THE EFFECT OF EXTRUSION COOKING ON RESISTANT STARCH FORMATION IN RICE FLOUR SNACK ENRICHED WITH CHICORY ROOT

UTICAJ POCESA EKSTRUDIRANJA NA SADRŽAJ REZISTENTNOG SKROBA U PIRINČANOM FLIPS PROIZVODU OPLEMENJENOM KORENOM CIKORIJE

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ABSTRACT

The aim of this study was to evaluate the influence of extrusion process variables on the resistant starch content (RS) in a sample of rice snacks with added chicory root (addition: from 20-40%). The effect of different levels of feed moisture (16.3 to 22.5%) and screw speed (500 to 900) rpm, as well as chicory root addition, during extrusion cooking on the resistant starch content of extruded products, was investigated. Results of our experiments have demonstrated a decrease in the resistant starch content after extrusion, which is also observed in some other studies. The resistant starch content was in a range of 0.1302 g/100g to 0.5302 g/100g. According to Yoon's model, the screw speed had the greatest negative influence, while the increased feed moisture had a positive effect on resistant starch content, as well as the share of chicory addition.

Keywords: resistant starch, extrusion, chicory root, rice.

REZIME

Cikorija (lat. Cichorium intybus) je kultura čija popularnost neprestano raste zbog brojnih lekovitih, kulinarskih i hranljivih svojstava. Budući da cikorija sadrži brojna korisna jedinjenja, poput polifenola, inulina, oligofruktoze, laktona, vitamina i minerala, ona se može smatrati potencijalnim nosiocem funkcionalnosti hrane. Cilj ovog istraživanja je bio da se proceni uticaj procesnih parametara tokom ekstrudiranja na sadržaj rezistentnog skroba u uzorcima od pirinčanog brašna sa dodatkom mlevenog korena cikorije, sa udelom od 20-40%. Takođe je ispitan i efekat različitog sadržaja vlage u uzorcima (od 16,3 do 22,5%) i brzine obrtanja pužnice (od 500 do 900 o/min) tokom procesa ekstrudiranja, gde su upotrebom dvopužnog ekstrudera pripremljeni uzorci. Veštačka neuronska mreža (ANN) se koristila za predviđanje eksperimentalnih izlaznih parametara, koja je primenjena na Yoonov model, kako bi se utvrdio relativni uticaj nezavisnih promenljivih (vlaga materijala, brzina obratanja pužnice, sadržaj korena cikorije) na zavisnu promenljivu (sadržaj rezitentnog skroba). Rezistentni skrob (RS) ima veliki potencijal u prehrambenoj industriji zbog mogućnosti snižavanja glikemijskog indeksa, kao pozitivnog uticaja na zdravlje ljudi. Na sadržaj rezistentnog skroba u hrani utiče način pripreme, kao i tehnološki procesi, što je takođe primećeno i u našim rezultatima. Sadržaj rezistentnog skroba se kretao u intervalu od 0,137 g/100g do 0,529 g/100g, pri čemu je najveći sadržaj postignut pri uslovima gde je sadržaj vlage bio 19,4%, brzina obrtanja pužnice 700 o/min i sa udelom od 30% mlevenog korena cikorije (0,529 g/100g). Najveći negativan uticaj na rezistentni skrob zabeležen je pri većem broju obrtanja pužnice, dok je sadržaj vlage imao pozitivan uticaj na rezistentni skrob, što je slučaj i sa udelom korena cikorije.

Ključne reči: rezistentni skrob, ekstrudiranje, koren cikorije, pirinčano brašno.

