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Investigation of New Food Processing Possibilities for Buckwheat

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ABSTRACT

In this work, the possibility of exploiting 'Hajnalka', a Hungarian buckwheat variety, was investigated as a raw material for hydrothermal technologies. The physical and chemical effects of hydrothermal food processing operations on certain characteristics of buckwheat were also examined. Regarding the ultrastructure of grains, great changes could be observed in every case. The techno-functional properties, e.g. the water and oil binding capacities of hydrothermally treated grains increased. The total protein content was high, as for groat and flake 15.5 g/100 g dry matter. The lysine content (3.18 and 3.10 g/100 g protein for groat and flake, respectively), as well as vitamin (riboflavin, niacin and tocopherol 2.8, 50.0 and 152 mg/kg DM, respectively) and mineral content in the buckwheat flake samples remained unchanged. After extrusion 44.5% of the total tocopherol remained in the samples, while the content of K and Mg was also significantly reduced (28.3 and 42.2%, respectively) when puffed buckwheat products were produced. About 64% of the total phenolic compounds remained in the extruded and puffed buckwheat products, while the radical scavenging activity decreased to 65 and 49% of the initial level, as a result of processing. After extruding and puffing, rutin content decreased to undetectable level. Trypsin inhibitor activity of buckwheat grains was significantly diminished during various processing operations. The microbiological state fulfils the requirement for safe food and shelf life of the new buckwheat products is satisfactory.

Keywords: chemical composition, extrusion, flake, hydrothermal technology, nutritive value, puffing

INTRODUCTION

Buckwheat is a pseudo-cereal, which can play an important role in healthy nutrition. It is an undemanding plant suitable for organic farming. Its nutritive value is higher than that of other cereals: it has a high protein content, a favourable amino acid composition, and high mineral and fibre content (Edwardson 1996; Krkoskova and Mrazova 2005). Due to its composition, it can easily be utilized to increase the nutritive value of cereal-based foodstuffs as well as to prepare traditional dishes (mush and cakes) and dietetic foods (coeliacia, slimming diet, diabetes, cardiovascular diseases (Edwardson 1996; Fabjan *et al.* 2003; Arendt *et al.* 2004; Krkoskova and Mrazova 2005).

During traditional milling procedures (dehulling, milling), especially when making white wheat flour of different grains, 20-80% of the original vitamin and mineral content and 90% of the fibre content of the grains are transferred into the bran fraction. Furthermore, a significant part of the valuable protein and fatty acid components under the seedcoat is lost (Kent 1975; Peterson *et al.* 1986). During kitchen technological operations (baking, boiling), further nutrient losses occur (Rodler 2005). All the above claims are true for the milling and kitchen technological processing of pseudo-cereals as well.

With new hydrothermal procedures (flaking, extrusion, puffing) and application of moisture, high temperature and short-time high pressure, new foodstuffs can be produced, which differ from conventional ones in their appearance, preserving nearly the full range of nutrients in the entire grain. The simultaneous effect of moisture and heat causes great changes in the fine structure of starch and its voluminous structure making these products suitable for breakfast cereals and snacks. Of course, new technologies require new machinery, new technological lines and thoroughly cleaned raw materials. Flaked, extruded and puffed cereals and more recently, pseudo-cereals are used as ready-to-eat meals or as ingredients in snack formulations. Of the advantages of these products lightness, crispiness and qualities related to their cellular structure and degree of expansion are of special interest (Owusu-Ansah *et al.* 1984).

The pseudo-cereal seeds have a compact and relatively homogeneous internal structure, but there are significant differences compared to the structure of cereal grains. The starch granules of buckwheat are very small (1-7 μm) and regular, clearly grouped in regular clusters delineated by the presence of air spaces between them. In contrast, the starch granules in rice are densely packed (Mariotti *et al.* 2006). During hydrothermal procedures, radical changes take place in the structure of pseudo-cereal grains. The fast boiling with short passing time and high temperature explores the starch granules of size 5-30 nm carefully, not changing the quality of the proteins, vitamins and fats contained in them. The high temperature treatment reduces the amount of antinutritive substances and also the number of microbes (Baumeler 1986).

