



## Food Science and Applied Biotechnology

e-ISSN: 2603-3380

Journal home page: [www.ijfsab.com](http://www.ijfsab.com)  
<https://doi.org/10.30721/fsab2021.v4.i2>



### Research Article

#### Extrusion of wheat semolina and cocoa shells

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#### Abstract

Extrusion of wheat semolina and milled cocoa shells using a single screw extruder Brabender 20DN was carried out. Full factorial experiment 23 was used to investigate the effect of the quantity of cocoa shells, moisture of the material and temperature of the matrix on the density and expansion index of extrudates. Feed screw speed and screw speed were fixed at 30 and 200 rpm, respectively. Compression ratio of the screw was 4:1. Expansion index values range between 2.0 and 3.36 and a density between 0.099 and 0.223 g/cm<sup>3</sup>. The increase in moisture content and quantity of cocoa shells leads to a decrease expansion index, while density of extrudates an increase

**Keywords:** cocoa shells, extrusion, wheat semolina, density, expansion index, extrudates

**Abbreviations:** EI – expansion index

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#### Article history:

Received 11 December 2020

Reviewed 20 April 2021

Accepted 14 May 2021

Available on-line 10 October 2021

<https://doi.org/10.30721/fsab2021.v4.i2.133>

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## Introduction

The food processing industry generates a huge quantity of by-products, including pomace, peel, husks, shells, bran, washings, etc., which have a lower production value and create considerable environmental pollution (Sharma et al. 2016). The use of these by-products has become a growing trend in the food industry in recent years, including the production of extruded products. One of the motives is to increase the nutritional value of new products, since the consumers are aware of the close relationship between nutrition and health, so the demand for food enriched with nutritionally valuable ingredients and functional food is becoming a growing trend (Jozinovic et al. 2014). Another motive is certainly the utilization of these nutritionally valuable raw materials, thereby reducing overall waste (Jozinovic et al. 2014; Yagci and Gogus 2010).

Cocoa (*Theobroma cacao L.*) is an important and economic crop in developing countries. The production of cocoa beans in 2016-2017 was 4.7 million tons worldwide (Panak Balentic et al. 2018).

Cocoa production generates substantial quantities of waste. Indeed, only 10% of the total cocoa fruit weight is used for its commercialization, while the remaining 90% is discarded as waste or by-products (Chandrasekaran 2012; Panak Balentic et al. 2018; Rojo-Poveda et al. 2020). Once the cocoa dry bean has been obtained, the coproducts that remain consist mainly of three fractions: cocoa pod husk, cocoa bean shells and cocoa mucilage (Barazarte et al. 2008). Cocoa bean shells removed from the cacao beans after baking and grinding (Fig. 1). It has been mainly utilized for mulching and as fuel (Fioresi et al. 2017). Cocoa bean shells is high in nutritive value but it is limited use in animal feeds because of its toxic theobromine content (Hartati 2010). However, it could be applicable in human nutrition, having large quantities of dietary fiber (50-60%), protein (11-18%) and polyphenols (1.8-5.8%) (Redgweel et al. 2003; Lecumberri et al. 2007).

The purpose of this study was to investigate the effects of quantity of cocoa shells, moisture of the mixture and temperature of matrix on the expansion index (EI) and density ( $\rho$ ) of the obtained extrudates from wheat semolina and cocoa shells



Figure 1. Cocoa bean shells

## Materials and Methods

### Materials

Cocoa shells were used during experimentation (Fig. 1). These were utilization material for the production of chocolate, and were provided by “Gailot Chocolate” Plovdiv. The average composition of the cocoa shells was 6% moisture, 14% proteins, 45% carbohydrates, 3% fats and 1.2% theobromine. The wheat semolina was supplied by “Dimitar Pilev” Haskovo, with a moisture of 13 %. The cocoa shells and the wheat semolina were mixed in the desired proportions with the addition of water to achieve the specified moisture (Table 1).

### Extrusion

The extrusion was performed on a Brabender 20 DN single-screw laboratory extruder (Toshkov 2011) at varied process parameters (Table 1). Constant conditions during extrusion were: nozzle diameter 3 mm; screw compression ratio 4:1; extruder screw speed 200 rpm; feed screw speed 30 rpm; temperatures in the first and second extruder zones 140 and 150°C.

### Analysis methods

#### Statistical processing

A full factorial experiment ( $N=2^3$ ) was used during processing. The independent variables were the cocoa shells content ( $X_1$ ), moisture of the extrusion mixture ( $X_2$ ) and temperature of the matrix ( $X_3$ ). Experimental plan with the natural and encoded values of the three factors is presented in Table 1.

