweed family (Polygonaceae); however, from the viewpoint of commodity science, buckwheat seeds are classified as cereals, although the plant itself is classified as pseudocereals (Pseudocerealia). The most popular cultivable species include common buckwheat (*Fagopyrum sagittatum* = *Fagopyrum esculentum*) and Tartary buckwheat (*Fagopyrum tataricum*) (Campbell, 1997). Today, buckwheat is grown in the countries of Asia, Central Europe and South Africa as well as in Canada, the United States and Brazil (Wijngaard & Arendt, 2006).

Oats (*Avena*) belong to the grass family (Gramineae), and the genus includes six species, five of which are distinguishable as arable crops: unilateral oats (*Avena orientalis*); lopsided, bristle or black oats (*Avena strigosa*); short oats (*Avena brevis*); naked or hull-less oats (*Avena nuda*) and common oats (*Avena sativa*), which are the most widespread. The common wild oat (*Avena fatua*) is considered to be a cereal weed (Fu, 2018). Approximately 70% of the world's supply of grain oats, seed and industrial-grade oats comes from the 27 countries of the European Union (EU), Russia, Canada and the United States (Strychar, 2011).

Buckwheat and oats have become the objects of many scientific studies that are aimed at confirming their nutritional properties and demonstrating health values (Wijngaard & Arendt, 2006; Sterna *et al*., 2016). Due to the increase in available information, both buckwheat and oats have found a wide variety of applications in the dietetic, medical, pharmaceutical, cosmetic and chemical industries (Varma *et al*., 2019). The dietary value of buckwheat grain results from the high biological value of its proteins, trace elements, dietary fibre and several natural antioxidants, including tocopherols, phenolic acids and flavonoids (Wijngaard & Arendt, 2006). The nutritional value of oats results from the rich protein content of high biological value, a high proportion

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of unsaturated fatty acids and a high dietary fibre content, both soluble and insoluble (Sayar & White, 2011). The soluble oat fibre β-glucan deserves special attention due to its effect of lowering blood cholesterol in animals and humans (Befall & Hallfrisch, 2011). The U.S. Food and Drug Administration (Federal Register, 2006) and the EU European Food Safety Authority (EU EFSA, 2010) have recommended a daily intake of soluble fibre (β-glucan) of at least 3 g/d.

Globally, bread is the most common dietary component. Hiller *et al*. (2011) presented the significance of different types of bread, wheat and rye in the preventive nutritional intervention of colorectal cancer. The enrichment of bread with bioactive compounds or compounds with a documented impact on human health can be used as a simple and effective way to improve consumer health (Lim *et al*., 2011; Gawlik-Dziki *et al*., 2013; Szawara-Nowak *et al*., 2016).

As presented in the reviews by Haros and Sanz-Penella (2017) and Webster (2011), both buckwheat flour (BF) and oat flour (OF) already have applications in bakery products, particularly as components of wheat bread, but they could also be used in gluten-free products (Wronkowska *et al*., 2013; Duta & Culetu, 2015). This study examined whether a combination of the two flours, both with proven nutritional properties, could produce breads that are technologically as well as sensorially attractive.

This study aimed to evaluate the influence of various proportions of OF and BF on the technological properties, staling and sensory properties of model bakery products.

Materials and methods

Materials

Commercially available BF (*F. esculentum* Moench) and OF (*A. sativa* L.) were purchased from the local industry (Melvit S.A., Kruki, Poland). The contents of carbohydrate, proteins, ash and fat of BF and OF, according to the producer declaration, were: 65.2 and 60.4%; 19.2 and 15.4%; 3.2 and 2.1% and 0.7 and 7.1%, respectively, on a dry matter (DM) basis. The proximate composition of the experimental breads was determined by the Association of Official Agricultural Chemists (AOAC, 2005) methods: proteins (method 950.36), the total carbohydrate (method 996.11) and ash content (method 930.22).

