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Research Article

Investigation of mass flow rate during extrusion of rice flour enriched with carrot

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Abstract

The present study was conducted to examine the effects of carrot 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 mass flow rate of "Brabender 20DN" single screw extruder during extrusion of rice flour through a full factorial experiment. The results showed that the content of carrot flour had no significant effect on the mass flow rate. The other two factors both had positive effect in an almost identical degree on the mass flow rate which was further proved by the close coefficient values in the obtained regression model.

Keywords: extrusion, mass flow rate, rice, carrot

Abbreviations: no abbreviations

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Introduction

At present the trend in global nutrition aims to reduce food processing in order to preserve all of the beneficial substances that are otherwise unstable. Extrusion is a relatively new process for food preparation. Characteristic of this technology is the extremely short time used for heat treatment which provides safe and edible products, while retaining much of the thermally labile biologically active substances - vitamins, antioxidants, etc. It leads to an increase in the digestibility of nutrients which increases the nutritional value of the products produced.

Rice (*Oryza sativa* L.) is one of the main agricultural crops used for human food. An estimated 480 million tons of rice are produced annually in the world (USDA, 2015). Currently, rice flour is the most used ingredient in the production of gluten-free bread and bakery products (Hager et al., 2012; Moroni et al., 2010).

Carrot (*Daucus carota*) is a root vegetable of the genus of two-year-old plants of the *Apiaceae* family and is one of the most popular in the world (Prakash et al., 2004, Zhang and Hamauzu, 2004). It has a high nutritional and medical value (Handelman, 2001; Hozawa et al., 2007; Kamiloglu et al., 2015) because it is rich in carotenoids such as α-carotene, β-carotene and lutein (Handelman, 2001). Carrot contains a large amount of natural antioxidants. Among vegetables, it is the main source of β-carotene and provides 17 % of total vitamin A consumption (Arscott and Tanumihardjo, 2010). Cellulose in carrots improves intestinal digestion and peristalsis, releasing the body from toxins.

The purpose of this study was to investigate the mass flow rate during the production of extrudates from rice and carrot flour.

Materials and Methods

1. Materials

The study was conducted with rice from Familex Ltd. (Bulgaria), purchased from the market. The rice was milled into flour in a laboratory stone mill BG Agro (Bulgaria).

Dry carrots, purchased from the market, were milled by a laboratory stone mill BG Agro (Bulgaria).

Rice and carrot flour were mixed at 90:10 and 80:20 ratio. The samples were then moistened to achieve a specific humidity, homogenized and placed in polyethylene bags for refrigeration storage at 5 °C for 12 hours. Samples were tempered for 2 h at room temperature before extrusion.

Drinking water, complying with Ordinance № 9 of the Ministry of Health of 16.03.2001 on drinking water quality, was used for moistening of the samples.

2. Equipment

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

2.2. Laboratory mill BG Agro (Bulgaria);

2.3. Electronic scale - KERN 442-43 (KERN & SOHN *GmbH, Germany*) was used to weigh the amount of flour.

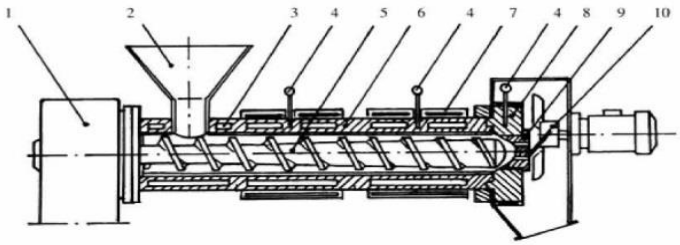


Fig. 1. **Transection of a single screw extruder**
1 – electric motor, 2 – hopper for power supply, 3 – cooling system, 4 – thermocouples, 5 – screw, 6 - cylinder, 7 – heating system, 8 – output (matrix), 9 – nozzle, 10 – cutting device (knife).

3. Methods

3.1. Determination of the nitrogen content and calculation of the crude protein content — Kjeldahl method, ISO 20483: 2013.

3.2. 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.

3.3. Total sugars, (%)

Total sugar content was determined following the reducing sugars procedure after their inversion with the help of concentrated HCl.

3.4. Extrusion

The extrusion was carried out on a Brabender 20DN (Brabender GmbH & Co KG, Germany) single screw extruder 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.

3.5. Mass flow rate (Q, kg/h) was calculated as follows:

$$Q = \frac{m}{\tau}.3600 \qquad (1)$$

where: m is a mass of the sample, kg; τ = 10 s – extrusion time of the sample.

3. 6. Statistical processing

A full factorial experiment (N = 2^3) was used to show the interaction between carrot flour (X_1), moisture (X_2), and working screw speed (X_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 threefold 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_0, b_i, b_{ij} are respectfully a free coefficient, coefficient of linear effect and coefficient of interaction.

