Influence of buckwheat and chestnut flour addition on properties of corn extrudates

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Summary

The aim of this study was to determine the effect of buckwheat and chestnut flour addition to corn meal (ratio meal : flour = 70 : 30, 50 : 50 and 30 : 70) on extrudate properties. Blends (25 % moisture) were extruded at two temperature regimes: 80/90 °C and 75/180 °C. Physical, chemical and rheological properties, and digestibility of the obtained extrudates were investigated in relation to non extruded samples. Addition of chestnut flour to corn meal resulted in increase of fibre, ash and fat content, and decrease of protein content, while buckwheat flour addition resulted in increase of all measured components. Chestnut and buckwheat flour addition increased whiteness and decreased yellowness of non-extruded samples. While extrusion of corn meal resulted in increase of whiteness, extrusion of both types of mixtures resulted in its decrease. Bulk density increased and expansion ratio, hardness and fracturability decreased by addition of chestnut and buckwheat flour. Extrusion of all investigated samples resulted in decrease of peak, hot and cold viscosity and increase of water absorption index. Total polyphenol content and antioxidant activity increased by the addition of buckwheat and chestnut flour, but the extrusion caused their decrease.

Keywords: extrusion, buckwheat flour, chestnut flour, physical properties, rheological properties

Introduction

Extrusion is widely used process in food industry – it is used for production of snack products, pasta, textured vegetable proteins, modification of flour for bakery industry, starch modification etc (Alavi et al., 2002). Due to simultaneous action of high pressure, shear and high temperature, structure and digestibility of proteins and starch are highly modified in extruded material (Anton et al., 2009).
Due to growth of consumers' awereness of importance of proper (healthy) nutrition and increasing interest for so-called "functional food", food industry, including extrusion processes, is challenged to produce healthy products with increased content of fibre, resistant starch, antioxidants, vitamins etc. (Chillo et al., 2010; Charalampopoulous et al., 2002). Numerous researches have investigated impact of extrusion on properties of mixtures of corn or wheat meal with other cereals or pseudo-cereals, which were added to meal to increase nutrition value and decrease caloric value of the product. Sobota et al. (2010) investigated extrusion influence on properties of mixtures of corn meal and wheat flour and reported decrease of protein content and increase of total and soluble fibre content. Perez-Navarrete et al. (2006) reported that extrusion of corn meal with lima bean addition resulted in increase of protein digestibility and significant increase of soluble fibre content. Stojceska et al. (2010) reported that extrusion technology could be utilized to increase level of total dietary fibre in gluten-free products made from vegetables, fruits and gluten-free cereals.
Buckwheat is a pseudo-cereal which attracted much interest of researchers due to its positive health impact. According to some authors, buckwheat has prebiotic action, could be used in treatment of allergic inflammation, reduces serum glucose level, suppresses gallstone formation and cholesterol level and is not toxic to Celiac patients (Sensoy, 2006).
Sensoy et al. (2006) reported that roasting of buckwheat significantly reduces its antioxidant activity, whereas extrusion process does not influence it at all and Rayas-Duarte et al. (1998) reported increase of protein digestibility due to addition of buckwheat flour to corn meal prior to extrusion process.
Sacchetti et al. (2004) investigated influence of extrusion and chestnut flour addition on snack-like rice based extrudates. They reported that this mixture could be used for production of extrudates with

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favourable sensory properties. However, high content of sugars in chestnut flour benefited browning reactions during extrusion, which confirmed results of Morini and Maga (1995), who reported increase of colour intensity due to extrusion of chestnut flour.
The aim of this research was to investigate influence of chestnut and buckwheat flour addition on properties of corn extrudates – mainly chemical composition and technological properties.

