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Effect of Wheat Bran Addition and Screw Speed on Microstructure and Textural Characteristics of Common Wheat Precooked Pasta-Like Products.

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Key words: extrusion-cooking, precooked pasta-like products, common wheat flour, wheat bran, microstructure, texture, sensory characteristics

The present paper describes the wheat bran addition on microstructure, texture, colour and sensory characteristics of enriched precooked pasta--like products. Precooked pasta-like products were processed on a single screw extrusion-cooker TS-45 with L:D=16:1, shaped on the circular open die. Screw speed during the extrusion-cooking ranged from 60 to 120 rpm. Wheat bran were added in the amount from 5 to 25% of common wheat flour mass. The microstructure showed unmodified bran fractions at low screw speed, in turn higher rpm disrupted wheat bran cell walls. Hardness of dry pasta-like products, evaluated with the cutting test, was diminishing with a higher bran content in the recipe and was increasing with rpm applied. The firmness of hydrated products was decreasing with increasing bran addition (20 and 25% of bran in the recipe), whilst processing at low rpm caused poor quality of pasta-like products with great adhesiveness and stickiness. The higher bran content affected also the lower sensory notes. Colour measurement showed lower L^* values for both raw and hydrated products with higher bran addition.

INTRODUCTION

There are known technological solutions for processing precooked or instant pasta using different types of extruders [Baumann, 1977; Huber & Wenger, 1998; Seltzer & Hamilton, 1985; Wang *et al.*, 1999]. The nutritional value and sensory characteristics of these pasta-like products depend on processing technology and final treatment needed for starch gelatinization (steaming or fat frying) [Juan & O'Ngadi, 2004]. Application of extrusion-cooking allows high starch gelatinization without any additional treatment [Huber, 1988; Vasanthan, 2003; Wang *et al.*, 1999; Wójtowicz & Mościcki, 2009]. Proper selection of process parameters, such as temperature, pressure, heating-cooling program or moisture content of raw materials affect processing intensity, starch gelatinization and the formation of a stable shape and structure of a finished product [Singh & Smith, 1997; Wójtowicz & Mościcki, 2008; Yalla & Manthey, 2006].

In response to potential health benefits and dietitians' suggestions, new assortments of healthy products are widely developed, *i.e.* enriched bread, breakfast cereals, cookies, snacks or pasta containing whole grains, bran or germs [Chillo *et al.,* 2008; Pınarlı *et al.,* 2004]. For the technological reasons, pasta products based on fiber-rich raw materials or with high bran contribution in the recipe, are difficult to process due to a high content of fiber, thus in many bakery and snacks products they are replaced with functional fiber additives or resistant starch [Sozer *et al.,* 2007].

A variety of characteristics may be evaluated for an assessment of pasta properties and the effect of additives applied. The most common are: cooking and overcooking time, colour, stickiness, bulkiness, cooking loss, and sensory characteristics. Ample results have been reported for textural parameters, including hardness, firmness, adhesiveness, stickiness, elasticity, elongation, springiness, texture modulus, like Young modulus or tensile and compression [D'Egidio & Nardi, 1996; Ross, 2006; Sissons *et al.*, 2008a,b]. In turn, microstructure analyses are often used for visual confirmation of internal structure changes in food components during pasta-like products processing and afford a number of possibilities to explain products' properties and quality [Wang *et al.*, 1999; Wójtowicz, 2005; Wójtowicz & Mościcki, 2009].

The aim of this study was to evaluate the microstructure, colour, textural and sensory characteristics of enriched common wheat precooked pasta-like products and the influence of both: wheat bran addition and a screw speed on the quality of products processed by extrusion-cooking.