The mathematical processing of the experimental results was done using the software Statgraphics XIV trial version.

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 the mixtures with 10 % and 20 % carrot.

Table 1. Design of the experiment with natural and coded values of the factors

№	Natural values			Coded values		
	Content of carrot 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 % carrot flour. When using a 20 % carrot flour, the reducing sugars, total sugars and total protein content increased ($p < 0.05$). The results obtained for the mass flow rate from the full factorial experiment are presented in Table 3. The results showed that the mass flow rate ranged between 3.96 kg/h and 6.12 kg/h.

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

Mixture with	Composition		
	Reducing sugars, %	Total sugars, %	Total proteins, %
10 % carrot flour	5.06 ± 0.6^a	7.6 ± 0.4^a	5.45 ± 0.3^a
20 % carrot flour	8.8 ± 0.5^b	11.87 ± 0.8^b	6 ± 0.4^b

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

Table 3. Experimental values for mass flow rate (Q, kg/h)

№	Q, kg/h
1	4.59±0.38
2	3.96±0.32
3	5.79±0.26
4	6.01±0.45
5	6.12±0.07
6	6.05±0.35
7	5.80±0.13
8	5.73±0.18
7	5.80±0.13
8	5.73±0.18

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

$$Q = 15.191 + 1.075X_2 + 1.106X_3 + 0.357X_1X_2 - 1.232X_2X_3 \quad (3)$$

$R^2 = 99.6\ \%$

The Pareto chart of the effect of factors on the mass flow rate is presented in Fig. 2. It showed that the factors X_2 and X_3, with the exception of X_1, had both a significant effect.

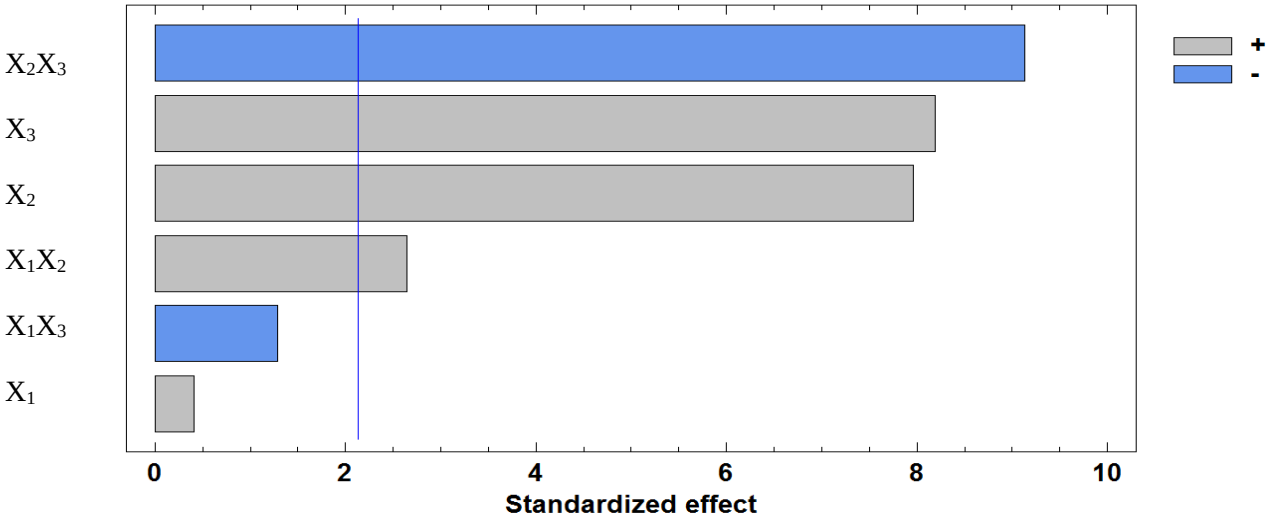


Fig. 2. Pareto chart of the effect of factors on the mass flow rate

The single effect of the factors studied on the mass flow rate is presented in Figure 3. It showed that the factors X_2 and X_3 had the same positive effect on the mass flow rate as it was shown by the coefficients in equation 3: 1.075 for X_2 and 1.106 for X_3. Among the three factors studied, X_1 had the lowest effect.