Materials and methods

Corn meal was supplied at local market, under trade mark „K-plus“. Buckwheat flour was produced by Rösselmühle Ludwig Polsterer Ges.m.b.H, Graz, Austria; and chestnut flour by Castellino di C. V. & C. snc., Villanova Mondovi, Italy.
Buckwheat or chestnut flour was added to corn meal in ratios: 30:70; 50:50 or 70:30. Total moisture of the mixtures was set to 25 % and mixtures were extruded in extruder Do-Coder, Brabender, GmbH, Duisburg, Germany. *Extrusion* parameters were as follows: screw: 1:1; screw speed: 65 rpm; die: 4 mm; temperature profile: 75/180 °C. Obtained extrudates were cut to 10 cm long sticks and air-dried.
Protein content was determined according to ISO 5983-2:2005 method, *fat content* according to ISO 6492:2001, *crude fibre content* according to ISO 6865:2000, *crude ash* according to ISO 5984:2002 and *resistant starch content* according to AOAC 2002.02 method. Total phenol content and DPPH scavenging activity were determined as described by Kopjar et al. (2009).
Extrudate diameter and expansion ratio were measured according to Brnčić et al. (2008), where expansion ratio (ER) was calculated as follows (Eq. 1):

$$ER = \textit{extrudate diameter}\ (\text{mm}) / \textit{die diameter}\ (\text{mm}) \quad (1)$$

Bulk density (BD) of extrudates was measured according to Pan et al. (1998) and calculated according to Eq. 2:

$$BD = \textit{extrudate mass}\ (\text{g}) / \textit{extrudate volume}\ (\text{mL}) \quad (2)$$

Texture analysis was performed on texturometer TA.XT2 Plus, Stable Microsystem using method „Measurement of the hardness and fracturability of pretzel sticks“ with following settings: Pre-Test Speed: 1.0 mm/s; Test Speed: 1.0 mm/s; Post-Test Speed: 10.0 mm/s; Distance: 3mm; Trigger Type: Auto - 5g.

Colour was measured using Chroma Meter CR-300, Konica Minolta, Japan with granular materials attachment. The instrument was calibrated using white tile and colour was expressed in CIE-Lab parameters as L* (whiteness/darkness), a* (redness/greenness) and b* (yellowness/blueness) and in CIE-LCh parameters as C* (Chroma) and h* (hue). Five measurements were performed on each sample.
Influence of extrusion on *extrudate pasting properties* was evaluated by Brabender micro viscoanalyser 803202, Brabender GmbH & Co, Duisburg, Germany. 7 % suspensions were heated from 30 °C to 92 °C at 7.5 °C/min, held at 92 °C for 5 min, cooled from 92 °C to 50 °C at 7.5 °C/min and held at 50 °C for 1 min.
Water absorption index (WAI) was determined according to Sosulski (1962). With exception of colour measurement which was done in five replicates, all analyses were done in triplicates.
Experimental data were analyzed by analysis of variance (ANOVA) and Fisher's least significant difference (LSD) with significance defined at $P<0.05$. All statistical analyses were carried out using software program STATISTICA 10.0 (StatSoft, Inc, USA).

Results and discussion

Chemical composition of raw and extruded mixtures of corn meal with chestnut and buckwheat flour is shown in Table 1. Addition of buckwheat flour increased protein, fat, fibre and ash content of analysed samples, while addition of chestnut flour decreased protein content with increase of other investigated parameters. Increase of analysed parameters by addition of buckwheat flour was due to increased content of these constituents in buckwheat flour (Nikolić et al., 2011).
Decrease of protein content by addition of chestnut flour was expected, since corn meal contains app. 9.5 % proteins (Brnčić et al., 2008) and chestnut flour contains 6 – 8 % protein (de la Montana Miguelez et al, 2004). In addition, increase of fat, fibre and ash content was also expected, since chestnut flour contains higher amounts of these constituents than corn meal (de la Montana Miguelez et al., 2004; Brnčić et al., 2009).
Resistant starch (RS) content decreased significantly by addition of buckwheat and chestnut flour, probably due to smaller starch granule size of added flours (Correia et al., 2012; Qian et al., 1998) which makes them more susceptible to enzyme attack (Franco et al., 1992). Further decrease of RS content after extrusion of all samples was due to increased

