Effect of watermelon seed flour quantity on the density and expansion ratio of extrudates

*Nesho T*oshkov[1*], *Siyka* Kodinova[1], *Apostol* Simitchiev[2], Milena Nikolova[3], *Alexandar* Slavov[3] and *Bojidar* Bozadjiev[4]

[1]Department of Process engineering, Technical Faculty, University of Food Technologies, 4002 Plovdiv, Bulgaria
[2]Department of Machines and Apparatus for Food Industry, Technical Faculty, University of Food Technologies, 4002 Plovdiv, Bulgaria
[3]Department of Engineering Ecology, Faculty of Economics, University of Food Technologies, 4002 Plovdiv, Bulgaria
[4]Department of Technology of cereals, fodder, bread and confectionary products, Technological Faculty, University of Food Technologies, 4002 Plovdiv, Bulgaria

Abstract. Watermelon (*Citrullus vulgaris*) seeds which are considered as waste have a high nutritional value due to the high content of proteins, minerals and unsaturated fatty acids and for that reason they are suitable for production of functional extruded products. Therefore the focus of this experiment is to investigate the effect of watermelon seed flour content, temperature of the matrix and moisture content on the density and expansion ratio of extrudates from corn grits. A single screw extruder Brabender 20 DN was used for the extrusion cooking. A full factorial experiment 2^3 with independent parameters watermelon seed flour content (3 % and 10 %), temperature of the matrix (160 °C and 180 °C) and moisture content (14 % and 18 %) was applied. The expansion ratio varies between 1.76 and 2.56 while the density change from 0.103 g/cm^3 to 0.159 g/cm^3 respectively. The statistical analysis showed that the expansion ratio decrease with the increase of the moisture content and watermelon seed flour content while the density increase.

1 Introduction

Extrusion is an advantageous and novel technology for production a brand new foods with a certain texture, composition, varying shapes and characteristic features [1, 2]. It represents a combination of mixing, cooking and forming process at high temperature for a short time [3, 4]. Extrusion cooking has become a well-used technology in food industry because it is an efficient, low-cost and environment-friendly process which will continue to explore new areas of application [5]. The versatility of this processing is due to the incorporation of newer ingredients and functionalities to create products that are cost-effective and nutritious [6].

Corn and rice flours are typically used for the production of extrudates and that's why these products are rich in sugars, have a high calorie content and a low nutritional value [5]. Moreover the extrudates made from a single component do not manage all the essential nutritional requirements [7]. On this basis the nutritional properties of these products can be improved by adding a different ingredients with high quantity of bioactive compounds [8, 9].

Food industry and agricultural sector generates a lot of waste annually and this leads to a negative effect on the environment [10]. The utilization of wastes and by-products reduce this harmful influence and allows the production of food products with increased sensory, physicochemical and nutritional characteristics [11].

Watermelon seeds which are consider as waste can be used for the production of extrudates with high nutritional value [12, 7]. Watermelon seeds are highly nutritious due to the content of fat, protein, minerals such as Mg, K, P, Fe, Zn, Na, Ca, Cu, vitamins (A, B) and other phytochemical compounds [13]. The presence of nine essential amino acids along with glutamic acid, lysine and tryptophan make the seeds an indispensable supplement. The seeds are also a good source of different types of fats like monounsaturated fat, polyunsaturated fat and omega-6 fatty acid [14].

The aim of the experimental work was to look over the effect of watermelon seed flour quantity, temperature of the matrix and moisture content on the density and expansion ratio of extrudates from corn grits.

* Corresponding author: nesho.t@abv.bg

a b

Fig. 1. Watermelon seeds (a) and watermelon seed flour (b).

2 Materials and methods

2.1 Materials

Watermelon seed flour (WSF). The watermelon (*Citrullus vulgaris*) seeds were obtained from different fresh and mellow watermelon fruits purchased from the provincial market in Plovdiv, Bulgaria. The watermelon seeds were ground in an electrical blender 'Nutribullet' (Model OC22300058, 600 W) into a fine powder (Fig. 1). After that the powder was sieved through a scientific sieve with a particle size 1mm for production of flour with average diameter 0.68 mm and packed for other purposes. The average chemical composition of the WSF was 8 % moisture content, 25.4 % fats and 3 % ashes.

