

EFFECT OF SELECTED PARAMETERS ON SECTIONAL EXPANSION INDEX AND BULK DENSITY DURING THE EXTRUSION OF CHICKPEA INSTANT SEMOLINA

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Introduction. Formulation of the problem

Extrusion is a powerful processing operation, which utilizes high temperature, pressure, and sheer force to produce highly expanded, low-density products with unique texture properties (i.e. crispiness, crunchiness). This brings more efficient use of energy, significant nutrient retention, and also reducing antinutritional factors [1].

Much of product development in the food industry is being driven by health-conscious consumers to expand their diets with plant-based protein alternatives. As part of a complementary diet, pulses are often combined with cereals to ensure a complete balance of essential amino acids is consumed to support proper growth and development. Pulses are well known to be rich in lysine but deficient in the thiol-containing amino acids (methionine and cysteine)

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Abstract. The extrusion process is one of the most popular in food technologies. It is with a low cost and short time. A four-factor Response surface methodology central composite rotatable design was used to study the effect of moisture content, barrel temperature, screw speed, and feed screw speed on sectional expansion index (SEI) and bulk density during extrusion of chickpea instant semolina for the instant product. The lowest value for the SEI was 102% (20% moisture content, 150°C barrel temperature, 190 rpm screw speed, and 65 rpm feed screw speed) and the highest value was 137% (23% moisture content, 160°C barrel temperature, 170 rpm screw speed, and 50 rpm feed screw speed). The regression models for the investigated responses were highly significant (according to P-value) with satisfactory coefficients of determination (R^2) 0.894 and 0.957. These results show that the predicted models for the investigated responses are adequate, indicating that the second-order polynomial model could be effectively used to represent the relationship between the selected parameters. The study showed that the expansion was influenced by moisture and temperature and it increased with increasing temperature for moisture content from 20 to 23% and after that decreased. Bulk density decreased with increasing feed moisture and barrel temperature in the extruder. The bulk density varied from 79 to 116 kg/m³ for both samples (23% moisture content, 160°C barrel temperature, 170 rpm screw speed, and 50 rpm feed screw speed) and (20% moisture content, 150°C barrel temperature, 150 rpm screw speed, and 65 rpm feed screw speed). The most important consequences for the science and practice resulting from the conducted research are that the resulting extrudates after grinding can be successfully used for the preparation of instant products with good characteristics, such as bulk density and sectional expansion index.

Keywords: extrusion, chickpea, sectional expansion index, bulk density

and tryptophan, whereas cereals are rich and deficient in the opposite [2].

For product development to occur, these ingredients typically need to be processed in some capacity to improve their functional and nutritional value. Extrusion technology has been leading the way in terms of processing capacity because of its ability to improve starch/protein digestion, lower levels of bioactive compounds (e.g., protease/amylase inhibitors), and reduce strong flavor profiles in grains [3]. The process combines mixing, shearing, cooking, and shaping into one continuous unit operation [4].

Analysis of recent research and publications

Extrusion cooking technology is one of the most used food processing techniques for producing a variety of food products from numerous ingredients [5-7].

Extrusion cooking of chickpea-based mixtures has been reported in recent years [8-10].

Pulse crops offer an important and affordable source of protein in human diets. They are also rich in dietary fiber, micronutrients such as vitamin B, minerals (as iron and zinc), and a variety of antioxidants [11]. Their nutrient density has also led many food processors to employ them as a functional food item in fortifying other foodstuffs, especially cereals which are limited in lysine content. Chickpea is the third most important pulse crop produced in the world after dry beans and field peas. Although chickpeas have a high potential for the development of functional foods due to their high protein and fiber content, gluten-free, low glycemic index, and antioxidant potential, the presence of certain antinutritional factors such as phytates, polyphenols, and enzyme inhibitors in chickpea limits their use as a food ingredient.

Research has shown that chickpeas are an excellent source of protein (24.4%), dietary fiber (9.0%), complex carbohydrates (60.0%), folate, and trace minerals such as iron, molybdenum, manganese. In addition, chickpeas have been reported to reduce the levels of cholesterol and blood glucose. Chickpeas have a high (40–50%) starch content [10], which may favor an extrusion process to produce directly expanded foods. The processing of chickpeas into extruded food is limited. The extrudates exhibited increased density and breaking strength, indicating poor textural effects of chickpea flour inclusion.