**Table 1.** Experimental plan in natural and encoded values

№	Natural values			Encoded values		
	Content of cocoa shells, %	Moisture content, %	Temperature of the matrix, °C	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>
1	5	14	180	-1	-1	+1
2	5	14	160	-1	-1	-1
3	10	14	160	+1	-1	-1
4	5	20	160	-1	+1	-1
5	5	20	180	-1	+1	+1
6	10	14	180	+1	-1	+1
7	10	20	180	+1	+1	+1
8	10	20	160	+1	+1	-1

The steps of varying factors were chosen on the basis of preliminary investigations and literature data (Toshkov et al. 2017). 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:

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

where: b<sub>0</sub>, b<sub>i</sub> и b<sub>ij</sub> are free coefficient, linear effect coefficient and factor interaction coefficient.

All statistical processing were performed with statistical analysis software “Statgraphics XVII Centurion trial version”.

### Analysis of extrudates

The expansion index (EI) is calculated as the ratio of the average diameter of the extrudates to the diameter of the die nozzle. The density of the dry extrudates (ρ) is determined as the ratio between the mass and the volume of the cylindrical sample.

### Results and Discussion

Table 2 shows the mean values and standard deviations for the expansion index and density of the extrudates for all tested points. The results obtained show that the expansion index ranges between 2.0 and 3.36 and the density between 0.099

and 0.223 g/cm<sup>3</sup>. These results are consistent with those of extrusion of a single-screw extruder of mixtures of corn semolina and cocoa shells (Jozinovic et al. 2019; Toshkov et al. 2017); buckwheat flour (Jozinovic et al. 2012) and spelt flour (Jozinovic et al. 2016).

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

**Table 2.** Experimental results for the expansion index and density

№	Expansion index, EI	Density, ρ, g/cm <sup>3</sup>
1	3.22±0.110*	0.128±0.0011
2	3.36±0.093	0.099±0.0046
3	2.97±0.019	0.135±0.0012
4	2.55±0.025	0.159±0.0029
5	2.64±0.055	0.155±0.0030
6	2.79±0.047	0.140±0.0021
7	2.43±0.082	0.168±0.0010
8	2.00±0.043	0.223±0.0025

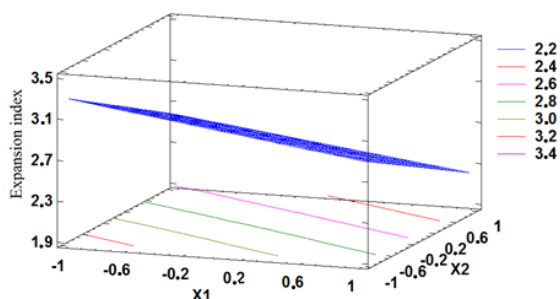
\*Standard deviation based on three-fold repeatability

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

$$EI = 2.746 - 0.194X_1 - 0.339X_2 + 0.038X_1X_3 + 0.104X_2X_3 \quad (2)$$

$$\rho = 0.151 + 0.0155X_1 + 0.0254X_2 - 0.0033X_3 + 0.0038X_1X_2 - 0.0092X_1X_3 + 0.0113X_2X_3 \quad (3)$$

The analysis of the regression equations showed that the factors  $X^1$  and  $X^2$  had negative effect on the expansion index, while factor  $X^3$  had no significant effect. Fig. 2 shows the response surface and contour lines for the expansion index variation, according cocoa shells content and moisture of the mixture. The image shows a decrease of the expansion index when increasing moisture and the amount of cocoa shells in the mixture. A greater influence on the expansion index exposes the moisture of the extrusion mixture. Increasing moisture reduces the degree of gelatinization, which reduces the expansion index and increases the density of the resulting extrudates. The expansion index decreases as the amount of cocoa shells increases, because the protein and the fiber content of the mixture increases.

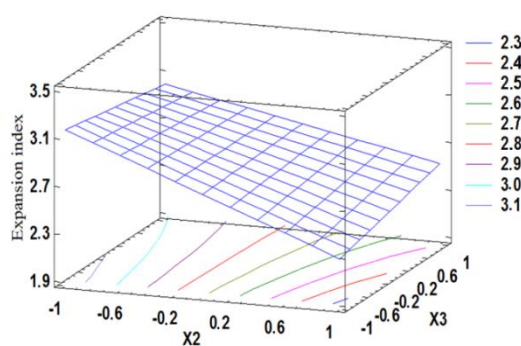


**Figure 2.** Response surface and contour lines for Expansion index (EI) variation, depending on the content of cocoa shells ( $X_1$ ) and moisture ( $X_2$ )

The effect of the moisture and temperature of the matrix on the expansion index is represented in Fig.3.

