Effect of buckwheat hull hemicelluloses addition on the bread-making quality of wheat flour

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Summary

Buckwheat hull hemicelluloses (BHH) obtained from seeds by alkaline extraction were applied at 0.3, 0.5, and 0.7% content to the bread wheat flour (BWF) and these additions were studied in relation to rheological properties of the dough as well as quality of bread characterized by laboratory baking tests and sensory evaluation. Addition of 0.5% BHH had a considerable effect on bread flour quality in relation to the resistance to extension and fermentation of dough. However, higher doses of BHH (> 0.7%) had a negative influence on gas development and fermentation of dough. Addition of BHH between 0.3–0.5% lead to improved sensory properties of fresh bread and higher scores for overall acceptability. During storage, the most evident changes were related to crumb hardening, when BHH reduced the crumb hardness producing a softer crumb than the control at any storage time. Also, higher elasticity of the crumb in comparison to the control was observed. In long-term storage, all breads containing BHH exhibited higher softness and elasticity than the control. Results showed that BHH can be used to improve the quality of bread to prepared from medium-quality wheat flours.

Keywords

buckwheat; hull hemicelluloses; wheat flour; dough; rheology; bread staling; sensory quality

Since ancient time, the pseudo-cereal buckwheat has been cultivated for both food and medicinal applications [1, 2]. Buckwheat plants are not grasses, but the seeds are usually classified among cereal grains because of their similar usage. In recent years, ground buckwheat has found many applications in bakery, pastry and pasta products. In comparison to cereal grains, buckwheat seeds have higher contents of proteins and essential amino acids [1, 3]. Hulls of buckwheat seeds have been reported to cause important beneficial physiological effects and act as a dietary fibre [4]. In addition, they are also of great interest because they represent a rich source of natural antioxidants [5, 6] as well as polysaccharides of the glucuronoxylan (GX) type [7].

Hemicelluloses, particularly arabinoxylans (AX) and arabinogalactan peptides, affect the baking performance of flour as well as the quality of bread and other products [8-14]. COURTIN and DELCOUR [13] summarized the results obtained with AX from wheat and rye grains. Addition of native water-extractable wheat AX to flour resulted in increased consistency and stiffness of the prepared dough [15]. Addition of native water-unextractable AX to dough resulted in higher dough consistency with a decreased mixing time [16]. An increasing baking absorption was reported to be linearly related to the amount of the added AX [8]. It was demonstrated that the overall dough characteristics were negatively correlated with the total AX content, but positively correlated with the percentage of water-extractable AX in the total AX [17]. Water-extractable and water-unextractable AX exhibit similar effects on gluten formation, and addition of AX, in general, lead to stiffer and less extensible gluten [18]. GX are the major constituents of dicotyl plant cell walls [10]. The effect of water-insoluble GX from beechwood pulp on bread making was studied [19]. Incorporation of these low-molecular-mass hemicelluloses strongly increased the water absorption capacity of the dough, but negatively affected the specific volume of the bread.

The aim of this study was to investigate the effects of hemicelluloses isolated from the hulls of

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buckwheat seeds on the bread-making quality of wheat flour. Farinograph, extensograph and maturograph tests were used to characterize the rheological properties of the dough. The quality of the baked product was tested on mini-breads by sensory evaluation and firmness measurements.

MATERIALS AND METHODS

Materials

The commercial bread wheat flour T1100 (BWF) was a product of PMD Union, Bratislava, Slovakia. Standard characteristics of the wheat flour such as wet gluten content and imbibition of glutens in a mild-acidic medium were determined by methods described in a previous paper [20] and these indicated its medium quality. Hulls from buckwheat (*Fagopyrum esculentum* L.) seeds were purchased from the local market. Hemicelluloses (BHH) were isolated from buckwheat hulls in the pilot plant of the Institute of Chemistry, Slovak Academy of Sciences (Bratislava, Slovakia) using a classical two-step alkaline extraction procedure, as previously reported [7]. In the first step, 5% NaOH at 60 °C was used and in the second step, 5% NaOH at room temperature was used. The extracts from both steps were combined and BHH were recovered by ethanol precipitation, followed by neutralization and dialysis of the precipitate and lyophilization of the retentate. The content of the water soluble fraction of BHH was calculated by subtracting the amount of the water-insoluble fraction separated by centrifugation of a 1% dispersion of BHH in distilled water for 15 min at $800 \times g$.