MATERIALS AND METHODS

Precooked common wheat pasta-like products processing

Common wheat flour (Polskie Młyny, Warszawa, Poland) was used as the base raw material. Wheat bran (Sante, Sobo-

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lew, Poland) was used in the amount from 5 to 25% of flour mass. Recipes with different bran addition were moistened to the final dough moisture content of 30% and processed using a modified single screw extrusion-cooker TS-45 (Polish design, Metalchem, Gliwice) with L:D=16:1 and compression rate of 3:1 at the temperature in the first zone – 85°C, second zone – 100°C, cooling zone – 75°C, and shaped on the open die with 12 outlets 0.8 mm each. Screw speed during the extrusion-cooking ranged from 60 to 120 rpm. After cooling and short drying (4 h at 40°C) to the moisture content of 6.5–7.0% the pasta-like products were stored in plastic bags at a room temperature before tests and described as dry products. Dry and hydrated products were taken for further analysis. Hydration process was performed by the addition of 300 mL of hot water just after boiling (98°C) to 25 g of enriched dry pasta-like products, according to their optimal preparation time [Wójtowicz, 2009]. After hydration, the samples were rinsed with cold water and drained for 5 min just before tests.

SEM analysis

SEM pictures of different composition precooked pasta--like products, processed at varied screw rpm were analysed at different magnifications to observe the surface and cross-section of dry samples. To this end, 0.5 cm pieces for surface and specimens of 2 to 3 mm in length for cross-section analyses were applied on carbon discs using a silver tape and sprayed with gold in a vacuum sublimator Sputter Coater CS100 (Unimed Electronics, Poland). The obtained specimens were examined with a BS-300 scanning electron microscope (Tesla, Czech Republic) at the accelerating voltage of 25 kV. Pictures were taken in magnifications of x100 and x600 for surface or x125, x600 and x2000 for cross-section analyses.

Textural properties

Universal testing machine Zwick BDO-FB0.5TH (Zwick GmbH & Co., Germany) was used for texture evaluation. Both, for hardness of dry products and firmness of hydrated pasta use was made of a steel blade 3 mm thick and 60 mm long, double-face truncated at an angle 45°. Hardness of dry pasta-like products enriched with bran and processed under different screw rpm was measured as breaking force (N) for single pasta thread during the breaking test as mean of 10 replications. Test head speed was 100 mm/min. Hardness was evaluated as the maximum force at break. Texture of hydrated products for firmness evaluation of hydrated pasta-like products was measured as cutting force in five replications for each sample depending on bran addition and screw speed applied during processing. Spaghetti firmness was defined as the height of the peak, which is analogous to the maximum cutting force (N) [Smewing, 1997]. Single pasta thread was removed after every single minute of hydration in hot water (98°C), cooled down immediately by soaking in cold water and cut. Test head speed of 100 mm/min was used and *TestXpert*® program was applied for curves analysis.

Colour profile measurements

Colour of pasta enriched with wheat bran was tested on dry and hydrated samples using Colour and Appearance Measurements System Lovibond CAM-System 500 (The Tintometer Ltd., UK). CIE-Lab scale was used for evaluation of L^* for brightness, a^* for (+)redness-(-)greenness and b^* for (+) yellowness-(-)blueness, accordingly. Measurements were performed in 20 replications. Calibration tile values were: $L^*=96.5$, $a^*=2.0$ and $b^*=0.4$.

Sensory evaluation

Sensory characteristics of pasta-like products with bran addition evaluated the taste, colour, flavour, firmness, stickiness, and overall quality of hydrated pasta. Enriched products were hydrated in hot water for adequate preparation time for each sample, rinsed with cold water, drained, and placed in warm conditions until testing. A 15-member semi-trained panel judged pasta-like products in a 5-point scale (1—for weak, 5—for very good).

Statistical analysis

The results were analysed by statistical software Statistica 6.0. Differences in means of results, due to wheat bran addition or the screw rpm applied, were tested and correlations between functional properties of pasta were examined. The analysis of variance ANOVA was conducted for significance at a confidence level of 95% ($p=0.05$); the significance of differences between mean values was assessed with the Duncan's multiple range test.