starch damage (Mendoza & Bressani, 1987) and was also reported by Hagenimana et al. (2006) for extruded rice flour.
Extrusion didn't influence ash and fibre content, protein content very slightly increased, while fat content decreased significantly. Decrease of fat content by extrusion was also observed by Živančev et al. (2010). It is estimated that decrease of fat content in corn by extrusion averages 40 % - some lipids are lost at die as free oil, and part of the lipids complexes with proteins and amylose (Singh S. et al., 2007).

Table 1. Chemical composition of raw and extruded mixtures of corn meal with buckwheat and chestnut flour

	protein (%)	fat (%)	crude fibre (%)	ash (%)	RS* (% d.m.)
non-extruded samples					
corn meal	6.63 ± 0.28	0.35 ± 1.03	0.36 ± 1.00	0.24 ± 0.01	6.54 ± 0.78
corn:buckwheat 70:30	8.92 ± 1.30	0.76 ± 1.40	0.48 ± 1.00	0.66 ± 0.01	4.98 ± 0.16
corn:buckwheat 50:50	9.18 ± 0.05	1.05 ± 2.38	0.47 ± 1.00	0.97 ± 0.01	2.82 ± 0.04
corn:buckwheat 30:70	10.33 ± 0.20	1.47 ± 0.66	0.53 ± 1.00	1.20 ± 0.01	2.11 ± 0.20
corn:chestnut 70:30	6.28 ± 0.08	1.39 ± 0.86	0.61 ± 1.53	0.82 ± 0.02	4.98 ± 0.01
corn:chestnut 50:50	6.36 ± 0.10	2.10 ± 0.59	0.72 ± 3.51	1.17 ± 0.01	4.76 ± 0.16
corn:chestnut 30:70	6.16 ± 0.01	2.89 ± 6.08	0.87 ± 1.00	1.61 ± 0.01	3.63 ± 0.01
extruded samples					
corn meal	6.79 ± 0.27	0.07 ± 0.46	0.32 ± 1.00	0.24 ± 0.01	1.18 ± 0.19
corn:buckwheat 70:30	9.15 ± 1.04	0.15 ± 0.72	0.43 ± 1.00	0.66 ± 0.01	0.45 ± 0.03
corn:buckwheat 50:50	9.32 ± 0.68	0.42 ± 0.87	0.48 ± 1.00	0.98 ± 0.01	0.47 ± 0.05
corn:buckwheat 30:70	10.03 ± 0.71	0.42 ± 1.80	0.50 ± 1.00	1.24 ± 0.01	0.34 ± 0.00
corn:chestnut 70:30	6.56 ± 0.06	0.46 ± 1.69	0.52 ± 1.00	0.82 ± 0.01	0.59 ± 0.08
corn:chestnut 50:50	6.56 ± 0.01	0.92 ± 2.22	0.54 ± 1.00	1.18 ± 0.01	1.02 ± 0.09
corn:chestnut 30:70	6.38 ± 0.04	1.32 ± 1.25	0.72 ± 1.00	1.55 ± 0.02	0.55 ± 0.00