INTRODUCTION

Chicory (lat. *Cichorium intybus* L.) is a perennial, greatly widespread meadow herb, which is planted all over the world (*Perović et al., 2021*). Chicory has a rich nutritional composition with many bioactive substances that have a beneficial effect on human health. The most common compound in chicory root is inulin, which makes chicory one of the richest sources of this prebiotic (*Perović et al., 2021, Al-Snafi, 2016*). It has a significant role in human health based on positive effects on the intestinal flora and the digestive tract, and lowers cholesterol, contributes to the regulation of blood sugar level, etc. (*Shoaib et al., 2016*). In addition to inulin, chicory is enriched with many other useful compounds such as polyphenols, sesquiterpene lactones, oligofructose, vitamins, minerals and other compounds present in chicory extracts which are associated with anti-inflammatory, anti-diabetic, anti-hepatotoxic, antihyperglycemic, and antimicrobial activity (*Bahmani et al., 2015*). Extrusion is a simple, continuous process in which extrudates are obtained by pushing material through the die. This process involves a combination of different conditions, including variations in moisture, temperature, pressure, and shear forces. The smallest changes in the process input parameters can affect the technological properties and quality of the extrudate. The extrusion cooking process causes physical and chemical changes in starch granules in different materials, thus affecting the texture and rheological properties, and increasing its digestibility (*Ashwar et al., 2020; Neder-Suárez et al., 2016; Shankar et al., 2010; Shankar and Bandyopadhyay, 2007*). Numerous tests have shown that the resistant starch content decreases (or increases digestibility) after extrusion because the destruction of granular structures occurs. High damage of granular structure and reduction of RS content occur due to shear forces, thermal treatment and heat pressure (*Cruz-Ortiz et al., 2020; Ye et al., 2018; Alsaffar 2011*). *Mahasukhonthachat et al. (2010)* proved that the digestibility of starch increased about ten times in extruded products compared to non-extruded ones. Resistant starch (RS) is a linear molecule α-1,4-d-glucan that belongs to dietary fiber which is not digestible, more precisely, it does not

break down in the stomach and small intestine, but bypassing into the large intestine where it metabolized into secondary products thanks to colon microflora (*Raigond et al., 2015; Drzikova et al., 2005*). The speed and extent of digestion can be influenced by a number of interrelated factors such as the ratio of amylose to amylopectin, type, distribution and particle size, an average molecular weight of components, and protein and sugar content in food (*Šárka et al., 2015; Alsaffar 2011; Drzikova et al., 2005*). Due to its beneficial effects, according to many studies, RS has an effect on the glycemic index, which leads to its reduction. Foods with a low glycemic index reduce the risk of various cardiovascular diseases, diabetes, and obesity (*Raigond et al., 2015; Alsaffar 2011; Dupuis et al., 2014; Smrčková et al., 2014*).

Therefore, the aim of this study is to formulate and produce a rice-based snack enriched with chicory root by the modern and automated twin-screw extruder and evaluate the influence of feed moisture (M), chicory root content (P) and screw speed (W) on resistant starch content.

MATERIAL AND METHODS

Extrusion experiments

Rice snack products with different contents of chicory root (20-40%) were obtained by extruding the mixture through a co-rotating twin-screw extruder (Model BTSK 30/28D, Bühler, Switzerland). The screw speed ranged from 500 to 900 rpm, while moisture content was set from 16.3% to 22.5%. The total length of the extruder barrel was 880 mm and the length/diameter ratio was 28:1. Temperatures in the 7 zones of the barrel were set in the following order: zone 1 fixed temperature, zones 2-4 set to temperatures of 60°C, zone 5 fixed temperature, zones 6 and 7 set to temperatures of 120°C. The feed rate of the mixture was 60 kg/h. The experimental design used in this study was the central composite rotatable (CCD), and Table 1 shows a list of samples obtained at different input extrusion parameters.

Measurement of resistance starch

The resistant starch content in snack products was determined using a commercial kit (K-RSTAR, Megazyme Int. Ireland, Wicklow, Ireland) based on the AOAC 2002.02 method.

Statistics

Artificial neural network (ANN) predicts the function that gives the output based on the input data, without the need to define the relationship between them (*Borah et al., 2015; Anderson, 1995; Garson, 1991*). With only small variations of the input parameters during extrusion, the quality of the product is also affected, so the final shape of the product relies on the data defined by this procedure (in this paper screw speed, feed moisture content, and chicory root content).

The artificial neural network was used to build a mathematical model. This model can be used to predict the output values according to its adequate interpretation properties (Borah et al., 2015).

