https://doi.org/10.17221/62/2018-PSE

Rheological properties of dough and baking quality of products using coloured wheat

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ABSTRACT

Hřivna L., Zigmundová V., Burešová I., Maco R., Vyhnánek T., Trojan V. (2018): Rheological properties of dough and baking quality of products using coloured wheat. Plant Soil Environ., 64: 203–208.

The experiment included testing of rheological properties of dough as well as the baking quality of bread flour and bran obtained by grinding coloured wheat grains with purple pericarp (cultivars Rosso, Konini and PS Karkulka) and blue aleurone (cv. Scorpion). Common wheat cv. Mulan was used for comparison. Formulas containing 10, 15 and 20% of bran were prepared. The addition of bran increased the water loss during baking by an average of 1.28%, specific volume of bread decreased by 2 to 10 mL, and the ratio number decreased from 0.57 to 0.51. The dynamic oscillatory rheometry simulated processes occurring during baking. A higher content of bran increased the complex viscosity of dough. In the initial stages of heating, the increasing presence of bran promoted dough weakening. Starch gelatinization was also influenced by the content of bran.

Keywords: *Triticum aestivum*; grain characteristics; dough rheology; baking experiment; anthocyanins

The effort to increase the nutritional values of commercial bakery products is a worldwide trend. An important role for the functional characteristics of these foods is played especially by antioxidants, which are able to capture free radicals (Pasqualone et al. 2015). Some specific genetic resources of wheat with unusual colouring of kernels have increased the content of beneficial substances with antioxidant effect as well as baking qualities of bread wheat. These include mainly cultivars with purple pericarp and blue aleurone that contain larger amounts of dyes (Bagheri and Seyyedin 2011).

Anthocyanins have many positive effects on human health. They prevent oxidative damage. They also exhibit preventive effects against cardiovascular diseases, cancer, rheumatoid arthritis, neurodegenerative diseases, and diabetes mellitus type 2 (Fang et al. 2002, Lutsey et al. 2007). And, these active substances cause the discoloration of unusual cultivars of wheat. The distinct coloration of the kernels is also caused by xanthophyll and carotenoid pigments. Colour wheat can be yellow, red, blue, and purple. In purple wheat, the dominant anthocyanins are cyanidin-3-glucoside and peonidin-3-glucoside. In the aleurone layer of blue wheat, the most represented is delphinidin-3-glycoside (Knievel et al. 2009). Martinek et al. (2012) show a higher content of anthocya-

The results and outcomes of the project (IP 38/2017) were prepared using instrumentation funded from the Research and Development for Innovations Operational Programme, Project No. CZ.1.05/4.1.00/04.0135 Teaching and Research Facilities for Biotechnological Disciplines and Extension of Infrastructure.

https://doi.org/10.17221/62/2018-PSE

Table 1. Milling and baking characteristics of used grain

Cultivar	Specific weight (kg/hL)	Protein content (%)	Zeleny sedimentation volume (mL)	Starch (%)	Hagberg falling number (s)
Mulan	79.53	10.6	29.0	68.9	328
PS Karkulka	78.60	14.2	21.4	65.8	350
Rosso	79.67	13.6	35.7	64.1	268
Konini	76.58	16.6	28.5	58.9	364
Scorpion	75.96	13.4	47.4	67.0	246

nins in the blue-grained cultivars compared with the purple ones. In the whole-grain flour from blue wheat, the content of anthocyanins is about 152.6 mg/kg, while the whole-grain flour from purple wheat contains about 92.83 mg/kg of anthocyanins (Abdel-Aal and Hucl 2003).

Colour wheat contains higher proportions of phenol compounds (Kequan et al. 2005, Liu 2007). Thanks to the content and effect of these substances, it may be possible to use coloured wheat grains in the production of functional foods. Colour pigments are contained mainly in the outer layers of the grain. Therefore, in order to increase the content of anthocyanins in the product, the addition of bran to the dough is needed.

