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EFFECT OF PROCESSING CONDITIONS AND CONCENTRATION OF WATER AND MILK SUSPENSIONS ON THE DYNAMIC VISCOSITY OF CORN-CRANBERRY GLUTEN-FREE INSTANT GRUELS

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A b s t r a c t. Selecting the parameters of the extrusion-cooking process makes it possible to produce various types of extrudates with a certain density, expansion, water absorption capacity, stickiness, etc. Porridges and gruels for children are products in a loose form, obtained from rice, corn, rye, oat, barley, buckwheat, millet or wheat flour, that can be produced with conventional drum-drying but also with the application of extrusion-cooking. The aim of the study was to evaluate the effect of dried cranberries addition level and processing conditions of instant corn-cranberry gruels on the dynamic viscosity of solutions with various concentrations and liquid medium used. The results showed that increasing content of cranberries in the recipe resulted in an increase of the dynamic viscosity value of extruded gruels suspensions. Increasing the screw speed during processing caused a decrease in the dynamic viscosity of extruded gruels in the case of aqueous suspensions tested at 40°C. Increasing viscosity along with the increase of screw speed was observed in all milk suspensions. Increasing the temperature of water and milk suspensions caused a decrease in the dynamic viscosity values of extruded corn-cranberry instant gruels. Higher values of dynamic viscosity were observed in the case of suspensions prepared with milk.

K e y w o r d s: extrusion-cooking, corn, cranberry, gluten-free, dynamic viscosity

INTRODUCTION

Porridges and gruels for children are products in a loose form, obtained from rice, corn, rye, oat, barley, buckwheat, millet or wheat flour. Products for children and babies are increasingly enriched with fruit or vegetable additives in the form of dried fruit, pulp or powder. Popular additives that enrich the taste and flavour include bananas, apples, pears, plums, peaches, raspberries, blueberries, apricots, cherries, grapes, oranges, strawberries, beets, etc. In addition, children's porridges

or instant gruels also contain vitamins, minerals, probiotics and prebiotics, and powdered milk, so they are valuable food for children (Kręcisz *et al.* 2017; Kręcisz 2016; Mościcki *et al.* 2007).

Cranberry is an evergreen, perennial low-stem shrub from the heath family (*Ericaceae*). Two of the four species of this plant are best known: cranberry (*Vaccinium oxycoccus*), growing in Poland in wetlands and swamps, and American cranberry (*Vaccinum macrocarpon*), growing in acidic areas of North America, Siberia and Europe. Cranberry fruits are small, spherical, with a smooth and thin skin. They are characterised by red or red-black colour and have a sour and tart flavour (Kręcisz *et al.* 2016). The unique chemical composition of the fruit gives the opportunity to produce a wide range of food, cosmetic, pharmaceutical and medicinal products. Cranberry has been known for centuries and used in medicine as a plant that supports the treatment of numerous diseases. Red fruits composition contains vitamins, mineral salts and numerous bioactive compounds that have a positive effect on the condition of the skin and for human health (Michalak *et al.* 2016). Cranberry is also a popular raw material used in the food industry for producers of syrups, juices, preserves, jams, drought and jelly. The constantly increasing knowledge about the positive impact of fruit and vegetable consumption, the greater demand for functional food, as well as the growing awareness of consumers encourage the food producers to search for attractive new products. New types of not-fried snacks prepared as dried fruit and vegetable slices or expanded by extrusion-cooking, microwave or hot-air heating are becoming more popular, especially those containing health-promoting ingredients (Camire *et al.* 2007, Wójtowicz *et al.* 2013, 2017, 2018).