RESULTS AND DISCUSSION

Microstructure of enriched pasta-like products

Microstructure of common wheat pasta-like products enriched with wheat bran observed on SEM, showed that the influence on both surface and the internal structure of precooked pasta-like products was caused by bran inclusion and extrusion-cooking screw speed. The surface of samples observed with magnification of x600 showed a significant influence of screw speed during processing on the outside uniformity, *i.e.* products processed at low screw rpm showed corrugated surface (Figure 1a, 1c), while higher screw rpm resulted in uniform and smooth surface of the products (Figure 1b, 1d). Bran addition used to enrich common wheat precooked pasta-like products caused more rugged surface but differences were more visible in the internal structure. In most cases the samples showed compact and dense structure formed as starch and protein matrix (SPM) with only few ungelatinized starch granules (S) visible close to bran (B) parts (Figure 2a). The application of low screw speed during processing caused greater changes in the internal composition observed on cross-sections of pasta-like products, than the highest rpm used. The impact of screw speed and thus treatment intensity on the internal structure was found to be significant. The samples of products enriched with 5% of wheat bran showed compact internal structure with rarely visible singular wheat bran unconverted parts (Figure 2a, 2b). In contrary, SEM observations of the samples enriched with 20% of wheat bran showed a much higher number of bran particles in the internal structure, where untreated bran surface and cellular character of the external fiber layer was clearly visible (Figure 3a, 3b). Due to fibrous composition of bran, separations of singular fibers during extrusion-cooking could be observed. More-

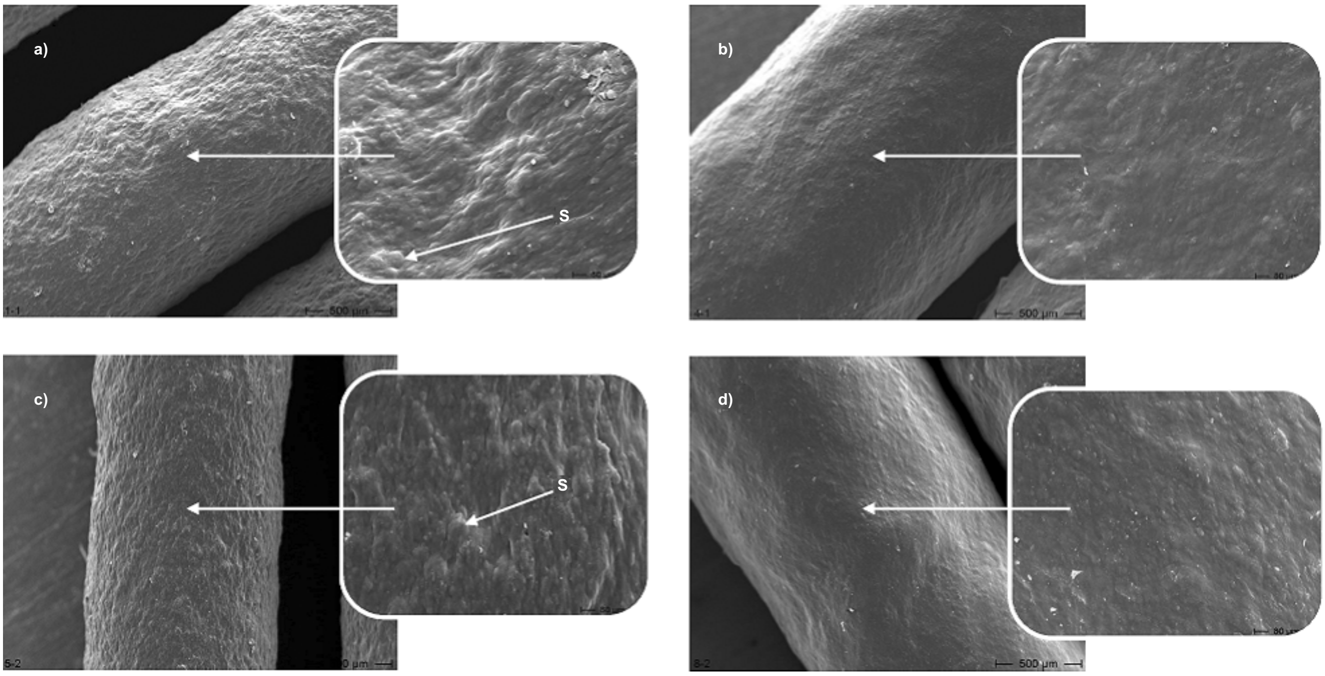

FIGURE 1. Surface of precooked pasta enriched with 5 and 20% of wheat bran processed at different screw speed: a) 5% of bran, 60 rpm, b) 5% of bran, 120 rpm, c) 20% of bran, 60 rpm, d) 20% of bran, 120 rpm. Magnifications: left pictures x100, right pictures x600. Notes: S – starch granule.

over, some spoil and/or empty places nearby fiber parts appeared which affected weaker structure and lower hardness of the products with high addition of wheat bran.

