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Research Article

Investigation of specific mechanical energy during extrusion of rice flour enriched with dried pumpkin

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Abstract

The present study examined the effects of pumpkin flour content (10 % and 20 %), moisture content of initial mixture (14 % and 20 %) and working screw speed (180 min^{-1} and 220 min^{-1}) on the specific mechanical energy of single screw extruder „Brabender 20DN" during extrusion of rice flour through a full factorial experiment. The results showed that the content of pumpkin flour and moisture content had negative effect on the specific mechanical energy (SME), while working screw speed had positive effect.

Keywords: extrusion, specific mechanical energy, rice, pumpkin

Abbreviations: There are no abbreviations used in the text

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Introduction

The ever-growing number of people suffering from celiac disease (gluten intolerance) increased the demand for gluten-free products worldwide. Due to their higher starch content and lower fiber content, one way of enrichment with bioactive substances is by extrusion in combination with different fruits and vegetables (Stojceska et al., 2010).

One of the most used raw materials in the world, along with wheat and corn, is rice *(Oryza sativa).* It is rich in bioactive substances such as γ-oryzanol, tocopherols, tocotrienols and phenolic compounds that have health properties due to their antioxidant activity (Fernandez-Orozco et al., 2008). It contains high amounts of folic acid (Kam et al., 2012), which prevents disturbances in early embryonic brain development. It is also involved in nucleic acid synthesis and protein metabolism (Czeizel and Dudás, 1992). The high content of group B vitamins (thiamine, riboflavin, pyrodoxin niacin), magnesium (Kayahara et al., 2000) as well as essential amino acids, fibers (Frias et al., 2005), increases its nutritional value.

Pumpkins belonging to the species *Cucurbita pepo L.* (also known as "zucchini"), *Cucurbita maxima* (called "winter pumpkin") and *Cucurbita moschata* (the "violin") are among the most common cultivated in Central European countries.

The giant pumpkin *(Cucurbita maxima)* is rich in antioxidants, vitamins and other biologically active ingredients: vitamin C, vitamin E, minerals, pectins and carotenoids. It has been found that 100 g of fresh pumpkin contains 80.0-96.0 g of water, 4.6-6.5 g of sugars, 0.6-1.8 g of protein, 0.0-0.2 g of lipids, and 0.5-1.3 g of fiber (Hui, 2004).

Nowadays, the pumpkin fruit is used for production of pumpkin flour, which is easy to store for a long time and is suitable in the production of different kind of foods. Adding pumpkin flour to the production of noodles, bread and cakes not only increases the content of various nutrients but also improves the taste of the products (Que et al., 2008).

Extrusion is widely applied in the production of formulated food. The advantage of the process is high efficiency, high processing volumes and continuity of production (Moscicki, 2011). The extrusion process ensures the production of products of various sizes, shapes and textures (Brennan et al., 2013). The most used materials for production of extrudates are starch-based products but in recent years, small amounts of fruits and vegetables are used in order to enrichment with biological-active components (Brennan et al., 2013; Potter et al., 2013). The optimization of the functional ingredient proportions in the extrudates depends on the nature of each raw material and influences on the process characteristics such as specific mechanical energy and mass flow rate. The main parameters which affected on the extrusion process are moisture content of the initial mixture, screw speed, temperature and pressure (Beck et al., 2018).

Therefore, the purpose of this study was to investigate the effect of pumpkin flour, moisture content and working screw speed on the specific mechanical energy during extrusion of rice flour.

Materials and methods

1. Materials

1.1 Rice flour

The study was conducted with rice of the enterprise “Familex Ltd.” (Bulgaria), purchased from the market.

The rice was ground to flour in a laboratory stone mill “BG Agro” (Bulgaria).

1.2 Pumpkin flour

The pumpkin flour was obtained from pumpkin from the species *Cucurbita maxima*. The pumpkin was washed, peeled and cut into pieces with 6 mm thickness using a slicer (Berkel 250 TG, Van Berkel, USA).

The cut pumpkin pieces were dried in a convection oven (Lainox Aroma PE/005D, Lainox, Italy) with hot air at 70 °C for 480 min until moisture content of 8.1 %, then milled with a blender (Moulinex Type A 505, Moulinex, France). Flour with a particle size below 450 μm was sealed in polymeric bags and stored at 5 °C before use.