The extrusion-cooking technique has simplified the process of heat treatment of raw materials associated with the production of instant gruels for children. The complete automation of the processing, and the elimination of direct staff contact during the production of food products, make it possible to maintain high hygienic-sanitary parameters which are important when manufacturing products for the youngest consumer group. By selecting the parameters of the extruder, it is possible to produce extrudates with a certain density, expansion, water absorption capacity, stickiness, etc. (Kręcisz 2016, Mościcki *et al.*, 2007). The most-used material in the extrusion-cooking process of gluten-free products is corn flour or grit, but it also gives the opportunity to use various raw materials, among others rice (Kręcisz *et al.* 2017), buckwheat (Gondek *et al.* 2013, Wójtowicz *et al.* 2013), amaranth (Gondek *et al.* 2013). The extrusion-cooking method gives many possibilities to modify and enrich the composition of food products with nutrients containing new raw materials or additives, and even wastes, i.e. bran, pits, skins or pomace (Makowska *et al.* 2015, Mościcki 2011). Numerous studies were carried out to improve the nutritional value of extrudates by adding bioactive ingredients to the basic raw

materials, such as acorn flour (Gondek *et al.* 2016), potato juice (Kowalczewski *et al.* 2012), extracts from legumes (Anuonye *et al.* 2010), dried berry fruits (Camire *et al.* 2007), purple potatoes (Nayak *et al.* 2011), tomatoes (Dehghan-Shoar *et al.* 2010, Wójtowicz *et al.* 2018), soy protein concentrate (Surówka *et al.* 2016) and other waste materials from agri-food processing (Stojceska *et al.* 2010).

The aim of the study was to evaluate the effect of fruit addition level and processing conditions of instant corn-cranberry gruels on dynamic viscosity of solutions with various concentrations and liquid medium used.

MATERIALS AND METHODS

The raw materials blends used for the tests were prepared by mixing corn grits (DASCA, distributor: Awiko, Lublin, Poland) with an addition of 1, 2, 3, 4 and 5% of dried cranberry fruits. Raw materials were ground to particle size lower than 1 mm before the extrusion. The blends were moistened up to 14%. The corn-cranberry blends were processed using a single-screw extruder TS-45 with L/D=12 (ZMCh Metalchem, Gliwice, Poland). The range of temperatures of the extrusion-cooking process was 125/130/135°C, respectively, in the three extruder sections. The process was carried out with various rotational screw speeds, at 80, 100 and 120 rpm. The die used had a single opening of 3 mm in diameter. The extrudates were dried in a laboratory shelf air dryer at 40°C for 24 hours and ground in the laboratory mill LMN10 (TestChem, Radlin, Poland) to obtain gruels with less than 1 mm in granularity.

Fig. 1. Testing machine Zwick BDO-FB0.5TH with mounted "back-extrusion cell" device

The dynamic viscosity tests of suspensions of extruded gruels with the addition of dried fruit were carried out using the Zwick/Roell BDO-FB0.5 TH universal testing machine (ZwickRoell GmbH, Ulm, Germany) equipped with a back extrusion chamber (Fig. 1). During the measurements, a Plexiglass chamber with a height of 60 mm and an internal diameter of 50 mm, and a cylindrical piston having 46 mm diameter and 20 mm of height were used. The dynamic viscosity was determined in two measuring cycles during the head distance on the 20 mm path in the up-down cycle. The mean dynamic viscosity was the average of the measurements in two cycles. The test speed of the first cycle was 50 mm min^{-1}, which resulted in a shear rate of 7.51 s^{-1}, while the speed of the second cycle was 100 mm min^{-1}, which gave a shear speed of 15.03 s^{-1} (Gujral *et al.* 2002, Klimek *et al.* 2014).The tests were carried out with water and milk (Mlekovita, UHT 3.2% fat) suspensions at 10 and 20% concentration and at two temperatures: 20 and 40°C. The weighed sample of the extrudate was combined with distilled water or milk at 20°C. In the case of measurements with warm water or milk, the weighed sample of the extrudate was combined with the liquid at an initial temperature of 70°C, which allowed to obtain the final temperature during the tests at 40°C. All extrudate samples were mixed with water or milk for 10 minutes to obtain a homogenous consistency. The results obtained during the double back extrusion tests were analysed using *testXpert II* 3.3. v.11 software determining the viscosity of individual measurements. Measurements were recorded 3 times.