Corn semolina. The experimental work was managed with 'Familex' corn semolina (13 % moisture content). It was conducted from the local market in Plovdiv, Bulgaria. The WFS and the corn 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		
	Watermelon seed flour content, %	Tempera-ture of the matrix, ºC	Moisture content, %	X_1	X_2	X_3
1	3	160	14	-1	-1	-1
2	3	180	14	-1	+1	-1
3	10	160	14	+1	-1	-1
4	3	160	18	-1	-1	+1
5	3	180	18	-1	+1	+1
6	10	160	18	+1	-1	+1
7	10	180	14	+1	+1	-1
8	10	180	18	+1	+1	+1

2.2 Extrusion cooking

A single-screw laboratory extruder Brabender 20 DN (Duisburg, Germany) [15] was accomplished for the extrtrusion at diverse process parameters (Table 1). The fixed conditions during process 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 response surface methodology through a full factorial experiment (N = 2^3) was used during processing. The watermelon seed flour content (X_1), the temperature of the matrix (X_2) and the moisture content (X_3) were independent variables in this work. 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 literature data and the basis of preliminary investigations [16, 17]. 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:

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

where: b_o, 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 extrudates

Expansion ratio (ER). The expansion ratio is calculated as the ratio of the average diameter of the extrudates to the diameter of the die nozzle (3 mm) [18].

$$ER = \frac{De}{Dd} \qquad (2)$$

where: *De* – diameter of the extrudate, mm; *Dd* – diameter of the die nozzle, mm.

Density (ρ). The density of the dry extrudates (ρ, g/cm^3) is determined as the ratio between the mass and the volume of the cylindrical sample [19, 18] and is calculates as follows:

$$\rho = \frac{(4\ x\ m)}{(\pi\ x\ d^2\ x\ L} \qquad (3)$$

where: *m* – mass of extrudate, g; *d* – diameter of sample, cm; *L* – extrudate lenght, cm.

3 Results and discussion

The mean values and standard deviations for expansion ratio (ER) and density (ρ) of extrudates depending on the three tested factors – watermelon seed flour content, temperature of the matrix and moisture content are shown in Table 2. The results show that the expansion ratio (ER) varies between 2.56 (watermelon seed flour content 3 %, temperature of the matrix 160 °C, moisture content 14 %) and 1.76 (watermelon seed flour content 10 %, temperature of the matrix 160 °C and

moisture content 18 %) respectively. At the same condition of the tree investigated factors the variation of the density is between 0.103 g/cm^3 and 0.159 g/cm^3.

Table 2. Experimental results for the expansion ratio (ER) and density (ρ).

№	Expansion ratio, ER	Density, ρ, g/cm^3
1	2.56 ± 0.022*	0.103 ± 0.0038*
2	2.50 ± 0.034	0.105 ± 0.0027
3	2.24 ± 0.041	0.115 ± 0.0036
4	2.12 ± 0.022	0.145 ± 0.0016
5	2.18 ± 0.023	0.124 ± 0.0025
6	1.76 ± 0.023	0.159 ± 0.0020
7	2.16 ± 0.032	0.122 ± 0.0041
8	1.77 ± 0.027	0.130 ± 0.0006

*Standard deviation based on three-fold repeatability

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

$$ER = 2.16125 - 0.177X_1 - 0.20542X_3 - 0.01375X_1X_3 + 0.02625X_2X_3 \quad (4)$$

$$R^2 = 98.4\% \quad F = 0.4 < Fc = 3.2$$

$$\rho = 0.1255 + 0.006167X_1 - 0.00525X_2 + 0.01425X_3 - 0.00733X_2X_3 + 0.001337X_1X_2X_3 \quad (5)$$

$$R^2 = 97.4\% \quad F = 0.1 < Fc = 3.6$$

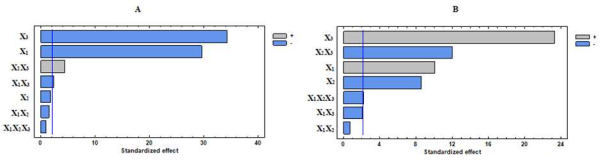

Fig. 2. Standardized Pareto charts for Expansion ratio (A) and density (B).