Pseudo-cereal flakes can be produced in two different processes. In the first, flakes are produced from a product milled with a drum dryer. These flakes are fully cooked. Buckwheat flakes prepared in this way can be used as excellent basic material for flavoured children's meals, baby foods and curative infant formulas. In the second process, the buckwheat flakes are prepared from fully dehulled grains after a steaming pre-treatment by the use of flattening rolls. Such flakes are excellent breakfast foods and may be used as muesli components (Biacs *et al.* 2002). On average 100, 100, 97 and 80%, respectively, of the most important vitamins (riboflavin, pyridoxin, niacin, thyamine) of the cereal raw materials (rye, wheat, barley and oat) remain in the flaked products (Barna *et al*. 1997).

Different groats and flours are in general the main raw materials for extrusion to be mixed with other components (flavourings, colours, etc.) and expanded by pressing through the opening of the extruder head at 115-120°C by the extruder screw at high pressure for 12 sec. Fazzolare *et al.* (1992) produced extruded snack products with low fat

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content by using buckwheat flour. Pasta products have been prepared with extrusion from buckwheat flour by Matsuhashi *et al*. (1992). The water binding capacity of the extruded product was 1.5 times higher than that from traditional buckwheat flour. The cooking time of the extruded pasta products made from buckwheat flour has been shortened from 10 to 5 min compared to those made of traditional flour. After cautious extrusion of maize (115-120°C, 1-2 sec) 100% riboflavin, 89% niacin, 77% pyridoxin and 70% thiamine remained in the extruded product according to Barna *et al.* (1997). Due to it being a delicious, crispy, easy-to-digest product, extruded buckwheat is an excellent material for baby foods. The outer surface can be roasted or flavoured. Cereals and pseudo-cereals may be puffed in an oven or puffing gun. Generally two technological processes can be used for this purpose. Oven puffing is based on the sudden application of heat at atmospheric pressure, setting the seed's moisture content correctly. The water in the grain is vaporized *in situ* thereby expanding the product. Oven-puffed products are usually made from rice, maize or a mixture of them. In gun puffing sudden transfer of grain containing superheated steam from high to low pressure is required to allow the water to suddenly vaporize and cause expansion (Kent and Evers 1994). Puffed buckwheat can be made from both unhulled and dehulled buckwheat raw materials. When unhulled buckwheat grains are puffed the hull is removed after the process in an air flow or by mechanical means. In the gun the whole seeds of different cereals such as rice, wheat or buckwheat grains are puffed after each other. Full-grain cereals expand in small-sized closed forms (10 g properly wetted seeds per form) after exposure to a high pressure (9-10 MPa) and high temperature (267-294°C) for 3-5 sec followed by sudden opening of the form. During expansion, grains of high starch content stick together, causing the expansion to result in cereal or pseudo-cereal slices depending on the composition. As regards the hydrothermic procedures, the greatest structural changes and the highest reduction in nutritive value has been found when the seeds were puffed. However, considerable quantities of niacin, pyridoxin, riboflavin and thiamine have been retained by 100, 68, 62, 2% of the original content in the cereal grain, respectively (Barna *et al.* 1997).

According to the literature, buckwheat contains considerable level of antioxidants, including polyphenols. The values of 3903 mg/kg DM total polyphenolics and 184 mg/kg DM rutin have been measured in buckwheat seeds by Holasova *et al*. (2002). Sensoy *et al.* (2006) found that the total content of phenols was not affected by processing (200°C, 10 min) in dark or white buckwheat flour. Baking (200°C, 10 min) reduced antioxidant activity slightly whereas extrusion (170°C) did not cause any change.