Bread-making process

The bread dough formula consisted of both flours in different proportions: 600 g of OF (O); 600 g of BF (B); 480 g of OF and 120 g of BF (OB); 480 g of BF and 120 g of OF (BO) or 300 g each of OF and BF (OB50%). Additionally, 60 g of compressed yeast (*Saccharomyces cerevisiae*, Lesaffre SA Poland, Wołczyn, Poland) and 8 g of sodium salt were used. Based on the water absorption properties of the flour as determined with a farinograph, the quantity of water used for the dough preparation was as follows: 120 g/100 g of flour for the O, B and OB50% formulas and 104 g/100 g of flour for the OB and BO formulas. A GM-2 mixer (ZBPP, Bydgoszcz, Poland) was used to mix the ingredients for 3 min. The dough was fermented at 37°C and 80% relative humidity for 60 min with a puncture after 30 min. The dough was then divided into 250 g portions, proofed up to optimum development (for approximately 30 min at 37°C and 80% relative humidity) and baked at 220°C for 50 min. An electric oven (model DC-21; Sveba Dahlen AB, Fristad, Sweden) with an incorporated proofing chamber was used for the baking test.

Technological characteristics of bread

The yield of the dough or bread was determined by the amount of dough or bread obtained per 100 parts (by weight) of flour. The baking loss was analysed based on bread weight (hot, after baking) and the weight of the dough used, and it was expressed as a percentage of the weight of the dough before baking. The loaves were weighed 1 h after removal from the oven. A rapeseed displacement method was used to determine the loaf volume (AACC, 1995).

A TA.HD*plus* texture analyser using TPA Exponent Software (Stable Micro Systems Ltd., Godalming, UK) and equipped with a 30 kg load cell was used to determine the texture profiles (texture profile analysis [TPA] tests) of fresh bread and bread after storage for 24 h in polyethylene bags at room temperature. Bread slices (25 mm thickness) taken from the middle of the bread loaf underwent a double compression cycle of up to 40% deformation of its original height (P/35 probe). The selected settings were as follows: 2.0 mm/s for pre-test/test/post-test speed, 5 s of relaxation time, 10 g of trigger force and trigger mode on auto. The bread was compressed twice to give a two-bite texture profile curve, and hardness parameters were calculated by the software of the texturometer.

The colour of the flour, bread crumb and crust were analysed using ColorFlex spectrophotometer (HunterLab, Reston, VA, USA). The results were expressed with reference to the CIELAB system illuminant D65 using a visual angle of 10°. The measurements were performed through a 3 cm diameter diaphragm containing an optical glass. The parameters determined were: L^* ($L^* = 0$ [black] and $L^* = 100$ [white]), a^* ($-a^*$ = greenness and $+a^*$ = redness) and b^* ($-b^*$ = blueness and $+b^*$ = yellowness).

Differential scanning calorimetry

The dough samples were prepared as described for the bread-making process but without yeast; 20–40 mg of dough samples was weighed in stainless steel pans (PE 0319-0218, Perking-Elmer, Waltham, MA, USA). The differential scanning calorimetry (DSC) measurements were made with a DSC-7 calorimeter (Perking-Elmer, Waltham, MA, USA). The calorimeter scan conditions for the simulation of the temperature profile in the centre of the bread crumb during baking were based on the methodology described by Sanz-Penella *et al*. (2010). The melting enthalpy and the temperature axis were calibrated with indium. The samples were held at 25°C for 1 min, heated from 25 to 100°C at the rate of 11.7°C/min, held at this temperature for 44 min and then cooled to 25°C. To analyse starch retrogradation, the heated–cooled pans were stored at room temperature for 24, 48, 72 and 96 h, and heated again in the calorimeter from 25 to 100°C at a rate of 10°C/min (Sanz-Penella *et al*., 2010). An empty pan was used as a reference. There were three replicates of all samples. The temperature at the onset of gelatinisation (T_o), the peak temperature (T_p), the gelatinisation temperature at the conclusion (T_c) and the melting enthalpy (ΔH) were recorded. The peak height index (PHI) was calculated as the ratio $\Delta H/(T_p - T_o)$ (Vasanthan & Bhatty, 1996).