Concentrations of these natural antioxidants and their proportions can fluctuate variably depending on a number of factors. Hydrothermal processing has a vast impact; degradation of polyphenols is directly proportional to rising temperature (Hou et al. 2013). Zhao et al. (2013) adds that the degradation of polyphenol dyes is caused not only by temperature and water, but also by the heating method. Wheat bran is not only the source of natural anthocyanins, but also vitamins, minerals, and fibre. Esposito et al. (2005) found that the content of soluble fibre in wheat bran ranges from 0.9% to 0.41%, while the insoluble fibre content is between 20.9% and 63%. Dietary fibre improves intestinal peristalsis, helps maintain proper levels of cholesterol and blood glucose, and supports the metabolism of fats (Liu 2007, Topping 2007). The addition of bran to the dough also extends shelf life of products. In addition to these positive effects, there may also be some undesirable effects such as volume reduction of bakery products (Kurek and Wyrwisz 2015). The aim of this study was to evaluate the effects of various additions of bran on the rheological properties of wheat dough and properties of biologically leavened bread.

MATERIAL AND METHODS

Material. In the assessment, four cultivars of coloured wheat were used, namely PS Karkulka, Rosso and Konini (purple cultivars) as well as Scorpion (blue cultivar). Common wheat cv. Mulan served for comparison. Table 1 summarizes the values of the grain specific weight (determined according to ISO 7971-2, 2010), protein content (ICC standard No. 167, 2000), Zeleny sedimentation volume (ISO 5529, 2011), starch content (ISO 10 520, 1997) and the Hagberg falling number (ISO 3093, 2011). Protein and starch contents are calculated in dry matter. The grain was then milled on a laboratory mill Chopin Moulin CD1 (Villeneuve-la-Garenne Cedex, France). Flour and bran were used to produce each formula. Within the baking experiment, a total of 15 baking formulas were baked and assessed (Table 2).

Table 2. Experiment cultivars

Wheat cultivar	Adding 10% bran		Adding 15% bran		Adding 20% bran	
	flour (g)	bran (g)	flour (g)	bran (g)	flour (g)	bran (g)
Mulan	450	50	425	75	400	100
PS Karkulka	450	50	425	75	400	100
Konini	450	50	425	75	400	100
Rosso	450	50	425	75	400	100
Scorpion	450	50	425	75	400	100

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Bread preparation and evaluation of bread quality. Wheat flour + bran (500 g), salt (7.5 g), sugar (5 g), yeast (25 g), oil (5 g) and water (300 mL) were placed into the bowl of the Zelmer Profi 380 kneader and were kneaded for 1.0 ± 0.5 min. Water addition was the same for all formulas. The dough was allowed to rise in a proofer at 32 ± 1°C and humidity of 80 ± 5% for 20 ± 5 min. After removal from the proofer, the dough was left for 10 ± 1 min to mature at the room temperature and weighed. The dough was manually shaped into loaves weighing 80 ± 1 g, and again allowed to rise at 32 ± 1°C and humidity of 80 ± 5% for 25 ± 5 min. Before loading into oven, the loaves were wetted with water and then baked at 230°C to 240°C in a laboratory oven with the Spólka proofer (Bydgoszcz, Poland). Just before baking, the oven was steamed with 50 mL of water. The baking time was 20 ± 2 min.

The baking experiment identified the basic characteristics of bread, namely baking loss, specific volume of bread, and the ratio number (height to width ratio of bread). It is necessary to supplement the methodology for determining the parameters.

Rheological properties of dough while warming. Oscillatory temperature ramp 30–90°C at 0.058°C/s was performed using the HAAKE RheoStress 1 (Thermo Scientific, Waltham, USA).

The dough samples were prepared according to the formulation used in breadmaking without oil and yeast. After mixing, the dough was left to rest at 30 ± 1°C for 5 ± 1 min in a sealed bowl. The sample was placed between 35 mm P35 Ti L parallel plates and compressed to a gap adjusted to 1.5 mm. The dough edges were afterwards trimmed with a spatula. The exposed side of the sample was coated with methyl silicone polymer Lukopren N1000 (Lučební závody a.s., Kolín, Czech Republic) to minimize dough drying out during the measurement. Temperature sweep test was performed at the strain of 0.1% and the frequency of 1 Hz within linear viscoelastic region (Burešová et al. 2017). The output from the HAAKE RheoWin software (version 1.3) were values of complex viscosity (η*). Gradients for the declining and rising parts of the curve B_1, B_2, and B_3 were calculated (Figure 1). Gradients B_1, B_2, and B_3 describe the extent of protein denaturation, starch gelatinization process, and dough stability during baking, respectively (Collar et al. 2007).

Statistical analysis. The results were statistically analysed using the ANOVA method. Statistical significance of differences was assessed using the Fisher's *LSD* (least significant difference) test at the significance level α = 0.05. Statistical analysis was performed with the Statistica 12 programme (StatSoft, Inc., Palo Alto, USA).

