

Physical characteristics of extrudates from wheat semolina enriched with cocoa bean shells

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Abstract. Response surface methodology was used to investigate the effect of cocoa bean shells content (5 % and 10 %), moisture content (14 % and 20 %) and temperature of the matrix (160 °C and 180 °C) on the physical characteristics of wheat semolina extrudates with cocoa bean shells. The extrusion was carried out on a single screw extruder Brabender 20 DN. A full factorial experiment 2³ was used to evaluate the influence of above mentioned parameters on the water absorption index (WAI), water solubility index (WSI) and moisture content (W). The water absorption index varies between 7.13 g/g and 9.91 g/g, water solubility index between 9.34 % and 22.48 % and moisture content between 7.75 % and 11.31 % respectively. The data show that the increase of the moisture content from 14 % to 20 % increases the water absorption index and decreases the water solubility index while the increase of cocoa bean shells content from 5 % to 10 % results in lower water absorption index and higher water solubility index. Temperature of the matrix has no influence on the moisture content and water absorption index. The water solubility index decreases when the temperature of the matrix increases.

1 Introduction

In the recent years the agriculture and food industry generates a huge quantity of waste and by-products annually which causes a vast economic problems due to the pollution of the environment [1, 2]. The waste are considered as a cheap source of dietary fiber, protein, and bioactive compounds such as phenolic compounds, antioxidants, minerals, and vitamins and can be successfully involved as a supplement in the food products [3-5]. The negative environmental impacts could be lower by the utilization of by-products and their reuse could improve the nutritional value of products for human consumption [3].

The basic raw material for the production of different cocoa products such as cocoa powder, cocoa butter and chocolate is dried and fermented cocoa beans. Cocoa bean shells (Figure 1) are one of the by-products of cocoa beans obtained in the chocolate industry and they are well known as waste [2, 6]. Despite this fact it was established that cocoa bean shells are rich in dietary fibers and polyphenols and could be used as food-additives or supplements of high nutritional value [7].

Extrusion is one of the most commonly used food manufacturing processes [8, 9]. It represent a complex technology which combines separate operation such as mixing, conveying, shearing, kneading, heating and

shaping [9, 10]. Moistened expansible starch and protein containing materials alters under combination of different working parameters in which the microstructure, chemical characteristics and macroscopic shape of food product is changed [11]. The starch gelatinization, protein denaturation and inactivation of many native enzymes are the most significant chemical reactions which occurs during extrusion [12].



Fig. 1. Cocoa bean shells [13].

Water absorption index (WAI) and water solubility index (WSI) can be applied to evaluate the functional characteristics of extrudates and to predict the food behavior over time. Two basic group of factors can affect the values of (WAI) and (WSI). The first one is related to the properties of the raw materials and the second one to the extruder conditions [12]. Production of food products with desired characteristics is not possible without knowledge of the extrusion process [9].

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The objective of this study was to investigate the impact of cocoa bean shells content, moisture content and temperature of the matrix on the physical characteristics (water absorption index, water solubility index and moisture content) during extrusion of wheat semolina and cocoa bean shells.

2 Materials and methods

2.1 Materials

Cocoa bean shells. The experimental work was conducted with cocoa bean shells, presented in figure 1. They were waste raw material in chocolate production and were kindly provided by the company “Gaillot Chocolate” Plovdiv. The average chemical composition of the cocoa bean shells was 10 % moisture content, 14 % proteins, 45 % carbohydrates, 3 % fats and 1.2 % theobromine.

Wheat semolina. The wheat semolina with moisture content of 13 % was delivered from the Dimitar Pilev Mill Complex in the village of Konush. The cocoa bean shells and the wheat semolina were mixed together in the desired proportions with the addition of water to achieve the specified moisture content (Table 1).

Table 1. The experimental design with natural and coded values.