Sensory evaluation of oat–buckwheat breads

A panel of eight people (seven women and one man; 24–51 years of age) was recruited and selected from the staff of Institute of Animal Reproduction and Food Research of Polish Academy of Sciences (IAR&FR PAS) in Olsztyn and was trained according to the International Organization for Standardization (ISO) guidelines (2014). All panellists had completed 120 h of training in all aspects of sensory techniques and analysis, and they also had approximately 100 h of testing experience with various food products. Before their participation in the experiments, the panellists were trained on sensory descriptors using breads purchased from a local supermarket. Loaves of experimental breads were sliced (15 mm thickness) and served to the assessors in transparent plastic boxes. The samples were individually coded with a three-digit number and presented to assessors in a random order in two independent sessions (two replications for each bakery product). Mineral water was offered between the samples. The sensory properties were evaluated using quantitative descriptive analysis in accordance with the standardised procedure ISO/DIS 13299:2003. Seventeen attributes (descriptors) describing the appearance, odour, taste and texture of the breads were selected and described in detail for profiling. The intensity of each sensory attribute was evaluated on a 10-cm linear scale that described the degree of linking on both sides from “none” to “very intensive”. The data were converted to numerical values (from 0 to 10 units).

Statistical analysis

Two replicates of all types of breads were baked (five loaves in each replicate). Ten replicate measurements were performed for analyses of chemical composition, technological parameters, hardness and colour.

The measurement of thermal properties was performed in triplicate, from freshly prepared three dough samples (without yeast) for all experimental recipes.

For the sensory analysis, data obtained from two repetitions for each assessor (eight people) were averaged and then subjected to statistical analysis in accordance with the standardized procedure ISO/DIS 13299:2003.

The results are presented as the mean ± s.d. All data were analysed using a one-way analysis of variance (ANOVA) with the Fisher least significant difference (LSD) test ($P < 0.05$) (Williams & Abdi, 2010). All analyses were performed in STATISTICA for Windows (StatSoft Inc., Tulsa, OK, USA, 2001).

Results and discussion

The BF had higher protein (19.2% DM), ash (3.2% DM) and starch (65.2% DM) contents than the OF (15.4% DM, 2.1% DM and 60.4% DM, respectively). The protein content of the OF used in this study was comparable with the values reported by other authors, which varied from 15 to 20% (depending on the genotype and growing environment) and is higher than other cereals (Peterson, 2011). Sterna *et al*. (2016) stated that the protein content in oat grains depends on the variety (hulled and naked oat) and amounts to approximately 10%, whereas a much higher content, approximately 16%, is found in naked oats. The evaluation of the protein content of four Polish varieties of oats (Dragon, Skrzat, Sławko and Bajka) by Czubaszek (2003) showed that the protein content ranged from 12.5 to 14.5%. According to Piątkowska *et al*. (2010), the average mineral content, presented as ash, in the grain of 14 oat varieties was approximately 1.7%. Stempińska and Soral-Śmietana (2006) found a protein concentration of 12% in three Polish buckwheat varieties (Kora, Panda and Luba), and the content of minerals ranged from 2.2 to 3.4%. Buckwheat grain is a highly starchy material and contains from 59 to 70% starch (Wijngaard & Arendt, 2006). In contrast, Czubaszek (2003) reported that the starch content in four oat varieties ranged from 42 to 56%.

Oat–buckwheat breads tested in this study were significantly different in their protein and mineral content, which is presented as ash content (Table 1). Only the starch content did not significantly differ in the experimental products. These results are mainly a reflection of the significant quantitative differences found in the raw materials used: OF and BF. The bread made from 100% and 80% BF (B and BO, respectively) contained the highest amounts of protein and ash. Bojňanská *et al*. (2009) stated that the proportion of BF in wheat bread determines the higher protein and mineral content of this product.

Table 1: Proximate chemical composition of experimental breads (% DM)

	O	B	OB	BO	OB50%
Proteins	14.27 ± 0.03[e]	20.58 ± 0.24[a]	15.73 ± 0.82[d]	19.64 ± 0.56[b]	18.67 ± 0.27[c]
Ash	2.72 ± 0.11[e]	4.02 ± 0.21[a]	3.02 ± 0.14[d]	3.80 ± 0.12[b]	3.50 ± 0.08[c]
Starch	58.47 ± 2.81	59.22 ± 2.74	57.95 ± 5.22	60.34 ± 1.69	58.64 ± 2.56

O = oat bread (100% oat flour); B = buckwheat bread (100% buckwheat flour); OB = oat–buckwheat bread (80% oat flour and 20% buckwheat flour); BO = buckwheat–oat bread (80% buckwheat flour and 20% oat flour); OB50% = oat–buckwheat bread (50% oat flour and 50% buckwheat flour); DM = dry matter; proteins ($N \times 6.25$).
Data are expressed as the mean ± s.d. ($n = 10$).
Different letters within the same row indicate statistically significant differences at $P < 0.05$ in the Fisher LSD test.