RESULTS AND DISCUSSION

Table 3 lists the results of the baking experiment. Loss of moisture occurs during baking. In common bakery products, these losses range from 10% to 13% depending on the shape and weight of the product, the time and temperature of baking, dough moisture, type of flour, etc. (Hampl and Příhoda 1985). The highest loss through baking (13.83%) was observed in the cv. Rosso with 20% of added bran. In contrast, the lowest loss through baking was measured in the cv. Scorpion 2015 with 10% of added bran. With increasing content of bran in dough, baking losses increased on average. Bran is strongly hygroscopic, but it has a low affinity for water. This results in the release of more previously absorbed water during the baking process (Roozendaal et al. 2012).

The most important quality parameter is the specific volume of baking products. The higher the specific volume of baking goods, the more suitable is the wheat cultivar for bakery production (Müllerová and Skoupil 1988). Specific volume of bread was reduced with the addition of bran. Bread produced from cv. Mulan with 20% added bran had the lowest specific volume (252 mL/100 g). The highest volume (348 mL/100 g) occurred in breads made from the cv. Konini with 10 per cent of added bran. It turned out that the

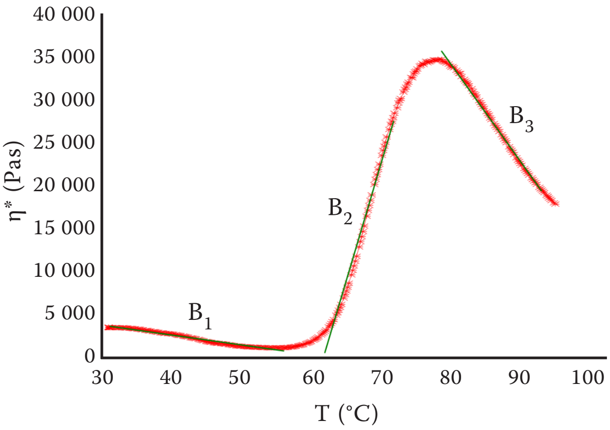

Figure 1. The method of calculation of the slopes between the ascending and descending parts of curve; B_1 – protein breakdown; B_2 – gelatinization rate; B_3 – cooking stability rate

https://doi.org/10.17221/62/2018-PSE

Table 3. Results of the baking experiment

Wheat cultivar	10% bran added			15% bran added			20% bran added		
	1	2	3	1	2	3	1	2	3
Mulan	10.89	264	0.49	10.88	260	0.58	11.39	252	0.48
PS Karkulka	12.22	292	0.59	11.77	292	0.52	11.88	284	0.56
Konini	11.23	348	0.53	12.61	344	0.51	13.10	342	0.49
Rosso	12.41	272	0.67	10.71	272	0.65	13.83	264	0.53
Scorpion	10.36	296	0.55	11.51	292	0.52	13.31	280	0.47
Average	11.42	294	0.57	11.50	292	0.56	12.70	284	0.51

1 – loss through baking (%); 2 – specific volume of bread (mL/100 g); 3 – ratio number (height/length)

cultivars with 10% and 15% of bran did not show large differences, and volume reduction of breads averaged only 2 mL/100 g. Further increase to 20% did already show a significantly deeper reduction. The found results can be put into context with the ability of bran particles to interfere with formation of the gluten network in dough. Simultaneously, they also bind large amounts of water, which is needed for the development of gluten. Insufficient formation of gluten and violation of its structure consequently causes lower volume of bread (Brennan and Cleary 2007, Almeida et al. 2013).

Bread shape is related to the ratio number. Kučerová et al. (2014) consider flour to be very good, if the value of ratio number is 0.700, and good, when the ratio number ranges from 0.601 to 0.699. This value was reached only in the Rosso wheat cultivar with 10% and 15% of added bran. With increasing content of bran in the product, the ratio number decreased. Products with the highest addition of bran were characterized by low and flat shape.

The volume and shape of bread very closely correlate with its porosity. Achieving the desired porosity of bread depends upon the optimal course of viscosity changes in the dough during baking. The dough viscosity during baking must first enable the gradual accumulation of gas in closed pores. After exceeding the critical pressure of gas in the pores, the dough breaks, gas migrates between the neighbouring pores, and then escapes from the product to the ambient environment (Zhang et al. 2007, Mondal and Datta 2008). At this stage of baking, the texture of the product does not collapse, because the texture is fixed due to the viscosity of starch paste. Changes in viscosity during baking of wheat dough depend primarily on the changes in starch and properties of proteins. The course of changes is influenced by the temperature of dough during baking and the amount of water present (BeMiller and Whistler 2009). During baking, the dough temperature inside the product will increase from 30°C to 90°C (Ranken et al. 1997).