2. Equipment

2.1. Laboratory extruder Brabender 20DN (Brabender GmbH & Co KG, Germany), presented in Figure 1;

2.2. Laboratory mill BG Agro, Model 370-90-01 (Batex Ltd., Bulgaria);

2.3. Slicer Berkel 250 TG, (Van Berkel, USA);

2.4. Convection oven Lainox Aroma PE/005D, (Lainox, Italy);
2.5. Blender Moulinex Type A 505, (Moulinex, France);
2.6. Electronic scale – an electronic weighing scale KERN 442-43, (KERN & SOHN GmbH, Germany) was used for weighing the amount of flour.

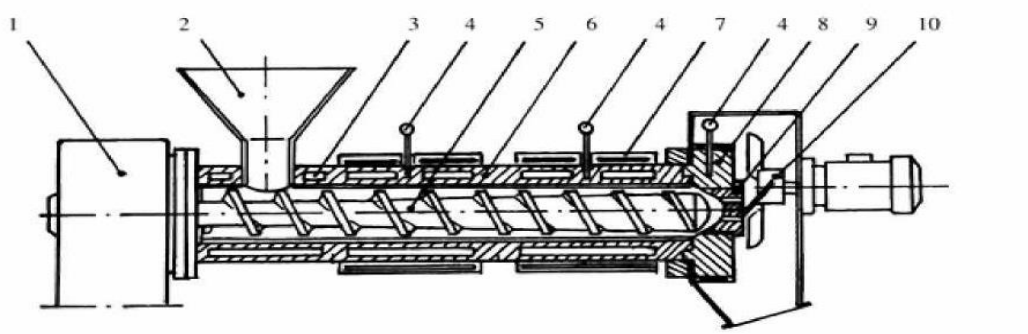


Fig. 1. **Transection of a single screw extruder**
1 – electric motor, 2 – hopper for power supply, 3 – cooling system, 4 – thermocouples, 5 – screw, 6 - cylinder, 7 – heating system, 8 – output (matrix), 9 – nozzle, 10 – cutting device (knife).

3. Methods

3.1. Preparation of the extrusion samples
The ratio of the rice and pumpkin flour was chosen on the basis of preliminary investigations and literature data (Promsakha na Sakon Nakhon et al., 2018): 90:10 and 80:20, respectively.
3.2. Determination of ash yield by incineration, ISO 2171: 2007.
3.3. Determination of the nitrogen content and calculation of the crude protein content - Kjeldahl method, ISO 20483: 2013.
3.4. Total lipids**,** SAOAC 945.16, 2000.
Total lipids were determined by continuous extraction in a Soxhlet apparatus for 12 h using hexane as solvent. After evaporation of the solvent, the oil content was determined gravimetrically.
3.5. Reducing sugars, (%)
Reducing sugars content were determined indirectly by titration of excess copper sulfate remaining after reduction of the Felling solution. In excess of potassium iodite, the divalent copper from the felling solution released an equivalent amount of free iodine by the equation:

$$2CuSO_4 + 4KI = 2CuI + 2K_2SO_4 + I_2$$

The separated iodine was titrated with sodium thiosulphate solution in the presence of a starch indicator.
3.6. Total sugars, (%)
Total sugar content was determined following the reducing sugars procedure after their inversion with the help of concentrated HCl.
3.7. Extrusion
Brabender 20DN single screw extruder was used for the extrusion with: nozzle diameter 3 mm; screw compression ratio 4:1; feeding screw speed 40 min^{-1}; temperatures in the first, second and third zones, 140 ºC, 160 ºC and 180 ºC respectively.
Specific mechanical energy (SME, (W.h)/kg) was calculated according to the following formula:

$$SME = \frac{M_C.n.\pi}{30.Q} \qquad (1)$$

where: M_c – torque of the extruder, measured by an electro-mechanical device built in its drive, N.m; n – working screw speed, min^{-1}; Q – mass flow rate of the extruder, kg/h.
3.8. Statistical processing
The interaction between pumpkin flour (X_1), moisture (X_2) and working screw speed (X_3) was investigated through a full factorial experiment ($N=2^3$). The design of the

experiment with natural and coded values of the three factors is presented in Table 1. The steps of varying factors were chosen on the basis of preliminary investigations and literature data (Promsakha na Sakon Nakhon et al., 2018). Experiments at each point in the design were conducted with a three-fold repetition.