Additionally, Gambuś *et al*. (2011) showed that a 20% addition of OF to wheat and wheat–rye breads significantly increased the protein, dietary fibre and fat contents compared with the control wheat or wheat–rye bread.

The technological parameters of the experimental dough and bakery products are presented in Table 2. The highest yields of dough and bread ($P < 0.05$) were found in products prepared from 100% OF (O). Significant differences in the volume of tested breads were observed. The presence of oats in the recipe (OB and OB50%) had a positive impact on bread volume. Both of these breads exhibited the highest values for volume. Oats, similar to other grains rich in fibre, generally have a detrimental effect on bread quality as described by Salmenkallio-Marttila *et al*. (2011). The addition of OF to wheat and wheat–rye bread resulted in a significant decrease in baking loss, yield of bread and volume of bread in comparison with control wheat bread as shown by Gambuś *et al*. (2011). Bojňanská *et al*. (2009) found a significant reduction in the volume of wheat bread with increasing content of BF.

The texture is a multidimensional property of food that results from molecular, microscopic and macroscopic structures. The features describing texture include, among others, hardness, elasticity, chewiness, cheekiness and plasticity. The TPA test is one of the most popular tests used in the analysis of food texture. The hardness of experimental breads at 2 and 24 h after baking was examined, and the data obtained are presented in Table 2. The presence of BF significantly ($P < 0.05$) increased the hardness of fresh bread (Table 2). The highest value of hardness (70.3 N) was obtained in fresh bread prepared from 80% BF (BO). The lowest hardness value (37.4 N) was recorded for fresh bread with 50% OF and 50% BF. A similar relationship was found for bread stored for 24 h in a plastic bag; the presence of BF increased the hardness of the bread (Table 2). An increase in hardness was noted in all samples after 24 h of storage, but the lowest value (43.6 N) was observed in the OB50% bread. For bread prepared from 80% OF (OB), the increase in hardness with storage was not statistically significant compared with the fresh sample. The hardness of the bread crumb was increased during storage, which is a documented phenomenon (Schiraldi & Fessas, 2017). The increase in bread crumb hardness is one of the results of the loss of water during storage and starch retrogradation, as starch is one of the main ingredients of flour. Gambuś *et al*. (2011) did not find a significant effect on texture parameters such as the hardness and chewiness of wheat and wheat–rye breads with 20% OF in the recipe. Wronkowska *et al*. (2013) found that in fresh gluten-free bread, an increase in the amount of BF caused a decrease in crumb hardness. Moreover, it was shown by the same authors that 40% BF significantly delays the staling process of gluten-free bread. However, Lin *et al*. (2013) noticed that 15% BF in wheat bread caused an increase in the hardness and chewiness of bread.

The OF was significantly ($P < 0.05$) lighter and yellower than the BF, whereas the BF was characterised by higher redness (Table 2). The crust and crumb colour parameters (L*, a* and b*) of the experimental breads are presented in Table 2. A significantly lighter crust colour was noted for the OB bread compared with the B, BO and OB50% breads. The BO bread had the darkest crust. The highest value for the a* parameter was observed in the OB50% crust. The crusts of the O, OB and OB50% breads had similar b* parameter values.

Differences in the colour of the crumb and the size of the pores of the experimental breads are shown in Figure 1. The crumb of the O bread had the highest values for L* and b* compared with the other experimental breads. The introduction of OF to the recipe significantly increased ($P < 0.05$) the lightness of both crust and crumb. In this study, it should be noted that the bread crumb colour differences were associated with statistically significant differences in the colour of the flour used for baking (Table 2). Among the tested products, the oat bread (Figure 1A) was characterised by the lightest colour, whereas the buckwheat bread (B) was the darkest (Figure 1E). Similarly, BF used as an ingredient in traditional Turkish lavaş bread, which is prepared from wheat flour, increased the darkness of the crumb colour (Yildiz & Bilgiçli, 2012). There was also a difference in the porosity of the