Analytical methods

The methods used for saccharide analysis, determination of proteins and molecular mass have been previously described in detail [21, 22]. The total soluble phenolics were quantified according to the method of Matthaus [23] using the Folin-Ciocalteu reagent (Merck, Bratislava, Slovakia). The absorbance was measured at 750 nm with the Specord M-20 UV-VIS spectrophotometer (Spectronic Instruments, Muskegon, Michigan, USA). A calibration curve was constructed for the concentration range of 0-0.05 $mg.ml^{-1}$ using tannic acid as a standard.

Characterization of dough

Farinograms

Farinograph (Brabender, Duisburg, Germany) is the instrument most frequently used all over the world for determining the water absorption and mixing characteristics of flours. The following dough parameters (ICC standard No. 115/1) [24], were determined using the Farinograph tests: water absorption (%), dough development time (min), stability (min), degree of softening (expressed in Farinograph units, FU) and mixing tolerance index (FU).

The dough was prepared from BWF (300 g) or from the mixture of the flour with BHH addition of 0.3, 0.5, and 0.7% at temperature of 30 °C.

Extensograms

The Brabender Extensograph (Brabender) was used to measure the extensibility of dough and its resistance The following dough parameters (ICC standard No. 114/1) [24] were determined: energy (cm^2), resistance to extension (expressed in Extensograph units, EU), maximum resistance to extension (EU) and extensibility (mm).

The dough was prepared in the Brabender Farinograph at the same conditions as described in section Farinograms, with 5.1 g NaCl added to water. A test piece of the dough (150 g) was stretched with a device moving at a constant speed. The dough samples were measured after resting periods of 20 and 65 min.

Maturograms

Brabender Maturograph (Brabender) records the fermentation behaviour of dough in relation to the proofing time by means of a sensing probe which touches the dough periodically (2 min). The maturogram test is not included in any international or Slovak standard method. The resulting zigzag curve – maturogram – characterizes the increase of the dough volume and its rheological properties during the proofing time. Four characteristics can be measured: final proof period (min), dough level (expressed in Maturograph units, MU), elasticity (MU) and fermentation stability (min).

The bread-making formula (ICC standard No. 131) [24] included 300 g flour, 5.1 g NaCl, 4.5 g saccharose, 12 g fresh baker‘s yeast and 3 g margarine. After mixing in the Brabender Farinograph, the dough was divided into two pieces and allowed to relax for 45 min before testing. The test pieces (150 g) were formed into balls in the farinograph and immediately placed to the maturograph. Measurements were performed for approximately 1 h until the maximum of the maturogram was visible within the gauge frame.

Preparation of mini-breads and their quality testing

Bread-making test

The dough was prepared at the same conditions as mentioned in the previous section. Kneaded dough after maturing at 30 °C for 45 min was divided into four pieces of 100 g each. These samples were molded and fermented for the period derived from the maturogram test. Then they were baked in a laboratory oven at 230 °C for 15 min. After cooling at laboratory temperature (21–23 °C) for 2 h, the breads were packed into plastic bags and stored at 21–23 °C for 24, 48 and 72 h.

Physicochemical characteristics of BHH-containing breads were compared to those of control breads (without BHH). The results are averages of four independent experiments.

The Student's t-test for 6 degrees of freedom was used for statistical analysis. Two levels of significance (P); $P = 0.05$ (significant*) and $P = 0.01$ (highly significant**) were applied.

Sensory evaluation of the baked products

A panel of six members, composed of adult males and females (22–30 years old, students in Food technology and specialists without a formal certification in sensory evaluations) was used to perform the sensory evaluation of the product, crust, crust + crumb and crumb, and to determine the quality parameters of mini-breads containing BHH in comparison to control mini-breads. The order of presentation of the samples was random. The scaling method coupled to a verbal concept five-point scale (4–0) was used to estimate the product quality.