*RS, resistant starch

Total phenol content and antioxidant activity proportionally increased by addition of buckwheat flour to corn meal, whereas addition of chestnut flour resulted in their decrease (Table 2). Increase of total phenolics by addition of buckwheat flour was also observed for ginger nut biscuits by Filipčev et al. (2011) and for gluten-free breads by Sakač et al. (2011). Antioxidant activity of buckwheat is ascribed to presence of rutin, which possesses strong ability to scavenge DPPH (Yang, Guo & Yuan, 2008) and is often denoted as vitamin P1.
Although total phenolic content of all samples decreased by extrusion due to heat sensitivity of some antioxidant compounds, antioxidant activity of corn meal: buckwheat flour mixtures determined by DPPH assay increased. During heat treatment different synthesis reactions occur (i. e. formation of Maillard reaction products) which can result in formation of products that may mask real decrease of total phenolic compounds and attribute to DPPH scavenging activity (Sakač et al., 2011).
Expansion ratio decreased proportionally to the amount of buckwheat and chestnut flours added (Fig. 1). This observation is in accordance with research of Anton et al. (2009), who observed decrease of expansion of corn meal extrudates by bean flour addition. Increase of protein and fibre content results in decrease of expansion due to interactions of these components with starch. In addition, fibre can rupture cell walls and prevent air bubbles from expanding to their maximum potential (Anton et al., 2009).
Bulk density of extrudates increased by addition of buckwheat and chestnut flour. It is well established that addition of high-fibre and high-protein materials to starch based extrudates results in increase of density (Onwulata et al., 2001; Veronica et al., 2006; Anton et al., 2009).
Hardness of extrudates with addition of buckwheat or chestnut flour was lower than corn meal extrudate, however, it increased proportionally to the increase of flour content (Fig. 2). Fracturability of extrudates decreased proportionally to the amount of flour added (Fig. 2). Texture properties of extrudates are highly influenced by expansion degree (Anton et al., 2009).
Colour is one of the most important attributes of food product, since it is often indicator of freshness and cooking degree. Addition of both buckwheat and chestnut flour to corn meal resulted in increase of lightness (L* values) and hue (h), and decrease of redness (a*), yellowness (b*) and chroma (C) values (Table 3).

Table 2. Total phenol content and antioxidant activity of mixtures of corn meal with buckwheat and chestnut flour before and after extrusion process

	total phenols (g/L)	**antioxidant activity DPPH (mmol trolox/100 g)**	**antioxidant activity ABTS (mmol trolox/100 g)**
non-extruded samples			
corn meal	6.84±0.23	11.21±0.019	0.90±0.033
corn:buckwheat 70:30	7.75±0.07	11.64±0.059	2.57±0.036
corn:buckwheat 50:50	7.91±0.18	11.75±0.046	2.69±0.006
corn:buckwheat 30:70	8.27±0.27	11.95±0.078	3.42±0.022
corn:chestnut 70:30	8.07±0.36	11.84±0.007	3.92±0.040
corn:chestnut 50:50	7.65±0.04	11.81±0.072	3.75±0.032
corn:chestnut 30:70	7.14±0.21	11.44±0.038	2.72±0.025
extruded samples			
corn meal	1.49±0.47	11.92±0.078	1.23±0.018
corn:buckwheat 70:30	6.32±0.21	11.74±0.059	1.02±0.013
corn:buckwheat 50:50	6.47±0.29	12.00±0.070	1.99±0.027
corn:buckwheat 30:70	6.83±0.25	12.12±0	2.78±0.028
corn:chestnut 70:30	7.30±0.11	11.21±0.017	2.79±0.004
corn:chestnut 50:50	6.29±0.15	11.09±0.076	1.68±0.035
corn:chestnut 30:70	6.06±0.15	11.08±0.043	1.53±0.039