Kreft *et al.* (2006) found 230, 88 and < 78 mg/kg DM rutin in raw, precooked buckwheat groat and in buckwheat paste, respectively. According to Park *et al*. (2000) a Korean buckwheat variety ('Suwon 1') contained 28 mg/100 g of rutin in groats, before boiling, but this decreased to 0.5 mg/100 g after boiling. Popped groats showed higher rutin content (5 mg/100 g) than boiled groats. After boiling, Lugasi and Blázovics (2001) measured a 50% loss in the flavonoid and rutin content. As flavonoids are not sensitive to heat, only dissolving should be expected. It is well known that uptake and bioavailability of flavonoid increase when the water in which the foodstuffs are cooked is also consumed. In the case of hydrothermic procedures, seeds lose water very rapidly giving up to considerable loss in water-soluble nutrients. The solubility of rutin in cold water (4°C) has been reported to be 0.125 mg/L, and 51 g/L dissolves in water at 80°C (Kim *et al.* 2005). The total dietary fibre and the soluble dietary fibre content increased during the extrusion of barley samples at 90-140°C and 20-50% moisture content, while changes in insoluble dietary fibre content have been found to be dependent on variety (Vasanthan *et al.* 2002).

In this study the possibility of exploiting a Hungarian buckwheat variety as raw material for hydrothermic technologies was examined. The physical and chemical effects of the hydrothermal food processing operations on certain characteristics of the buckwheat pseudo-cereal were also examined.

MATERIALS AND METHODS

Plant materials

The examined buckwheat variety *Fagopyrum esculentum* Moench was the common Hungarian 'Hajnalka' variety. Its seed coat is dark brown, while the dehulled seeds are cream-coloured or possibly greenish. Buckwheat seeds were grown in 2008 in East Hungary near Nyíregyháza in acidic sandy soils (low in organic matter).

Parameters applied for hydrothermal processing technologies

1. Flaking

The buckwheat was flaked at the Lajosmizse plant of Fortunate Ltd. (Hungary). As a part of our experiments, pseudo-cereal flakes were produced in the plant. Moisture content of the dry-dehulled buckwheat seeds was set at 15-15.5%, which is optimal for flaking. Whole seeds were treated in a heat column for 3-3.5 h at 60°C using counter current hot air then shocked with steam at a pressure of 0.11 MPa at 100-120°C for 15-20 min. This was followed by passing the seeds through between pairs of large metal rolls and the finally drying. Flakes prepared from the dry-dehulled buckwheat are white, cream-coloured or possibly greenish.

Heat treatment aimed at producing favourable taste and aroma substances, while the objective of steaming was to soften the seeds, explore starch, improve the microbiological status and inactivate enzymes.

2. Extrusion

The extrusion was carried out in a laboratory-scale, single-screw extruder (Brabender, Germany). The screw speed was 150 rpm, while the screw compression ratio was 1:5. Heating temperatures were 160, 180 and 200°C. The diameter of the extruder's outlet die was 4 mm. Buckwheat raw material used for extrusion was groats of dehulled buckwheat with 400-800 μm granules, completely extruded without the addition of any other material, after having set various parameters such as moisture content and resting time (wetted to 18% and rested for 3 h as optimal). The final extrusion temperature was 200°C for 1-3 sec; this product was investigated in this study. Its diameter and porosity were compared to the same parameters of the extruded products of corn-grits that can be best extruded under the same conditions. Colour of the buckwheat extrudate was light brownish.

3. Puffing

Puffing was carried out at the Lajosmizse plant of Fortunate Ltd. (Hungary) in a closed puffing gun (5-5 kg material per loading) at 230-246°C roasting temperature for 7 min after a steaming treatment at high pressure (0.8-0.9 MPa) for 3 min, the pressure and temperature being suddenly reduced by opening the cover of the puffing gun. Prior to the treatment moisture content of the buckwheat was tuned exactly to 13% and it was rested for 5 h. Buckwheat was puffed in hull. After puffing, buckwheat had white colour with brown spots on it, and had a shape like an opened tetrahedron. After puffing, buckwheat hull was eliminated in a mechanical way (screening and sorting with air-flow).