Table 2: Technological parameters, hardness and colour of crust and crumb of experimental breads

	O	B	OB	BO	OB50%
Technological parameters					
Yield of dough (%)	211 ± 5^{a}	205 ± 8^{a}	196 ± 13^{b}	188 ± 12^{c}	184 ± 18^{c}
Yield of bread (%)	171 ± 5^{a}	165 ± 7^{ab}	158 ± 11b^{c}	154 ± 9^{cd}	151 ± 15^{d}
Baking loss (%)	16 ± 1	19 ± 3	17 ± 2	15 ± 1	16 ± 1
Volume of bread (cm^{3}/100 g)	166 ± 15^{b}	164 ± 19^{b}	192 ± 13^{a}	158 ± 12^{b}	189 ± 12^{a}
Mechanical parameters: hardness (*N*)					
Fresh bread	48.72 ± 5.12^{cB}	61.11 ± 4.09^{bB}	54.60 ± 3.36^{cA}	70.32 ± 3.02^{aB}	37.43 ± 3.71^{dB}
24 h of storage	57.53 ± 4.91^{cA}	69.64 ± 6.76^{bA}	57.92 ± 7.48^{cA}	77.47 ± 6.29^{aA}	43.65 ± 5.74^{dA}
Crust colour					
L*	42.92 ± 2.69^{ab}	41.28 ± 2.45^{c}	43.57 ± 5.89^{a}	39.72 ± 2.58^{d}	41.57 ± 1.82^{bc}
a*	8.03 ± 0.84^{d}	9.82 ± 0.61^{c}	10.41 ± 1.45^{b}	10.88 ± 1.09^{b}	11.62 ± 1.63^{a}
b*	23.57 ± 1.78^{a}	19.90 ± 0.90^{c}	23.91 ± 2.17^{a}	20.79 ± 1.72^{b}	24.05 ± 2.66^{a}
Crumb colour					
L*	51.46 ± 3.45^{a}	43.76 ± 1.64^{d}	48.00 ± 1.64^{b}	41.72 ± 1.75^{e}	46.03 ± 1.44^{c}
a*	3.76 ± 0.45^{c}	4.21 ± 0.17^{ab}	4.21 ± 0.17^{ab}	4.39 ± 0.24^{a}	3.88 ± 0.17^{c}
b*	20.17 ± 0.64^{a}	10.07 ± 0.41^{c}	10.07 ± 0.41^{c}	11.95 ± 0.47^{b}	13.87 ± 0.42^{b}
Colour	**Oat flour**			**Buckwheat flour**	
L*	85.27 ± 0.31^{a}			83.17 ± 0.41^{b}	
a*	1.13 ± 0.04^{b}			1.52 ± 0.08^{a}	
b*	10.97 ± 0.23^{a}			9.01 ± 0.16^{b}	

O = oat bread (100% oat flour); B = buckwheat bread (100% buckwheat flour); OB = oat–buckwheat bread (80% oat flour and 20% buckwheat flour); BO = buckwheat–oat bread (80% buckwheat flour and 20% oat flour); OB50% = oat–buckwheat bread (50% oat flour and 50% buckwheat flour); DM = dry matter; proteins ($N \times 6.25$).
Data are expressed as the mean ± s.d. ($n = 10$).
Different letters within the same row (a–e) or column (A–B) indicate statistically significant differences at $P < 0.05$ in the Fisher LSD test.

