

MODELLING OF EXTRUSION PROCESS FOR EVALUATION OF SPELT WHOLEGRAIN SNACK EXPANSION

MODELOVANJE PROCESA EKSTRUDIRANJA U CILJU ODREĐIVANJA STEPENA EKSPANZIJE FLIPS PROIZVODA OD SPELTINOG INTEGRALNOG BRAŠNA

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ABSTRACT

The effect of extrusion parameters, including feed rate (15–25 kg/h), screw speed (250–750 rpm) and feed moisture (15–25%) on the expansion index of spelt wholegrain snack products was investigated. Wholegrain spelt flour was extruded using co-rotating twin-screw extruder (Bühler BTK 30/28D, 7 sections, length/diameter ratio = 28:1, Bühler, Uzwil, Switzerland). The obtained data demonstrate that increased feed moisture leads to a decrease in the expansion of extrudates. Increasing in screw speed resulted in higher elasticity, which has resulted in the greater expansion index. The following operating conditions: screw speed (750 rpm), feed moisture (20%) and feed rate (20kg/h) provided the highest expansion index (1.93). The screw speed has the greatest positive influence on the expansion index obtained by Yoon's model.

Keywords: extrusion, snack, influence, Yoon's model, expansion.

REZIME

U današnje vreme, povećana proizvodnja i upotreba speltinog integralnog brašna u ishrani ljudi povećava potrebu za definisanjem i karakterizacijom snek proizvoda od ove sirovine. Male promene u ulaznim procesnim parametrima tokom procesa ekstrudiranja utiču ne samo na izlazne procesne parametre nego i na kvalitet proizvoda ekstrudiranja. Stoga, ispitan je uticaj parametara ekstrudiranja, uključujući protok materijala (15–25 kg/h), učestanost obrtanja pužnice (250–750 o/min) i vlažnosti materijala (15–25%) na stepen ekspanzije snek proizvoda od speltinog integralnog brašna. Speltino integralno brašno ekstrudirano je primenom dvopužnog ekstrudera Bühler BTK 30/28D (Bühler, Uzwil, Švajcarska). U ovoj studiji matematička analiza započinje razvojem polinoma drugog stepena (SOP) kako bi se izvršila analiza varijanse (ANOVA) za rangiranje ulaznih promenljivih u odnosu na indeks ekspanzije. Vrednosti za indeks ekspanzije predviđene su korišćenjem ANN koji je kasnije primenjen za računanje relativnog uticaja nezavisnih promenljivih na zavisnu promenljivu. Povećajući vlažnost ulaznog materijala i učestanosti obrtanja pužnice tokom ekstrudiranja dolazi do velikog smanjenja odnosno povećanja ekspanzije ekstrudata, respektivno. Sa ciljem da se dobije najveći stepen ekspanzije (1,93) korišćeni su sledeći parametri ekstrudiranja učestanosti obrtanja pužnice (750 o/min), vlažnosti polaznog materijala od 20% i protoka materijala od 20 kg/h. Na osnovu rezultata dobijenih korišćenjem Yoonovog modela pokazano je da na stepen ekspanzije najveći uticaj ima uestanost obrtanja pužnice.

Ključne reči: ekstrudiranje, snek, uticaji, Yoonov model, stepen ekspanzije.

INTRODUCTION

An increased interest in healthy food has led to the higher demand for alternative cereals, where spelt takes a significant place due to its biological, agronomic, nutritional and medical characteristics, as well as its rich nutritional properties (Zieliński *et al.*, 2008). A high content of nutritionally valuable components (proteins, vitamins, minerals, fibers) makes the spelt suitable for the production of a wide range of food products (Krulj *et al.*, 2019). Nowadays, increased production and use of spelt wholegrain flour in human nutrition increase the necessity to define and characterize snack products made by extrusion from this raw material (Kojić *et al.*, 2019). During the extrusion operation, even small variations in processing parameters affect the whole process as well as the product quality. A quick and easy way to make different snack products is to vary their recipes and therefore the interest in the use of extruders in the production of functional snack products has great potential (Riaz, 2000). It is obvious that different raw materials lead to the creation of the final product with different color, texture, taste and nutritional composition (Kim *et al.*, 2009).

One of the most important characteristics of snack products, which is on top of the list of consumer requirements for extruded products, is expansion. Products with a high expansion and porosity indicate the efficiency of the extrusion cooking process and are positively correlated with consumer acceptability (Kumar *et al.*, 2018). Higher values of expansion and lower values of density are highly desirable characteristics of snack products (Bisharat *et al.*, 2013).

In recent year artificial neural networks (ANN) were used for optimization and modeling of the food extrusion cooking process (Borah *et al.*, 2015; Lohani & Muthukumarappan, 2017; Singha & Muthukumarappan, 2017), and therefore it was applied in our experiments for expansion index quantification of snack product.

