



ENERGY CONSUMPTION DURING PRODUCTION OF CORN EXTRUDATES IN RELATION TO THE PROCESS PARAMETERS

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ABSTRACT

The objective of the paper was to determine the impact of the rotational screw speed and the level of moisture of raw material on the efficiency and energy consumption of the extrusion-cooking process. Measurement of the extrusion-cooking process efficiency (Q) was carried out through determination of the extrudates mass and energy consumption was determined with the use of a specific mechanical energy (SME). Based on the research results it was found out that the factor which significantly decides on the measured values was a rotational screw speed. Along with the increase of this parameter the energy consumption and extrusion-cooking process efficiency increased during processing of corn grits. Extrusion-cooking process efficiency depended also on the level of moisture of raw material. At lower moisture of raw material the efficiency decreased along with the increase of the screw speed and above 18% of the moisture level it increased. Reverse relation was reported during testing the energy consumption of the extrusion-cooking process.

Introduction

Due to the present lifestyle, which is characterized by easy food consumption, which does not require a long time of preparation, gruels and mush for children are the most popular products for which modern parents are increasingly looking (Wójtowicz, 2008a).

The extrusion-cooking process, in brief, is processing of powdered material under high pressure and high temperature (Combrzyński et al., 2016, Oniszczyk et al., 2006). Extrusion-cooking is one of several methods used for production of baby foods. This special process has many advantages, i.a., deactivation of some anti-nutritional factors such as trypsin and protease inhibitors as a result of which products prove higher digestibility. Due to the applied pressure and thermal treatment extruded products do not need to be cooked later. An entirely automated production line allows ensuring high hygienic and sanitary standards, which is significant at the production of this type of products (Ekielski et al., 2013; Mościcki et al., 2007; Mouquet et al., 2003; Wójtowicz, 2008a). Baby food is in the form of powdered products obtained from corn, rice, wheat, oat or buckwheat flour. Corn is the most popular raw material used in the extrusion-cooking process. These kinds of products are often enriched with dried fruits, powdered milk, vitamins and mineral components,

to provide balanced and nutritious baby food (Ramirez-Jimenez et al., 2003; Naz et al., 2005; Wójtowicz, 2008a; Jurga, 2011).

Scope and objective of the paper

The objective of the paper was to assess the impact of rotational screw speed and the level of raw material moisture on the selected exploitation parameters of the extrusion-cooking process of instant corn gruels.

The scope of the paper included production of corn extrudates and determination of the impact of the selected process parameters on the energy consumption and process efficiency of instant corn gruels.

Research methods

Research material was in the form of commercial corn grit (Radix-Bis, Rotmanka, Poland) with the moisture of 11%. Raw material was moistened to the varied level of moisture (W): 12, 14, 16, 18, 20, 22% and processed with the extrusion-cooking treatment using a single screw extruder TS-45 (ZMCh Metalchem, Gliwice, Poland) with L:D=12:1. A screw with the compression degree of 3:1 and one forming die with the opening diameter of 3 mm were applied. Extrusion-cooking was carried out at the temperatures of 120/130/135°C in particular barrel sections at variable screw rotations (n) which were 60, 80, 100, 120 (rpm).

Moisture of raw material mixtures was determined with the drying method with the use of a laboratory drier according to PN-A-888034 (1998). Measurements of the process efficiency (Q) were carried out through determination of the extrudates mass within the specified time for all samples. Measurements were carried out in 5 replications, as the final result the average from measurements was assumed. Efficiency was expressed in $\text{kg}\cdot\text{h}^{-1}$ according to the formula:

$$Q = \frac{m}{t} \text{ (kg h}^{-1}\text{)} \quad (1)$$

where:

- Q – process efficiency,
- m – mass of extrudates obtained during the measurement, (kg)
- t – measurement time, (h)

The power consumption was recorded with the use of a standard wattmeter connected to the drive unit of the extruder. Having regard to the TS-45 extruder characteristic, the engine load and the process efficiency were determined, and the obtained values were calculated into specific energy consumption (Ryu et al., 2011, Mitrus and Combrzyński 2013, Wójtowicz, 2008b):

$$SME = \frac{n \cdot P \cdot O}{n_m \cdot 100 \cdot Q} \text{ (kWh kg}^{-1}\text{)}, \quad (2)$$

where:

- SME – specific mechanical energy,
- n – screw rotations, (rpm)
- n_m – maximum screw rotations, (rpm)

Energy consumption...

- P – electric power, (kW)
 O – engine load, (%)
 Q – efficiency, ($\text{kg}\cdot\text{h}^{-1}$)

Statistical analysis of the obtained results with the use of Statistica 10.0 program (StatSoft, Polska) was carried out.