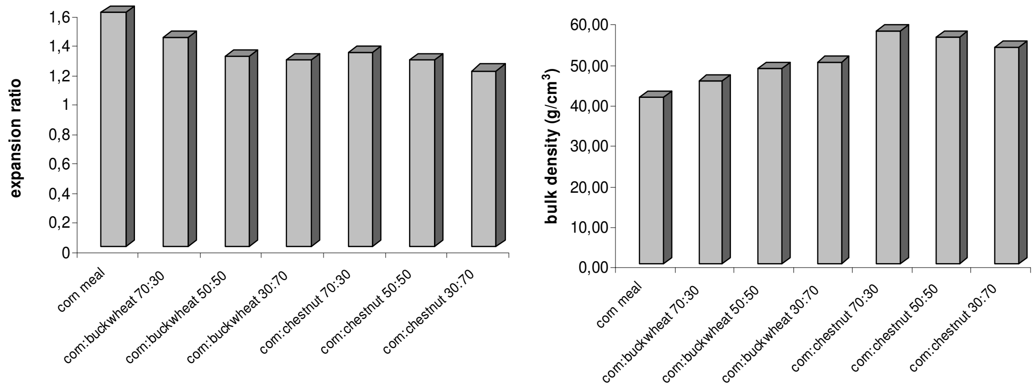

Fig. 1. Expansion ratio and bulk density of extruded mixtures of corn meal with buckwheat and chestnut flour

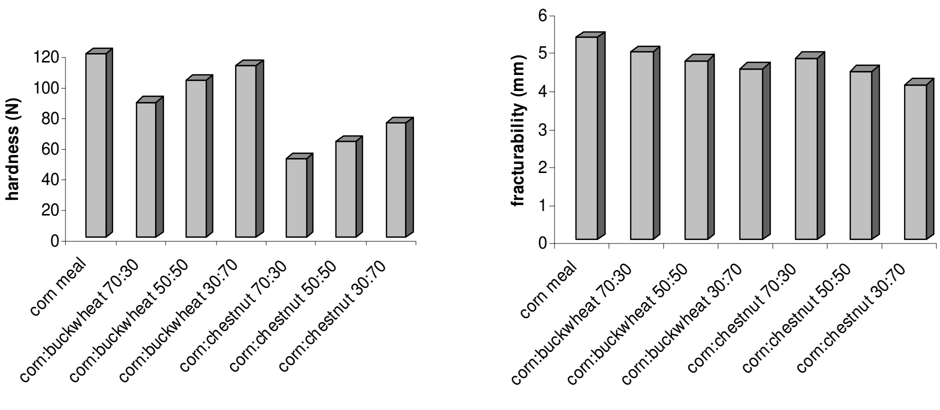

Fig. 2. Texture properties of extruded mixtures of corn meal with buckwheat and chestnut flour

Table 3. Influence of extrusion process on colour parameters of mixtures of corn meal with buckwheat and chestnut flour

	L*	**a***	**b***	**C**	**h°**
non-extruded samples					
corn meal	60.94 ± 0.17	2.42 ± 0.08	39.56 ± 0.17	39.90 ± 0.16	86.3 ± 0.3
corn:buckwheat 70:30	59.16 ± 0.18	0.37 ± 0.05	17.47 ± 0.70	18.29 ± 0.69	89.0 ± 0.2
corn:buckwheat 50:50	62.00 ± 0.12	0.14 ± 0.03	11.29 ± 0.20	11.26 ± 0.04	89.3 ± 0.2
corn:buckwheat 30:70	62.74 ± 0.02	0.26 ± 0.03	8.78 ± 0.12	8.82 ± 0.05	88.2 ± 0.1
corn:chestnut 70:30	62.65 ± 0.03	0.53 ± 0.02	15.20 ± 0.11	15.26 ± 0.11	88.1 ± 0.0
corn:chestnut 50:50	64.11 ± 0.01	0.05 ± 0.01	10.92 ± 0.02	10.93 ± 0.01	89.9 ± 0.1
corn:chestnut 30:70	65.06 ± 0.08	- 0.16 ± 0.02	10.22 ± 0.00	10.27 ± 0.05	90.8 ± 0.2
extruded samples					
corn meal	62.84 ± 0.06	0.81 ± 0.01	40.31 ± 0.02	40.37 ± 0.02	88.9 ± 0.0
corn:buckwheat 70:30	52.40 ± 0.13	2.32 ± 0.02	19.05 ± 0.11	19.08 ± 0.05	83.2 ± 0.1
corn:buckwheat 50:50	53.17 ± 0.08	2.17 ± 0.04	16.13 ± 0.07	16.24 ± 0.05	82.5 ± 0.1
corn:buckwheat 30:70	51.29 ± 0.10	2.72 ± 0.04	13.54 ± 0.03	13.81 ± 0.02	78.7 ± 0.1
corn:chestnut 70:30	52.89 ± 0.02	3.51 ± 0.03	23.13 ± 0.06	23.44 ± 0.03	81.4 ± 0.1
corn:chestnut 50:50	49.87 ± 0.09	4.15 ± 0.04	17.75 ± 0.09	18.00 ± 0.16	76.5 ± 0.2
corn:chestnut 30:70	47.09 ± 0.11	4.38 ± 0.05	14.50 ± 0.04	15.17 ± 0.03	73.0 ± 0.1