For modelling of the dependencies with coded values, a linear regression equation with interactions of the factors was used:

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

where: b_o, b_i, b_{ij} are respectfully a free coefficient, coefficient of linear effect and coefficient of interaction.

A software "Statgraphics XIV trial version" was used for the mathematical processing of the experimental results.

The Least Significant Difference (LSD) method was used at a level of significance 0.05, using Microsoft Excel 2010, for comparison of the chemical composition of mixtures with 10 % and 20 % pumpkin.

Table 1. Design of the experiment in natural and coded values of the content of pumpkin flour (X_1), moisture content (X_2) and working screw speed (X_3)

№	Natural values			Coded values		
	Content of pumpkin flour, %	**Moisture, %**	**Working screw speed, min^{-1}**	**X_1**	**X_2**	**X_3**
1	10	14	180	-1	-1	-1
2	20	14	180	+1	-1	-1
3	10	20	180	-1	+1	-1
4	20	20	180	+1	+1	-1
5	10	14	220	-1	-1	+1
6	20	14	220	+1	-1	+1
7	10	20	220	-1	+1	+1
8	20	20	220	+1	+1	+1

Results and Discussion

Table 2 shows the composition of initial mixtures from rice and 10 % and 20 % pumpkin flour. When using a 20 % pumpkin flour, the ash, fats, reducing sugars, total sugars and total protein content increased ($p < 0.05$).

The results obtained for the specific mechanical energy from the full factorial experiment are presented in Table 3. The results showed that the specific mechanical energy varies between 77.41 (W.h)/kg and 253.87 (W.h)/kg. The lowest values were obtained with a 10 % pumpkin flour content, 20 % moisture, and screw speed of 180 min$^{-1.}$ The highest values were obtained with a 10 % pumpkin flour content, 14 % moisture and working screw speed of 220 min^{-1}.

Table 2. Composition of initial mixtures from rice and pumpkin flours

Mixture with	Composition				
	Ash, %	Fats, %	Reducing sugars, %	Total sugars, %	Total proteins, %
10 % pumpkin flour	1.57±0.04^a	0.43±0.03^a	2.54±0.08^a	9.38±0.09^a	7.9±0.09^a
20 % pumpkin flour	2.79±0.06^b	0.52±0.03^b	6.62±0.06^b	12.65±0.11^b	8.7±0.07^b

Note: Small letters (a, b) were used to compare the composition of mixtures with 10 % and 20 % pumpkin.

Table 3. Experimental values for specific mechanical energy (SME, (W.h)/kg)

№	SME, (W.h)/kg			
	1	2	3	Average value ± Standard deviation
1	137.21	138.1	140.89	138.73±1.92
2	81.09	88.81	84.83	84.91±3.86
3	79.1	76.6	82.62	79.44±3.02
4	81.85	78.5	80.74	80.36±1.71
5	244.6	251.25	250.03	248.63±3.54
6	97.97	96.61	98.51	97.69±0.98
7	96.55	104.14	94.49	97.06±2.86
8	84.47	87.14	87.58	86.4±1.68

The following adequate model was obtained at a confidence level of 0.95:

$$SME = 114.153-26.8117X_1-28.3383X_2+18.2917X_3+24.3767X_1X_2-13.5867X_1X_3-12.3783X_2X_3 \quad (3)$$

$R^2 = 96\ \%$

The analysis of the regression equation showed that the factors X_1 and X_2 had negative effect on the specific mechanical energy, while factor X_3 affected positively. The energy consumed is determined by the degree of macromolecular transformations and interactions that occur during the extrusion process, hence the rheological properties of the melted material. The increasing of moisture and pumpkin content resulted in a reduction in the viscosity of the dough in the extruder and henced in the mechanical energy consumed. The working screw speed leads to increased mechanical energy consumption (Chandrakant et al., 2019, Alam et al., 2016, Stojceska et al., 2010). The Pareto chart for the effect of factors on the specific mechanical energy of the extruder is presented in Figure 2. The three factors had significant effect. The factors X_1 и X_2 both had approximately the same negative effect on the examined parameter, as evidenced by the coefficients in equation 3: - 27.654 for X_1 and – 29.638 for X_2. Among the three factors examined, X_3 had the lowest effect.