High expansion ratio, low bulk density, and a firm texture are desirable end product characteristics; these characteristics are governed by the properties of the raw materials and the extrusion process variables such as feed rate and moisture content, die diameter and shape, temperature, screw profile, and speed [12].

The extrusion of the food material gelatinizes starch, denaturation the protein, and heats the water with thermal energy from a barrel and mechanical energy from friction. Bubbles in extruders grow and expand when the product comes out of the die due to a pressure difference. Volumetric expansion is an important factor for the texture of extruded products. The viscosity, elasticity, and degradation of starch have been reported as factors that influence the expansion of extrudates. da Silva et al., 2014 study that expansion properties of starch and proteins decreased when they were damaged, and the decrease of a diametric expansion with the decrease of elastic characteristics when the moisture content of extrudate was increased. In addition to the elastic properties of melt, the degradation of starch also was considered a factor for the sectional expansion. It is well known that the addition of legumes to cereals produces an increase in both the amount and the quality of the protein mix. Extruded legumes are able to expand and are regarded as highly feasible for the development of value-added high nutrition, low-calorie foods [13].

The effects of ingredient properties and processing conditions on final product quality are also

reflected by their influence on process responses or extruder system parameters such as motor torque, die pressure, product temperature, and specific mechanical energy (SME). As they are a result of different combinations of extrusion conditions such as feed moisture, screw speed, and barrel temperature, system parameters can be used to describe or compare extrusion processes under different operating conditions. It has been shown that SME correlates well with extrudate properties such as expansion, density, and texture characteristics [10].

The study aimed to evaluate the impact of selected parameters on sectional expansion index and bulk density during the extrusion of chickpea instant semolina.

To achieve this goal, it is necessary to solve the following problems:

- to evaluate the sectional expansion index of chickpea extrudates obtained under different extrusion conditions with varying moisture content of chickpea semolina, barrel temperature, screw speed, and feed screw speed;
- to evaluate the bulk density of chickpea extrudates obtained under different extrusion conditions with a varying moisture content of chickpea semolina, barrel temperature, screw speed, and feed screw speed.

Research materials and methods

Raw materials and preparation

The raw material chickpea (*Cicer arietinum* L.) was variety № 27, from the 2019 harvest, and it was grown in Institute of Plant Genetic Resources “Konstantin Malkov”- Sadovo, Bulgaria.

Chickpea was ground using a hammer mill and passed through standard sieves. The chickpea semolina was mixed with distilled water to be obtained various moisture contents (Table 1). The wet materials were placed and kept in sealed plastic bags for 12 h in a refrigerator at 5°C to uniform the moisture. The samples were tempered for 2 h at room temperature prior to extrusion.

Extrusion process

The samples were extruded in a laboratory single screw extruder (Brabender 20 DN, Germany). The extruder barrel was 476.5 mm in length and 20 mm in diameter. The feed screw speed was 20, 35, 50, 65, 80 rpm. The screw speed was 130, 150, 170, 190, 210 rpm. Feed zone temperature and metering zone temperature were kept constant at 100 and 150°C, respectively. The temperature of the extruder die was 140, 150, 160, 170, 180°C. The compression ratio of the screw was 3:1 and the die diameter was 4 mm.

Sectional expansion index

Sectional expansion index (SEI, %) was measured as the ratio of the diameter of the extrudate to that of the die. The diameter of extrudate was determined as the mean of 10 random measurements using a Vernier caliper.

$$SEI = \frac{D_e}{D_0} \cdot 100 \quad (1)$$

where D_e is average diameter of the extrudates (mm), D_0 – diameter of the die (mm).

Bulk density

Bulk density (ρ , kg/m³) of extrudates was calculated as [9]:

$$\rho = \frac{4 \cdot m}{\pi \cdot D^2 \cdot L} \quad (2)$$

where m is the mass of a length L of cooled extrudate with diameter D . Ten replicates of extrudate were randomly selected and a mean taken.