The surface of the commercial spaghetti appeared to be dense and compact, and coated with a smooth protein film with few openings and some visible starch granules of varying size. The pasta-like pea product processed by Wang *et al.* [1999] also exhibited a dense, compact structure, with relatively few swollen starch granules. Their products appeared to be completely coated with a gelatinized starch and protein matrix. Izydorczyk *et al.* [2005] reported the presence of specks in fiber-rich barley fractions supplemented noodles, clearly originated from the fragments of the endosperm cell walls, aleurone and bran, embedded within the noodle's internal structure. Micrographs of the control durum raw noodles showed a much more uniform and continuous protein–starch matrix. Similar effects have been noticed during our observations (Figure 3a, 3b). Insufficient water content

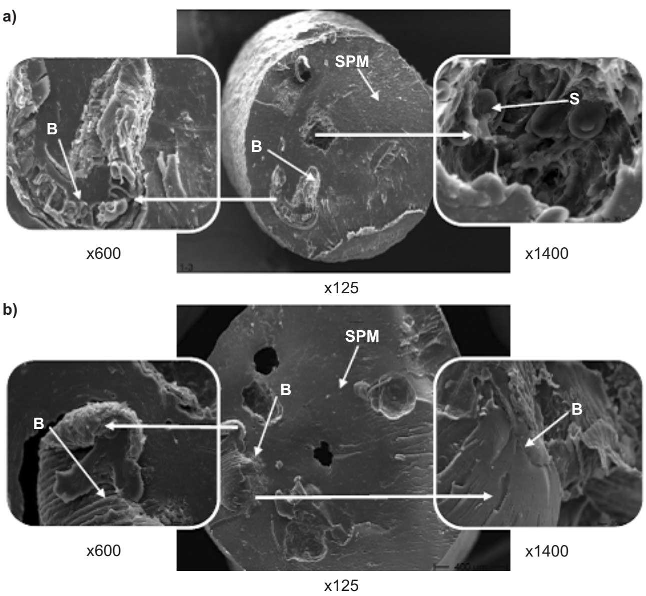

FIGURE 2. Cross-section of precooked pasta enriched with 5% of wheat bran processed at: a) 60 rpm, b) 120 rpm, with different magnifications. Notes: SPM – starch-protein matrix, S – starch granule, B – bran fraction.

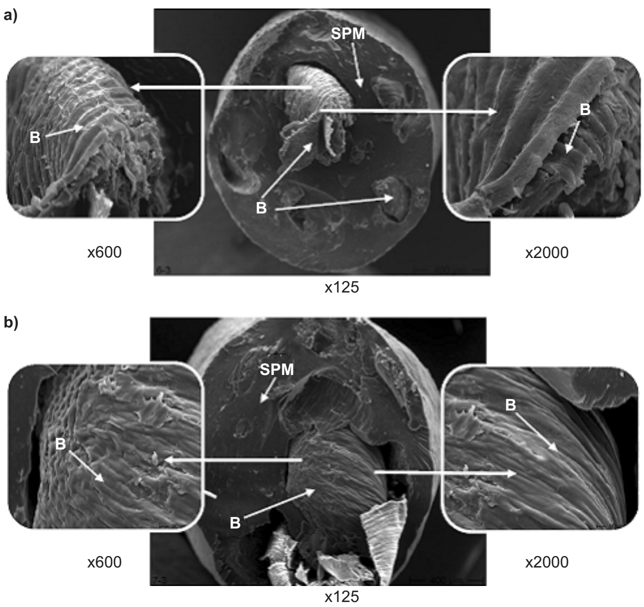

FIGURE 3. Cross-section of precooked pasta enriched with 20% of wheat bran processed at: a) 80 rpm, b) 100 rpm, with different magnifications. Notes: SPM – starch-protein matrix, S – starch granule, B – bran fraction.