Thermally-induced changes of dough viscosity may be related to the content of proteins and their characteristics, starch content and degree of its damage, the content and properties of non-starch polysaccharides, fibre and the amount of water present. The substances present in dough are known to interact with each other. The bran added to the dough can be expected to affect these interactions. At the beginning of the measurement, values of complex viscosity gradually decreased (Figure 2), as evidenced by the negative values of the B_1 parameter (Table 4). In this phase of the measurement, the dough progressively softened. Softening can be put into the context with a gradual release of water from the denatured proteins. Although dough behaviour at this phase of heating can be expected to be influenced by the content of proteins and their characteristics, mechanical load caused by kneading the dough may have played a role in samples with a higher proportion of bran, which supported the dough softening of most tested cultivars.

This corresponds with a high water binding capacity by bran and the inability to sustain this moisture (Roozendaal et al. 2012). The temperature at which softening stopped was not affected by adding bran. In contrast, the values of the minimum complex viscosity η^*_{min} were significantly different. In general, increased addition of bran increased the value of minimum viscosity. Significant differences ($P = 0.95$) were recorded after adding 15% and 20% of bran. To prepare the samples, the same amount of water was used. Water can be expected to be absorbed by proteins, damaged starch granules, bran and other substances. The amount of water absorbed by differ-

https://doi.org/10.17221/62/2018-PSE

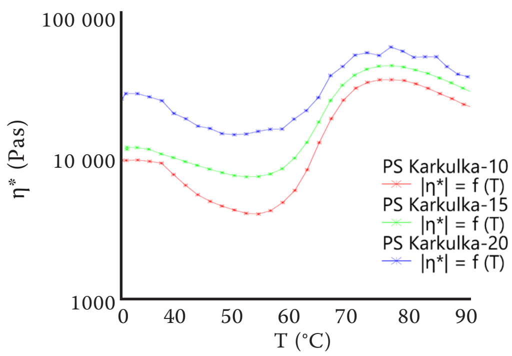

Figure 2. Thermally-induced changes in complex viscosity flour prepared from PS Karkulka with 10, 15 and 20% bran addition

ent substances is, moreover, impacted by the content and solubility of wheat polysaccharides, which was also evident during the starch gelatinization process.

It can be assumed that the higher share of bran in the dough, the more water was bound in the bran. Therefore, the dough with the addition of bran was stiffer at the beginning of the measurement than dough without bran. After reaching the temperature of denaturation of the proteins, the denatured proteins began to release water. Based on the results, it can be assumed that the water bound in bran was also released. However, the presence of swollen bran significantly (P = 0.95) increased the dough consistency, wherein the dough consistency with the addition of 15% and 20% of bran was significantly higher than in the dough with only 10% of bran.

During further warming, the dough progressively solidified as evidenced by the positive values of B_2 (Table 4). Solidification of the dough can be explained by achieving of starch gelatinization temperature. At this temperature, water released from the protein was gradually consumed by starch to swell the starch granules and subsequent gelatinization. During gelatinization, swollen starch granules ruptured, amylose from the outer parts of the granules was released into the environment and the amylose double helix disintegrated. After the release from the granule, amylose chains gradually restored the regular arrangement and interlinked with hydrogen bonds, which resulted in a sharp rise in complex viscosity values. If the sample included 15% or 20% of bran, then the bran contained bound water that was in the sample without bran used for starch gelatinization. It can be assumed that starch gelatinization in samples with 15% and 20% of bran content was slowed by lower amounts of free water. The described influence of bran on the behaviour of dough in this phase of measurement was only detected in some samples of bran. Therefore, its influence on the dough behaviour was not as significant as in the initial stages of warming. Additionally, higher peak complex viscosity was reached in dough prepared from cvs. Rosso and

Table 4. The effect of adding wheat bran on the performance of dough during warming from 30°C to 90°C

