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Research Article

Physical characteristics of extrudates from corn semolina flavored with cocoa shells

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Abstract

Extrusion of corn semolina milled with cocoa shells using a single screw extruder “BRABENDER 20 DN” was carried out. Full factorial experimental 22 was used to investigate the effects of the quantity of cocoa shells and moisture of the material on the water absorption index (WAI) and water solubility index (WSI). Working screw speed and feed screw speed were fixed at 200 and 40 rpm, respectively. Compression ratio of the screw was fixed at 4:1. Temperatures of the first, second and third zone were 150, 155 and 160°C. Water absorption index values range were between 6.71 and 7.6 g/g and the water solubility index between 25.38 and 35.33%. The increase in moisture content and quantity of cocoa shells leads to an increase in water absorption index and a decrease in water solubility index. Organoleptic characteristics of extrudates were also analysed. The increase in moisture content leads to more unsatisfactory organoleptic characteristics of the extrudates. Practical applications: Cocoa shells in an amount of up to 10% can be used in the production of extrudates by mixing with corn semolina. Water absorption index values range between 6.71 and 7.6 g/g and the water solubility index between 25.38 and 35.33%. Sensory characteristics of extrudates values range between 3.8 and 4.8. The resulting regression models can be used to optimize the process. The best sensory characteristics were obtained for extrudates with moisture content of 14% and a cocoa shells content of 5%. In general, results show that cocoa shells can be mixed with corn semolina for the production of extrudates, which allows us to recommend extrusion processing of cocoa shells as an alternative technology in utilization processing of raw cocoa materials.

Keywords: extrusion, corn semolina, cocoa shells, water absorption index, water solubility index, sensory characteristics.

Abbreviations:

WAI - water absorption index

WSI - water solubility index

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Introduction

The extrusion process is very popular in the food industry and can efficiently serve to create innovative products and also for the recovery of waste materials (Cisneros and Kokini 2002). During the process the dampened materials are plasticized, sterilized and moulded under a combination of high pressure, temperature and mechanical impact. In this treatment, the material is treated hydrothermally and mechanically, homogenizing, esterifying, altering its volume and structure upon drainage from the matrix nozzle, drying in the pressure and temperature drop and acquiring a certain shape (Anton et al. 2009). Extrusion is widely used for the processing of cereal raw materials (flours, greens, flakes, etc.), where different kinds of snacks and structured products are obtained but have low nutritional and biological value and taste qualities (Onwulata et al. 2001). Due to the increasing demands of consumers in search of a healthier diet, there is growing interest in the so-called "Functional foods," the food industry, and in particular the extrusion process, is directed to the production of products with increased fibre content, resistant starch, antioxidants, vitamins, etc. (Charalampopoulous et al. 2002; Chillo et al. 2010). Most studies are directed to extrusion of mixtures of corn or wheat flour or semolina with different cereal or "pseudo-cereal" crops to increase nutritional value and reduce calories in the finished product (Sobota et al. 2010; Perez-Navarrete et al 2006). The Latin name of the cocoa tree *Theobroma cacao L.*, which grows in West Africa, South East Asia and the central parts of South America (Lecumberri et al. 2017) is translated as "the food of the Gods". Its fruits are cocoa beans, from which cocoa butter, cocoa paste and cocoa powder are prepared. They are wrapped in pods (shells) containing 20 to 50 grains (Okiyama et al. 2017). After their baking and grinding, the shells that have been removed becomes a waste product. They contain valuable biologically active substances - polysaccharides, proteins, vitamins, caffeine, tannin, theobromine, organic acids and others (Redgwell et al. 2003). Cocoa shells have a high antioxidant ability (Martinez et al. 2017) and can therefore be used as an additive in various foods (Fioresi et al. 2017). They are also used for feeding animals, fertilize and improve the soil as an additive in the production of briquettes for heating, paper making, heavy metals absorption in sewage and others (Okieimen and Imanah 2006; Fioresi et al. 2017). The purpose of this study was to investigate the effects of quantity of cocoa shells and feed moisture on the water absorption index (WAI), the water solubility index (WSI) and sensory characteristics of the obtained extrudates from corn semolina and cocoa shells.