(below 30%) and low screw speed (60 rpm) were reported to prevent the formation of solid structure of samples, and singular swollen starch granules were clearly visible [Wójtowicz & Mościcki, 2009]. Applications of higher dough moisture content and higher screw speed during the extrusion-cooking generated more compact and uniform structure corresponding with high starch gelatinization degree and formation of SPM.

Texture of dry and hydrated precooked common wheat pasta-like products

Hardness of dry samples evaluated with the cutting test was observed to decrease with increasing bran content in the recipe (R^2=-0.41) and increased with screw speed used (R^2=0.60). Their hardness ranged from 17.3 N for products processed at 120 rpm to 2.6 N when 60 rpm was applied. Addition of wheat bran influenced intensive hardness decrease (R^2=-0.87) of enriched pasta processed at 120 rpm (Figure 4) from 16.8 N when 5% of bran was added to 4.2 N, when 25% of bran was applied. In the case of lower screw speed, the differences were much smaller. Lee *et al.* [2008] observed the texture of dry noodles and found that the cutting force of the noodle samples was significantly affected by the level of alginate added as a fiber source. While the control exhibited the lowest cutting force, the use of alginate yielded an increase in the cutting force of the noodles.

The firmness of hydrated products was measured after every single minute of hot water hydration. Values of cutting forces were dependent on both: bran addition and screw speed used (Figure 5). The main differences in cutting forces were observed between first to third minute of hydration, longer hydration time mitigated the differences and after four minutes of hydration firmness values were lower than 1 N for most of the samples. Only products enriched with 5% of bran showed higher firmness throughout hydration time, especially those processed at 100 and 120 rpm. Extrusion-cooking at low rpm caused low firmness, great adhesiveness and stickiness. The presence of a high amount of crude fiber (up to 20%) disrupted the internal structure of pasta, making difficult the keeping of dough consistency due to weak mixing of pasta components. Wang *et al.* [1999] presented a similar tendency for pea flour pasta-like products processed using a twin-screw extruder. Measurements of the screw speed influence on mechanical properties of extrudates usually showed the increased hardness of extrudates with higher rpm used [Wójtowicz, 2009]. It results from intensive starch transformation and formation of protein matrix inside the products. Pasta firmness can be related to the hydration of starch granules during the cooking process and the subsequent embedding of gelatinizing starch granules in a matrix of partially denatured protein. Increasing amount of bran lowered the total starch content, whereas increasing fiber content made transformation of starch into homogenous SPM more difficult. As such, the decrease in firmness may be associated with reduced starch gelatinization in the pasta [Brennan *et al.,* 2004].

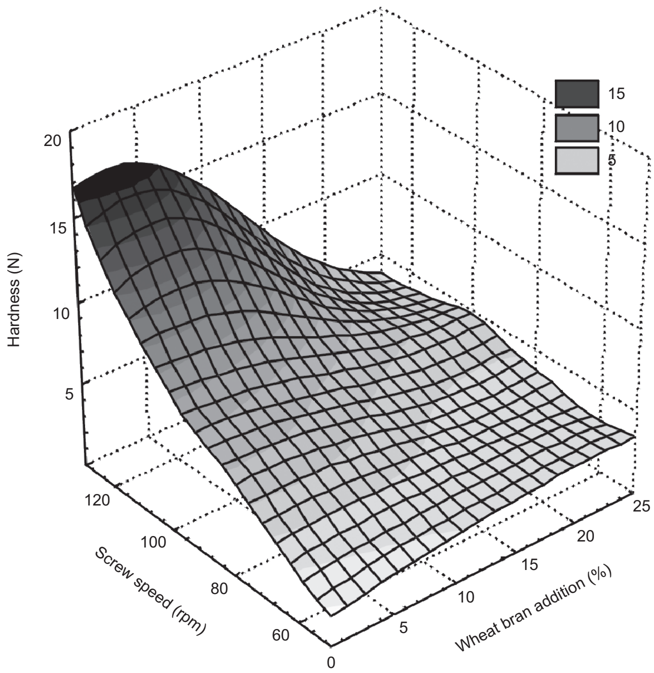

FIGURE 4. Hardness of dry precooked pasta enriched with different levels of wheat bran processed at different extrusion-cooking screw speed.