The extrudate's quality depends on the feed moisture content, extruder type, screw configuration, the change in temperature through the barrel and die, and feed rate (Singha & Muthukumarappan, 2017). Hence, our main focus was to investigate the influence of screw speed (SS), feed moisture content (M) and feed rate (FR) on the expansion index in the snack product.

MATERIAL AND METHOD

Extrusion

Spelt flour was extruded using co-rotating twin-screw extruder (Bühler BTKS 30/28D, 7 sections, length/diameter ratio = 28:1, Bühler, Uzwil, Switzerland). The extrusion cooking process was described previously in our work (Kojić et al. 2019).

Expansion index

Expansion index was calculated as the ratio of the diameter of the extrudate and the diameter of the die (Alvarez-Martinez et al., 1988). Six samples were used for each extrudate to calculate the mean.

Experimental design and modeling

In this study mathematical analysis starts with developing the second-order polynomial (SOP) model in order to perform the analysis of variance (ANOVA) to rank input variables over the expansion index. The values for the expansion index were predicted by ANN. The procedure for constructing ANN and Yoon model can be found in the paper Kojić et al. (2019).

RESULTS AND DISCUSSION

The minimal number of experiments was achieved using a central composite rotatable design (CCRD). The number of experiments was 17 with three central points (Table 1).

The obtained expansion index is shown in Table 1. and indicates differences in EI content depending on changes in parameters during extrusion.

Table 1: Experimental design with product and process response (expansion index) obtained for extrusion of spelt flour with CCRD.

Variables				Product response
CCRD runs	M (%)	FR(kg/hr)	SS(rpm)	EI
1	20	20	500	1.82
2	20	20	250	1.54
3	17	17	350	1.60
4	20	20	750	1.93
5	20	20	500	1.81
6	23	17	350	1.69
7	17	17	650	1.90
8	25	20	500	1.72
9	20	25	500	1.78
10	23	17	650	1.88
11	20	15	500	1.83
12	23	23	650	1.86
13	20	20	500	1.81
14	15	20	500	1.92
15	17	23	650	1.89
16	23	23	350	1.62
17	17	23	350	1.82

Increased feed moisture (M) leads to a decrease in the expansion index of extrudate (Ding et al., 2006). In the same study, it was determined that there is no influence of feed rate (FR) on expansion index, which was also observed in our results (Figure 1). Harmann and Harper (1973) found the two most significant factors important for expansion: dough viscosity and

elastic force in the extrudate. During expansion, bubbles grow based on the difference between the pressure inside the bubble and the atmospheric pressure on the bubble wall, as a driving force, which increases with pressure and temperature (Panmanabhan et al., 1989). The effect of feed moisture on the expansion index can be explained by the fact that the dough during extrusion with a higher moisture content of the material produces a lower vapor pressure (probably due to the reduction of temperature in the barrel), which leads to reduced expansion index (Hagenimana et al., 2006). Increased feed moisture content during extrusion would change the amylopectin molecular structure of the material reducing the dough elasticity thus decreasing the expansion but increasing the density of extrudate (Alvarez-Martinez et al., 1988). A decrease in the expansion index with increasing feed moisture has been observed in many studies (Filli et al., 2012; Ding et al., 2005; Lazou et al., 2010; Chakraborty et al., 2011; Gulati et al., 2016; Singh et al., 2007; Diaz et al., 2015). Diaz et al. (2013) found a negative correlation between the expansion index and feed moisture and a positive correlation with the screw speed in maize-based extrudates containing amaranth and quinoa, which is also confirmed by the results in our study (Figure 1). Chávez-Jauregui et al. (2000) found that the expansion increases at higher screw speed (SS) for maize-based extrudates containing quinoa and amaranth flour, respectively. It has been also confirmed that the expansion of these extrudates increases with increasing screw speed in the work of Diaz et al. (2015). Increasing screw speed during extrusion leads to lower dough viscosity and higher elasticity, which contributes to higher extrudate expansion (Fletcher et al., 1985; Ding et al., 2006). In the work of Altan et al. (2009) it was found a statistically significant effect of screw speed on extrudate expansion ($p < 0.05$). The highest expansion index (1.93) was achieved at the following operating conditions: screw speed (750 rpm), feed moisture (20%) and feed rate (20kg/h). Özer et al. (2004) in their study indicates that increasing the screw speed is a powerful tool for adjusting the expansion of the final product. When the screw speed increases, there is an increase in the shear forces inside the extruder barrel, during which uniform dough is formed, which consequently acquires better expansion properties when coming out of the die.