Results and discussion

Efficiency of the extrusion-cooking process of corn gruels varied from 11.4 to 32.16 ($\text{kg}\cdot\text{h}^{-1}$), in relation to the applied parameters. The highest process efficiency was observed during processing of mixture with the moisture of 14% at the screw rotations of 120 (rpm). The lowest values of efficiency were reported during processing at the highest level of moisture of raw materials and screw speed of 60 (rpm).

The tests proved that the rotational screw speed has a significant impact on the process efficiency. The value of the investigated parameter increased along with the increase of the rotational speed of the extruder screw. During the research it was found out that the efficiency of the extrusion-cooking process initially increased with the increase of the moisture level up to 16%, and afterwards it decreased with the use of raw materials with a higher level of moisture (Fig. 1). A similar relation was proved by Rzedzicki and Kasprzak (2004) during extrusion of corn – grass pea mixtures where the increase of the moistening level of raw materials mixtures caused decrease of the extrusion-cooking process capacity. Trela and Mościcki (2007) reported in their research a similar relation where along with the increase of the rotational screw speed, the process efficiency increased (corn, wheat and rice flour were processed with the extrusion-cooking).

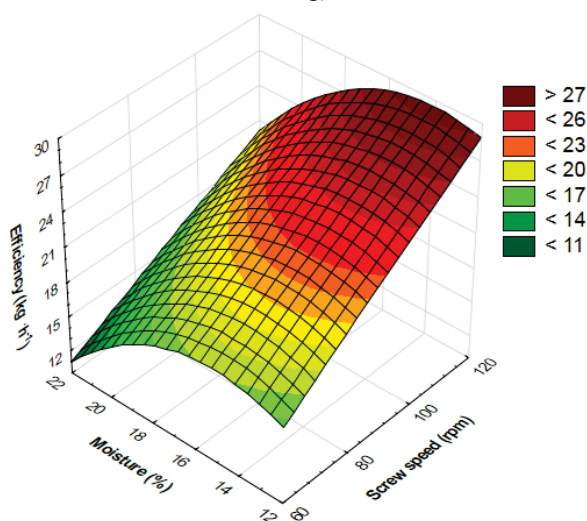


Figure 1. Efficiency of the extrusion-cooking process of instant corn gruels in relation to the rotational screw speed and the level of raw material moisture

During the research it was found out that the value of *SME* determined as an electric energy input needed to obtain 1 kg of product was at the level of 0.072-0.246 kWh·kg⁻¹ (259.2-885.6 kJ·kg⁻¹) in relation to the applied process parameters. The lowest energy consumption was determined during extrusion-cooking of corn grits with the level of raw material moisture of 14 and 16% treated at the rotational screw speed of 60 (rpm). The highest energy consumption was determined during treatment of raw materials moistened to 20 and 22% and at the level of 120 (rpm) extruder's screw speed.

The research proved a significant impact of the extruder's screw rotational speed on the *SME* value. The increase of rotations caused obtaining higher values of *SME* during the corn gruels extrusion-cooking process. A similar relation was observed by Wójtowicz and Juško (2012) during processing of wheat flour and spelt flour with single screw extruder.

Moreover, an impact of raw materials' moisture on the energy consumption during processing was reported. At lower initial moisture of raw materials mixture, i.e. 12 and 16% along with the increase of screw speed the values of tested parameter decreased. On the other hand, from moisture of 18% a slight increase of *SME* was reported (fig. 2).

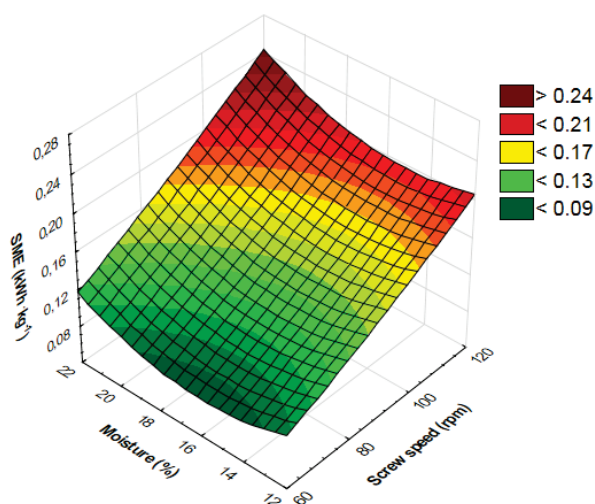


Figure 2. Energy consumption of the extrusion-cooking process of instant gruels in relation to the rotational screw speed and the level of raw material moisture

The obtained results of measurements were subjected to two-way analysis of variance carried out using Statistica software. The first factor was the moisture of raw material mixture (*W*), and the second was the rotational screw speed (*n*). Analysis of variance was performed for each factor separately and for their interactions. The obtained results were presented in tables 1 and 2. Moreover, regression equations and correlations coefficients were evaluated (Table 3).

Energy consumption...