Response surface methodology

Response surface methodology (RSM) was applied to determine the best conditions for extrusion. RSM is a statistical method that uses quantitative data from appropriate experimental designs to determine and simultaneously solve multivariate equations. These equations can be graphically represented as response surfaces, which can be used in three ways: (1) to describe how the test variables affect the response; (2) to determine the interrelationships among the test variables; and (3) to describe the combined effects of all test variables on the response [15].

Experimental design and data analysis

For RSM, a central composite rotatable design was used to investigate the effect of the moisture content (X_1), barrel temperature (X_2), screw speed (X_3), and feed screw speed (X_4) on the sectional expansion index and bulk density (responses, y_i) in 27 runs of which 16 were for the factorial points, 8 were for axial points, and 3 were for center points [11]. Experimental data analysis using RSM was performed using SYSTAT statistical software (SPSS Inc., Chicago, USA, version 7.1). Data was fitted into a polynomial equation that shows all of the possible interactions of the independent variables (X_1 , X_2 , X_3 , and X_4) and their effects on the response (the sectional expansion index and bulk density). For RSM, the levels of the independent variables were established according to literature information and preliminary experimental study. Based on that study, the independent variables used in the central composite rotatable design model are presented in Table 1. To analyze the responses (Y_i), the experimental data were fitted with the polynomial regression equation of the following form:

$$y = b_0 + \sum_{i=1}^n b_i X_i + \sum_{i=1}^n b_{ii} X_i^2 + \sum_{i=1}^n \sum_{j=1}^n b_{ij} X_i X_j \quad (3)$$

where y is the predicted response (dependent variable) for the sectional expansion index and bulk density, respectively; X_i and X_j are the independent

variables; b_0 , b_i , b_{ii} , b_{ij} are regression coefficient for intercept, linear, quadratic and interaction terms.

The analysis of variance (ANOVA) was also used to evaluate the quality of the fitted model for the sectional expansion index and density in RSM. The statistical difference was based on the total error with a confidence level of 95%.

Results of the research and their discussion

Expansion, as measured by expansion index and density, is used to express product characteristics after extrusion. The values of the expansion index and density are dependent on the feed moisture, screw speed, and temperature of extrusion. These values are also dependent on all ingredients contained in the extruded foods, such as starch, protein, fat, sugar, fibers, and so on. All these ingredients have different effects on extrudate expansion [10].

Sectional expansion is a measure of sectional expansion area of chickpea extruded. The mean values of the sectional expansion index and density are shown in Table 1.

The data indicate that all the investigated variables varied significantly according to the applied process parameters of extrusion. From the table it shows that lowest value for the SEI was 102% (20% moisture content, 150°C barrel temperature, 190 rpm screw speed, and 65 rpm feed screw speed) and the highest value was 137% (23% moisture content, 160°C barrel temperature, 170 rpm screw speed, and 50 rpm feed screw speed). Bulk density has been linked with the expansion ratio in describing the degree of puffing in extrudates. The observed values for the bulk density varied from 79 to 116 kg/m³ for both samples (23% moisture content, 160°C barrel temperature, 170 rpm screw speed, and 50 rpm feed screw speed) and (20% moisture content, 150°C barrel temperature, 150 rpm screw speed, and 65 rpm feed screw speed), respectively.

Each of the estimated effects and interactions are shown in the standardized diagram, the Pareto chart (Figure 1).

It consists of horizontal blocks with lengths proportional to the absolute values of the estimated effects, divided by their standard errors. A vertical line that represents the value of the Student criterion at 95% confidence level has been added to facilitate the chart. The quadratic effect that was due to the screw speed (factor C) had the highest impact on the sectional expansion index (Figure 1a), followed by the quadratic effect of the feed screw speed (factor D).

Similar results are observed by Filli *et al.*, 2012 [16] which have extruded of pearl millet and cowpea flour mixtures. They have reported that the quadratic effect of the variable screw speed significantly ($P < 0.05$) influenced the SEI. The linear effect that is due to the moisture content (factor A) had the highest impact on the bulk density (Figure 1b), followed by the quadratic effect of the barrel temperature (factor B).