Firmness measurement of the baked products

Deformation and relaxation of the crumb were measured by means of an automatic penetrometer AP 4/1 (Feinmess, Dresden, Germany). The constant force of the cylinder (length 90 mm, weight 14 g) with 34 g and/or 84 g headers was applied to 30 mm wide slices from the centre of the loaf. Deformation in mm represented the penetration depth at the given time (5, 30, 60 and 120 s). Measurements were performed at 2, 24, 48 and 72 h after baking.

Relaxation was expressed as the difference between the maximum deformation (10 mm) and the value of the sample after 60 s.

RESULTS AND DISCUSSION

The objective of this study was to investigate the influence of BHH on the processing parameters of dough prepared from BWF of a medium quality, and to evaluate the quality of mini-breads. The

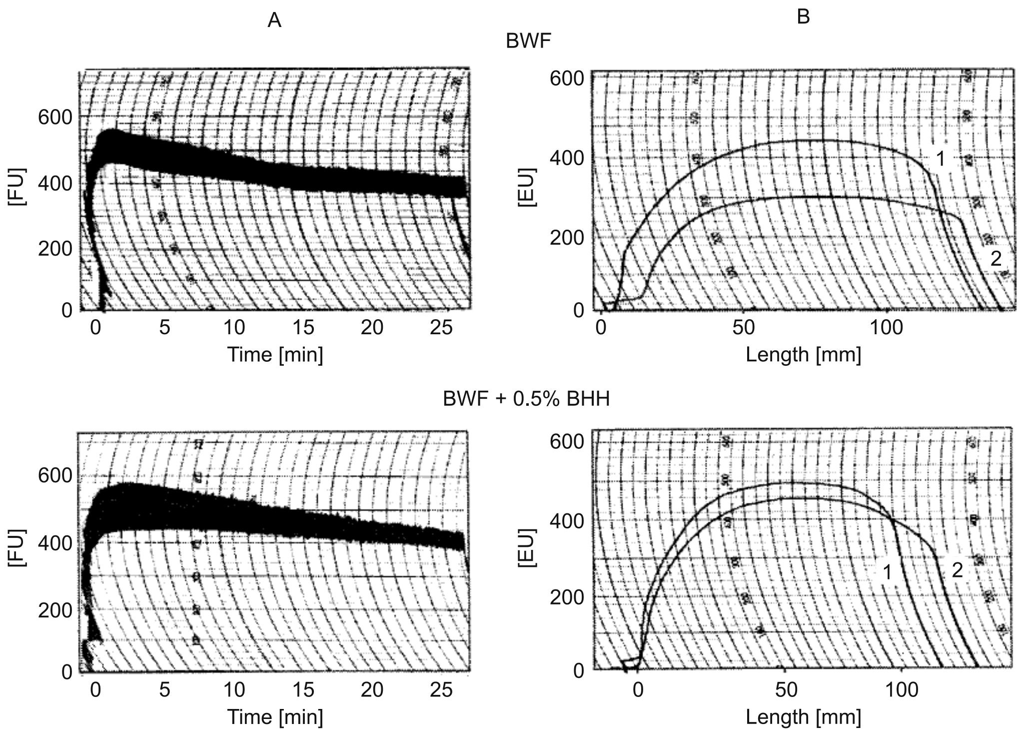

Fig. 1. Farinograph (A) and extensograph (B) curves of the dough from BWF and BWF with a BHH addition of 0.5%.
Resting time of the dough was 20 min (1) and 65 min (2).

Tab. 1. Effects of the BHH addition on some farinogram parameters of BWF.