Extrusion of corn meal caused increase of lightness, decrease of redness and increase of yellowness, which attributed to perception of less expressed yellow colour compared to non-extruded sample. However, when buckwheat or chestnut flour was added, influence of extrusion was opposite: lightness decreased and redness and yellowness increased. Chroma values increased and hue decreased with more pronounced decrease when chestnut flour was added. Colour of extruded products is result of non-enzymatic browning and pigment degradation reactions – their kinetics, reaction mechanisms and process design and control (Valadez-Blanco et al., 2007). Ilo & Berghofer (1999) investigated influence of different extrusion parameters on colour change of maize grits. They reported decrease of lightness (L*) and increase of redness (a*) values due to browning reactions, and increase of yellowness (b*) due to pigment destruction and non-enzymatic browning reactions.

Pasting properties of mixtures of corn meal with buckwheat or chestnut flour are shown in Table 4. Addition of buckwheat flour to corn meal significantly increased pasting temperature and viscosities of non-extruded samples, whereas addition of chestnut flour didn't have so marked influence of these properties.

Table 4. Pasting properties of extruded and non-extruded mixtures of corn meal with buckwheat or chestnut flour

	Pasting temperature (°C)	Peak viscosity (BU)	Viscosity at 92 °C (BU)	After 20 min at 92 °C (BU)	Viscosity at 50 °C (BU)
non-extruded samples					
corn meal	575.5 ± 75.66	97 ± 26.87	580 ± 73.54	991 ± 104.65	954 ± 63,64 b
corn:buckwheat 70:30	827 ± 4.24	199 ± 2.83	825.5 ± 2.12	1190 ± 18.38	1177.5 ± 4.95
corn:buckwheat 50:50	929 ± 14.14	221.5 ± 6.36	929.5 ± 6.36	1377 ± 1.41	1323 ± 7.07
corn:buckwheat 30:70	995 ± 9.90	332 ± 2.83	966 ± 19.80	1488 ± 1.41	1427.5 ± 7.78
corn:chestnut 70:30	589 ± 2.83	200.5 ± 7.78	589.5 ± 2.12	1028 ± 21.21	971.5 ± 19.09
corn:chestnut 50:50	539.5 ± 12.02	300.5 ± 14.85	525 ± 15.56	838.5 ± 4.95	817 ± 4.24
corn:chestnut 30:70	522.5 ± 0.71	433.5 ± 2.12	475 ± 1.41	820 ± 16.97	746 ± 11.31
extruded samples					
corn meal	260.5 ± 19.09	209.5 ± 28.99	247.5 ± 0.71	431 ± 14.14	436.5 ± 10.61
corn:buckwheat 70:30	144.5 ± 9.19	118.5 ± 3.54	136 ± 2.83	197.5 ± 6.36	198 ± 9.90
corn:buckwheat 50:50	198.5 ± 2.12	172.5 ± 0.71	186.5 ± 2.12	265.5 ± 3.54	262.5 ± 3.54
corn:buckwheat 30:70	213 ± 0.00	185 ± 1.41	190.5 ± 2.12	273.5 ± 0.71	269.5 ± 3.54
corn:chestnut 70:30	240.5 ± 0.71	129.5 ± 4.95	228 ± 1.41	374.5 ± 12.02	360.5 ± 10.61
corn:chestnut 50:50	172 ± 4.24	81 ± 1.41	171 ± 2.83	216 ± 2.83	198.5 ± 3.54
corn:chestnut 30:70	129 ± 1.41	56.5 ± 0.71	129 ± 1.41	135 ± 1.41	125.5 ± 2.12