Materials and Methods

Materials

Cocoa shells from cocoa seeds of the "Rio" variety (Fig.1) were used during experimentation. These shells were utilization material for the production of chocolate, and were kindly provided by "Gaillot Chocolate" Plovdiv. The chemical composition of the shells is presented in Table 1. The corn semolina was supplied by ET "Olimpiya Chalamova" Plovdiv, with a moisture of 11 % and average particle size of 1.138 µm. The cocoa shells and the corn semolina were milled and mixed in the desired proportions with the addition of water to achieve the specified moisture (Table 2).

Figure 1. Cocoa shells

Table 1. Chemical composition of cocoa shells

Indicator	Value
Proteins	14 %
Carbohydrates	45 %
Fats	3 %
Theobromine	1.2 %
Caffeine	0.1 %
Organic acids	1.1 %
Vitamin D	0.2 %
Vitamin B_1 and B_2	0.08 %
Water	10 %

Table 2. Experimental plan in natural and encoded values

№	Natural value		Encoded values	
	Content of cocoa shells, %	Moisture, %	X_1	X_2
1	5	14	-1	-1
2	5	20	-1	+1
3	10	14	+1	-1
4	10	20	+1	+1

Table 3. Rating system

№	Indicators	K coefficient	A Points	B Evaluation
1	Form, appearance	1		
2	Surface	2		
3	Expansion, porosity	3		
4	Roughness	2		
5	Chew assessment, consistency	3		
6	Scent, test	9		
Sum		ΣK = 20	-	ΣB=
FR: Final rating		FR = ΣB/ΣK		

Extrusion

The extrusion was performed on a Brabender 20 DN single-screw laboratory extruder (Toshkov 2011) under the following conditions: nozzle diameter 3 mm; screw compression ratio 4:1; extruder screw speed 200 rpm; feed screw speed 40 rpm; feed screw speed 40 rpm; temperatures in the first, second and third extruder zones 150, 155 and 160°C.

Analysis methods

Statistical processing. A full factorial experiment (N=22) was used during processing. The independent variables were the cocoa shells content and moisture of the extrusion mixture. Experimental plan with the natural and encoded values of both factors is presented in Table 2. Experiments at all points of the plan were conducted with a three-fold repeatability.

To model the dependencies in encoded form, a linear regression equation with factor interactions was used:

$$y = b_o + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} x_i x_j \qquad (1)$$

where: b_o, b_i and b_{ij} are free coefficient, linear effect coefficient and factor interaction coefficient. All statistical processing were performed with statistical analysis software Statgraphics Centurion trial version.

Analysis of extrudates. The water absorption index and water solubility index were determined as outlined by Anderson et al. (1969): the extrudate was ground then 0.2 g was mixed with 5 cm^3 of distilled water. The mixture was suspended in water at 30°C for 30 min, gently stirred during this period, and then centrifugalised in centrifuge CH 90-2A at 3000 rpm for 20 min. The supernatant was decanted into an evaporating dish of known weight and then was dried at 10°C until constant mass. The cooled trial was weight.

The WAI was calculated using the formula:

$$\mathrm{WAI} = \frac{m_g}{m_s} \quad (2)$$

The WSI was calculated using the formula:

$$\mathrm{WSI} = \frac{m_{ds}}{m_s}.100 \quad (3)$$

where: WAI – water absorption index, g/g; WSI – water solubility index, %; m_g – weight of sediment, g; m_s – weight mass of sample, g; m_{ds} – weight of dry solids after evaporation of the supernatant, g.