As the statistical analysis, RSM (response surface methodology) was used for fitting polynomial models ($Y=b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{22}X_2^2$), where X_1 was the cranberry content (CC) and X_2 was the screw speed (SS) applied, and quadratic equations of tested characteristics depending on variables used in the experiment (Tab. 1).

Table 1. Adequacy of two-variable model fit to tested characteristics of instant corn-cranberry gruels

Parameters	Fitted models	R^2
WC 10	WC 10 = 0.10+0.09CC+0.01SS–0.02CC^2+0.0002CCSS–3.89E–5SS^2	0.36
WW 10	WW 10 = 0.23+0.15CC+7.76E–5SS–0.02CC^2–0.0003CCSS+1.34E–6SS^2	0.55
WC 20	WC 20 = –8.38+1.23CC+0.34SS–0.11CC^2+0.002CCSS–0.002SS^2	0.77
WW 20	WW 20 = 10.82+0.56CC–0.09SS–0.01CC^2+0.001CCSS+0.0004SS^2	0.88
MC 10	MC 10 = 1.03+0.22CC–0.01SS–0.01CC^2–0.001CCSS+0.0001SS^2	0.69
MW 10	MW 10 = 0.70–0.01CC–0.001SS+0.004CC^2+0.0001CCSS+1.48E–5SS^2	0.64
MC 20	MC 20 = 16.25+0.14CC–0.06SS–0.06CC^2+0.02CCSS+0.0002SS^2	0,84
MW 20	MW 20 = 9.58+0.17CC+0.03SS+0.08CC^2–0.001CCSS+7.58E–5SS^2	0.62

CC – cranberry content; SS – screw speed; 10 – suspension 10%; 20 – suspension 20%; WC– water cold; WW – water warm; MC – milk cold, MW – milk warm

The obtained results were tested with bidirectional ANOVA analysis of variance with interactions, and Tukey's test for comparison of means ($\alpha < 0.05$) was carried out with the Statistica software (Statistica version 10.0, USA). The first factor was cranberry content (CC) and the second was the screw speed (SS).

RESULTS AND DISCUSSION

The results of dynamic viscosity measurements of 10% suspensions of extruded gruels in cold or warm water, depending on the level of additive applied and variable screw speed during processing, are presented in Fig. 2a and 2b, respectively. The dynamic viscosity of extruded instant gruels ranged from 0.47 to 0.62 Pa s for suspensions with water at 20°C and from 0.36 to 0.49 Pa s for aqueous suspensions at 40°C, depending on the variables used. Increasing the water temperature caused a slight decrease in the value of dynamic viscosity.

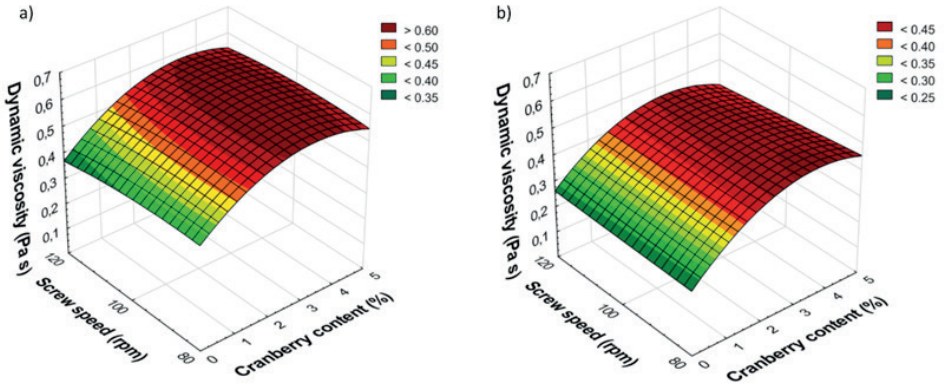

Fig. 2. Viscosity of 10% cold (a) and warm (b) suspension of extruded gruels with water in relation to cranberry content and screw speed applied