BHH[a] [%]	Water absorption [%]	Development time [min]	Stability [min]	Degree of softening [FU]	Mixing tolerance index [FU]
0	60.1	2,5	4.0	160	125
0.3	61.1	4,0	6.0	140	90
0.5	61.2	4.0	6.5	125	70
0.7	61.1	4.0	7.0	100	60

a - % of BHH related to the flour. FU - Farinograph units.
Water absorption - percentage of water required to yield a dough consistency of 500 FU; development time - time to reach a maximum consistency; stability - time at which dough consistency is 500 FU; degree of softening - the difference between the maximum of the curve and the value after 12 min; mixing tolerance index - consistency difference between the height at the maximum and the value after 5 min.

saccharide composition in combination with FT-IR and NMR analyses of BHH [7, 25] revealed that the recovered hemicelluloses comprised mainly 4-*O*-methylglucuronoxylan (GX), a typical hemicellulose component of dicotyl plant cell walls. Besides the prevailing xylose, glucose, arabinose, and galactose (67.4, 17.0, 6.4, and 4.1%, respectively), BHH contained 4-*O*-methylglucuronic acid (5.5%). Besides carbohydrates, proteins (8.2%), ash (8.7%) and phenolics (21.1%) were present. The estimated content of carbohydrates in BHH was about 60%. Its mean molecular mass was 60 000. This value is low in comparison to that of AX (135 000–200 000) isolated from cereal flours [8]. The results from standard analysis of the BWF showed a high wet gluten content (38.8%). The wet glutens in BWF were elastic and tensible, but the flour was of medium quality. This can be explained by the low imbibition of the glutens in mild-acidic medium.

The control dough, prepared from the flour and water according to the ICC standard, was sticky and soft, and had a low mechanical stress resistance (Fig. 1). The consistency of the dough and the quantity of water required (measured by the farinograph) is shown in Tab. 1. The dough reached optimal properties in a short development time, but then the curve decreased fast, indicating low stability (Fig. 1).

As shown in Tab. 1, addition of BHH had no effect on water adsorption of the dough, which was prepared without NaCl. In comparison to the control dough, the stability of BHH-containing dough increased and the mixing tolerance index decreased. The optimum dose of BHH was 0.5%.

The extensograph (Tab. 2) and maturograph tests (Tab. 3) documented more precisely the changes in dough properties resulting from the addition of BHH. Water adsorption of the dough, prepared by the addition of NaCl, increased with an increasing amount of BHH only up to 0.5%. The influence of BHH concentration can be explained by the fact that BHH contains 49% of the water-soluble fraction. The water-soluble (WS) and water-insoluble (WIS) pentosan fractions from wheat have different influence on the water absorption of the dough [8, 11]. Our previous rheological measurements on the WS and WIS

Tab. 2. Effects of the addition of BHH on some extensogram parameters of BWF.

BHH [%]	E [cm^2]	R_w [EU]	R_{max} [EU]	E_b [mm]	R_w/E_b
Resting time of the dough 20 min					
0	96	365	410	145	2.6
0.3	113	405	460	135	3.0
0.5	113	405	460	135	3.0
0.7	119	530	580	118	4.5
Resting time of the dough 60 min					
0	76	310	345	128	2.4
0.3	83	395	390	124	3.2
0.5	90	390	420	126	3.1
0.7	105	435	485	128	3.4

EU - Extensograph Units.
E - energy (area of the curve); R_w - resistance to extension (after 50 mm); R_{max} - maximum resistance to extension; E_b - extensibility (length of the curve in mm).

Tab. 3. Effects of the BHH addition to BWF on the fermentation behaviour of the dough and the bread-making properties.

BHH [%]	Final proof period [min]	Dough level [MU]	Elasticity [MU]	Fermentation stability [min]	Water absorption [%]	Height-to-width ratio [cm.cm^{-1}]
0	38.0	690	240	8.0	57.5	0.571
0.3	41.0	710	250	12.0	58.5	0.681
0.5	41.0	760	240	10.0	60.9	0.727
0.7	47.0	770	250	8.0	60.4	0.633

MU - Maturograph units.
final proof period - time from the beginning to the maximum of the curve; dough level - distance between the zero line and the maximum of the curve; elasticity - width of the record at the curve maximum; fermentation stability - time during which the curve maximum is visible within the gauge frame.

Tab. 4. Influence of the BHH addition on the sensory quality of mini-breads.

