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Quality and Nutritional Properties of Corn Snacks Enriched with Nanofiltered Whey Powder

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Abstract

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Corn snacks containing 0, 3, 5, and 10% of nanofiltered whey powder, obtained from the raw material of 12 and 14% moisture contents were analysed. Colour, texture, sensory properties, protein, available lysine, and acrylamide contents were determined in extrudates. When the whey powder content increased above 5%, the extrudate breaking force decreased and the colour became darker. The addition of 10% of whey powder resulted in lower scores for porosity, colour, taste, and overall desirability. Such a level of the addition caused a significant increase in protein and available lysine contents in extrudates, but unfortunately, the product had also significantly higher acrylamide content. In extrudates obtained from the raw material of 12% moisture the amount of acrylamide was higher and the amount of available lysine was lower than that in extrudates obtained from the raw material with 14% moisture content. From the nutritional point of view it is better to extrude the raw material of higher feed moisture with the addition of nanofiltered whey powder.

Keywords: acrylamide; available lysine; extrusion-cooking; physical properties

Whey is a waste by-product of the manufacture of cheese. It contains many valuable components remaining after milk has been curdled and strained. Typical whey contains about 94% of water, 4–5% of lactose, 0.7–1.1% of protein, 0.1–0.6% of fat, vitamin B_2, organic acids, and highly bioavailable calcium. The main whey proteins are: β-lactoglobulin, α-lactalbumin, immunoglobulins as well as lactoferrin and lactotransferrin (Marshall 2004), that is why whey can be a good source of high biological value protein. One of the ways of whey utilisation could be its use as an additive to extruded products. Attempts are made to use whey protein concentrates or dried whey for that purpose (Onwulata *et al.* 2001; Onwulata & Konstance 2006; Onwulata 2010).

During an extrusion process the wet raw material is subjected to high temperature, pressure, and intense shear forces. These factors cause intensive changes in raw material components.

Quality and nutritional value of extruded snacks depend both on the kind of raw materials used and on the extrusion conditions. Many studies were carried out to determine the effect of dry whey or whey protein addition on expansion, density, solubility, and water absorption of the product (Onwulata *et al.* 2001). In our research we focused on nutritional properties and sensory quality of extrudates containing nanofiltered protein powder. On the one hand, the addition of whey can increase the high-quality protein content in extrudates, on the other hand, it can cause an increase in the intensity of acrylamide formation. This compound is formed during the Maillard reaction, especially in heat-processed starch-rich foods such as extruded products. The precursors of its creation are asparagine and reducing sugars, including lactose which is a component of whey (Forstova *et al.* 2014). Lactose can also react with protein-bound lysine resulting in the formation of

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Nε-carboxymethyllysine, pentosidine, pyrraline or other advanced glycation end products (Tressi *et al.* 2002). As a result of these reactions the amount of available lysine may be reduced.

The aim of the study was to determine the effect of the addition of nanofiltered whey powder (NWP) on physical properties, sensory quality, as well as protein, acrylamide, and available lysine contents in corn snacks produced from the raw material of different moisture content.

MATERIAL AND METHODS

Material. Raw materials for the experiment were corn grits and NWP. The corn grits (particle size 850–1250 μm) were purchased from Corn Mill (Woniesc, Poland). The whey was a by-product of the production of ageing Dutch-type rennet cheeses. Whey was condensed 3 times by nanofiltration and spray dried. The powder contained 75.2 g of lactose, 12.4 g of protein, and 4.9 g of minerals per 100 g of dry matter. Corn grits were moistened 24 h before the extrusion process. The amount of added water was calculated so as the feed moisture of mixed corn grits and whey powder was 12% (FM12) and 14% (FM14).

Extrusion. Samples were extruded with a TS-45 single screw extruder (Metalchem, Gliwice, Poland) with an L/D ratio of 12 : 1 and compression rate of 3 : 1 (screw diameter 45 mm; capacity 25 kg/h; motor power 14 kW). The following process parameters were applied: temperature in individual sections 140/180/140°C, screw rotations 90 rpm and nozzle diameter ø= 3.0 mm. The content of NWP in blends was 3, 5, and 10%. Extrudates made of corn grits without NWP addition were the reference samples.

Physical characteristics of extrudates. Breaking strength of samples was determined by the three-point bending test using a TA.XT plus texture analyser (Stable Micro Systems, Surrey, UK). The experimental conditions for breaking strength tests were as follows: test speed 3.0 mm/s, trigger force 50 g, supports distance 50 mm.

The colour was measured using a Chroma Meter CR-410 (Konica Minolta Sensing Inc., Osaka, Japan) on the CIE $L^*a^*b^*$ scale.