A similar dependence was shown by Klimek *et al.* (2014), examining extruded porridge made from corn. Analysing the results of viscosity measurements of suspensions with the participation of water at 20°C, an increase in dynamic viscosity was observed as the level of cranberries increased up to 2% at all screw speeds. Simultaneously, with further increase of the amount of the additive, a drop of dynamic viscosity was observed, especially at higher rotational speeds of the extruder screw. The value of dynamic viscosity was significantly ($p = 0.000$) influenced by the addition of cranberries; the rotational speed of the screw did not have any significant impact on the value of the tested parameter (Tab. 2). When analysing the measurements of extruded instant gruels at 40°C, it was observed that with increasing amount of fruit additive up to 4%, the average value of dynamic viscosity of

tested suspensions increased, while a further increase of cranberry addition, from 4 to 5%, caused a slight decrease in the value of the tested parameter. The rotational speed of the screw did not significantly affect the value of dynamic viscosity (Tab. 2). There was a tendency to lower the viscosity of tested suspensions at a temperature of 40°C along with the increase of screw speed during the production of extruded gruels with 4 and 5% cranberry supplementation.

Analysing the results of dynamic viscosity measurements of 20% water suspensions of extruded gruels at 20 and 40°C, depending on the content of cranberry and the variable screw speed used during processing (Fig. 3b and 3b, respectively), it was observed that the average value of dynamic viscosity increased significantly with the increasing amount of fruit additive (Tab. 2).

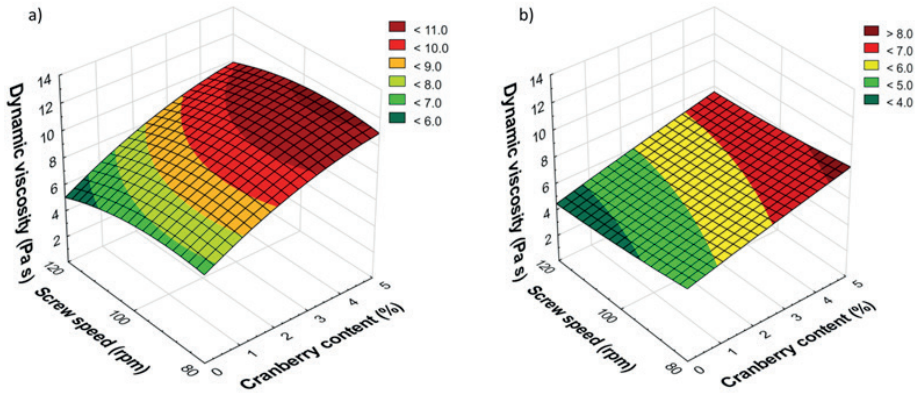

Fig. 3. Viscosity of 20% cold (a) and warm (b) suspension of instant grits with water in relation to cranberry content and screw speed applied

The values of the analysed parameter ranged from 6.19 to 11.00 Pa s for water suspensions at 20°C and from 5.19 to 8.21 Pa s at 40°C. Klimek *et al.* (2014), investigating extrudates made with corn, showed that the dynamic viscosity of 20% aqueous suspensions at 20°C was on average 18.18 Pa s, whereas at a higher temperature (40°C) the viscosity was 12.40 Pa s. Increasing the temperature of water caused a slight decrease in the value of the tested parameter, similarly as it was observed for aqueous suspensions with a concentration of 10%. The analysed results indicated that with increase of screw speed during the processing of instant gruels containing 1-3% of cranberry dried fruit the average viscosity value decreased, whereas in recipes with a higher fruit content an increase in the tested parameter for the 20°C test was observed. The tests results showed a decrease in the mean value of dynamic viscosity with the increase of the screw speed for samples tested at temperature of 40°C.