BHH[a] [%]	0.0	0.3	0.5	0.7
Crumb[b]				
Adhesion	2.8 ± 0.4	3.8 ± 0.4	4.0 ± 0.0	3.3 ± 0.2
Hardness	2.7 ± 0.5	3.3 ± 0.5	4.0 ± 0.0	3.7 ± 0.2
Color	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
Porosity	3.2 ± 0.4	3.0 ± 0.6	3.8 ± 0.4	3.0 ± 0.0
Elasticity	3.0 ± 0.6	3.3 ± 0.5	4.0 ± 0.0	3.5 ± 0.3
Crust + Crumb[b]				
Flavour	3.0 ± 0.6	4.0 ± 0.0	4.0 ± 0.0	3.3 ± 0.2
Aroma	3.8 ± 0.4	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
Crust[b]				
Hardness	3.2 ± 0.7	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
Color	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
Product[b]				
Form	1.8 ± 0.7	3.7 ± 0.5	3.8 ± 0.4	3.7 ± 0.22
Score	31.5 ± 1.7	37.2 ± 0.9	39.7 ± 0.5	36.5 ± 1.9

a - % of BHH related to the flour, b - means ± standard error values from the evaluation of six panelists, where the verbal concept five-point scale (4-0) was used to evaluate the quality (4 - very good, 0 - unacceptable quality).

fractions of GX isolated from beech wood [26] revealed that the apparent viscosities of dispersions were different for the two fractions, and the apparent viscosity of blends was affected by the ratio of WS and WIS GX fractions. After addition of BHH, an energy increase (expressed by the area of the extensogram) was achieved, indicating that the flour was stronger and gave a shorter dough. The addition of 0.5% BHH to BWF had a positive effect on the resistance to extension and fermentation of the dough (Fig. 1), which suggests that it can be used to improve the flour quality as well as to adjust the rheological optimum of the dough. The higher values of resistance to extension (R_w) and low values of the extensity (E_b) indicate that breads from this dough achieved desirable height/width ratio and good shape (Tab. 2). However, at a higher content of BHH (0.7%) in BWF dough, an opposite effect was observed. In spite of the increased energy and height/width ratio values, the gas development and fermentation of the BWF dough was negatively influenced. These results were obtained after the resting period of 20 min. After resting for 60 min, the quality of the dough decreased, however, this decrease was less pronounced in dependence on the BHH content.

Addition of BHH positively affected the dough level (Tab. 4). The final proof period, determined by the maturograph test as a specific volume of the bread, was applied in baking experiments. The final proof period values increased with an increase in the BHH content. The dough level of all BHH-containing doughs was higher in comparison to the control dough, and the values of 770 MU and 760 MU were appropriate for bread baking. The fermentation stability was also affected by the addition of BHH. The results suggest that the optimum level of the addition of BHH to

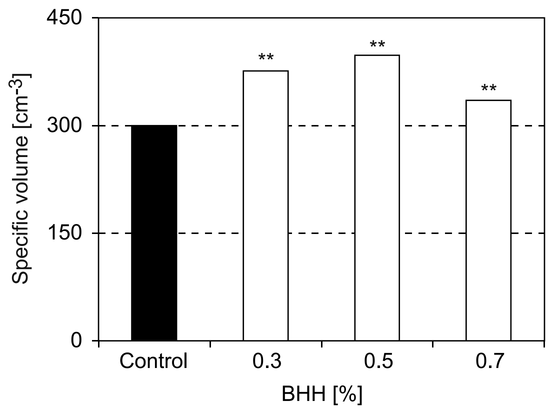

Fig. 2. Influence of the BHH addition on the specific volume of control breads.
The specific volumes are significantly different** (P = 0.01) for control breads versus breads with an addition of 0.3–0.7% of BHH.

BWF was 0.3–0.5%. Farinograph, extensograph and maturograph curves indicate that the addition of 0.5% BHH to BWF improves the quality of the dough.

A bakery experiment was performed to determine the quality of the baked products (mini-breads). The results are summarized in Tab. 3. As shown in Fig. 2, the addition of BHH to BWF had a significant effect on the specific volume of mini-breads. All mini-breads had a higher height/width ratio in comparison to the control. Similar results were obtained by Maeda and Morita [14], who added WS and WIS pentosans extracted from polished wheat grains a to very soft wheat flour. The loaf volume of the bread was significantly larger upon the addition of both fractions.