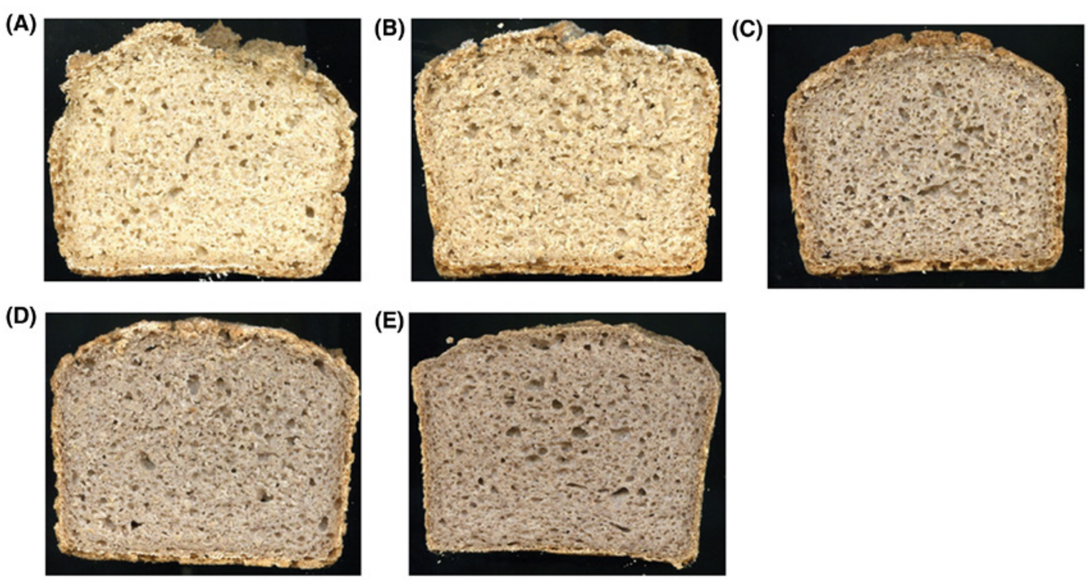

Figure 1. Scanned image of experimental bread crumbs: (A) 100% oat flour (O), (B) 80% oat flour and 20% buckwheat flour (OB), (C) 50% oat flour and 50% buckwheat flour (OB50%), (D) 20% oat flour and 80% buckwheat flour (BO) and (E) 100% buckwheat flour (B).

bread, which reflects the distribution and size of the pores. The smallest pores were found in the oat bread (Figure 1A) and were evenly distributed. In contrast, the buckwheat bread (Figure 1E) showed an uneven distribution of pores of varying sizes with the largest pores in the middle of the slice. The addition of BF to oat bread (OB, OB50%) (Figure 1B,C) produced a clear increase in the number of larger pores. In this study, crumb porosity was determined based on the scans shown in Figure 1. However, as shown by Zghal *et al*. (2002), calculating Young's moduli by the slope of the stress–strain curve is the method for evaluating porous crumb structure. These authors found a positive correlation of Young's modulus with crumb brightness and density and a negative correlation with cell wall thickness, mean cell area and number of missing cell walls.

The thermal properties of the experimental breads are shown in Table 3. There were no significant differences in the onset (T_o), peak (T_p) or conclusion (T_c) gelatinisation temperature among all experimental breads. The highest enthalpy of starch gelatinisation (ΔH_G) was recorded for bread prepared from 100% BF (B). The OF used in the buckwheat bread recipes (BO and OB50%) significantly decreased (P < 0.05) the enthalpy of starch gelatinisation. The staling of bread involves several factors; one of the most important factors is the process of starch retrogradation (Schiraldi & Fessas, 2017). In this study, starch retrogradation was measured by DSC over a 5-d storage period (Table 3). The rate of retrogradation enthalpy was slow during the first 48 h of storage at 4°C, mainly for the O and BO samples. An increase in the enthalpy of starch retrogradation during the measurement period (up to 96 h) was noted for all experimental breads. The OF used in the buckwheat bread recipes (BO and OB50%) decreased the value of starch retrogradation enthalpy compared with the bread made from 100% BF (B). The decrease in the hardness of bread with a higher proportion of OF during the 24-h storage period (Table 2) is consistent with this finding. Zhang *et al*. (1998) found that the use of OF in the bread-bakery system could decrease the rate of starch retrogradation. Paton (1987) found that the enthalpy of oat starch gelatinisation was 9.1 J/g, which was lower than other analysed starches (rice and wheat). The enthalpy of gelatinisation of buckwheat starch isolated by wet milling was approximately 15 J/g of starch DM (Wronkowska & Haros, 2014). In this study, a baking process was used, and the dough samples were heated from 25 to 100°C and maintained at this temperature for 44 min. These parameters could affect the results obtained during the DSC analysis. The size of buckwheat starch is from 3 to 9 mm and the granules are irregular (Repo-Carrasco-Valencia & Valdez Arana, 2017); oat starch granules are also small (from 2 to 11 mm) and are characterised by an irregular shape (Sayar & White, 2011). Starches with large or irregular granules have higher ΔH and PHI values, whereas the reverse was true for starches with small oval or round granules (Shujun *et al*., 2007). In the starches from two different yams (granules oval or round with an average size of 5–50 mm), the ΔH_G and PHI were approximately 10.5 and 1.16, respectively (Wang *et al*., 2011). For 26 corn lines (spherical granules, from 10 to 30 mm), the enthalpy of gelatinisation and the PHI ranged