However, extrusion resulted in more pronounced decrease of both pasting temperature and viscosities in corn meal: flour mixtures than in control sample. Decrease of peak viscosity is correlated to higher extent of degradation and gelatinisation of starch (Hagenimana et al., 2006). However, since peak viscosity of extruded corn meal: buckwheat flour increased with increase of proportion of buckwheat flour, it can be concluded that ungelatinised starch polymers in buckwheat flour were present even after extrusion (Hagenimana et al., 2006).

Cold paste viscosity is indicator of starch retrogradation during cooling. Extrusion resulted in significant decrease of viscosity values at 50 °C in all investigated samples. This phenomenon has already been reported for extruded flours (Hagenimana et al., 2006; McPherson et al., 2000).

Water absorption index values of all extruded samples were significantly higher compared to non-extruded counterparts (Fig. 3) due to protein denaturation, starch gelatinisation and swelling of crude fibre which occurred during extrusion (Singh B. et al., 2007).

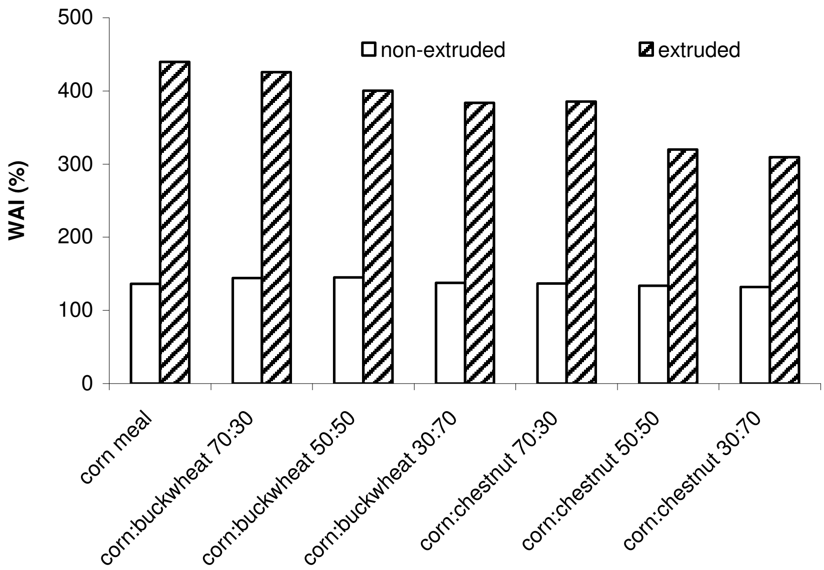

Fig. 3. Water absorption index (WAI) of non-extruded and extruded mixtures of corn meal with buckwheat and chestnut flour

Conclusions

Addition of buckwheat flour to corn meal increased content of fibres and polyphenols, which suggests that buckwheat flour may be used as supplement in production of functional extruded products. Chestnut flour addition contributed to fibre and mineral content, which is indicative of its potential for usage as supplement in production of functional extruded products, as well.

Although addition of buckwheat flour may be more significant from the "health benefiting" point of view, extrudates produced with addition of chestnut flour would be more acceptable to consumers, due to lower hardness compared to extrudates with addition of buckwheat flour.

In addition to production of final products, extruded mixtures of corn meal with buckwheat or chestnut flour could be used as modified flours due to unique pasting properties.

Additional research is needed for definition of extrusion parameters for production of extruded snack products based on corn meal with addition of buckwheat or chestnut flour with desirable bulk density and hardness.

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