№	Natural values			Coded values		
	Cocoa bean shells content, %	Moisture content, %	Temperature of the matrix, °C	X ₁	X ₂	X ₃
1	5	14	180	-1	-1	+1
2	5	20	160	-1	+1	-1
3	5	20	180	-1	+1	+1
4	10	20	160	+1	+1	-1
5	5	14	160	-1	-1	-1
6	10	20	180	+1	+1	+1
7	10	14	180	+1	-1	+1
8	10	14	160	+1	-1	-1

2.2 Extrusion

The extrusion was performed on a Brabender 20 DN single-screw laboratory extruder [14] at varied process parameters (Table 1). Constant conditions during extrusion were: nozzle diameter 3 mm; screw compression ratio 3:1; extruder screw speed 200 min⁻¹; feeding screw speed 30 min⁻¹; temperatures in the first and second extruder zones 140 °C and 150 °C.

2.3 Analysis methods

2.3.1 Statistical processing

A full factorial experiment (N = 2³) was used during processing. The independent variables were the cocoa bean shells content (X₁), the moisture content (X₂) and the temperature of the matrix (X₃). The experimental

design with natural and coded values of the three investigated factors is presented in Table 1. The steps of variation of the examined factors were chosen on the basis of preliminary investigations and literature data [14]. A three-fold repetition was used at each point in the experimental design.

A linear regression equation with interactions of the factors was used to model the dependencies in coded values:

$$y = b_0 + \sum_{i=1}^n b_i X_i + \sum_{i=1}^n \sum_{j=1}^n b_{ij} X_i X_j \quad (1)$$

where: b_0 , b_i и b_{ij} were a free coefficient, coefficient of linear effect and coefficient of interaction respectively.

The critical value of Fishers-criterion Fc was used to evaluate the adequacy of the models. All statistical processing were performed with software “Statgraphics XVII Centurion trial version”.

2.3.2 Analysis of process characteristics

Water absorption index (WAI) and water solubility index (WSI). The water absorption index and water solubility index were determined as outlined by AACC method 56 - 20 [15]: the extrudate was ground then 0.2 g was mixed with 5 cm³ of distilled water. The mixture was suspended in water at 30 °C for 30 min, gently stirred during this period, and then centrifugated in centrifuge CH 90 - 2A at 3000 min⁻¹ for 20 min. The supernatant was decanted into an evaporating dish of known weight and then was dried at 105 °C until constant mass. The cooled trial was weight.

The WAI was calculated using the formula:

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

The WSI was calculated using the formula:

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

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.

Moisture content (W). Moisture content of extrudates was determined following AACC method 44-19 [16] at 135 °C for 2 h.

3 Results and discussion

The mean values and standard deviations for water absorption index (WAI, g/g), water solubility index (WSI, %) and moisture content (W, %) depending on the three tested factors – cocoa bean shells content, moisture content and temperature of the matrix are shown in Table 2.

Table 2. Experimental results for the water absorption index (WAI), water solubility index (WSI) and moisture content (W).

No	Water absorption index, WAI, g/g	Water solubility index, WSI, %	Moisture content, W, %
1	8.16 ± 0.27*	16.42 ± 0.31*	8.71 ± 0.28*
2	8.87 ± 0.10	11.38 ± 0.36	10.92 ± 0.37
3	9.91 ± 0.11	9.34 ± 0.30	11.31 ± 0.50
4	7.71 ± 0.23	11.50 ± 0.35	10.41 ± 0.23
5	8.13 ± 0.07	20.51 ± 0.43	8.77 ± 0.18
6	7.32 ± 0.33	11.07 ± 0.36	10.66 ± 0.21
7	7.13 ± 0.24	16.12 ± 0.12	7.80 ± 0.20
8	7.34 ± 0.11	22.48 ± 0.56	7.75 ± 0.05

*Standard deviation based on three-fold repeatability

The results show that the water absorption index (WAI) varies between 7.13 g/g at cocoa bean shells content 10 %, moisture content 14 %, temperature of the matrix 180 °C and 9.91 g/g at cocoa bean shells content 5 %, moisture content 20 %, temperature of the matrix 180 °C. According to the water solubility index the highest value of 22.48 % was obtained at cocoa bean shells content 10 %, moisture content 14 %, temperature of the matrix 160 °C and the lowest value of 9.34 % cocoa bean shells content 5 %, moisture content 20 %, temperature of the matrix 180 °C. The moisture content ranges between 7.75 % and 11.31 %. These results are similar with the results obtained during extrusion of corn semolina and cocoa bean shells [17].