Wheat cultivar	Bran share (%)	B_1 (Pa s/°C)	T_{min} (°C)	η^*_{min} (Pa s)	B_2 (Pa s/°C)	T_{max} (°C)	η^*_{max} (Pa s)	B_3 (Pa s/°C)
Mulan	10	–310 ± 20^{cd}	49 ± 3^{a}	4900 ± 300^{b}	1800 ± 200^{bc}	70 ± 9^{a}	35 000 ± 2000^{ab}	–900 ± 100^{cd}
	15	–190 ± 30^{e}	48 ± 3^{a}	5300 ± 500^{b}	2300 ± 200^{d}	70 ± 9^{a}	36 000 ± 2000^{b}	–1000 ± 100^{g}
	20	–210 ± 30de	47 ± 4^{a}	9300 ± 900^{c}	2600 ± 200^{d}	70 ± 8^{a}	44 000 ± 3000^{c}	–1100 ± 100^{f}
PS Karkulka	10	–220 ± 30^{cd}	49 ± 4^{a}	4200 ± 700^{ab}	3400 ± 200^{f}	70 ± 8^{a}	35 000 ± 3000^{ab}	–910 ± 100^{a}
	15	–310 ± 40de	50 ± 4^{a}	7600 ± 400^{c}	3000 ± 200^{ef}	69 ± 7^{a}	44 000 ± 2000^{c}	–1000 ± 100^{b}
	20	–740 ± 90^{b}	46 ± 3^{a}	15 000 ± 1000^{d}	2600 ± 100^{d}	70 ± 8^{a}	61 000 ± 4000^{d}	–1400 ± 200de
Konini	10	–61 ± 7^{f}	51 ± 3^{a}	2800 ± 100^{a}	1370 ± 90^{ab}	86 ± 9^{a}	29 000 ± 2000^{a}	–1000 ± 100^{a}
	15	–230 ± 30de	51 ± 4^{a}	19 000 ± 1000^{e}	1500 ±100^{b}	68 ± 9^{a}	48 000 ± 3000^{c}	–700 ± 100^{ab}
	20	–400 ± 60^{c}	51 ± 3^{a}	27 000 ± 2000^{f}	1060 ± 70^{a}	72 ± 8^{a}	68 000 ± 4000^{d}	–1000 ± 100de
Rosso	10	–80 ± 10^{f}	59 ± 4^{b}	4800 ± 300^{b}	1800 ± 100^{bc}	78 ± 8^{a}	36 000 ± 2000^{b}	100 ± 10de
	15	–94 ± 7^{f}	60 ± 4^{bc}	5900 ± 400^{b}	1600 ± 200^{b}	80 ± 9^{a}	41 000 ± 3000^{bc}	520 ± 80^{cd}
	20	–260 ± 20^{d}	55 ± 4^{b}	14 300 ± 900^{d}	2300 ± 300^{d}	73 ± 9^{a}	57 000 ± 3000^{d}	–1000 ± 100^{bc}
Scorpion	10	–210 ± 30de	53 ± 3^{ab}	3900 ± 200^{ab}	2800 ± 200^{e}	84 ± 9^{a}	37 000 ± 2000^{b}	–1300 ± 100^{cd}
	15	–420 ± 60^{c}	51 ± 3^{a}	9800 ± 900^{c}	2700 ± 200de	71 ± 8^{a}	48 000 ± 3000^{c}	–1100 ± 100^{d}
	20	–1500 ± 100^{a}	57 ± 3^{b}	37 000 ± 3000^{g}	2600 ± 200^{d}	74 ± 9^{a}	99 000 ± 6000^{e}	–800 ± 100de

The mean values ± standard deviation followed by different letters in the column differ significantly (P < 0.05)

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Scorpion flour, which exhibited a higher activity of amylase recorded as lower values of the Hagberg falling number. Although the presence of bran had no significant effect on the temperature at which the maximum value of complex viscosity had been reached, the peak viscosity values were generally higher for samples with a higher proportion of bran. Even if the differences in the temperature at which the peak complex viscosity were not significant, the variation between flours may be attributed to the different content of the substances, variation in their characteristics, and also to the interactions between substances.

In conclusion, testing of the use of mill products (flour, bran) obtained from the coloured wheat demonstrated that it is possible to apply them in the manufacture of bakery products. Bakery product quality was greatly influenced by the quality of the raw materials used. It turned out that a higher amount of added bran gave lower product quality, increased loss through baking, and reduced the specific volume of bread and value of ratio number. Adding higher amounts of bran significantly affected the viscoelastic properties of dough and textural properties of the product.

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Received on January 25, 2018
Accepted on April 9, 2018
Published online on April 18, 2018