When compared to control mini-breads, those prepared from BWF containing BHH gave higher specific volumes (SV) at a high level of statistical significance. The best SV had mini-breads from BWF after the addition of 0.5% BHH. Denli and Ercan [11] compared the influence of pentosans from wheat and rye on breads prepared from two flours of different quality. The SV and structure of bread were significantly dependent on the quality of flour, the doses of pentosans and their origin. The addition of large doses of WIS and low doses of WS wheat pentosans to stronger wheat flours had even a negative effect.

The effect of BHH on the specific volume of mini-breads at all concentrations, in comparison to the control, was significantly positive (P = 0.01; Fig. 2). Specific volumes of mini-breads prepared with a 0.5% BHH addition to BWF were the highest. These values were significantly (P = 0.01) higher then those observed for the mini-breads prepared from BWF with the highest (0.7%) and lowest (0.3%) addition of BHH.

Six panelists, who judged each specific sensory characteristic, performed the sensory evaluation of the fresh breads. A five-point scale was used and overall acceptability was calculated by weighed arithmetic means. From sensory evaluation of the product, crust, crust/crumb and crumb, the highest point number was achieved in the case of mini-breads containing 0.5% BHH in comparison to the control (Tab. 4). BHH reduced the crumb, crust hardness and increased the porosity of breadcrumbs. The incorporation of WS cereal pentosans to dough was reported to increase the water absorption [27] and loaf volume of the breads [28] and might contribute to a softer crumb texture. This was explained by the plasticizing effect of wa-

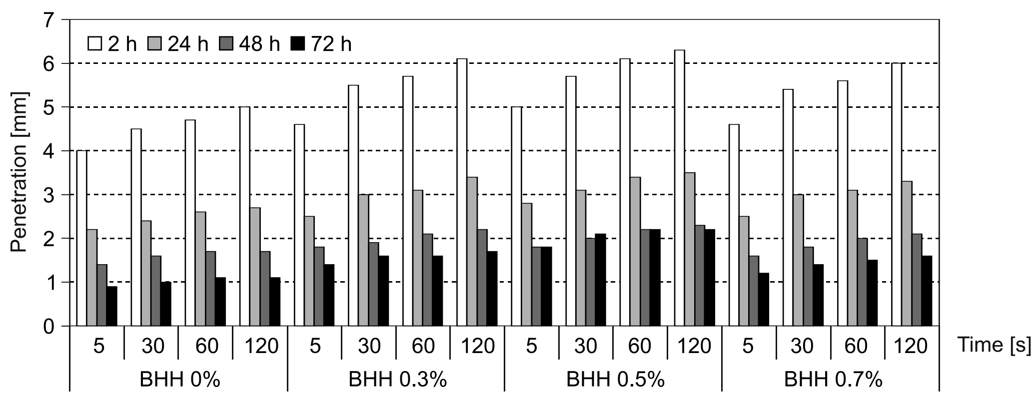

Fig. 3. Effects of the BHH addition on the penetration of breads from BWF.
Measurements were performed at 2, 24, 48 and 72 h after baking, and the penetration depth was measured at the given time (5, 30, 60 and 120 s). BHH was added at concentrations of 0.3, 0.5 and 0.7%.

ter on the gluten-starch network [13]. The buckwheat hull hemicellulose has a light brown colour and the BHH-containing breads were darker, but the colour was homogeneous. Such effect was not taken as negative.

Using the penetrometer method, firmness and resilience of the bread crumb after the first compression was tested. During storage, the most evident changes are related to crumb hardening expressed as penetration depth. As seen in Fig. 3, BHH-containing breads showed an increase in the penetration values: control < 0.7% < 0.3% < 0.5%, when compared to the fresh control bread. Addition of BHH to BWF increased the specific volume of breads in the same order (Fig. 2) and improved the bread quality (Tab. 3). These breads had higher specific volumes and softer breadcrumbs (Fig. 2) as well as higher elasticities (Fig. 4) than the controls over the 3-days storage period. Highly significant correlation between the fresh breadcrumb firmness and firmness at any storage time was found. This agrees with previous observations [29]. Recently, different commercial hydrocolloids (alginate, xanthan, κ-carrageenan and hydroxypropylmethyl cellulose - HPMC) were tested as bread improvers and anti-staling agents [30, 31]. All hydrocolloids were able to reduce the loss of moisture during bread storage, but only alginate and HPMC showed an anti-staling effect retarding the crumb hardening.