Analytical methods

1. Bulk density

Grain density was evaluated by measuring the weight of a known volume of sample. Samples were poured into graduated cylinder, gently tapped 10 times and filled to 500 ml. Results are expressed as g/L (Mariotti *et al*. 2006).

2. Water and fat binding capacity

Water binding capacity was determined by the method of Sosulski (1962) using 5 g milled sample, while fat binding capacity was measured by the method of Lin *et al.* (1974) using 0.5 g sample.

3. Determination of chemical composition

Moisture content was measured by drying at 105°C up to constant weight. Oil content was determined by extraction with petrol ether in Soxhlet equipment, whereas ash content was measured by dry ashing at 550°C until constant weight. Crude protein content was specified on an Elementar Rapid N Cube equipment. Dietary fibre content was determined by the AOAC Method No. 991.431 (2003). The amino acids were separated by ion exchange chromatography in a Biotronic LC 3000 amino acid analyser. Macro and micro elements were determined by atomic absorption spectroscopy in line with the official AOAC Methods No. 986.15 (2003), 965.09 (2003), 983.02 (2003).

Following acidic and enzymatic extraction, the vitamin content of the buckwheat samples was determined by an Alliance Waters HPLC system consisting of a Model 2695 separation module with Zorbax eclipse XDB column (C-18, 3.5 μm), a Model 2996 photodiode array detector and a Model 2475 fluorescent detector. The system was operated by Empower software. Standard ergosterol, α-tocopherol and β-carotene were purchased from Sigma-Aldrich. Authentic materials for other carotenoids were supplied by the Department of Bio- and Medical Chemistry, Medical School, University of Pécs (Pécs, Hungary, Daood *et al.* 2008).

4. Determination of rutin content

The rutin content was determined by HPLC. Circumstances of the extraction and HPLC separation were arranged according to the modified method of Kim *et al.* (2005).

Buckwheat samples (5-20 mg) were extracted with 1 ml of 10% methanolic phosphoric acid and vortexed for 5 min under an infra-red lamp (about 35°C). After centrifugation at 10,000 rpm, the supernatant was pipetted into an Eppendorf tube of 2 ml. This procedure was repeated twice with 500 μl of 10% methanolic phosphoric acid and the supernatant was pooled and filtered. An Alliance Waters 2690 HPLC system equipped with a photodiode array detector (Waters 996) was used for separation of polyphenols. The compounds were separated on Nucleodur Sphinx RP column (5 μm, 250 mm × 4.6 mm; SORBTECH, Atlanta, USA) with gradient elution with A (water/formic acid 900/10) and B (water/formic acid/acetonitril 390/10/600) solution and were detected at 320 nm for quantitative determination (Sass-Kiss *et al.* 2009). The rutin as authentic compound was purchased from Merck (pa).

5. Determination of total phenolic

Total phenolic content was determined by the Folin-Ciocalteu's photometric method according to Singleton (1969). One g of whole meal buckwheat flour was extracted in 50 ml of 80% methanol. About 0.3-0.5 ml of the filtrate was pipetted into a test-tube and completed with distilled water up to 4.25 ml, and at last 0.25 ml Folin-Ciocalteu reagent and 0.5 ml saturated Na_2CO_3 solution were added. Having left the samples in a dark place for 30 min, the absorbance was measured by spectrophotometer (UY-160 A, Shimadzu, Japan) at 750 nm by using blank samples. Total phenolic content was calculated according to a calibration curve prepared with gallic acid (Sigma-Aldrich).