Colour evaluation

Colour measurements showed lower L^* values, for both: dry (from 71.6 to 56.1), and hydrated (from 81.3 to 68.9) pasta-like products with higher bran addition (R^2=-0.93 and R^2=-0.94, accordingly). For common wheat flour pasta--like products processed without additives L^* values reached 83.8 for dry and 87.8 for hydrated pasta. There were no significant differences between colour of the samples as affected by the screw speed applied during extrusion-cooking. It was confirmed during sensory assessment by a semi-trained panel. The greenness-redness balance for dry pasta-like products varied from -4.6 for control samples without bran addition to 3.6 for products enriched with 25% of wheat bran. The same tendency was observed for the hydrated products (Table 1). The appearance of red colour may be due to non-enzymatic browning related to Maillard or carbonyl-amino reactions developed between proteins and sugars [Mościcki *et al.*, 2007]. But also the nature of bran used in the experiments may be the key factor of redness improvement with increasing wheat bran addition (R^2=0.97 for dry and R^2=0.99 for hydrated products). Yellowness of pasta-like products was observed mainly in the wheat bran-enriched samples, especially in dry products (R^2=-0.98). Common wheat has poor yellow index because of the negligible presence of carotenoids, therefore precooked pasta-like products showed minimal values of yellow colour. For hydrated samples with bran addition not exceeding 15%, the b^* values were observed to increase, whereas the higher bran content in the recipe affected lower values of yellow colour and an intensive increase of redness in these samples. Both, for dry and hydrated products, the b^* values were much higher for pasta-like products enriched with wheat bran compared to the common wheat control sample. Similar tendencies were observed by Chillo *et al.* [2008], Pınarlı *et al.* [2004] and Izydorczyk *et al.* [2005].