Sensory analysis. The quality of the obtained products were evaluated through sensory analysis. A special rating system was established for the purpose by (Seibel et al. 1984). The maximum score is 100 points, with each indicator having a different weighting factor (Table 3). The product was evaluated according to the listed indicators. A score of 1 to 5, which corresponds to the quality of the product, according to the relevant indicator, was used (Table 4). The score was recorded in column A. The following formula was used to fill column B.

$$B = K.A \quad (4)$$

Table 4. Rating evaluation

Evaluation	Quality
1	Bad
2	Unsatisfactory
3	Satisfactory
4	Good
5	Very good, Excellent

The final rating FR was calculated by the equation:

$$FR = \frac{\sum \boldsymbol{B}}{\sum \boldsymbol{K}} \quad (5)$$

With the five point qualifying system, a final assessment of the quality of the finished product was made, based on the total number of points obtained:

- 4.50÷5.00 points – the production is very good;
- 4.00÷4.49 – the production is good;
- 3.50÷3.99 points – production needs some improvements;
- below 3.50 – production need significant improvements.

The developed sensory analysis method is suitable for evaluation of finished products and can be used in industrial production (Simitchiev 2013).

Results and Discussion

Table 5 shows the mean values and standard deviations for the water absorption index and water solubility index of the extrudates for all samples. The results obtained show that the water absorption index ranges between 6.71 and 7.6 g/g and the water solubility index between 25.38 and 35.33%. These results are similar with those of extrusion of a single-screw extruder of mixtures of corn semolina and goji berry (Dushkova et al. 2013); lentil (Lazou and Krokida 2010) and mixtures of rice grits and fruit waste (Yagci and Gogus 2008) .

Table 5. Experimental results for the water absorption index and water solubility index

№	Water absorption index, WAI, g/g	Water solubility index, WSI, %
1	6.71±0.2*	35.33±0.29
2	7.31±0.19	29.34±0.22
3	7.19±0.17	29.64±0.31
4	7.6±0.2	25.38±0.07

*Standard deviation based on three-fold repeatability

The following adequate mathematical models were obtained at the 5% significance level:

$$WAI = 7.20417 + 0.190833.X1 + 0.254167.X2 \quad (6)$$

$$WSI = 29.9217 – 2.41.X1 – 2.56167.X2 + 0.43333.X1.X2 \quad (7)$$

A committee of five or more selected assessors or experts, specially trained for the method, according to BSS EN ISO 8586:2014 is required to conduct the organoleptic evaluation. The selection of assessors was made in accordance with the criteria of item 4.4.of ISO 6658:2017 – good health and good teeth condition and general hygiene, motivation (desire, interest), accessibility for normal recruitment. The head of committee had been selected as an assessor with proven sensory sensitivity, with a considerable amount of preparation and experience in sensory analysis, capable of performing consistent, repeatable sensory assessment of different products. Training of fifteen evaluators was conducted using the repeat test method. Each assessor was presented with three types of confectionary. The same test was carried out twice more to ensure that the assessor did not accidentally gave the correct answer. After conducting the training and checking the results, seven assessors who showed the best ability to recognize different products were selected. The average results of the taster cards of each assessor are presented on Table 6.

Table 6. Experimental results for sensory characteristics

Taster card									
Evaluation - A		Product №							
1 – bad; 2 – unsatisfactory; 3 – satisfactory; 4 – good; 5 – very good, excellent		1		2		3		4	
Indicator	**K**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
1	1	5	**5**	4	**4**	4	**4**	4	**4**
2	2	4	**8**	3	**6**	3	**6**	3	**6**
3	3	5	**15**	4	**12**	5	**15**	3	**9**
4	2	4	**8**	3	**6**	3	**6**	2	**4**
5	3	5	**15**	4	**12**	4	**12**	3	**9**
6	9	5	**45**	4	**36**	5	**45**	5	**45**
C: Sum.	20		**96**		**76**		**88**		**77**
Final		**4.8**		**3.8**		**4.4**		**3.85**	

It lists the average evaluations of the tested products. According to most literature sources (Kadan et al. 2003; Ding et al. 2005; Ding et al. 2006; Rosentrater et al. 2009; Kannadhason et al. 2011), the inlet moisture of the mixture and the extrusion temperature had the greatest influence on the water solubility index and the water absorption index. Figure 2 shows the response surface and the contour lines for the variation of the water absorption index depending on the humidity of the mixture and the cocoa husk content.