6. Determination of free radical scavenging capacity

Scavenging capacity of free radicals was determined by Yamaguchi's method (1988) in a spectrophotometric manner presenting the result in Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, Fluka) units. The reagent was a 1 mM DPPH (2,2-diphenyl-1-picrylhydrazyl, Sigma-Aldrich) in methanol solution (freshly diluted 10 fold with 80% methanol). Extraction of the buckwheat samples (1 g + 50 ml methanol) was made with 80% methanol; after an adequate dilution 0.05 ml filtrate was pipetted into a test-tube adding 2 ml reagent. Samples were incubated at 37°C for 30 min and measured by a spectrophotometer (UV-160 A, Shimadzu, Japan) at 517 nm against 80% methanol. The absorbance value of the sample containing antioxidant was subtracted from that of the blind sample not containing antioxidant. Calibration was performed from a Trolox stock solution (1 mmol/L). Free radical scavenging capacity was presented in Trolox unit as calculated from the difference. All reagents were of analytical or HPLC grade as required.

7. Determination of trypsin inhibitor activity

The activity of trypsin inhibitors was measured by applying BAPA (*N*-α-benzoyl-L-arginine-4-nitroanilid hydrochloride, Sigma) as substrate according to Kakade *et al*. (1974).

Examination of microbiological status

The microbiological examinations were carried out according to valid ISO standards.

Statistical analyses

All analysis was done at least in triplicate. Data are given in mean or in mean ± standard deviation.

When appropriate, data were analysed for significant differences by two sample (independent group) Student's *t*-test in Microsoft Excel statistical program. Significant differences were obtained if $P<0.05$.

RESULTS AND DISCUSSION

With hydrothermic procedures, partially or completely explored and gelatinized buckwheat products of pleasant flavour determined by simple tasting, and large volume were produced. As a result of the hydrothermal procedures, the grain structure changed significantly, becoming more porous, and expanding volume with high degree, while the physical properties of the starch were modified and water and oil binding capacity of grains increased. Fat fraction bound to the protein and carbohydrate molecules increased, leading to changes of texture and rheological characteristics of the complex system.

Buckwheat flakes were white-cream coloured and 0.6-0.7 mm thick. Buckwheat extruded in 100% is of pleasant, light yellowish colour and its diameter was smaller by only 12% as related to maize having the best extrusion properties. Puffed buckwheat has white colour with brown spots and opened tetrahedron form. Changes in the moisture content and bulk density as a function of puffing are shown in **Table 1**. In our samples moisture changed from 18.5 ± 0.1 to 7.5 ± 0.1 g/100 g, while bulk density changed from 735.6 ± 7.1 to 109.0 ± 9.2 g/L. Great differences found in bulk densities, which were due to the high degree of expansion. Our results are in good agreement with those published by Mariotti *et al*. (2006). The water and oil binding capacity increased significantly as compared to that of untreated seeds (**Table 2**). The extruding and puffing treatment radically enhanced the water binding capacity of the buckwheat products, by 234 and 193%, respectively. According Mariotti *et al*. (2006) puffed grains adsorbed large amount of water (150-300%) already in the first 30 s. The oil binding capacity was lower in the extruded buckwheat (104%), while in puffed buckwheat it was 243%. During our experiments, we concluded that the optimal settings of moisture content and resting time before the hydrothermal treatments can increase the volume of puffed seeds by 30-70%.

The most important chemical components of the raw buckwheat dehulled seeds, buckwheat flakes, puffed buckwheat seeds are shown and compared to raw material data from the literature (USDA) in **Table 3**. It is clear that content of protein and lysine as essential amino acid did not substantially change in flakes. Protein, lysine and minerals content was measured also in the extruded buckwheat sam-

Table 1 Moisture and physical characteristics (average ± SD) of raw and puffed grain.

