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EFFECT OF DIE HOLE DIAMETER IN THE EXTRUDER ON ENERGY CONSUMPTION AND QUALITY INDICES OF MAIZE-BUCKWHEAT EXTRUDATE

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Key words: extruder, die hole, buckwheat

There are presented results of investigations on the effect of die hole diameter in the extruder on energy consumption and extrudate quality indices: volumetric expansion ratio, water absorption index (WAI), and water solubility index (WSI).

A mixture of maize and buckwheat grit was extruded in a single-screw extruder KZM-2 equipped with two exchangeable dies of various outlet holes: 12 and 14 mm. The content of buckwheat grit in the mixture was adjusted to: 15, 30, 45, 60, and 100%.

It was found that a decrease in the die hole diameter caused an increase in specific energy consumption of the process, but also an improvement in quality indices of the extrudate (expansion ratio, WAI and WSI), possibly due to increased residence time of raw material inside the extruder and better mixing inside the machine.

INTRODUCTION

Thermal and mechanical processing with the use of extruders has been commonly applied for the improvement of plant products used in the food industry. The products obtained in this way are of good nutritional properties, achieved by combining the heat treatment and mechanical stresses to change the internal structure of the material. The strong mechanical effects are achieved by intensive material mixing inside the extruder and substantial expansion of the material leaving extruder's die. Expansion is one of the main parameters determining the extrudate's quality, influenced by the composition of the mixture subjected to extrusion, and by technological parameters of the process: temperature or geometry of extruder's working units. The diameter of die holes is a key parameter affecting the product's expansion. It is known from numerous references that a decrease in die hole diameter causes an increase in material expansion [van Zuilichem *et al*., 1975; Hayter *et al*., 1986]. Other investigations [Harper & Tribelhorn, 1992; Sokhey *et al*., 1997] proved the effect of hole geometry on expansion indices (LEI, SEI, VEI), however, it was found also that an increase in hole length resulted in a reduction of VEI, a decrease in LEI and an increase in SEI.

Most of the published investigations were carried out with homogeneous materials, mainly maize grit or ground grain [Arhaliass *et al*., 2003], wheat flour [Bouzaza *et al*., 1996] or sometimes maize starch. Substantial interests in functional food enhance the introduction of raw materials of a high nutritional value to typical maize mixtures. One of such additions is buckwheat of valuable properties [Krasakova & Mrazova, 2004], which becomes popular not only in Poland but all over the world. Buckwheat can be easily extruded, however, to obtain the product acceptable by customers it is essential to achieve the proper expansion ratio of extrudate and several desired textural properties.

The work was aimed at investigating the effect of die hole diameter on selected quality indices of extrudate: expansion ratio, solubility, water absorption and specific energy consumption.

MATERIAL AND METHODS

There was used a single-screw extruder KZM-2 of screw speed n=200 rpm and screw length to diameter ratio of L/D=6.5. Investigations were carried out with exchangeable dies of various outlet holes: 12 and 14 mm. The extruder was equipped with heating elements of 3000 W, enabling to maintain a constant temperature of the extrusion process equal to 120°C. There was extruded a mixture of maize ground grain and buckwheat grit of moisture content 15% and various contents of buckwheat grit: 15, 30, 45, 60 and 100%.

The volumetric expansion ratio was determined with Alvarez-Martinez method [1988], while water solubility index (WSI) and water absorption index were determined with Andersson method [1969]. The method included careful mixing the comminuted extrudate (mass of 2.5 g and particle size of 180-250 μm) with 25 mL of distilled water. The excess of water was separated in a centrifuge at 3000 rpm during 10 min, then the sample was weighed and dried at 105°C.

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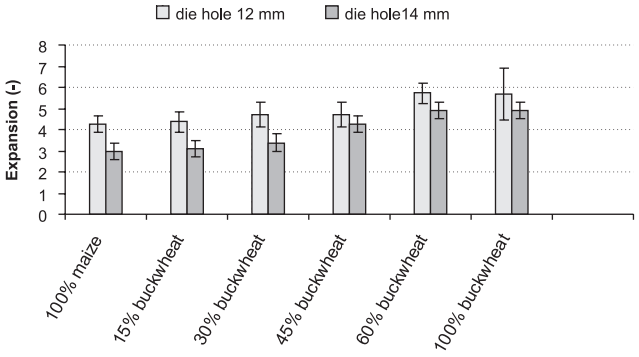

FIGURE 1. Effect of die outlet hole diameter on expansion ratio of maize--buckwheat extrudate.

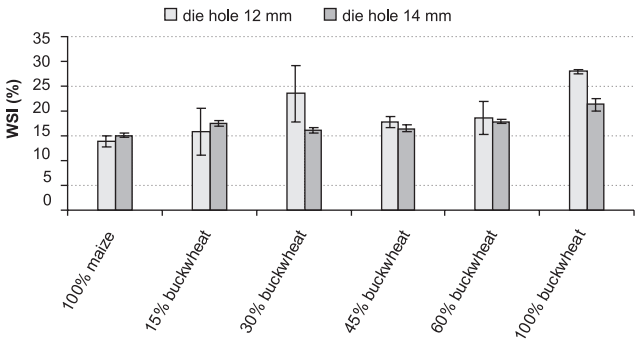

FIGURE 3. Effect of die outlet hole diameter on water solubility index (WSI) of maize-buckwheat extrudate.