It is of importance that the addition of BHH to BWF, which is weak due to the low imbibition of its gluten in mild-acidic medium, improved the baking properties of the flour and the quality of the baked product (Tab. 3, Fig. 2). Similar results were obtained by Maeda and Morita [14]. The addition of WS and WIS AX to a very soft wheat flour significantly increased the loaf volume and retarded the firmness of breadcrumbs during the storage for 3 days. WIS AX had a more satisfactory effect, but was needed in a considerably larger amount to yield a good quality of the baked products. Results of the relaxation analysis, demonstrated in Fig. 4, allowed us to conclude that the addition of BHH to BWF increased the elasticity of fresh breadcrumbs markedly during the storage. Starch recrystallization is considered to be a major factor contributing to bread staling. On the basis of the changes in breadcrumb compressibility it was shown [32] that the addition of WS pentosans retarded the starch retrogradation process. In contrast, Biliaderis et al. [8] reported that the higher moisture contents of WS AX-containing breads resulted in acceleration of starch retrogradation (determined by differential scanning calorimetry), but significantly decreased the crumb firmness of the fresh breads and during the storage. Results of bread staling studies by differential scanning calorimetry seem to contradict those obtained by the firmness measurements but, according to Biliaderis et al. [8], the crumb firmness measurements provide information on mechanical properties of the products which are also dependent on the water contents.

The possible effects of phenolic compounds present in BHH on the dough properties and gluten quality are still unclear. Recently, addition of ferulic acids was reported to produce a more extensible dough [27]. Their addition could shorten the dough development time, increase the rate of dough breakdown, and make the dough sticky [33]. Interactions between the present phenolics and proteins might be of importance as well.

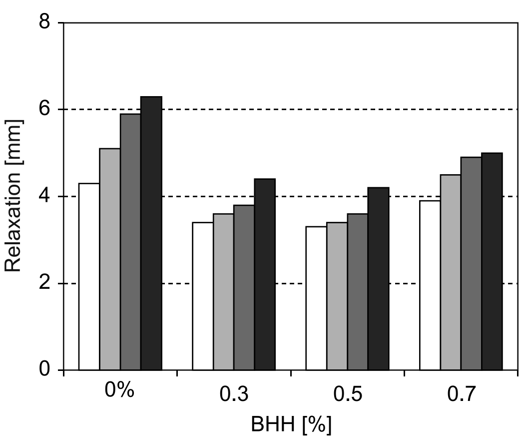

Fig. 4. Effects of the BHH addition on staling of the bread evaluated on the basis of changes in the bread crumb compressibility of the flour.
The measurements were performed at 2, 24, 48 and 72 h after baking. BHH was added at concentrations 0.3, 0.5 and 0.7%.

CONCLUSIONS

The optimum contents of BHH in the BWF dough ranged between 0.3–0.5%, providing a positive effect on resistance to extension and fermentation stability of the dough. Rheological experiments showed that incorporation of BHH, applied at low levels, had positive effects on the bread quality. These results were confirmed by a bakery experiment. A statistically significant relationship between BHH addition and the specific volume of BWF/BHH breads was found (control < 0.7% < 0.3% < 0.5%). At sensory evaluation, the best results were achieved at the addition of 0.5% BHH to BWF. All fresh and BWF/BHH breads after storage showed a higher elasticity of the crumb compared to the control. The BWF/BHH breads had higher penetration values and the hardness of the fresh breadcrumb significantly correlated with the crumb hardness at all storage times. The addition of BHH to BWF at a 0.5% level can be used to improve the flour quality, i.e. it can make flours stronger.

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