Based on the performance of the model, the optimal number of neurons in the hidden layer for RS calculation was selected and was 4. The optimum number was chosen based on the technique by limiting the distinction between anticipated ANN values and exploratory outcomes. The ranges of input parameters were $500 < V < 900$ rpm, $16.3 < M < 22.5\%$ and $20 < P < 40\%$. Instead of conventional ANOVA, the influence of variables can be determined using Yoon's method, more precisely using weights calculated during ANN modeling that was used to estimate the influence of input variables (*Yoon et al., 1993*):

$$RI_{ij}[\%] = \frac{\sum_{k=0}^{n}(w_{ik}w_{kj})}{\sum_{i=0}^{m} abs \sum_{k=0}^{n}(w_{ik}w_{kj})} \cdot 100\%$$

where RI_{ij} is the relative importance of the *i*-th input variable on the *j*-th output, w_{ik} is the weight between the *i*-th input and the *k*-th hidden neuron, and w_{kj} is the weight between the *k*-th hidden neuron and the *j*-th output.

RESULTS AND DISCUSSION

The obtained resistant starch content is shown in Table 1. *Robin et al. (2016), Jozinovic et al. (2012)* and *Wolf (2010)* indicate differences in RS content depending on changes in parameters during extrusion. They found that the resistant starch content is influenced by the input parameters, which was also confirmed in our study. In our study, the observed value for non-extruded rice flour was 20.504 g/100 g at a moisture content of 12.75%. This indicates that different extrusion conditions led to a reduction in the RS content, compared to non-extruded products, which is in line with research conducted by *Martínez et al. (2014)* who changed the functionality of wheat flour by extrusion.

During extrusion at a screw speed of 700 rpm, feed moisture of 19.2%, and chicory root content of 30%, the lowest resistant starch content was observed (0.137 g/100g).

Table 1. Resistant starch content in samples obtained under different extrusion conditions using CCD experimental design

Sample Number	Screw Speed (RPM)	Moisture content (%)	Chicory root content (%)	Resistance starch (g/100g)
1	818.9	21.2	35.9	0.177
2	700.0	19.4	30.0	0.233
3	818.9	17.6	35.9	0.224
4	700.0	19.4	30.0	0.246
5	818.9	21.2	24.1	0.348
6	700.0	22.5	30.0	0.359
7	900.0	19.4	30.0	0.274
8	818.9	17.6	24.1	0.175
9	700.0	19.4	30.0	0.238
10	581.1	21.2	24.1	0.361
11	700.0	16.3	30.0	0.139
12	700.0	19.4	40.0	0.137
13	500.0	19.4	30.0	0.330
14	700.0	19.4	30.0	0.248
15	581.1	17.6	24.1	0.175
16	581.1	21.2	35.9	0.529
17	581.1	17.6	35.9	0.287
18	700.0	19.4	20.0	0.160
19	700.0	19.4	30.0	0.231
20	700.0	19.4	30.0	0.247

According to ANN results, the optimal ANN model was MLP 3-10-1, with 3 inputs (M, V, P), ten neurons in the hidden layer, and 1 output (resistance starch content).