The investigated indices were calculated as follows:

WAI =weight of sediment/weight of dry solids
WSI(%) = weight of dissolved solids/ weight of dry solids

The extrudate density was determined by the modified displacement method [Ekielski & Osiak, 2003] and volumetric expansion ratio was calculated according to Alvarez-Martinez [1988].

The mechanical strength of extrudate was measured with the use of Instron 4301 equipped with a knife head. The results of particular tests were recorded in a computer with the use of Lab. Instron program.

The obtained results were subjected to a statistical analysis with ANOVA module for the main effects in Statistica 6.0 program. The effect of buckwheat addition on quality indices of extrudate at various die hole diameters was determined. The mean values of quality indices were taken as an estimator: expansion, WAI, WSI and energy consumption, at a significance level of $p<0.05$. The following hypothesis was advanced: H_0 – the die outlet hole diameter does not influence the above-mentioned quality indices during extrusion of maize-buckwheat mixtures.

RESULTS

Volumetric expansion ratio

Based on the obtained results, the hypothesis H_0 (at a significance level of 0.00 and 0.00) on the lack of the effect of die hole diameter on volumetric expansion ratio can be rejected, therefore, there is a statistically significant dependence between these factors. In measurements (Figure 1) there was found an increase in the expansion ratio for both die hole diameters: 12 and 14 mm, when buckwheat content was increased. The highest value of this coefficient (5.6 at buckwheat content of 80%) was found for die hole of 12 mm.

Texture – mechanical strength

The results of Anova test allow also for the rejection of the hypothesis H_0 on the lack of the effect of die outlet hole diameter on mechanical strength index at a significance level of 0.00 and 0.18. This means that the hole diameter affects significantly the investigated index. The highest value of extrudate mechanical strength (Figure 2) was found for the maize content of 100% (0.15 J/mm^2 for hole diameter of 14 mm and 0.07 J/mm^2 for hole diameter of 12 mm). No statistically significant effect of buckwheat content in the mixture on mechanical strength was found in the study (Table 1).

Water solubility index (WSI) and water absorption index (WAI)

The hypothesis H_0 on the lack of the effect of die hole diameter on water solubility index (WSI) can not be rejected, therefore, there is no statistically significant dependence between these factors. However, the hypothesis H_0 for water absorption index (WAI) can be rejected at a significance level of 0.00 and 0.0088. The buckwheat content influences significantly the values of both indices (WSI and WAI). The highest

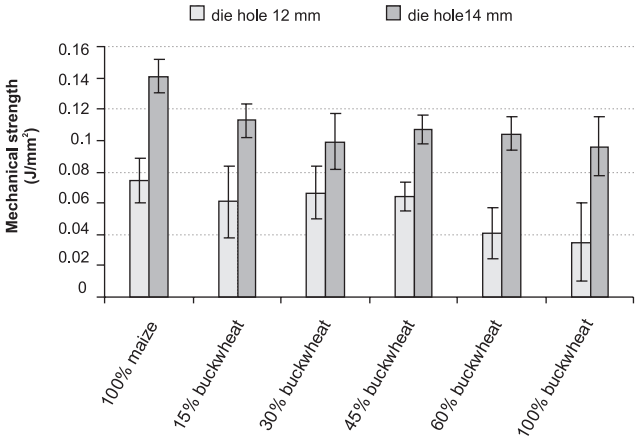

FIGURE 2. Effect of die outlet hole diameter on mechanical strength index of maize-buckwheat extrudate.

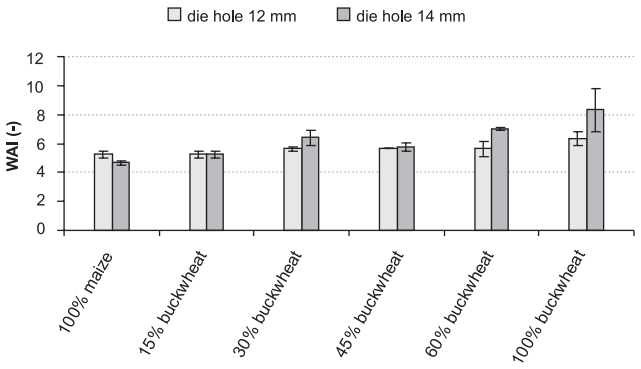

FIGURE 4. Effect of die outlet hole diameter on water absorption index (WAI) of maize-buckwheat extrudate.

TABLE 1. Results of Anova test for die outlet hole diameter on energy consumption and quality indices of maize-buckwheat extrudate.