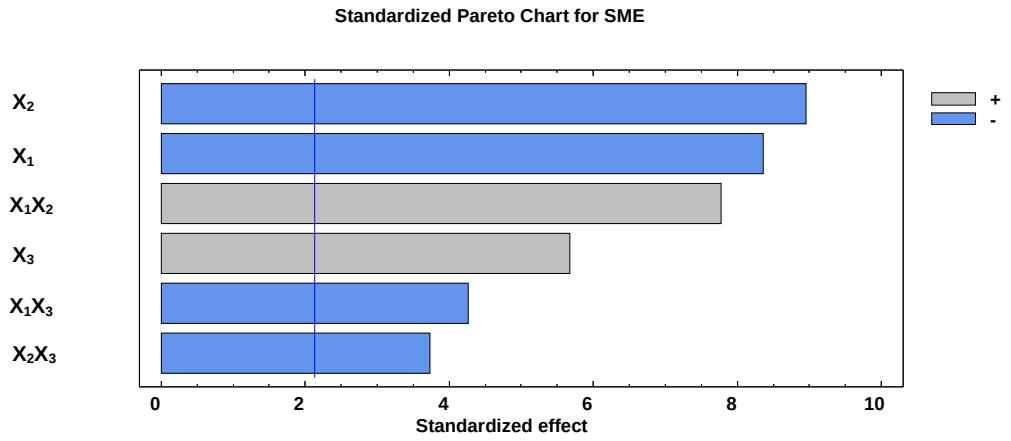


Figure 2. Pareto chart of the effect of factors on the specific mechanical energy

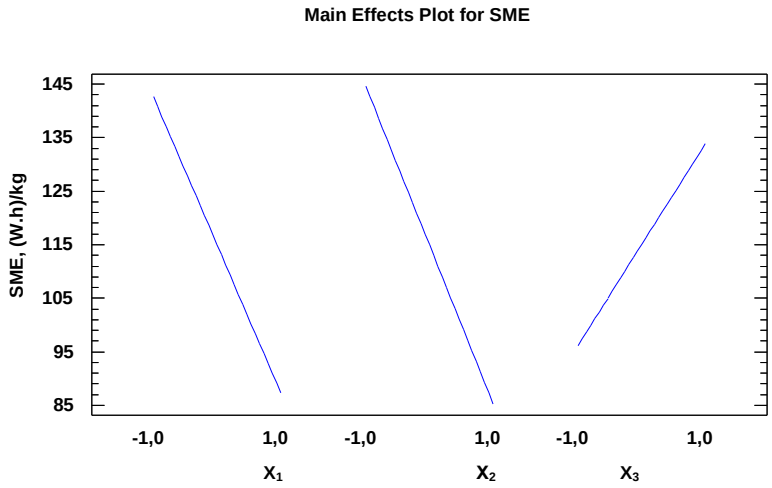


Figure 3. Single effect of the factors on the specific mechanical energy on the extruder

The effect of the content of pumpkin flour (X_1) and moisture (X_2) on the specific mechanical energy is represented in Figure 3. It could be seen that a more negative effect of X_1 on SME
was at 14 % moisture, rather than at 20 % and X_2 at 10 % pumpkin flour content, rather than at 20 %.

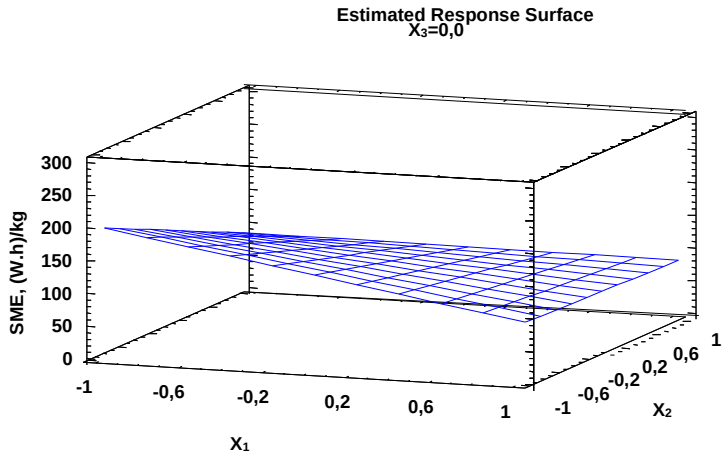


Figure 4. Response surface for specific mechanical energy depending on the content of pumpkin flour (X_1) and moisture (X_2)