Sample	Moisture (g/100 g)		Bulk density (g/L)		Expansion rate after puffing
	Raw	Puffed	Raw	Puffed	
Wheat (a)	12.9 ± 0.1	7.6 ± 0.1*	873.3 ± 6.5	164.0 ± 29*	5.3
Buckwheat (a)	14.1 ± 0.1	7.2 ± 0.1*	786.3 ± 2.6	71.2 ± 1.9*	11.0
Buckwheat (groat)	18.5 ± 0.1	7.5 ± 0.1*	735.6 ± 7.1	109.0 ± 9.2*	8-10

(a): Mariotti *et al.* 2006
groat = dehulled buckwheat
Buckwheat sample was analysed in triplicate.
* values are statistically different from raw ($P < 0.05$) according to the two sample Student's *t*-test

Table 2 The techno-functional properties of wheat, buckwheat flour, buckwheat products.

Sample	Water absorption capacity (g/100 g)	Oil absorption capacity (g/100 g)
Wheat flour (BL 55)	182.9 ± 1.2	184.0 ± 2.7
Buckwheat groat (whole meal flour)	208.2 ± 0.5	172.8 ± 0.2
Buckwheat extruded	488.0 ± 5.2*	180.1 ± 4.8
Buckwheat puffed	401.5 ± 9.4*	419.5 ± 4.5*

Each sample was analysed in triplicate.
* values are statistically different from buckwheat groat ($P < 0.05$) according to the two sample Student's *t*-test

Table 3 Nutritive value of buckwheat groat, buckwheat flakes, and puffed buckwheat.

Components	Buckwheat groat	Buckwheat flake	Buckwheat puffed	Buckwheat groat (a)
Nutritional value (g/100 g DM)				
Protein	15.5	15.5	15.3	14.2
Fat	3.3	3.2	3.3	3.5
Fibre	1.3	1.3	1.2	
Ash	2.3	2.2	2.2	2.9
N-free extract	77.6	77.8	78.0	
Energy (KJ)	1520	1520	1523	1578
Dietary fibre	13.1	13.0	9.8*	11.3
Amino acid content (g/100 g protein)				
Lysine	3.18	3.10	2.07*	5.07
Methionine	0.75	0.90	0.50*	1.30
Threonine	1.97	2.00	1.50*	3.82
Mineral content (mg/100 g DM)				
Na	3.5	3.7	4.3	12.4
K	578.0	575.0	415.0*	649.4
Mg	263.0	250.0	152.0*	282.5
Ca	31.0	31.0	29.7	46.1
Cu	0.8	0.9	0.8	0.6
Zn	2.8	2.7	2.5	3.5
Mn	1.6	2.7	0.9	2.3
Fe	3.6	3.6	4.2	4.6

(a) http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl
DM: dry matter
Each sample was analysed in triplicate.
* values are statistically different from groat ($P < 0.05$) according to the two sample Student's *t*-test

ple and the values obtained were similar to the corresponding results of the puffed buckwheat. The dietary fibre content in puffed buckwheat was somewhat lower, but being still a high value (9.8 g/100 g dry matter, DM). In raw 'Hajnalka' buckwheat groat and in flaked buckwheat product three vitamins were determined (riboflavin, niacin and tocopherol); but in the buckwheat extrudate only the tocopherol content was tested. The content of riboflavin, niacin and tocopherol (2.8, 50.0, 152 mg/kg DM) in the raw buckwheat seeds did not change during flaking. After extrusion, 44.5% of the total tocopherol content remained in the buckwheat. The total tocopherol content of buckwheat groat of 'Hajnalka' from 2008 contained α-, γ- and δ-tocopherol in the rate of 3.4, 92.1 and 4.3%, while in the literature published, the rate was very similar to our results, 4.0, 90.2 and 5.7%, respectively (USDA). According to our results, the Hungarian buckwheat snack products are especially rich in K (415-578 mg/100 g DM), Mg (152-263 mg/100 g DM), and Fe (3.6-4.2 mg/100 g DM). The changes in the mineral content showed that the mildest hydrothermal treatment was the flaking. Significant loss occurred in K and Mg content (28.3 and 42.2%, respectively) in puffed products. It was caused by dissolution during moistening and conditioning and by the very quick water removal from the seed during puffing. Changes in total phenolic components, rutin content and radical scavenging capacities during processing could be attributed to the aforementioned reasons (**Table 4**). In our experiments the content of total phenolic substances, rutin and radical scavenging capacities for buckwheat flakes are identical to those measured in the raw groats. The extruding and puffing caused significant decrease in these compounds, the total content of phenolic substances was lower by 36.5% in both cases, rutin content could not be detected after the treatments and radical scavenging capacities was lower by 35.5 and 51.5%, respectively. Sensoy *et al.* (2006) found, that extrusion (170°C) did not cause any change in antioxidant activity, but after roasting (200°C, 10 min) it was lower by 13.4%. These results confirmed our experimental data, in which the mildest treatment was flaking, while the technological parameters used for extruding and puffing strongly influenced the chemical composition of the products.