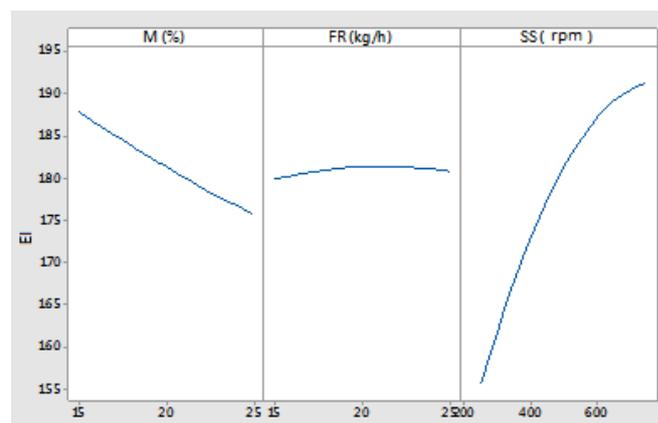


Fig. 1: Influence of process parameters moisture (M), feed rate (FR), screw speed (SS) on EI

Yoon's interpretation method was used to determine the relative influence of input variables in the ANN model (Yoon et al., 2017). This method was applied based on the weight coefficients of the developed ANN. From the presented Yoon model, it can be observed that the screw speed has the greatest influence on the expansion index (approximately 60%). There is a negative influence of feed moisture on EI and a positive

influence of screw speed. The feed rate has an insignificant influence on the expansion index (Figure 2).

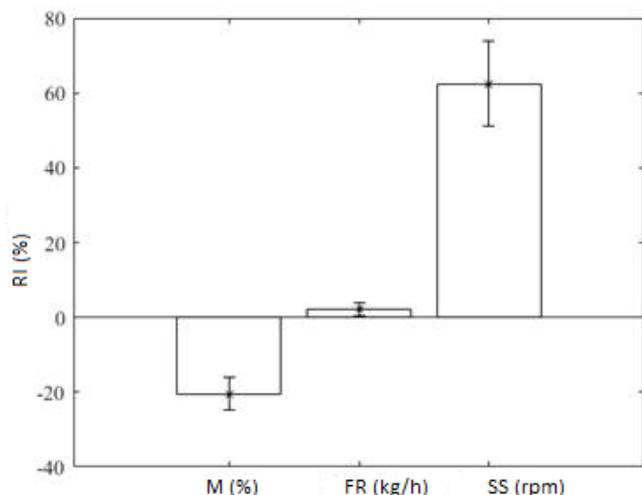


Fig. 2: The relative importance of the extrusion parameters on the expansion content determined using the Yoon interpretation method

The analysis of variance for a second-order polynomial model for EI during the extrusion process is presented in Table 2.

Table 2: Analysis of variance for second-order polynomial for EI calculation (sum of squares)

Terms	df	EI	F	p
M	1	0.018*	6.606	0.037
M ²	1	0.000	0.015	0.906
FR	1	0.000	0.036	0.854
FR ²	1	0.000	0.049	0.831
SS	1	0.155 ⁺	57.072	0.000
SS ²	1	0.009	3.332	0.111
M × FR	1	0.011**	4.140	0.081
M × SS	1	0.000	0.166	0.696
FR × SS	1	0.004	1.490	0.262
Error	7	0.019		
r ²		0.913		

df – degrees of freedom; F - Fisher test; p - p value; ⁺statistically significant at p<0.01 level; * statistically significant at p<0.05 level; ** statistically significant at p<0.10 level

The linear term of SS was most influential in the SOP model for EI calculation, statistically significant at p<0.01 level, as well as the linear term of M (statistically significant at p<0.05 level), which is in accordance with the investigation of Filli et al. (2012) in which it was proven that statistically significant influence (p<0.05) of the linear terms of initial material's moisture and screw speed existed on the expansion index. The linear term of FR was not statistically significant in the SOP model.

The quadratic terms in the SOP model were not statistically significant, while the product term M × FR in the SOP model was statistically significant, but only at p<0.10 level. The other terms in the SOP model were not statistically significant. The

calculated coefficient of determination value (r²) for the SOP model and the calculated error term guaranteed the adequate prediction of EI during the extrusion process, as well as the good fitting to experimental results for EI (Table 2).

CONCLUSIONS

The present study analyzes the influence of extrusion cooking parameters like feed moisture content, screw speed and feed rate on expansion index in the extrudate. An artificial neural network (ANN) can be successfully used for the prediction of the expansion index. With increasing feed moisture the expansion of extrudate decreased. An increase in screw speed resulted in a higher expansion index (the greatest influence). In order to achieve the highest expansion index (1.93) operating parameters should be: screw speed (750 rpm), feed moisture (20%) and feed rate (20kg/h). An insignificant influence of feed rate on the expansion index was shown using Yoon's model.

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