The follow adequate models at confidence interval 95 % with significant coefficients were obtained:

$$WAI = 8.073 - 0.696X_1 + 0.382X_2 - 0.243X_1X_2 - 0.208X_1X_3 + 0.103X_2X_3 - 0.148X_1X_2X_3 \quad (4)$$

$$R^2 = 94.78 \% \quad F = 0.65 < F_c = 4.5$$

$$WSI = 14.854 + 0.439X_1 - 4.029X_2 - 1.613X_3 + 0.997X_2X_3 + 0.487X_1X_2X_3 \quad (5)$$

$$R^2 = 99.28 \% \quad F = 0.20 < F_c = 3.6$$

$$W = 9.541 - 0.387X_1 + 1.285X_2 \quad (6)$$

$$R^2 = 96.06 \% \quad F = 0.45 < F_c = 2.9$$

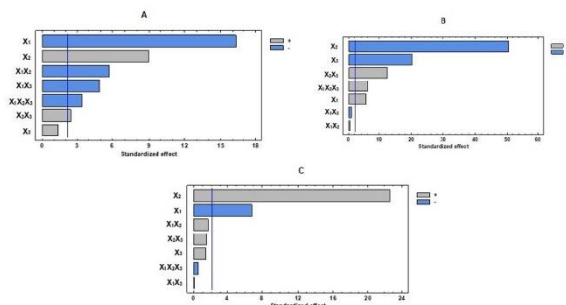


Fig. 2. Pareto charts for water absorption index (A), water solubility index (B) and moisture content (C).

The importance of the examined factor is presented in Figure 2. It shows that for the water absorption index (WAI) the factors X₁ (cocoa bean shells content) and X₂ (moisture content) as well as the factor interactions

between them are significant while the factor X₃ (temperature of the matrix) is insignificant. The biggest effect has the cocoa bean shells content (X₁) followed by moisture content (X₂). This is also confirmed by the obtained coefficients in equation (4) 0.696 for X₁ and 0.382 for X₂ respectively. According to the water solubility index (WSI) it can be seen that the three investigated factors and the factor interactions between them are significant except X₁X₃ and X₁X₂. The strongest influence has the moisture content (X₂) and the lowest cocoa bean shells content (X₁). Figure 2 shows that for moisture content (W) only factors X₁ and X₂ are significant. The biggest effect has the moisture content (X₂) where the obtained coefficient in equation 6 is 1.285 followed by cocoa bean shells content (X₁) with coefficient 0.387.

The final moisture content of the extrudates is one of the most important indicators that determines the quality of the product and has an impact on different parameters such as water adsorption, hardness, pellet durability index e.t.c. [18]. The lower moisture content of the final product leads to an increase in the storage period at room temperature. The moisture content of the final product is highly dependent on the input moisture content of the raw material. In the present experimental work the decrease of moisture content during extrusion was between 40 % to 45 %. The higher initial moisture content of the mixture at constant other extrusion conditions, for obvious reasons, contributes to a higher final moisture content of the extrudates. A higher initial moisture content was also observed in the extrudates. The lowest value of moisture content was obtained at high level of cocoa bean shells content and low level of moisture content (Figure 3).

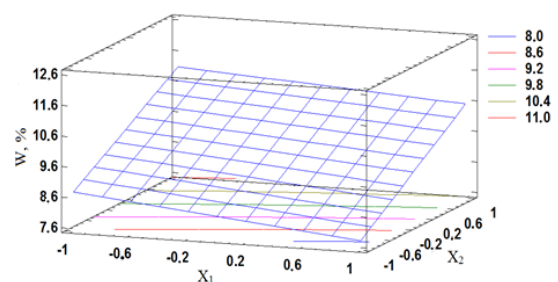


Fig. 3. Response surface of the moisture content of extrudates (W), depending on the cocoa bean shells content (X₁) and moisture content (X₂).