Among the antinutritive substances of the seed samples, the trypsin inhibitor activity was also examined in buckwheat samples. The results are presented in **Table 5**. Trypsin inhibitor activity of the buckwheat seeds is not too high, but reduction of the antinutritive substance contents could be achieved during the hydrothermal treatments of different

Table 4 Changes of the total phenolic substances, rutin content, radical scavenging capacity and retention (%) of 'Hajnalka' buckwheat depending on processing technologies.

Sample	Total phenolic content		Rutin content		Radicals scavenging capacity	
	GA/kg	DM %	mg/kg	DM %	TU/g	DM %
Buckwheat groat	3976	100	58.0	100	330	100
Buckwheat flake	4221	106	59.1	102	336	102
Buckwheat extruded	2523*	64	n.d.*	0	213*	65
Buckwheat puffed	2525*	64	n.d*	0	160*	49

GA = gallic acid; TU = trolox unit, n.d. = not detectable
Each sample was analysed in triplicate.
* values are statistically different from buckwheat groat ($P < 0.05$) according to the two sample Student's *t*-test

Table 5 Changes in trypsin inhibitor activity in 'Hajnalka' buckwheat products.

Sample	TIU/mg sample
Buckwheat groat	3.17 ± 0.05
Buckwheat flake	1.19 ± 0.06*
Buckwheat puffed	0.70 ± 0.04*

Each sample was analysed in triplicate.
* values are statistically different from buckwheat groat ($P < 0.05$) according to the two sample Student's *t*-test

temperature and time periods. The changes in the trypsin inhibitor activity can be explained by the differences in the parameters used for flaking and puffing. After flaking the 37.5% of trypsin inhibitor activity remained in the product, while after puffing only 22.1%. Ikeda and Kusano (1983) demonstrated that the buckwheat trypsin inhibitors are relatively thermostable, at 85°C the 78% of inhibitor activity could be measured.

Based upon microbiological tests, we can conclude that after hydrothermal treatments, total germ count was diminished by an order of magnitude and therefore the microbiological state of the products improved. After hydrothermal processing, moisture content of the products was low (below 8%) and the storage stability or shelf-life of the new products is considerably increased by this way.

CONCLUSIONS

According to our results, Hungarian buckwheat variety can be well utilized as raw material of hydrothermal technologies. The 'Hajnalka' variety can serve well as raw material for flaked, extruded and puffed products.

The hydrothermal procedures (high temperature and pressure and short-time treatment) improve the biological value of buckwheat only in a very moderate way. According to our results, the Hungarian buckwheat snack products are especially rich in essential minerals, and in compounds having antioxidant effect. The content of total phenolic compounds (2523-4221 mg GA/kg DM) and radical scavenging capacity (160-336 TU/g) are significant as well. These new buckwheat products are functional foods; they can be used as ready-to-eat meals or as ingredients in snack formulations. The nutritive value of buckwheat pseudocereal flakes, extrudates and puffed products is much higher than that of the corresponding cereal products.

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