The response surface for the specific mechanical energy depending on the content of the pumpkin flour (X_1) and the working screw speed (X_3) is shown in Figure 4. The factor X_1 affected negatively at both levels of the factor X_3. Factor X_3 had a positive effect on the specific mechanical energy, both at high and low levels of X_1. The factor X_3 had a stronger positive effect at low level of X_1, rather than at high level.

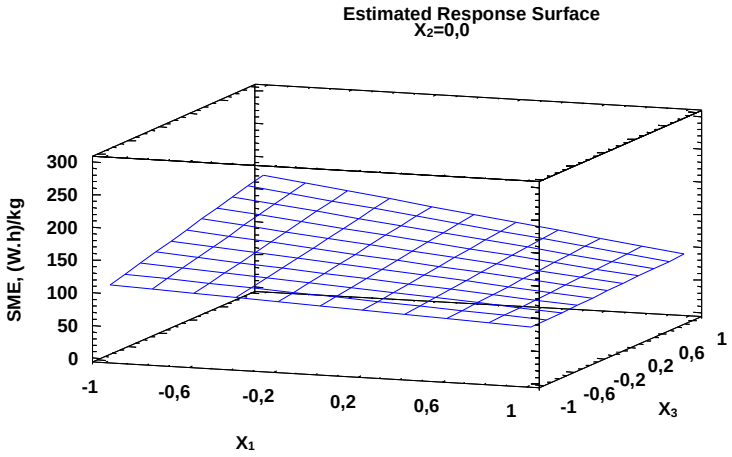


Figure 5. Response surface for deviation of specific mechanical energy depending on the content of pumpkin flour (X_1) and screw speed (X_3)

The response surface for the specific mechanical energy depending on the moisture content (X_2) and working screw speed (X_3) is presented in Figure 5. It can be seen that X_2 had negative effect, while X_3 had positive effect. The highest value of specific mechanical energy was obtained at 14 % moisture and working screw speed 220 min^{-1}. The lowest value was observed at 20 % moisture and 180 min^{-1}. A similar effect of reducing the specific mechanical energy with the increase in the moisture of mixture was reported in a large

number of studies involving the extrusion of rice, wheat and other cereal products in a similar type of extruder (Onwulata et al., 2001; Singh et al., 2007; Toshkov, 2011).

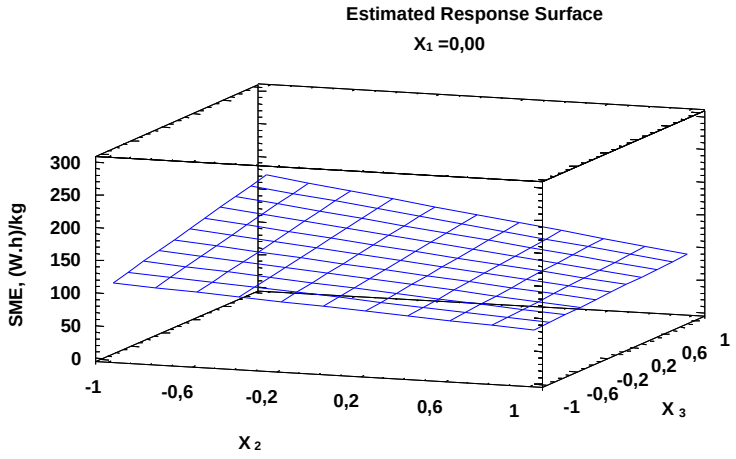


Figure 6. Response surface for the specific mechanical energy depending on moisture content (X_2) and screw speed (X_3)

Conclusions

The results showed that within the experimental design the specific mechanical energy varied between 77.41 (W.h)/kg and 253.87 (W.h)/kg. The highest values were obtained with a 10 % of pumpkin flour content, moisture content of 14 % and working screw speed of 220 min^{-1}. The content of pumpkin flour and moisture had negative effect on the specific mechanical energy, whereas the screw speed had positive effect.

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