The standardized Pareto charts (Fig. 2) show the influence of watermelon seed flour content (X_1), temperature of the matrix (X_2) and moisture content (X_3) on the expansion ratio (A) and density (B) of extrudates. The results show that according to the expansion ration the factors moisture content (X_3), watermelon seed flour content (X_1) as well as the factor interactions (X_2X_3) and (X_1X_3) are significant. The biggest effect has the moisture content (X_3), followed by the watermelon seed flour content (X_1). This tendency is verified by the obtained equation coefficients – 0.20542 for moisture content (X_3) and 0.177 for watermelon seed flour content (X_1). In relation to the density (Fig. 2 - B) it can be seen that all three factors and factor interactions except X_1X_3 and X_1X_2 are significant. Factors watermelon seed flour content (X_1) and moisture content (X_3) have a positive effect on the density while the factor temperature of the matrix (X_2) – negative. The strongest impact have the moisture content (equation coefficient 0.01425), followed by watermelon seed flour content (equation coefficient 0.00616) and temperature of the matrix (equation coefficient 0.00525).

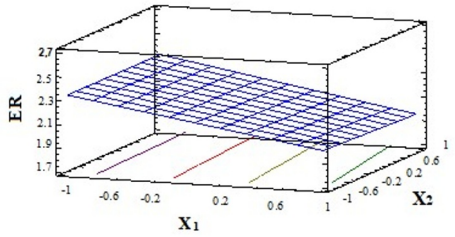

Fig. 3. Response surface of the expansion ratio (ER), depending on the watermelon seed flour content (X_1) and temperature of the matrix (X_2).

Expansion ratio is one of the basic parameters which can be adjust to produce a desirable sensory characteristics of extruded products [11]. The combine effect of watermelon seed flour content (X_1) and temperature of the matrix (X_2) on the expansion ration is presented in Fig. 3. It can be seen that the expansion ration decrease with the increase of the watermelon seed flour content (X_1) while the temperature of the matrix (X_2) had no significant effect (equation 4).

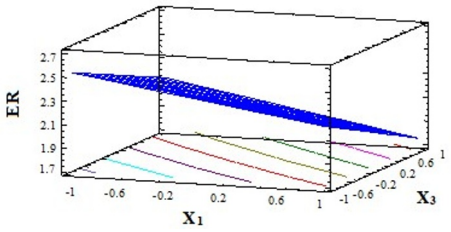

Fig. 4. Response surface of the expansion ratio (ER), depending on the watermelon seed flour content (X_1) and moisture content (X_3).

The expansion ration decrease with the increase of watermelon seed flour content and moisture content (Fig. 4). A greater influence of extrusion reduction with the increase of moisture content is observed at high level of watermelon seed flour content. The expansion ratio of the extrudates successively decreased with the increase of watermelon seed flour content and this is probably due to the higher protein and lower starch content which in turn influenced the gelatinization [20]. Similar results were established by [11] which found that the incorporation of higher quantity of defatted watermelon seed cake flour (DWCF) – 10 %, 20 %, 30 %, 40 % in rice-corn flour blend lead to a lower expansion ratio of extruded snacks. According to their reports extruded products with better physical and sensory evaluation were obtained when the content of DWCF was 20 % (w/w). [12] produced extruded snacks from rice-corn blend with addition of watermelon seed flour (WSF) in quantity of 10 %, 15 % and 20 % (w/w) and found that the increase of WSF from 10 % to 20 % led to a decrease in the expansion ratio from 7.00 ± 0.53 to 5.568 ± 0.18. According to the authors the optimal quantity of WSF was 15 % (w/w).

The effect of the three investigated factors on the density is presented in Fig. 5, Fig.6 and Fig. 7 respectively. It can be seen that the density increase with the increase of watermelon seed flour content which is due to the higher fat and fibre content of the mixture and

obtaining products with lower expansion ratio and higher density. Fig. 5 shows the weaker influence of temperature of the matrix on the density of extrudates.