The optimum number of hidden neurons was chosen upon a well-known technique by limiting the distinction between anticipated ANN values and exploratory outcomes, using sum-squared error amid testing as a performance indicator.
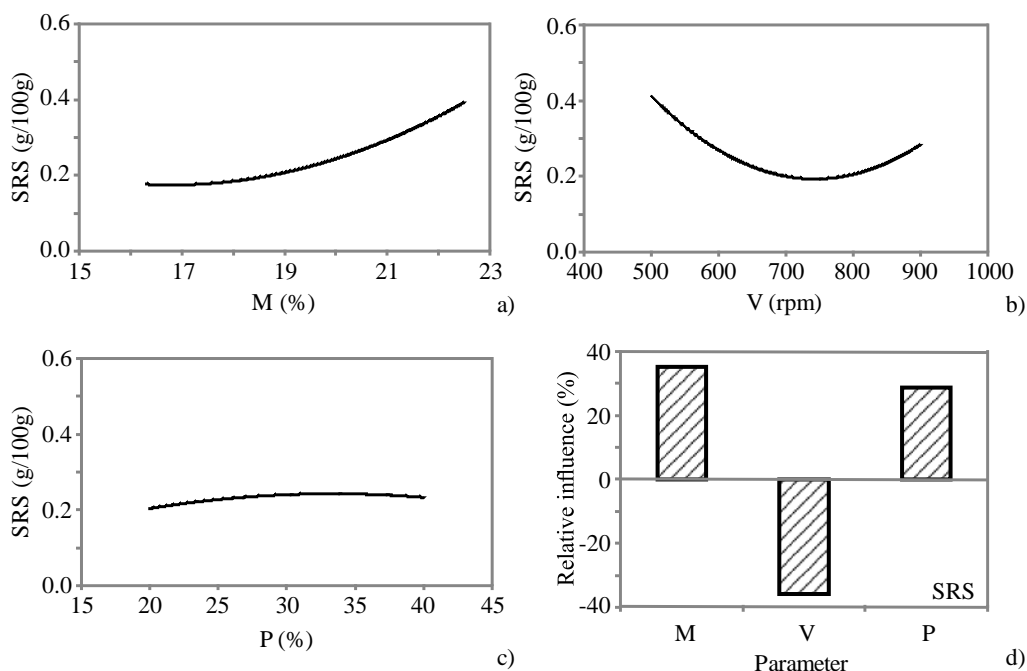
Fig. 1. Relative importance of process parameters
(M-moisture content, V-screw speed, P-chicory root content) determined using Yoon's interpretation method

Table 2. ANN model summary (performance and errors), for training, testing and validation cycles.

Net. name	Performance			Error			Train. algor.	Error funct.	Hidden activat.	Output activat.
	Train.	Test.	Valid.	Train.	Test.	Valid.				
MLP 3-10-1	0.999	0.998	0.998	0.000	0.003	0.002	BFGS 120	SOS	Tanh	Logistic

*A performance term represents the coefficients of determination, while error terms indicate a lack of data for the ANN model. ANN cycles: Train. – training, Test. – testing, Valid. – validation, algor. –algorithm, funct. – function, activat. – activation.

As indicated by the results, it was noticed that the optimal number of neurons in the hidden layer for *SRS* calculation was 4. The quality of the model fit was tested, and the residual analysis of the developed model is presented in Table 2.

The goodness of fit between experimental measurements and model-calculated outputs, represented as ANN performance (sum of r^2 between measured and calculated *SRS*), during training, testing and validation steps, are shown in Table 2.

The ANN model is complex (51 weights-biases) because of the high nonlinearity of the developed system. The r^2 values between experimental measurements and ANN model outputs, was: 0.999, during the training period.

The quality of the model fit was tested and the residual analysis of the developed model was presented in Table 3. The ANN model had an insignificant lack of fit tests, which means the model satisfactorily predicted the content of resistant starch. A high r^2 is indicative that the variation was accounted for and that the data fitted the proposed model satisfactorily

The control sample of pure rice flour had a resistant starch content of 2.070 g / 100 g at the screw speed of 800 rpm and the feed moisture of 16%. In comparison with non-extruded rice flour, a decrease in the content of RS was noticed, which is in accordance with the literature data. Resistant starch has similar properties as fiber and shows positive properties on human health, the only difference compared to dietary fiber, is that RS will not change the quality and sensory properties of the product (*Šárka et al., 2015; Alsaffar 2011*). According to the results obtained by *Ainsworth et al. (2007),* the addition of brewer's spent grain to corn flour leads to a slight increase in the RS content which is in accordance with our results (Figure 1c). However, by the addition of 30% of brewers spent grain at speeds of 100 rpm, higher values were obtained compared to the values obtained at a screw speed of 300 rpm *(Ainsworth et al., 2007)*. In the same study, the share of brewer's spent grain will not be statistically significant for the content of RS, which trend is confirmed in our results. This is consistent with the conclusion of Potter et al. (2013) who observed that in extruded products, at different production temperatures, enriched with various fruit powders, the retrograde starch content (types of resistant starch) increases. According to Yoon's model, the greatest influence on resistant starch was by the screw speed as well as the feed moisture, with approximately -35% and 35% relative importance. The proportion of chicory root had a positive effect on the resistant starch content, with a slightly lower relative

Table 3. The "goodness of fit" tests for the developed ANN model.