Consumer analysis. Snacks were subjected to consumer testing by a panel of 110 persons. Porosity, crispness, colour, taste, and overall desirability were evaluated on a 9-point hedonic scale from liked extremely (9) to disliked extremely (1).

Nutritional value of extrudates. Protein content was determined by Kjeldahl method using a Kjeltec System 1026 (Foss, Hillerød, Denmark). Nitrogen conversion factor 6.25 was used for protein calculation.

Available lysine (AL) content was determined using the fluorodinitrobenzene (FDNB) procedure of Carpenter (1960) with the modification proposed by Both (1971).

Acrylamide (AA) was extracted from samples with acetone-water. The chromatographic system consisted of Waters 2695 HPLC (Waters, Milford, USA) and Waters 2996 Photodiode Array Detector (detection wavelength 220 nm) with a 150 × 4.6 mm PLRP-S 100A, 5 μm column for AA was used in this experiment. EmpowerTM 1 software (Waters, USA) was used for data processing. Sodium dihydrogen phosphate (0.1 M in water) solution adjusted to pH 3.0 with *o*-phosphoric acid was used as the mobile phase with a flow rate of 0.8 ml/minutes. The mode of the HPLC instrument was isocratic with the injection volume of 10 μl. The AA detection limit was 1.0 ng/g.

Statistical analysis. The Statistica 10 software (StatSoft, Tulsa, USA) was used for statistical data analysis. Two-way ANOVA and Tukey's test were used to test the significance of differences at $\alpha = 0.05$. Furthermore, principal components analysis (PCA) was performed in an attempt to simplify the results and discriminate between the extrudate samples.

RESULTS AND DISCUSSION

Texture and colour of extrudates. The NPW addition changed the colour of extrudates. It caused darkening of the product, an increase in a^* and a decrease in b^* values (Table 1). The differences were more pronounced in samples prepared from FM14. The increase in a^* value resulted from the presence of compounds formed during caramelisation and the Maillard reactions (Ilo & Berghofer 1999). The intensity of the formation of these compounds depends not only on the process conditions but also it is promoted by a high content of lactose and protein in added whey powder (Tamanna & Mahmood 2015). Melanoidins formed in the Maillard reaction impart a darker colour to extrudates. Ilo and Berghofer (1999) showed that with the increasing feed moisture the brightness of the corn extrudates increased and the value of a^* was reduced.

The whey powder addition affected also the texture of the extrudates. Their hardness depends on raw material

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Table 1. Physical characteristics of extrudates enriched with nanofiltered whey powder (NWP)

	NWP (%)	Colour coordinates			ΔE	Breaking force (N)
		L^*	a^*	b^*		
FM12	0	85.1[d#]	5.7[a]	32.6[e]	0	179.1[c]
	3	81.3[c]	8.7[c]	29.5[c]	5.7	145.1[c]
	5	76.7[a]	10.6[d]	28.4[b]	10.6	102.5[b]
	10	78.9[b]	10.0[d]	27.5[a]	9.1	85.9[ab]
FM14	0	83.3[cd]	5.6[a]	32.2[e]	0	156.0[c]
	3	83.9[d]	6.9[b]	32.1[e]	1.4	122.7[bc]
	5	85.1[d]	7.2[b]	32.8[e]	2.4	87.2[ab]
	10	78.3[b]	10.6[d]	31.0[d]	7.2	62.9[a]

Means with the same letter in a column are not significantly different ($P < 0.05$); FM12 – feed moisture 12%; FM14 – feed moisture 14%; L^* – lightness; a^* – intensity of red (+) and green (–); b^* – intensity of yellow (+) and blue (–); ΔE – total colour difference;

composition, as well as feed moisture and extrusion conditions (Anton & Luciano 2007). It was shown that extrudate hardness defined as the breaking strength decreased with the addition of NWP. The 3% NWP addition did not bring about a decrease in the hardness of extrudates but higher additions, 5 and 10%, caused a significant drop in hardness. The decrease was more pronounced in snacks produced from FM14. Onwulata *et al.* (2001) studying texture properties of extruded corn, potato, and rice snacks incorporated with whey also observed that as the whey concentration increased, the breaking force significantly decreased.

Sensory analysis. Results of consumer analysis are presented in Table 2. The addition of 10% of NWP resulted in a significant decrease in porosity and colour scores of extrudates. However, the NWP did not affect the scores for crispness and taste of the product, which were even higher for extrudates with the 5% addition than for the control samples. And yet the 10% addition caused a decline of these scores. From the aspect of sensory quality there is no justification for applying higher amounts of NWP than 5% in corn extrudates. It was found that the product prepared from FM12 with the addition of whey at a level of 5% had the best sensory characteristics. Overall desirability of this extrudate was the same as that of the sample without any addition but its taste was scored higher. The samples produced from FM14 obtained worse scores than those from FM12.