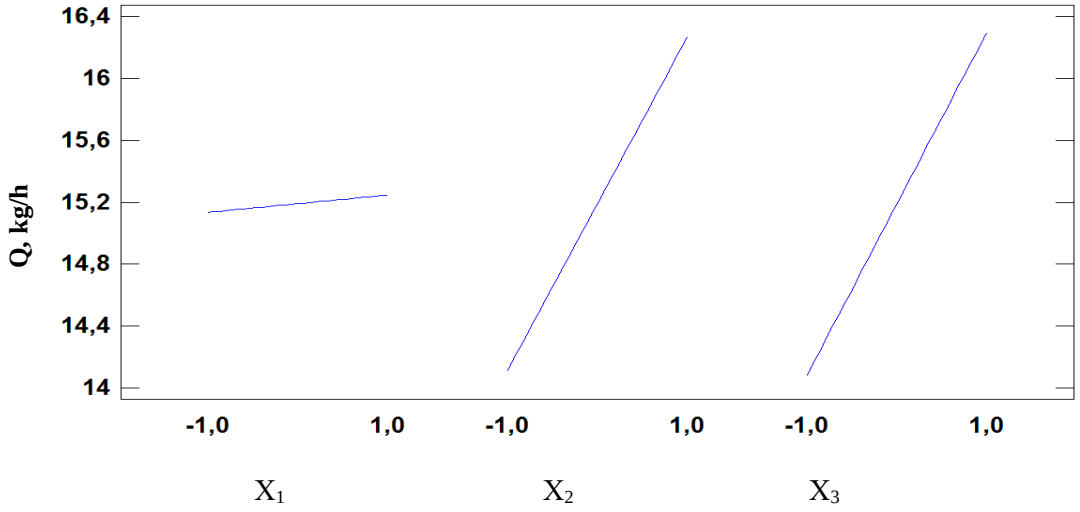


Fig. 3. Single effect of the factors investigated on the mass flow rate

A significant effect on the mass flow rate had the working screw speed and the moisture content of the mixture, while the carrot flour content had no significant effect. The increase in the moisture led to a decrease in the density of the dough material in the extruder and henced easier material leakage, and respectively a higher mass flow rate (Figure 4). The effect of moisture was more pronounced at low working screw speed, which is evident from the slope of the lines. The positive effect of the working screw speed could be explained by the reduction of the material processing time in the extruder, which leads to an increase in the mass flow rate (Wang et al., 2012).

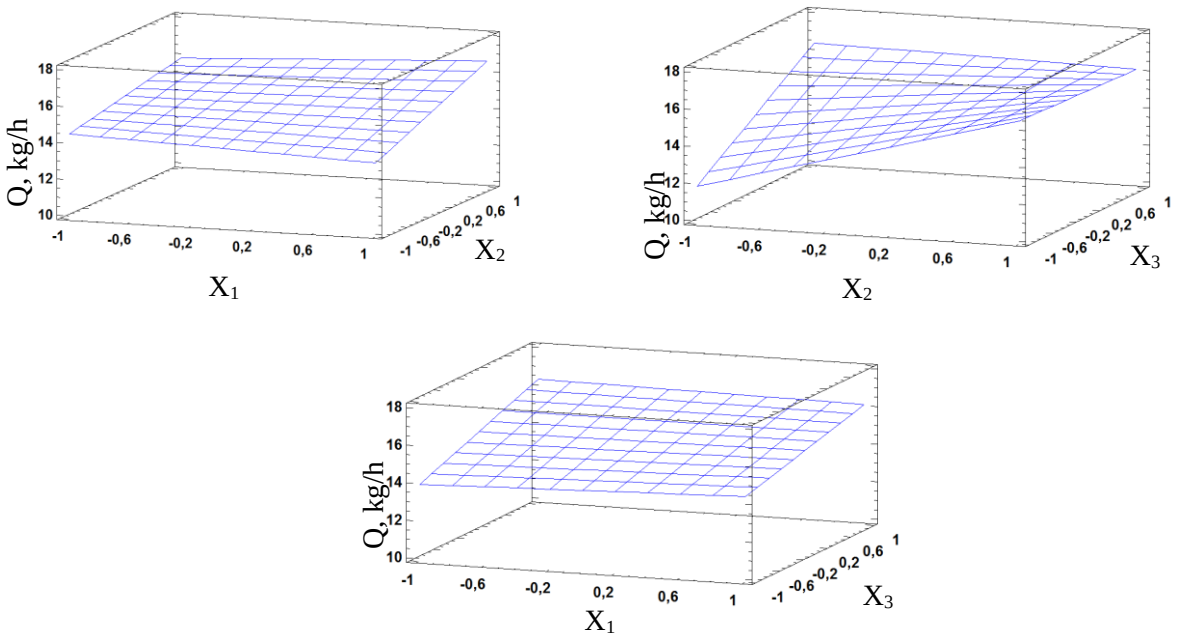


Fig. 4. Response surfaces of the mass flow rate depending on the three factors studied

Conclusions

The results showed that the content of carrot flour (10 % and 20 %) had no significant effect on the mass flow rate. The other two factors studied – the moisture of the initial mixture (14 % and 20 %) and working screw speed (180 min^{-1} and 220 min^{-1}) had positive effect in an almost identical degree on the mass flow rate which was further proved by the close coefficient values in the obtained regression model.

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