During the tests, it was found that the value of dynamic viscosity of 10% milk-gruels slurries at 20°C was on the average level of 0.83-1.17 Pa s, depending on the process parameters used and the cranberry content (Fig. 4a). The lowest dynamic viscosity was determined during the back-extrusion tests of extrudates with 1% cranberry content processed at a 80 rpm screw speed. The highest value of the tested parameter was determined when blends with 3 and 4% of cranberry additive were processed at 120 rpm screw speed. The results showed both a significant impact of the screw speed applied and of the content of cranberry on the value of dynamic viscosity (Tab. 2); increased speed and amount of fruit resulted in a higher viscosity during back extrusion tests. Analysing the results of dynamic viscosity measurements of 10% suspensions of extruded gruels in warm milk it was noted that with increasing amount of fruit additive the average value of dynamic viscosity of obtained suspensions increased (Fig. 4b).

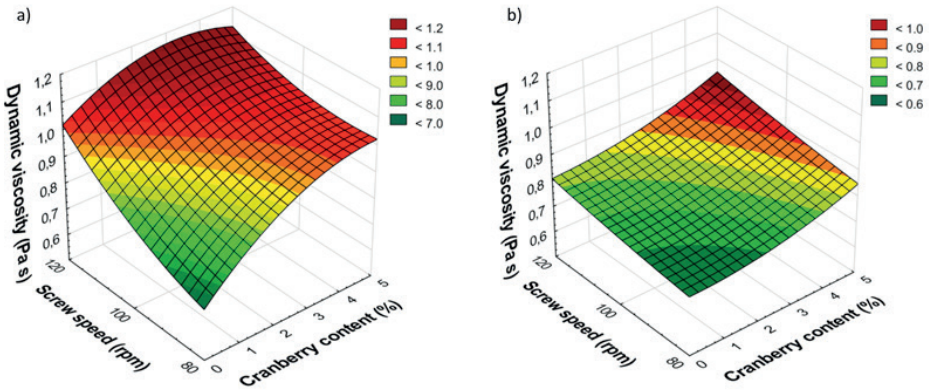

Fig. 4. Viscosity of 10% cold (a) and warm (b) suspension of corn grits with milk in relation to cranberry content and screw speed applied

The values of the analysed parameter ranged from 0.72 to 0.96 Pa s. Also in this case, the results showed a significant impact of the screw speed on the value of dynamic viscosity; increased speed during processing resulted in a higher viscosity of milk suspensions with corn-cranberry gruels. Increasing the temperature of milky suspensions caused a decrease in the dynamic viscosity of extrudates. A similar dependence was shown by Klimek *et al.* (2014) by examining extrudates made from corn.

Fig. 5a presents the results of dynamic viscosity tests, at 20°C, of 20% milk slurries of extrudates produced from corn-cranberry blends at variable screw speed and various amount of dried fruit. The statistical analysis showed a significant effect of the screw speed on the tested parameter (Tab. 2). The increase of the dynamic viscosity value was related to the increase of the rotational speed of the extruder screw, as it was observed for 10% milk-gruel slurries at the same temperature. The highest

values of the tested parameter (20.96 Pa s) were found in the case of recipes with cranberry content of 5% in extrudates processed at 120 rpm. Analysing the results of dynamic viscosity measurements of 20% milk slurries at 40°C, depending on the amount of cranberry fruit added in the recipe and on variable screw rotations used during their production, it was noted that increasing the cranberry content in the mixture increased the average value of dynamic viscosity of obtained suspensions. When increasing the screw speed during processing, an increase of the dynamic viscosity value of the extrudates was observed (Fig. 5b). The mean viscosity values determined during the study of corn gruels with various content of cranberry fruit ranged from 12.58 to 16.71 Pa s.