Table 1.
Analysis of variance of the extrusion-cooking process efficiency

Source of variability	Degrees of freedom	Sum of squares	Mean square	F Value	Critical level
Moisture (W)	5	806.1216	161.2243	2450.22	<0.0001
Screw speed (n)	3	1142.5920	380.8640	5788.21	<0.0001
Moisture-Screw speed ($W \cdot n$)	15	39.7056	2.6470	40.23	<0.0001
Error	48	3.1584	0.0658		

Table 2.
Analysis of variance of the SME of the extrusion-cooking process

Source of variability	Degrees of freedom	Sum of squares	Mean square	Value F	Critical level
Moisture (W)	5	0.0199	0.0040	1171.6	<0.0001
Screw speed (n)	3	0.1399	0.0466	13723.1	<0.0001
Moisture-Screw speed ($W \cdot n$)	15	0.0027	0.0002	53.3	<0.0001
Error	48	0.001	0.0000		

Table 3.
Regression equations describing the changes in process efficiency and energy consumption in relation to moisture content and screw speed applied

	Moisture (%)	Regression equations	R^2
Efficiency	12	$Q = 0.84 n^2 - 0.072 n + 15$	0.999
	14	$Q = 0.24 n^2 + 2.352 n + 18.68$	0.999
	16	$Q = -0.12 n^2 + 4.536 n + 13.92$	0.998
	18	$Q = -0.04 n^2 + 3.912 n + 11.08$	0.992
	20	$Q = -0.24 n^2 + 4.128 n + 9.24$	0.987
	22	$Q = -0.84 n^2 + 7.32 n + 4.92$	0.994
SME	12	$SME = -0.0045 n^2 + 0.0603 n + 0.0413$	0.999
	14	$SME = 0.0011 n^2 + 0.0323 n + 0.0385$	1.000
	16	$SME = 0.0006 n^2 + 0.0338 n + 0.044$	0.999
	18	$SME = 0.0008 n^2 + 0.0323 n + 0.0596$	0.989
	20	$SME = 0.0042 n^2 + 0.0245 n + 0.0758$	0.996
	22	$SME = 0.009 n^2 - 0.0026 n + 0.1103$	0.991

Results of the analysis of variance set in tables 1 and 2 prove that significant impact of varied conditions of the extrusion-cooking process on the results of process efficiency and energy consumption during instant corn gruels production at the assumed confidence interval of 95% was reported. It was noted that both the applied level of raw materials moisture and varied rotational screw speed influenced on the efficiency and energy consumption of the extrusion-cooking process.

High values of correlation coefficients (R^2) prove a significant impact of the screw speed and the level of moisture of raw material mixture both on the efficiency and energy consumption of the extrusion-cooking process (table 3).

Conclusion

The analysis of the obtained results allowed creating the following conclusions:

1. The increase of the screw rotational speed influenced both the efficiency and energy consumption of the extrusion-cooking process of instant corn gruels. The increase of screw speed caused the increase of efficiency and *SME*.
2. The level of moisture content of raw materials influenced the value of the investigated parameters. Along with the increase of raw material moisture from 12 to 16% the decrease of *SME* and increase of the process efficiency was reported. On the other hand, above 18% of moisture increased energy consumption value and decreased process efficiency was reported.
3. Higher values of *F* parameter in the analysis of variance indicated a greater impact of the rotational screw speed on the efficiency of the extrusion-cooking process. Similar observations were made in the case of *SME* results analysis.

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ENERGOCHŁONNOŚĆ WYTWARZANIA EKSTRUDATÓW KUKURYDZIANYCH W ZALEŻNOŚCI OD PARAMETRÓW PROCESU

Streszczenie. Celem pracy było określenie wpływu prędkości obrotowej ślimaka oraz poziomu dowilżenia surowca na wydajność oraz energochłonność procesu ekstruzji błyskawicznych kaszek kukurydzianych. Pomiar wydajności procesu (Q) ekstruzji przeprowadzono poprzez określenie masy ekstrudatu oraz pomiar energochłonności wyznaczano wykorzystując wskaźnik jednostkowego zapotrzebowania energii mechanicznej (SME). Opierając się na wynikach badań stwierdzono, że czynnikiem istotnie decydującym o mierzonych wartościach była prędkość obrotowa ślimaka. Wraz ze zwiększeniem tego parametru wzrastała energochłonność oraz wydajności procesu ekstruzji. Wydajność procesu ekstruzji zależała również od poziomu dowilżenia mieszanki surowcowej. Przy niższych wilgotnościach surowców wydajność zmniejszała się wraz ze wzrostem prędkości obrotowej ślimaka, natomiast powyżej 18% dowilżenia wydajność procesu zwiększała się. Odwrotną zależność zaobserwowano podczas badania energochłonności procesu ekstruzji.

Słowa kluczowe: ekstruzja, kaszka kukurydziana, SME , wydajność