Effect	One-way Analysis of Variance Sigma-limitation parameters Effective hypothesis decomposition				
	SS	Degree of freedom	MS	F	p
Expansion					
Free term	1302.042	1	1302.042	4584.234	0.000000
Buckwheat content (%)	21.830	5	4.366	15.372	0.000000
Die hole	26.049	1	26.049	91.713	0.000000
WAI					
Free term	472.7405	1	472.7405	3145.247	0.000000
Buckwheat content (%)	2.8694	5	0.5739	3.818	0.008855
Die hole	4.0333	1	4.0333	26.835	0.000015
WSI					
Free term	4826.248	1	4826.248	387.3936	0.000000
Buckwheat content (%)	279.228	5	55.846	4.4826	0.003789
Die hole*	19.006	1	19.006	1.5256	0.226693
Mechanical strength					
Free term	0.225448	1	0.225448	383.1224	0.000000
Buckwheat content (%)*	0.002922	1	0.002922	4.9656	0.030122
Die hole	0.004582	5	0.000916	1.5572	0.188237
Energy consumption					
Free term	0.444083	1	0.444083	3380.162	0.000000
Buckwheat content (%)	0.003990	5	0.000798	6.074	0.000579
Die hole	0.004083	1	0.004083	31.080	0.000005

* values of statistical index are not significant at $p<0.05$

WSI values (max. 27%) were found for die hole of 12 mm, while for WAI the highest values were found for die hole of 14 mm (Figures 3 and 4).

Energy consumption

The hypothesis H_0 on the lack of the effect of die hole diameter on energy consumption can be rejected, therefore, there is a statistically significant dependence between these factors. Only a small increase in energy consumption was found with an increased buckwheat content; the highest value of energy consumption occurred at 100% buckwheat content for die hole diameter of 12 mm (Figure 5).

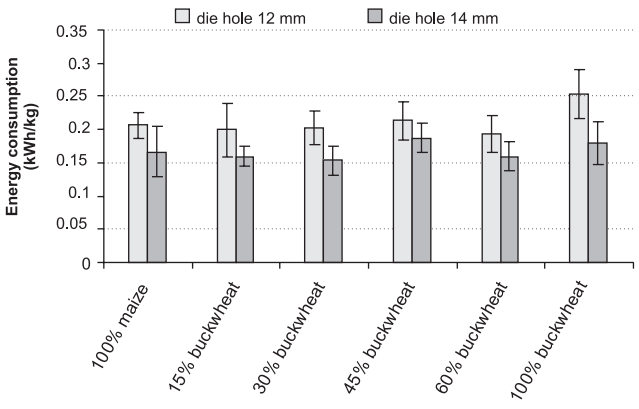

FIGURE 5. Effect of die outlet hole diameter on electrical energy consumption during extrusion of maize-buckwheat mixtures.

SUMMARY AND CONCLUSIONS

Extrusion has been known for many years, however the process itself has not been precisely investigated, and undertaken attempts of extrusion of new products meet a series of problems connected with improper selection of die hole diameter, screw selection, *etc*. Therefore, this calls for execution of more precise investigations on extrusion of various grain mixtures at different die hole diameter, its length or angle.

Based on the carried out investigations one can find that changes in hole diameter affect significantly all the investigated quality indices of maize-buckwheat extrudate, with the exception of water solubility index (WSI).

It was found that buckwheat content had no significant effect on mechanical strength of extrudate obtained at two die holes used, while a significant effect was observed in the case of die hole diameter. The mechanical strength increased even by 50%, when the die hole of 14 mm was used. An increase in die hole diameter caused a decrease in electrical energy consumption (even by 0.07 kWh/kg during extrusion of pure buckwheat). At the same time, a small increase in energy consumption was found at the increased buckwheat content in the mixture.

The highest energy consumption occurred during extrusion of 100% of buckwheat with die hole diameter of 14 mm.

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WPŁYW ŚREDNICY OTWORU MATRYCY EKSTRUDERA NA ZUŻYCIE ENERGII I WSKAŹNIKI JAKOŚCIOWE EKSTRUDATU KUKURYDZIANO–GRYCZANEGO

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W badaniach przedstawiono wpływ średnicy otworu w matrycy ekstrudera na jednostkowe zużycie energii i wybrane wskaźniki jakościowe ekstrudatu gryczano-kukurydzianego. Wskaźnikami, które oznaczano były: objętościowy współczynnik ekspansji (VEI), współczynnik wodochłonności (WAI), rozpuszczalność (WSI), wytrzymałość mechaniczna. Badania przeprowadzono w ekstruderze KZM-2 wyposażonym w dwie wymienne matryce o średnicy otworów odpowiednio 12 i 14 mm. Przygotowane mieszanki zawierały następującą zawartość gryki w stosunku do kukurydzy: 15, 30, 45, 60 i 100%. Ekstruzję przeprowadzano w temperaturze 120°C, wilgotność materiału wynosiła 15%.

Analiza wyników badań potwierdziła, że zmniejszenie średnicy otworu matrycy powoduje zwiększenie jednostkowego zużycia energii w czasie procesu, ale również zwiększenie wartości wskaźników jakościowych ekstrudatu (współczynnik ekspansji, WAI, WSI). Było to spowodowane wydłużeniem czasu przebywania surowca wewnątrz ekstrudera i lepszą wymianą ciepła pomiędzy cząsteczkami podawanego materiału.