The water absorption index (WAI) is a measure of the water absorbed by the starch and can also be used to determine the degree of gelatinization because the native starch does not absorb water at room temperature [19, 20]. The gelatinization of starch leads to degradation of the starch molecule, which absorbs more water, and therefore, the higher degree of gelatinization increases the water absorption index. The change of the water absorption index depending on the examined factors is shown in Figures 4 and 5.

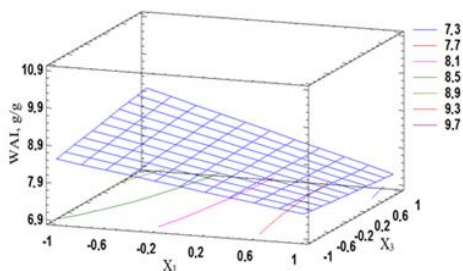


Fig. 4. Response surface of the water absorption index (WAI), depending on the cocoa bean shells content (X_1) and temperature of the matrix (X_3).

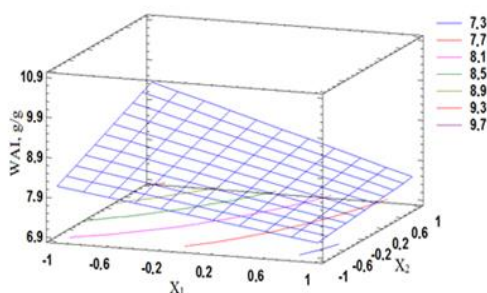


Fig. 5. Response surface of the water absorption index (WAI), depending on the cocoa bean shells content (X_1) and moisture content (X_2).

The increase of cocoa bean shells content leads to a decrease in the water absorption index while it increases when the moisture content is higher. Similar results during extrusion of corn grits and cocoa bean shells were obtained by [21]. The increase in the water absorption index (WAI) at higher moisture content at constant other parameters was more pronounced at a lower level of cocoa bean shells content (Figure 5).

The water solubility index (WSI) can be used as an indicator of the breakdown of molecular bonds and a measure of the amount of soluble components released from the starch after extrusion [20]. According to the literature [18, 22] the greatest influence on the water solubility index of the extruded products have the moisture content and temperature. Our results confirmed this tendency and as they increase at constant other parameters the water solubility index decreases (Figures 6 and 7). This is probably due to the greater degree of starch degradation during extrusion at lower moisture content [19].

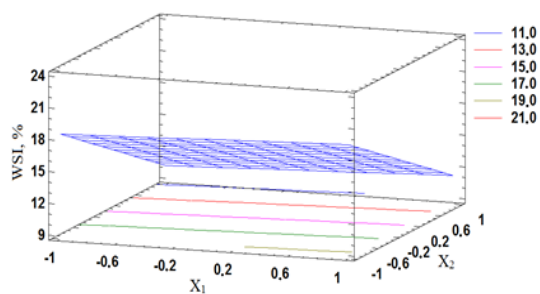


Fig. 6. Response surface of the water solubility index (WSI), depending on the cocoa bean shells content (X_1) and moisture content (X_2).

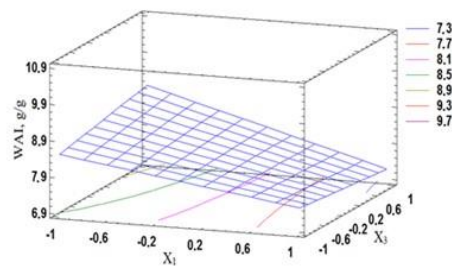


Fig. 7. Response surface of the water solubility index (WSI), depending on the moisture content (X_2) and temperature of the matrix (X_3).

4 Conclusion

Adequate mathematical regression models were obtained to explore the influence of cocoa bean shells content (5 % and 10 %), moisture content (14 % and 20 %) and temperature of the matrix (160 °C and 180 °C) on the water absorption and solubility indexes as well as the moisture content of wheat semolina extrudates with cocoa bean shells. The values of the water absorption index were between 7.13 g/g and 9.91 g/g. The water solubility index changed from 9.34 % to 22.48 %. The moisture content varied from 7.75 % to 11.31 % respectively.

The study was conducted with the kind support of the Science Fund of UFT-Plovdiv, project 06/19-N: Extrusion of cereal raw materials and cocoa shells.

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