Table 3: The effect of oat and buckwheat flours on the thermal properties of experimental breads

	O	B	OB	BO	OB50%
Thermal properties					
T_0 (°C)	66.3 ± 0.3	66.5 ± 0.3	67.5 ± 0.5	67.4 ± 0.1	67.7 ± 0.1
T_p (°C)	72.3 ± 0.5	74.4 ± 0.2	73.8 ± 0.4	73.9 ± 0.5	73.8 ± 0.1
T_c (°C)	81.6 ± 0.5	82.8 ± 0.2	84.3 ± 0.7	84.9 ± 0.3	83.6 ± 0.7
ΔH_G (J/g of starch DM)	9.1^b	10.3^a	8.4^c	7.9^d	8.5^c
PHI	1.5	1.4	1.5	1.2	1.1
Enthalpy of starch retrogradation (J/g of starch DM) during storage					
48 h	0.31^c	0.71^a	0.29^c	0.54b	0.42
72 h	0.71^a	0.76^a	0.58_c	0.66^b	0.50^c
96 h	0.85^a	0.89^a	0.63^{bc}	0.73^b	0.58^c

O = oat bread (100% oat flour); B = buckwheat bread (100% buckwheat flour); OB = oat–buckwheat bread (80% oat flour and 20% buckwheat flour); BO = buckwheat–oat bread (80% buckwheat flour and 20% oat flour); OB50% = oat–buckwheat bread (50% oat flour and 50% buckwheat flour); DM = dry matter; proteins ($N \times 6.25$); T_o = the onset temperature of gelatinisation; T_p = the peak temperature of gelatinisation; T_c = the conclusion temperature of gelatinisation; ΔH_G = enthalpy of gelatinisation based on dry mass basis of starch; PHI = peak height index; $\Delta H_G/(T_p - T_0)$.
Data are expressed as the mean ± s.d. (n = 3).
Different letters within the same row indicate statistically significant differences at P < 0.05 in the Fisher LSD test.