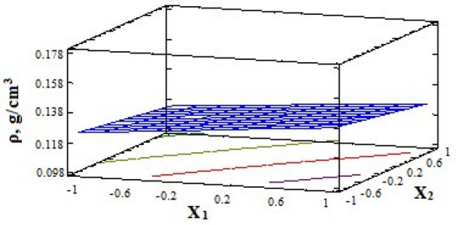

Fig. 5. Response surface of the density (ρ), depending on the watermelon seed flour content (X_1) and temperature of the matrix (X_2).

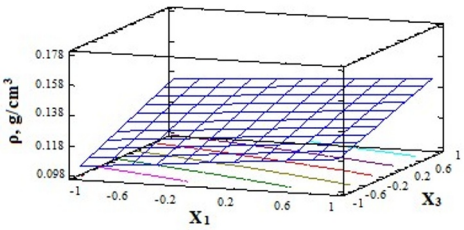

Fig. 6. Response surface of the density (ρ), depending on the watermelon seed flour content (X_1) and moisture content (X_3).

The simultaneous increase of watermelon seed flour content and moisture content at constant temperature of the matrix 170 ºC (Fig. 6) lead to a higher density of the obtained extrudates with 60 % (from 0.100 g/cm^3 to 0.160 g/cm^3) which is related to the reduced viscosity of the mixture in the cylinder and the lower pressure respectively.

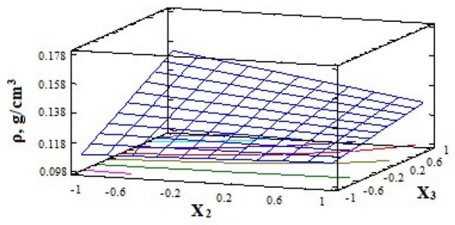

Fig. 7. Response surface of the density (ρ), depending on the temperature of the matrix (X_2) and moisture content (X_3).

The decrease in the density of the obtained extrudates with the increase in the temperature of the matrix is more pronounced at higher moisture content of the matrix of the mixture (Fig. 7). [21] reported that the expansion ratio increase when the temperature of the matrix is higher which reduces the density which is possible when the material is well cut and treated creating favorable conditions for easy deformation and forming. The presented response surface (Fig. 7) shows that at higher temperature of the matrix the increase of density with the increase of moisture content is less pronounced. This dependence shows that if we want to obtain extrudates with lower density and better sensory characteristics at higher moisture content of the mixture, we need to increase the extrusion temperature.

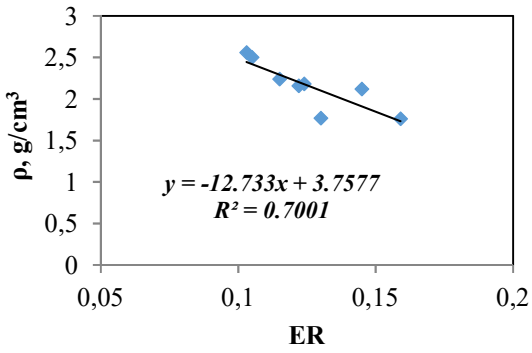

Fig. 8. Correlation between the expansion ratio (ER) and density (ρ, g/cm^3).

There is an inverse relationship between density and expansion ratio which means that the extrudates with lower expansion ratio have a greater density [22]. Fig. 8 shows the dependence of the two values for all experimental points and it can be seen that there is a weak linear correlation (R^2 = 0.7001). The weaker linear dependence is probably due to the fact that the expansion ratio reports only the radial expansion of the product while during the extrusion process there is also an axial expansion which leads to a decrease in the density of extrudates [23].

4 Conclusion

Adequate mathematical regression models were obtained to explore the influence of watermelon seed content (3 % and 10 %), temperature of the matrix (160 °C and 180 °C) and moisture content (14 % and 18 %) on the expansion ratio and density of extrudates from corn semolina and watermelon seed flour. The expansion ratio varies between 1.76 and 2.56 while the density change from 0.103 g/cm^3 to 0.159 g/cm^3 respectively. The extent of expansion ratio decrease with the increase of moisture content and watermelon seed flour content and is not affected by the temperature of the matrix. The density of the extruded products increase withy the increase of moisture content and watermelon seed flour content while the temperature of the matrix has a negative effect.

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