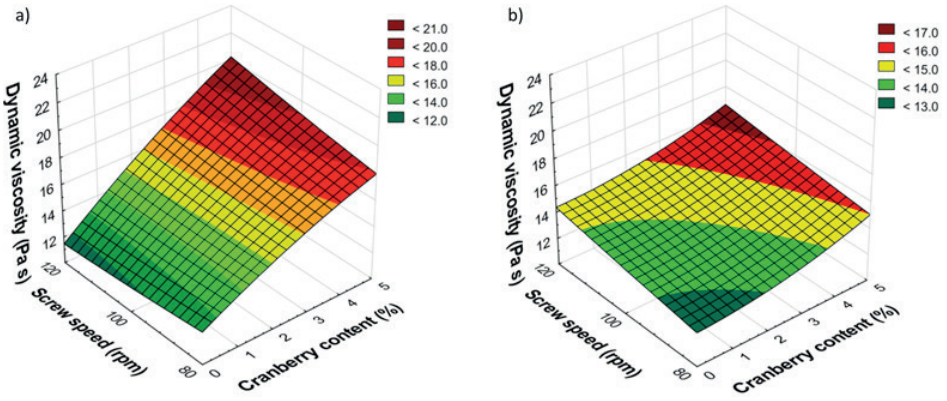

Fig. 5. Viscosity of 20% cold (a) and warm (b) suspension of corn grits with milk in relation to cranberry content and screw speed applied

The study showed that increasing the milk temperature of 20% suspensions of extruded corn-cranberry instant gruels resulted in a decrease in the value of the tested parameter. Klimek *et al.* (2014), examining extrudates made from corn with initial moisture content of 13% at extruder screw speed of 120 rpm, showed that the dynamic viscosity of 20% milk slurries at 20°C was higher (30.26 Pa s) than tested at 40°C (18.91 Pa s). In the present study, the addition of dried fruits increased the viscosity of extrudates slurries as compared to the corn ones.

Lower viscosity of instant gruels enriched with dried cranberry powder was related to the ability of gel formation of extruded gruels as reported by Kręcisz and Wójtowicz (2017b). They found that the volumetric gel index VGI values increased with increasing amount of fruits in the recipe. This is connected with the presence of pectins in various berries, which improves the absorption characteristics of instant gruels fortified with cranberries. In tested instant corn-cranberry gruels a lower impact of screw speed on the gel formation ability was observed (Kręcisz and Wójtowicz 2017b), which is also confirmed in the present work. Presented

results of dynamic viscosity also showed a lower impact of screw speed (lower values of F test) if water was used as liquid phase for slurries (Tab. 2). Kręcisz *et al.* (2018) reported also a lowering of water solubility index of extruded corn-cranberry instant gruels with increasing level of fruit additive, but the effects of increasing amount of additive and screw speed applied during processing were not significant.

Table 2. Analysis of variance and effect of variable process parameters and their interactions on selected characteristics of corn-cranberry instant gruels

SV	Sum of squares	df	Mean square	F test	p	Sum of squares	df	Mean square	F test	p
	Suspension 10%					Suspension 20%				
					WC					
CC	0.072	4	0.018	8.063	0.000	66.963	4	16.741	47.172	0.000
SS	0.004	2	0.002	1.004	0.378	17.357	2	8.679	24.454	0.000
CCxSS	0.021	8	0.003	1.156	0.357	5.624	8	0.703	1.981	0.084
Error	0.067	30	0.002			10.647	30	0.355		
					WW					
CC	0.065	4	0.016	9.483	0.000	33.764	4	8.441	83.301	0.000
SS	0.005	2	0.002	1.359	0.272	6.176	2	3.088	30.473	0.000
CCxSS	0.010	8	0.001	0.754	0.645	0.471	8	0.059	0.582	0.788
Error	0.051	30	0.002			3.039	30	0.101		
					MC					
CC	0.129	4	0.032	6.718	0.001	170.530	4	42.632	52.576	0.000
SS	0.298	2	0.149	30.869	0.000	7.218	2	3.609	4.451	0.020
CCxSS	0.059	8	0.007	1.516	0.193	10.848	8	1.356	1.672	0.147
Error	0.145	30	0.005			24.326	30	0.811		
					MW					
CC	0.108	4	0.027	13.052	0.000	30.059	4	7.515	8.2238	0.000
SS	0.069	2	0.035	16.787	0.000	21.868	2	10.934	11.965	0.000
CCxSS	0.008	8	0.001	0.465	0.871	2.379	8	0.297	0.325	0.949
Error	0.061	30	0.002			27.414	30	0.914		