Table 4: Sensory attributes and sensory profiles of experimental breads

	O	B	OB	BO	OB50%
Attributes					
Porosity	4.76 ± 0.02[a]	6.4 ± 0.01[a]	4.72 ± 0.04[a]	6.21 ± 0.02[a]	4.9 ± 0.02[a]
Crust colour	2.3 ± 0.01[d]	8.47 ± 0.01[a]	3.82 ± 0.01[c]	7.66 ± 0.02[a]	5.15 ± 0.01[b]
Crumb colour	1.71 ± 0.01[d]	8.26 ± 0.02[a]	3.31 ± 0.01[c]	7.23 ± 0.01[a]	4.74 ± 0.03[b]
Odour					
Buckwheat	0.13 ± 0.01[c]	6.69 ± 0.01[a]	1.54 ± 0.02[c]	5.55 ± 0.02[b]	4.14 ± 0.01[b]
Sweet	3.32 ± 0.01[a]	1.97 ± 0.01[a]	2.67 ± 0.01[a]	1.88 ± 0.01[a]	2.14 ± 0.01[a]
Bread	3.03 ± 0.01[b]	2.73 ± 0.01[b]	3.76 ± 0.03[a]	3.51 ± 0.01[a]	3.44 ± 0.02[a]
Oil	2.64 ± 0.01[a]	2.07 ± 0.02[a]	1.57 ± 0.03[a]	1.66 ± 0.02[a]	1.93 ± 0.01[a]
Acidulous	1.28 ± 0.03[a]	2.84 ± 0.03[a]	1.69 ± 0.04[a]	2.47 ± 0.01[a]	2.09 ± 0.03[a]
Taste					
Buckwheat	0.06 ± 0.02[d]	7.28 ± 0.01[a]	2.19 ± 0.03[c]	5.97 ± 0.01[a]	4.24 ± 0.02[b]
Bitter	6.26 ± 0.01[a]	6.58 ± 0.01[a]	6.04 ± 0.02[a]	6.09 ± 0.02[a]	5.39 ± 0.01[b]
Acidulous	1.47 ± 0.02[b]	2.52 ± 0.01[a]	1.61 ± 0.01[b]	2.79 ± 0.01[a]	2.36 ± 0.01[a]
Oil	3.87 ± 0.01[a]	1.96 ± 0.02[b]	2.46 ± 0.01[ab]	2.31 ± 0.02[ab]	2.44 ± 0.01[ab]
Strange	5.06 ± 0.01[a]	4.26 ± 0.02[a]	4.18 ± 0.03[a]	4.11 ± 0.03[a]	4.39 ± 0.02[a]
Aftertaste	6.58 ± 0.03[a]	6.57 ± 0.01[a]	5.95 ± 0.01[b]	6.07 ± 0.01[ab]	5.7 ± 0.03[c]
Texture					
Springiness	4.93 ± 0.01[ab]	3.19 ± 0.02[c]	5.38 ± 0.01[a]	4.01 ± 0.01[b]	5.03 ± 0.01[ab]
Mastication	4.52 ± 0.01[a]	4.24 ± 0.03[a]	4.22 ± 0.01[a]	4.22 ± 0.01[a]	4.44 ± 0.01[a]
Adhesiveness	3.28 ± 0.03[a]	3.94 ± 0.01[a]	3.36 ± 0.02[a]	4.25 ± 0.02[a]	3.76 ± 0.01[a]
Overall quality	3.19 ± 0.01[c]	3.11 ± 0.02[c]	4.26 ± 0.01[ab]	3.79 ± 0.0[bc]	4.58 ± 0.02[a]

O = oat bread (100% oat flour); B = buckwheat bread (100% buckwheat flour); OB = oat–buckwheat bread (80% oat flour and 20% buckwheat flour); BO = buckwheat–oat bread (80% buckwheat flour and 20% oat flour); OB50% = oat–buckwheat bread (50% oat flour and 50% buckwheat flour); DM = dry matter; proteins ($N \times 6.25$).
Data expressed as the mean ± s.d. ($n = 8$).
Different letters within the same row indicate statistically significant differences at $P < 0.05$ in the Fisher LSD test.
Range of sensory scores: 0 = none, 10 = very intensive.

from 8.11 to 11.2 and 1.5 to 3.5, respectively (Sandhu & Singh, 2005).

The results of the sensory analysis are presented in Table 4. Buckwheat breads (B and BO) had significantly higher ($P < 0.05$) values for crust and crumb colours. Additionally, the same bread (B) had the highest scores for buckwheat odour. When OF was used in the experimental bakery products, the overall sensory quality was significantly improved. The high values for overall quality for OB50%, OB and BO breads resulted from the significantly higher values exhibited by these breads during the analysis of individual attributes such as bread odour, acidulous taste and crumb springiness. The taste of the bread could be improved by the use of whole-grain oats because this adds a pleasant and nutty flavour to the product (Salmenkallio-Marttila *et al*., 2004). Gambuś *et al*. (2011) showed similar consumer acceptance scores for wheat and wheat–rye breads enriched with 20% OF compared with the control bread. Bojňanská *et al*. (2009) found that 10 and 20% additions of BF to wheat bread were accepted by consumers. Similarly, Wronkowska *et al*. (2013) found that an increasing amount of BF in gluten-free bread, replacing corn starch, improved the overall quality with regard to the sensory analysis of the products.

Conclusion

The effects of different proportions of OF and BF on the technological properties, staling and sensory properties of bakery products were analysed. Significant differences in the composition of BF and OF influenced the protein, starch and mineral content of the breads produced. Generally, the use of

BF in the recipes had a negative impact on the technological parameters of the dough and bread and increased crumb hardness. The use of OF delayed bread staling and resulted in a lighter colour and smaller pores in the bread crumb. The bread with the addition of OF was characterised by improved sensory properties and thus was found to be more attractive as compared with the bread with BF addition.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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