Table 1 – Central composite rotatable design for experimental runs with different combinations of extrusion variables

Run	X_1 (W, %)	X_2 (Tm, °C)	X_3 (N, rpm)	X_4 (nd, rpm)	SEI (%)	ρ (kg.m ⁻³)
1	-1 (20)	-1 (150)	-1 (150)	-1 (35)	123	105
2	+1 (26)	-1 (150)	-1 (150)	-1 (35)	131	87
3	-1 (20)	+1 (170)	-1 (150)	-1 (35)	116	97
4	+1 (26)	+1 (170)	-1 (150)	-1 (35)	107	98
5	-1 (20)	-1 (150)	+1 (190)	-1 (35)	112	114
6	+1 (26)	-1 (150)	+1 (190)	-1 (35)	111	95
7	-1 (20)	+1 (170)	+1 (190)	-1 (35)	120	89
8	+1 (26)	+1 (170)	+1 (190)	-1 (35)	105	87
9	-1 (20)	-1 (150)	-1 (150)	+1 (65)	114	116
10	+1 (26)	-1 (150)	-1 (150)	+1 (65)	126	83
11	-1 (20)	+1 (170)	-1 (150)	+1 (65)	112	107
12	+1 (26)	+1 (170)	-1 (150)	+1 (65)	106	102
13	-1 (20)	-1 (150)	+1 (190)	+1 (65)	102	115
14	+1 (26)	-1 (150)	+1 (190)	+1 (65)	126	92
15	-1 (20)	+1 (170)	+1 (190)	+1 (65)	121	100
16	+1 (26)	+1 (170)	+1 (190)	+1 (65)	133	80
17	-2 (17)	0 (160)	0 (170)	0 (50)	117	115
18	+2 (29)	0 (160)	0 (170)	0 (50)	124	93
19	0 (23)	-2 (140)	0 (170)	0 (50)	126	109
20	0 (23)	+2 (180)	0 (170)	0 (50)	121	99
21	0 (23)	0 (160)	-2 (130)	0 (50)	106	94
22	0 (23)	0 (160)	+2 (210)	0 (50)	116	87
23	0 (23)	0 (160)	0 (170)	-2 (20)	107	102
24	0 (23)	0 (160)	0 (170)	+2 (80)	128	99
25	0 (23)	0 (160)	0 (170)	0 (50)	137	81
26	0 (23)	0 (160)	0 (170)	0 (50)	136	80
27	0 (23)	0 (160)	0 (170)	0 (50)	136	79

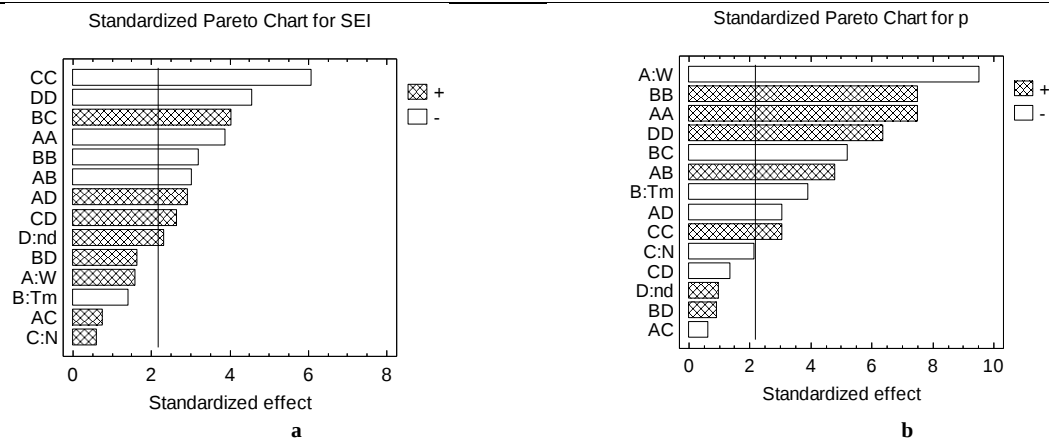


Figure 1. Estimated effects of regression model coefficients on the sectional expansion index (a) and bulk density (b)

The results of the statistical analysis of variance (ANOVA) for the sectional expansion index and bulk density show that 9 effects have P-values less than 0.05, indicating that they are significantly different from zero at the 95.0 % confidence level (Table 2).