Nutritional value of extrudates. The addition of NWP affects not only physical characteristics and sensory quality of extrudates, but also influences the nutritional value of the product (Table 3). The protein content of NWP was relatively low (12.4% in DM), however, it is well known that the amino acid composition of whey proteins is very advantageous. Whey proteins contain 9.1 g of lysine in 100 g of protein whereas cereal proteins contain only 1.6 g of lysine (Tomkins *et al.* 1994). The 5% addition of NWP resulted in an increase in the protein and AL

Table 2. Sensory analysis of extrudates enriched with nanofiltered whey powder (NWP)

	NWP (%)	Porosity	Colour	Crispness	Taste	Overall desirability
FM12	0	7.0[d#]	7.9[c]	6.6[bc]	6.2[bc]	6.3[b]
	3	5.1[bc]	3.5[a]	6.9[bc]	5.9[b]	6.2[b]
	5	5.4[bc]	5.7[b]	7.5[c]	7.2[c]	6.9[b]
	10	3.7[a]	4.2[a]	6.5[b]	5.1[a]	5.3[a]
FM14	0	6.3[cd]	7.1[c]	6.2[b]	6.1[b]	6.3[b]
	3	5.1[bc]	4.8[ab]	5.9[ab]	5.9[b]	5.2[a]
	5	3.8[ab]	5.0[b]	6.1[b]	5.7[ab]	5.8[ab]
	10	3.6[a]	4.4[a]	5.0[a]	4.8[a]	4.9[a]

Means with the same letter in a column are not significantly different ($P < 0.05$); FM12 – feed moisture; eed moisture 12%; FM14 – feed moisture 14%

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Table 3. Protein, available lysine, and acrylamide contents in extrudates enriched with nanofiltered whey powder (NWP)

	NWP (%)	Protein (g/100 g DM)	Available lysine (g/100 g DM)	Acrylamide (µg/kg DM)
FM12	0	7.39[a#]	0.176[ab]	392[b]
	3	7.35[a]	0.171[a]	462[c]
	5	7.71[b]	0.174[ab]	482[c]
	10	7.93[d]	0.188[bc]	887[e]
FM14	0	7.31[a]	0.173[a]	291[a]
	3	7.50[ab]	0.169[a]	364[b]
	5	7.60[bc]	0.184[bc]	503[c]
	10	7.81[cd]	0.195[c]	705[d]

Means with the same letter in a column are not significantly different (P < 0.05); FM12 – feed moisture 12%; FM14 – feed moisture 14%; DM – dry matter

content of the product by 4 and 6%, respectively. In the extrudate with 10% of the NWP protein and AL contents increased by 7 and 13%, respectively. A slightly greater amount of AL was noted in extrudates obtained from FM14 than in those from FM12. However, the amount of AL in the extrudate is the result of both the NWP amount and the extrusion process. The NWP used in the experiment contained a large amount of lactose. As a result of the extrusion a reaction between D-lactose and lysine occurs and it plays an important role in the modification of proteins. Compounds like Nε-carboxymethyllysine, pentosidine, pyrraline, or other advanced glycation end-products which were formed during extrusion may cause limited lysine availability in spite of its high content in the sample (Tressi *et al.* 2002). Mercier *et al.* (1979) found that during the extrusion of wheat flour with the addition of milk powder, at 200°C and feed moisture 15%, lysine availability declined by 50% and the 47% decline in lactose content was observed. The disintegration of amino acids and reaction of protein and sugars were kept to a minimum when the moisture content of the raw material was increased to 36% (Sing *et al.* 2007). Increased feed moisture had a protective effect against the lysine loss during extrusion cooking (Masatcioglu *et al.* 2011). Sing *et al.* (2007) stated that in order to reduce lysine losses, it is necessary to avoid extrusion cooking above 180°C at water content below 15% and to limit the amount of reducing sugars in the raw material.