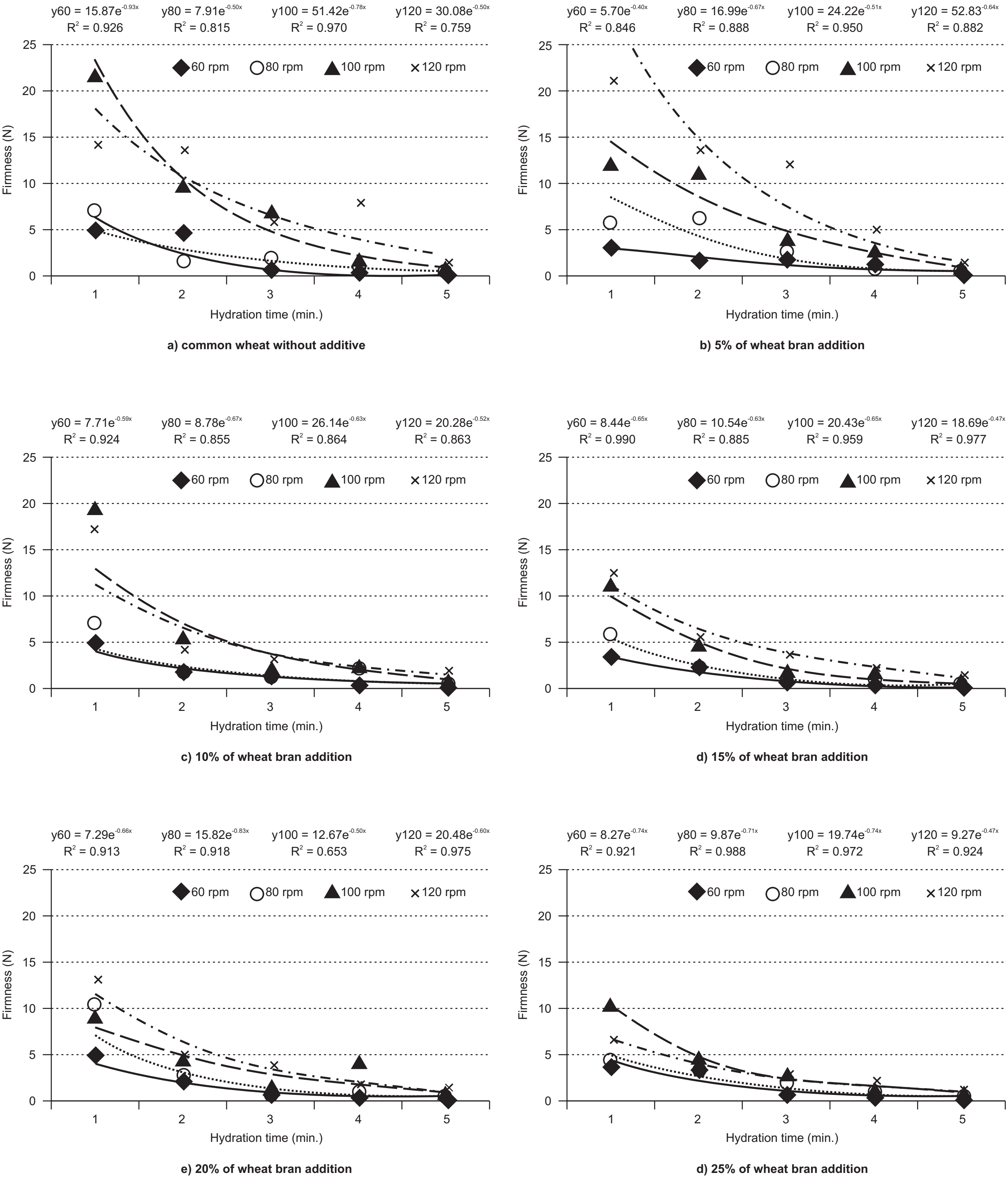

FIGURE 5. Firmness of hydrated precooked pasta enriched with different levels of wheat bran processed at different extrusion-cooking screw speed. Curves and coefficients are results of exponential functions.

Sensory properties

Results of sensory attributes evaluation, *i.e.* appearance, shape keeping, colour, taste and consistency of common wheat pasta-like products processed at 100 rpm determined by semi-trained panel, are presented in Table 2. There were significant differences between the tested samples as affected by both bran addition and screw speed used. The higher bran addition caused lower sensory scores (R^2=-0.95), which could be associated with the presence of harder in bite particles of bran and specific taste according to the floury taste of wheat bran. The application of the higher screw speed during extrusion-cooking improved the sensory qual-

TABLE 1. Colour values in $L^*a^*b^*$ scale of precooked dry and hydrated pasta-like products enriched with different amount of wheat bran processed at 100 rpm.

Wheat bran addition	Dry pasta-like products			Hydrated pasta-like products		
	L^*	a^*	b^*	L^*	a^*	b^*
Control	83.8±1.72[a]	-4.6±1.11[a]	16.1±2.25[a]	87.8±2.03[a]	-4.7±1.43[a]	12.0±2.12[a]
5%	71.6±2.24[b]	-3.2±1.67[b]	35.8±2.24[b]	81.3±2.14[b]	-3.3±1.33[ab]	27.8±2.62[b]
10%	63.5±2.63[c]	0.2±1.44[c]	34.0±2.24[bc]	75.6±2.17[c]	-2.0±1.52[b]	31.8±2.37[bc]
15%	62.1±3.72[c]	1.8±1.56[d]	32.7±2.74[c]	75.3±2.96[c]	-1.2±1.15[bc]	32.8±3.09[c]
20%	57.9±4.53[d]	3.1±1.94[e]	32.4±4.12[c]	74.7±2.30[c]	0.2±1.05[c]	32.1±2.04[c]
25%	56.1±3.38[d]	3.6±3.08[e]	30.0±3.07[d]	68.9±3.54[d]	1.1±1.66[d]	29.3±3.67[b]

L^* – brightness, a^* (+)redness, (-)greenness, b^* (+)yellowness, (-)blueness, values are means of 20 replications ± standard deviations; [a,b,c] – the same letters in columns indicate no significant differences between mean values at p=0.05 (Duncan's test).

TABLE 2. Sensory assessment of pasta-like products enriched with wheat bran processed at 100 rpm.