The polynomial equations obtained for the two responses, after removing the nonsignificant terms, are given in Table 3.

The regression models for the investigated responses were highly significant (according to P-value) with satisfactory coefficients of determination (R^2) 0.894 and 0.957. The R-squared is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit. When R^2 approaches unity, the empirical model fits the actual data better. The smaller is

R^2 , the less relevant the dependent variables in the model have in explaining the behaviour of variation [17]. It is suggested that for good fit model, R^2 should be at least 80%. The obtained results show that the predicted models for the investigated responses were adequate, indicating that the second-order polynomial model could therefore be effectively used to represent the relationship between the selected parameters.

The best way to visualise the effect of independent variables on dependent ones is to draw surface response plots of a proposed model like those given in Figure 2, which shows the combined effects of process variables (moisture content and barrel temperature) on sectional expansion index and bulk density.

Table 2 – Regression coefficients and analysis of variance (ANOVA) for the sectional expansion index and bulk density

Variables	Coefficients	Degree of freedom	Mean square	F-value	P-value
Sectional expansion index					
Constant	-953.579				
X_1	35.684	1	63.375	2.52	0.1386
X_2	8.8865	1	51.042	2.03	0.1799
X_3	0.6745	1	9.375	0.37	0.5531
X_4	-3.5951	1	135.375	5.38	0.0388*
X_1X_1	-0.4688	1	379.687	15.08	0.0022*
X_1X_2	-0.1271	1	232.563	9.24	0.0103*
X_1X_3	0.0156	1	14.063	0.56	0.4692
X_1X_4	0.0819	1	217.563	8.64	0.0124*
X_2X_2	-0.0347	1	256.687	10.20	0.0077*
X_2X_3	0.0253	1	410.063	16.29	0.0017*
X_2X_4	0.0138	1	68.063	2.70	0.1260
X_3X_3	-0.0165	1	927.521	36.84	0.0001*
X_3X_4	0.0110	1	175.563	6.97	0.0215*
X_4X_4	-0.0221	1	526.687	20.92	0.0006*
Bulk density					
Constant	1999.99				
X_1	-49.14	1	1107.04	90.42	0.0000*
X_2	-18.1156	1	187.042	15.28	0.0021*
X_3	2.012	1	57.0417	4.66	0.0519
X_4	-0.9164	1	12.0417	0.98	0.3409
X_1X_1	0.6331	1	692.613	56.57	0.0000*
X_1X_2	0.1396	1	280.563	22.92	0.0004*
X_1X_3	-0.0094	1	5.0625	0.41	0.5323
X_1X_4	-0.0597	1	115.563	9.44	0.0097*
X_2X_2	0.057	1	692.613	56.57	0.0000*
X_2X_3	-0.0228	1	333.063	27.20	0.0002*
X_2X_4	0.0054	1	10.5625	0.86	0.3713
X_3X_3	0.0058	1	115.113	9.40	0.0098*
X_3X_4	-0.0039	1	22.5625	1.84	0.1996
X_4X_4	0.0214	1	496.225	40.53	0.0000*

*Significant at 95% CI.

Table 3 – Model equations and P-value for the significantly effects of the independent variables of extrusion process on the sectional expansion index and bulk density

Dependent variable	Model	R ²	p-value
Sectional expansion index (%)	$y = -953.579 - 3.595X_4 - 0.46875X_1^2 - 0.127X_1X_2 + 0.0819X_1X_4 - 0.035X_2^2 + 0.025X_2X_3 - 0.016X_3^2 + 0.011X_3X_4 - 0.022X_4^2$	0.894	< 0.05
Bulk density (kg.m ⁻³)	$\rho = 1999.99 - 49.14X_1 - 18.116X_2 + 0.633X_1^2 + 0.14X_1X_2 - 0.06X_1X_4 + 0.057X_2^2 - 0.023X_2X_3 + 0.006X_3^2 + 0.021X_4^2$	0.957	< 0.05

Feed moisture and temperature have been identified as the main factor affecting extrudate expansion and density [16].