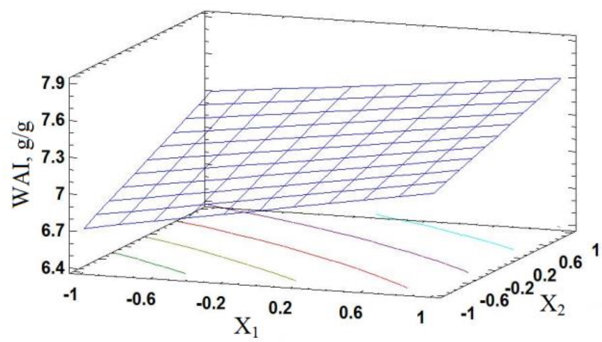

Figure 2. Response surface and contour lines for water absorption index (WAI) variation, depending on the content of cocoa shells (X_1) and moisture (X_2)

The water absorption index is a measure of the water absorbed by starch and can be used to determine the degree of gelatinization, because native starch does not absorb water at room temperature (Ding et al. 2005; Ding et al. 2006). Gelatinization of the starch leads to the degradation of the starch molecule, which absorbs more water, and therefore, with a higher degree of gelatinization, the water absorption index increases. The increase in moisture and cocoa content in the mixture results in an increase in the water absorption index, with a greater influence on humidity. The increase in the water absorption index with the increase in the moisture content of the mixture is more pronounced at the lower level of the cocoa content. This is probably due to the lower amount of protein in the mixture, which reduces the dextrinization of the starch and contributes to its gelatinization (Singh et al. 2007; Rosentrater et al. 2009; Lazou and Krokida 2010). In the solubility index the increase of the two independent variables leads to its decrease, again the humidity was the more significant factor (Fig. 3). The solubility index can be used as an indicator for the breakdown of molecular bonds and a measure of the amount of soluble components released from starch after extrusion (Ding et al. 2005).

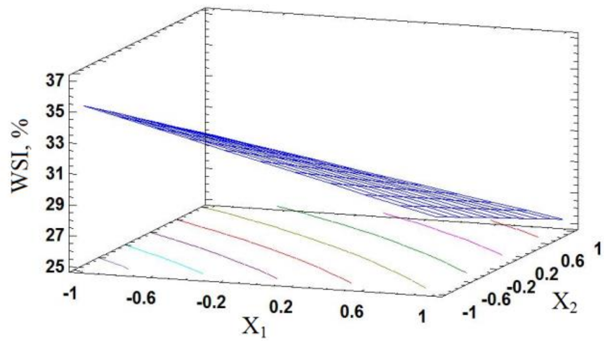

Figure 3. Response surface and contour lines for water solubility index (WSI) variation, depending on the content of cocoa shells (X_1) and moisture (X_2)

The reduction in the water solubility index with increased humidity and protein content in the mixture has also been reported in the extrusion of fish feed (Rosentrater et al. 2009; Kannadhason et al. 2011). Increasing the protein in the mixture results in the formation of starch-protein complexes and agglomerates that lose their ability to bind to water and thus reduce their solubility. Protein molecules denature, resulting in structural changes and hydrophilic groups such as - OH, -NH2, -COOH and -SH form crosslinks with starch, which reduces its degree of gelatinization, which in turn leads to a decrease in the water solubility index (Fernandes-Gutierrez et al. 2004). The highest score of 4.8 was obtained with the products from the first experiment, with a moisture content of 14% and a cocoa shells content of 5%, which was evaluated as very good. With close lower evaluations of 3.8 to 3.85, the products from samples 2 and 4 are in need of improvements. In these two samples, the moisture content is at the upper level, resulting in a lower expansion index and more unsatisfactory organoleptic characteristics of the final product.

Conclusions

Adequate mathematical regression models were obtained, showing the influence of cocoa shells content and the moisture of the mixture on the water absorption index and water solubility index. Water absorption index values range between 6.71 and 7.6 g/g and the water solubility index between 25.38 and 35.33%. The increase in moisture content and quantity of cocoa shells leads to an increase in water absorption index and a decrease in water solubility index. The best sensory characteristics were obtained for extrudates with moisture content of 14% and a cocoa shells content of 5%. These products are most suitable for direct consumption.

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