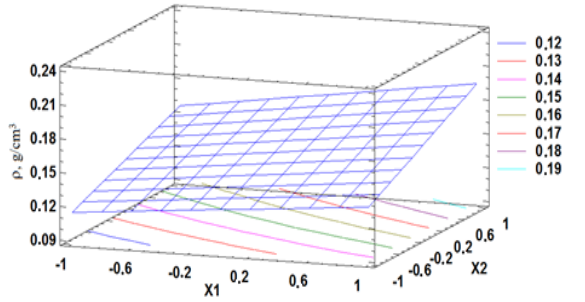
The moisture content affected negatively at both levels of the temperature of the matrix. The temperature of the matrix had a stronger positive effect at high level of moisture, rather than at low level.

Soluble fibers compete with starch for water, reducing water evaporation at the die end, hence expansion (Bisharat et al. 2013). Additionally, fibers reduce size of the water vesicles, which also decreased expansion (Stojceska et al. 2010). Proteins have an influence on the water distribution in the matrix through the macromolecular structure and conformation, changing viscosity of the dough in the extruder, in addition to agglomeration at high temperatures (Zhu et al. 2010), both resulting in reduced expansion and increased density.

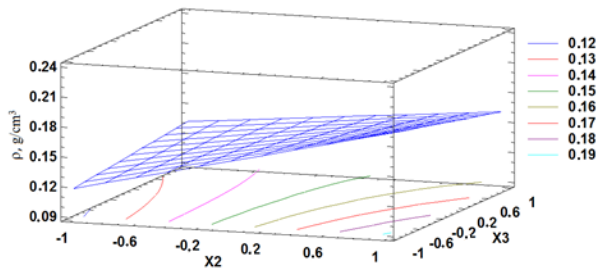


**Figure 3.** Response surface and contour lines for Expansion index (EI) variation, depending on the moisture content ( $X_2$ ) and temperature of the matrix ( $X_3$ )

The regression equation (3) showed that the factors  $X_1$  and  $X_2$  had positive effect on the density of extrudates, while factor  $X_3$  had negative effect. The response surface for the density of extrudates depending on the content of cocoa shells ( $X_1$ ) and moisture content ( $X_2$ ) is shown in Fig. 4. The lowest value was observed at 5 % cocoa shells and 14 % moisture, while the highest value was obtained at 10 % cocoa shells and 20 % moisture. Increasing the moisture of the extrusion material changes the molecular structure of amylopectin, reducing the elasticity and thus increasing the density of the resulting extrudates (Ding et al. 2006)

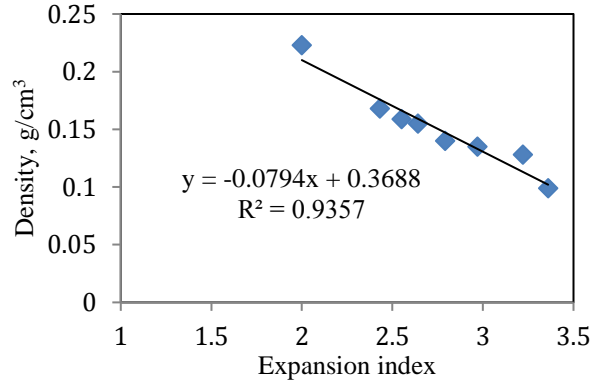


**Figure 4.** Response surface and contour lines for Density ( $\rho$ , g/cm<sup>3</sup>) variation, depending on the content of cocoa shells ( $X_1$ ) and moisture ( $X_2$ )



**Figure 5.** Response surface and contour lines for Density ( $\rho$ , g/cm<sup>3</sup>) variation, depending on the moisture content ( $X_2$ ) and temperature of the matrix ( $X_3$ )

The effect of the moisture and temperature of the matrix on the density of extrudates is represented in Fig. 5. It could be seen that a more positive effect of moisture on density of extrudates was at 160 °C, rather than at 180 °C. Temperature of the matrix had positive effect on density at 14 % moisture, while at 20 % moisture it had negatively effect.



**Figure 6.** Correlation between the expansion index and density

Fig. 6 shows the correlation between the expansion index and the density of the resulting extrudates for the tested points. There is a strict linear correlation ( $R^2=0.9357$ ) between the two values – increasing the expansion index decreases the density of the extruded products.

### Conclusions

Adequate mathematical regression models were obtained, showing the influence of quantity of cocoa shells, moisture of the mixture and the temperature of matrix on the density and expansion index of wheat semolina and cocoa shells. Expansion index values range between 2.0 and 3.36 and a density between 0.099 and 0.223 g/cm<sup>3</sup>. Increasing the moisture and the quantity of cocoa shells in the mixture results in a decrease in the expansion index, while the extrudates density increases.

### Acknowledgements

The authors would like to thank the “Gaillot Chocolate” Plovdiv for the waste cocoa shells. 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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