The expansion was influenced by moisture and temperature and it increased with increasing temperature for moisture content from 20 to 23% and after that decreased (Figure 2a). At higher moisture content, a further decrease in viscosity by an increase in temperature results in a reduced expansion [18]. Increased feed moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt, resulting in reduced specific mechanical energy and therefore reduced gelatinization, decreasing the expansion of extrudates [14]. Similar results are observed by Balandran-Quintana et al., 1998 [19] which have extruded pinto bean flours at three different die temperatures (140, 160, and 180°C), feed moisture content (18, 20, and 22%), and screw speeds (150, 200, and 250 rpm). They have reported that the

expansion increased with increasing temperature for 18 and 20% moisture feed. For 22% moisture, the expansion increased between 140 and 160°C and decreased abruptly between 160 and 180°C.

The extrudate density was found to be most dependent on feed moisture and temperature. Bulk density decreased with increasing feed moisture (Figure 1b and 2b). Insufficient amount of water available for vaporization appeared may be the main cause of high bulk density values [20]. An increase in the barrel temperature will increase the degree of superheating of water in the extruder encouraging bubble formation and also a decrease in melt viscosity [14] leading to reduced density, which was observed in this work.

Regarding the sectional expansion index and density, the results demonstrated that can be successfully prepared instant product with good physicochemical characteristics.

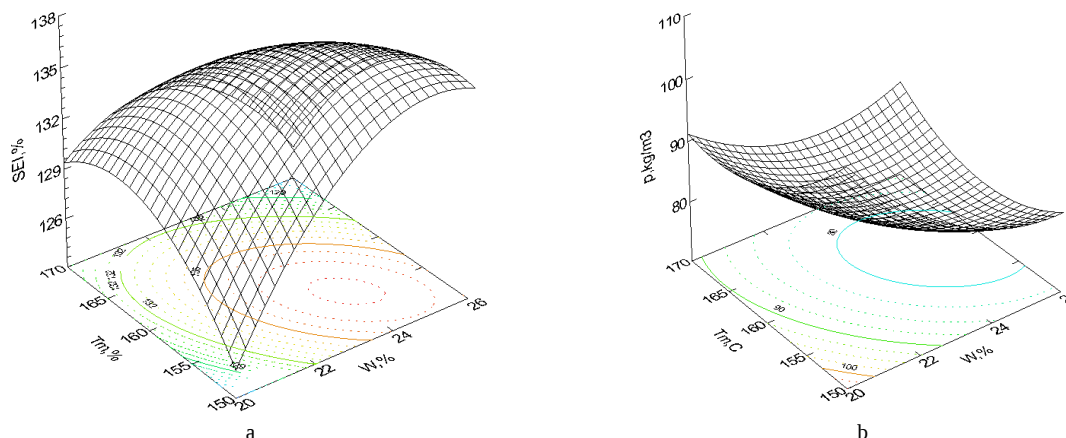


Fig. 2. Effect of moisture content and barrel temperature on sectional expansion index (a) and bulk density (b)

Conclusion

The sectional expansion index and bulk density during the extrusion of chickpea instant semolina produced on a laboratory single screw extruder was dependent on several process variables. The quadratic effect that was due to the screw speed had the highest impact on the sectional expansion index, followed by the quadratic effect of the feed screw speed. The linear effect that is due to the moisture content had the highest impact on the bulk density, followed by the quadratic effect of the barrel temperature. The expansion was influenced by moisture and temperature and it increased with increasing

temperature for moisture content from 20 to 23% and after that decreased. Bulk density decreased with increasing feed moisture and barrel temperature in the extruder. The most important consequences for the science and practice resulting from the conducted research are that the resulting extrudates after grinding can be successfully used for the preparation of instant product with good characteristics, such as bulk density and sectional expansion index.

Conflict of Interest: The authors declare that they have no conflict of interest.

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