χ^2	RMSE	MBE	MPE	SSE	AARD	r^2	Skew	Kurt	Mean	StDev	Var
1.1E-06	0.001	-1.4E-04	0.258	2.0E-05	0.028	0.998	-1.623	6.007	-1.4E-04	0.001	1.1E-06

significance of 28% (Fig. 1d). Higher screw speed (up to 750 rpm) produced extrudates with the lower content of resistant starch, which indicates that it has the greatest negative impact. However, if the screw speed was higher than 750 rpm, the RS content had a slight increase (Fig. 1b). Increasing screw speed increases the retention time of the samples in the extruder, causing the decomposition of starch (*Šárka et al., 2015*; *Dupuis et al., 2014*). In a study conducted by *Sandrin et al. (2019)*, it was observed that the RS content decreased significantly in extruded products, caused by increase screw speed, which is in accordance with our study. Similar observations were made by *Samray et al. (2019)*, who noticed that the RS content decreases under the higher shear stress during the production of bread crumbs by extrusion. On the other hand, increasing the moisture content has the greatest positive impact on RS (Figure 1a), which is in accordance with the observations of *Sarawong et al. (2014)*, who extruded green banana flour. However, they state that extruded products compared to native flour have a significantly lower content of RS, where the reduction ranged from 91.5 to 98.1% compared to the non-extruded product (*Sarawong et al., 2014*). Such conclusions were also made by *Kim et al.(2006)* who observed that the feed moisture was positively correlated with resistant starch in pastry wheat flour extrudates and that feed moisture at 60% could significantly increase the RS content. Many studies have investigated the influence of moisture as an initial parameter on the RS content and all concluded that extrusion in such conditions yields products with a higher RS content due to the strong formation of intermolecular hydrogen bonds in the amylose fraction (*Sarawong et al., 2014*). Increasing screw speed causes the disintegration between the crystal lamellae, which represent critical fracture points, and occurs due to shear forces. More precisely, extrusion increases digestibility (reduce RS content), which is a consequence of the degradation of molecules that occurs at high screw speeds, high temperatures, and lower moisture content (*Šárka et al., 2015, Smrčková et al., 2014*). Solubilization of amylose molecules and swelling of starch granules, during the increase of screw speed (thus increasing the residence time in the extruder), lead to the loss of the crystal structure of starch molecules, and thus to the low formation of RS (*Neder-Suárez et al., 2016*). It can be concluded that the results of this study in terms of the influence of extrusion parameters on the resistant starch content are justified and meaningful.

CONCLUSION

Resistant starch has acquired very important characteristics in the human diet due to its positive effect on human health. Thus, there is an increasing trend to incorporate RS in processed foods. Due to the complexity of the extrusion process, it is very difficult to compare studies that use even the same raw materials, because the values depend on the type of extruder, input parameters, as well as the composition of the starch. In processed foods resistant starch formation is influenced by various factors, including temperature, screw speed, feed moisture, during the extrusion cooking process. In our study, according to Yoon's model, the highest impact on resistant starch was caused by the screw speed, as well as the feed moisture content, with approximately -35% and 35% of relative importance, while the chicory root content had lower relative importance of approximately 28%. Screw speed had the greatest negative influence, while the increased feed moisture had a positive effect on resistant starch content, as well as the share of chicory. High damage of granular structure and reduction of RS content occur due to shear forces and heat pressure. The highest

resistant starch content was observed (0.529 g/100g) during extrusion at a screw speed of 581.1 rpm, feed moisture of 21.2%, and chicory root content of 35.9%.

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