Another negative consequence of extrusion is the formation of AA in the reaction between asparagine and reducing sugars (Mottram *et al.* 2002; Halford *et al.* 2012). Based on the EFSA investigations into the levels of AA in food (EC 2011) cereal products such as biscuits, crackers, wafers, crisp bread, and similar may contain up to 500 µg/kg. The AA content in tested samples ranged from 291 to 887 µg/kg and it increased with the increasing amount of NWP. The addition of 10% of NWP caused the increase in AA content by about 130% as compared to the control sample. When the amount of NWP in the sample was lower (3 and 5%), the differences were significantly smaller and ranged from 14% to 65%, respectively. It was noted that the obtained results were affected by the feed moisture. The AA content in samples of the same composition prepared from FM14 was by about 18% lower than that in snacks from FM12. The effect of feed moisture on the amount of AA formed in extrudates was also reported by Sing *et al.* (2007). Significantly higher content of AA in samples containing NWP is the result of high asparagine content in whey. According to Sindayikengera (2006) the content of this amino acid in whey protein is about 9% whereas in cereal products it is only about 3%. A high amount of lactose can also promote the formation of AA in the product.

In extrudates containing 10% of NWP, regardless of the feed moisture, the amount of AA exceeded the acceptable level of 500 µg/kg, but in potato snacks the concentration of AA is even higher (Mustafa *et al.* 2005). Mulla *et al.* (2011) indicated that it is possible to reduce acrylamide formation without altering the sensory properties of the extrudates by means of adding calcium chloride to the flour blend.

PCA was carried out to facilitate the interpretation of the effect of NWP amount and feed moisture on the characteristics of extrudates. Based on calculations two principal components were obtained that allowed explaining 82.31% of the total variance of the 12 variables analysed. The 1st and the 2nd principal component carry 54.54 and 27.77% of information about the tested products represented by the vari-

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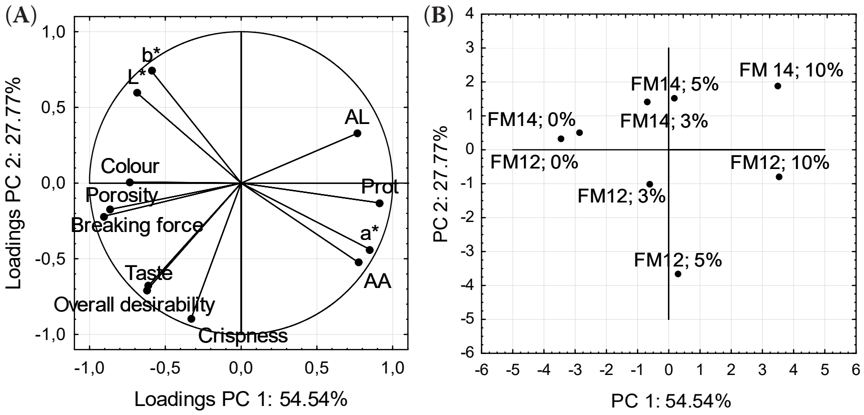

Figure 1. PCA plot of relationship between the descriptors and differentiation between the samples of obtained extrudates

L* – lightness; a* – intensity of red (+) and green (–); b* – intensity of yellow (+) and blue (–); AA – acrylamide; AL – available lysine; Prot – proteins; FM12 – feed moisture 12%; FM14 – feed moisture 14%

ables, respectively (Figure 1A). On the basis of the analysis correlations between AA content and colour coordinates (*L** and *b** – negative correlation; *a** – positive correlation) were observed as well as between overall desirability and taste, or between breaking force and porosity. AL content was negatively correlated with breaking force and desirable porosity.

A correlation between AA content and colour determinants in potato extrudates was noted also in the research of Majcher and Jelen (2007). This supports a thesis that formation of AA is accompanied by formation of brown melanoid compounds. As observed in Figure 1B corn snacks without NWP (FM12 and FM14) were very similar. The second cluster represents FM14 samples containing 3 and 5% of NWP. The remaining samples differed significantly and they did not form any clusters. So it can be concluded that NWP addition modifies the extrudate quality which depends also on the moisture content of the raw material subjected to extrusion.

CONCLUSIONS

NWP can be applied as an addition in extruded corn snacks. The 3% concentration of NWP changes the colour of the extrudates, but it neither causes any significant changes of product texture nor deteriorates their sensory properties. 5% of the NWP in extrudates alters physical characteristics of the products, but their sensory quality is still attractive. When the NWP content increases to 10%, snacks become darker and less hard even though it does not affect the crispness score. The 10% addition of NWP causes the contents of protein and AL to be indeed higher, but at the same time the AA content increases above the permitted level and sensory properties of snacks become deteriorated. From the nutritional point of view snacks made from FM14 have more favourable characteristics than those from FM12, on account of lower concentration of AA and higher amount of AL in products. Therefore it is fully justified to enrich extruded corn snacks with NWP at the amount of 5% of the product, using the raw material of the moisture content not lower than 14%.

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