SV – source of variation; df – degrees of freedom; p – probability value; CC – cranberry content; SS – screw speed; WC– water cold; WW – water warm; MC – milk cold, MW – milk warm

CONCLUSIONS

Application of the extrusion-cooking process using a single screw extruder allowed to obtain instant corn gruels enriched with the addition of cranberry fruit. On the basis of the conducted research and the analysis of the results, the following conclusions have been made:

1. Increasing content of cranberries in the recipe resulted in an increase of the dynamic viscosity value of suspensions of extruded gruels.

2. Increasing the screw speed during processing caused a decrease in the dynamic viscosity of extruded gruels in the case of aqueous suspensions tested at 40°C. Increasing viscosity along with the increase in screw speed was observed in all milk suspensions.

3. Increasing the temperature of water and milk suspensions caused a decrease in the dynamic viscosity value of extruded corn-cranberry instant gruels.

4. Higher values of dynamic viscosity were observed in the case of suspensions prepared with milk.

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WPŁYW WARUNKÓW WYTWARZANIA ORAZ STĘŻENIA WODNYCH I MLECZNYCH ROZTWORÓW NA LEPKOŚĆ DYNAMICZNĄ BEZGLUTENOWYCH KLEIKÓW KUKURYDZIANO-ŻURAWINOWYCH

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S t r e s z c z e n i e. Wybór parametrów ekstruzji umożliwia wytwarzanie różnych typów ekstrudatów o określonej gęstości, porowatości, zdolności pochłaniania wody, kleistości, itp. Kaszki i kleiki dla dzieci to produkty sypkie, które są otrzymywane na bazie ryżu, kukurydzy, owsa, jęczmienia, gryki, prosa, pszenicy lub żyta, przy użyciu konwencjonalnego suszenia bębnowego, ale także przy zastosowaniu techniki ekstruzji. Celem badań była ocena wpływu poziomu dodatku suszonych owoców żurawiny (1-5%) i warunków wytwarzania (80-120 obrotów ślimaka na minutę) błyskawicznych kaszek kukurydziano-żurawinowych na lepkość dynamiczną roztworów o różnych stężeniach (10 i 20%) przy różnej temperaturze (20 i 40°C) kleików z wodą i z mlekiem. Wyniki badań wykazały, że zwiększanie udziału żurawiny w recepturze spowodowało wzrost wartości lepkości dynamicznej zawiesin ekstrudowanych kleików. Zwiększenie obrotów ślimaka podczas obróbki spowodowało obniżenie lepkości dynamicznej ekstrudowanych kleików w przypadku wodnych zawiesin testowanych w temperaturze 40°C. Zwiększenie lepkości wraz ze wzrostem obrotów ślimaka zaobserwowano we wszystkich badanych zawiesinach mlecznych. Zwiększenie temperatury wody oraz mleka podczas testów spowodowało obniżenie lepkości dynamicznej ekstrudowanych błyskawicznych kleików kukurydziano-żurawinowych. Wyższe wartości lepkości dynamicznej obserwowano w przypadku zawiesin kleików bezglutenowych przygotowanych z mlekiem.

S ł o w a k l u c z o w e: ekstruzja, kukurydza, żurawina, produkty bezglutenowe, lepkość dynamiczna