Wheat bran addition	Sensory characteristics					Overall quality
	Appearance	Shape keeping	Colour	Taste	Consistency	
Control	5.00±0.00[a]	5.00±0.00[a]	5.00±0.00[a]	4.95±0.05[a]	5.00±0.00[a]	4.99[a]
5%	4.95±0.13[a]	5.00±0.00[a]	4.95±0.07[a]	4.95±0.08[a]	4.95±0.06[ab]	4.96[ab]
10%	4.65±0.30[b]	4.85±0.14[ab]	4.85±0.11[ab]	4.50±0.17[b]	4.85±0.09[b]	4.74[b]
15%	4.20±0.16[c]	4.60±0.20[b]	4.50±0.15[b]	3.60±0.33[c]	4.20±0.19[c]	4.22[c]
20%	3.55±0.37[d]	3.10±0.27[c]	3.65±0.22[c]	2.65±0.23[d]	3.25±0.31[d]	3.24[d]
25%	3.15±0.29[d]	2.40±0.18[d]	3.10±0.18[d]	2.20±0.22[e]	2.55±0.26[e]	2.68[e]

Values are means of scores given by 15-person panel ± standard deviations. Overall quality scores are means of all sensory characteristics. [a,b,c] – the same letters in columns indicate no significant differences between mean values at p=0.05 (Duncan's test).

TABLE 3. Overall quality of wheat bran enriched pasta-like products processed at different screw speed.

Screw speed (rpm)	Wheat bran addition						
	control	5%	10%	15%	20%	25%	R^2
60	4.32[c]	3.85[c]	3.62[c]	3.40[c]	2.82[c]	2.25[c]	*-0.98*
80	4.75[b]	4.65[b]	4.23[b]	3.96[b]	3.10[bc]	2.50[bc]	*-0.97*
100	4.99[a]	4.96[a]	4.74[a]	4.22[ab]	3.24[b]	2.68[b]	*-0.95*
120	4.98[a]	4.88[ab]	4.76[a]	4.40[a]	3.85[a]	3.45[a]	*-0.96*
R^2	*0.91*	*0.87*	*0.94*	*0,97*	*0.96*	*0.94*	

Values of overall quality scores are means of all sensory characteristics judged by 15-person panel. R^2 – correlation coefficient was calculated depending on screw speed used and separately for each of bran addition level; [a,b,c] – the same letters in columns indicate no significant differences between mean values at p=0.05 (Duncan's test).

ity (R^2=0.94), diminished viscosity and improved the shape keeping and taste of the products. This may be explained by better mixing of components during intensive baro-thermal treatment (higher shearing stress), formation of a starch-protein matrix during processing at the temperature higher than starch gelatinization temperature and higher moisture content in raw materials [Mościcki *et al.*, 2007]. The overall quality of pasta-like products enriched with wheat bran lowered, especially when bran level in the recipe was higher than 20% (Table 3). Darker colour was noted for the samples enriched with 20 and 25% of wheat bran, and shiny and smooth surface of pasta strands disappeared; products became sticky and lost their consistency. These products appeared to be darker than commercial durum or common wheat products, but it should not be considered to the lower quality of pasta, because consumers usually associate the pasta rich in dietary fiber with a darker colour [Izydorczyk *et al.*, 2005].

CONCLUSIONS

In summary, it may be concluded that the quality of precooked common wheat flour pasta-like products enriched with wheat bran was strongly dependent on both bran addition and screw speed used. The microstructure of samples processed at low screw speed showed the presence of ungelatinized starch granules and fibrous integrated structure of wheat bran. The higher screw speed applied during the extrusion-cooking allowed to form stable and compact internal structure. The addition of wheat bran determined the internal structure of products: a lot of bran particles were observed when bran addition exceeded 15%. This additionally influenced darker colour, higher redness and higher yellowness of dry and hydrated pasta-like products.

Increased bran content in the products lowered scores of their sensory characteristics. The most important factor in this respect appeared to be the screw speed applied during the extrusion-cooking. Processing of bran-enriched common wheat precooked pasta-like products at low screw speed caused poor product's quality with low firmness and high adhesiveness and viscosity. Higher screw speed applied during processing improved sensory attributes and firmness of the products. The best pasta-like products were obtained by extrusion-cooking at 100 and 120 rpm when moisture content of dough reached 30% and bran addition did not exceed 20%.

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