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EFFECT OF WHOLE WHEAT FLOUR MOISTENING AND EXTRUSION-COOKING SCREW SPEED ON THE SME PROCESS AND EXPANSION RATIO OF PRECOOKED PASTA PRODUCTS

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Summary. The paper presents the results of measurements of specific mechanical energy SME of extrusion-cooking process and expansion ratio of precooked pasta made from whole wheat flour. The different level of water addition to whole wheat flour was used due to the moisture content from 28 to 36%. Processing of whole wheat pasta products was performed on single-screw modified extrusion-cooker TS-45 with L/D = 18:1 using a differentiated screw speed 60, 80, 100 and 120 rpm. Pasta processing was carried out in the temperature range 80-100°C, shaping pasta in the form of threads by a forming die of 12 holes with a diameter of 0.8 mm. Depending on the screw rotations and the dough moisture content the process output and specific mechanical energy was determined and the expansion ratio of pasta was specified. The extrusion-cooking process output of whole wheat pasta products increased with the increase of the screw speed, increasing the moisture content of raw materials influenced on higher reduction of the process output. SME values ranged from 0.07 to 0.84 kWhkg^{-1} and were dependent on both the moisture content of raw materials and the screw speed rotations during the extrusion-cooking of pasta. Expansion ratio index of pasta increased with increased rpm applied during processing, the use of higher moisture content of raw materials affect the limiting expansion ratio of whole wheat precooked pasta products.

Key words: extrusion-cooking, precooked pasta, whole wheat flour, SME, expansion ratio

INTRODUCTION

Whole-grain products, whose popularity is still growing, improve the metabolism, reduce fat absorption by the human body and reduce the level of bad cholesterol in the blood. Whole-grain foods consumption may result in a decreased risk of cardiovascular disease and certain cancers, favorable effects on blood lipids and glucose, improved insulin resistance, and higher intakes of dietary fiber and micronutrients (Jacobs et al., 1998, Franz and Sampson, 2006, McKeown et al., 2002). The number of recommended servings of whole-grain foods per day was reported by Marquart et al. (2006) as 5 to 11 servings, but identification of whole-grain products by consumers was poor in the presented research data. Recommendations of the Food and Drug Administration confirm the need for the consumption of several food products, at least 3 servings a day, containing whole

grains in the form of cereal, bread, pasta, cakes and snacks (Slavin et al., 2001). Because of civilization diseases dietitians suggest to complement the diet of whole-grain products, which provide not only valuable for digestion fiber, but also because of the presence in wholemeal products of the large quantities of vitamins, particularly of B group, vitamin E and the macro- and micronutrients, like selenium, zinc, copper, magnesium (Schneeman, 1998, Slavin et al., 2001). Whole-grain foods also contain phytochemicals such as antioxidants, phenols, phytoestrogens and fermentable carbohydrates such as dietary fiber, resistant starch or oligocaccharides, which may be associated with cholesterol lowering, cardiovascular disease protection and cancer risk decreasing (Slavin et al., 2001). In light of the growing interest in the role of whole-grains in health and disease protection, and the paucity of whole-grain food consumption, new kinds of products are widely developed i.e. enriched breakfast cereals containing whole grains, bran or germs (Franz and Sampson, 2006).

For the technological reasons pasta products based on rich in fiber raw materials are difficult to process due to the large amount of fiber, so in many bakery and snacks products they are replaced by the functional fiber additives or resistant starch (Sozer et al., 2006). Whole-grain pasta may be the great complement to the diet reach in valuable nutrients (Olivier and Salvadori, 2006), and precooked pasta products based on whole-grain raw materials, not only enrich the human diet, but also shorten the preparation time of nutritious meal to a few minutes of hydration of the pasta in hot water before consumption.

Extrusion-cooking allows processing of precooked pasta with any additional processes (frying or steaming) from starchy and protein-rich raw materials, using appropriate process parameters such as temperature, allowing the starch gelatinization and the formation of a stabile finished products structure, and the screw speed of extrusion-cooking, which affect the pasta products expansion and time preparation for the consumption of precooked products (Wójtowicz, 2005, 2007, Wójtowicz and Mościcki, 2009, Yalla and Manthey, 2006). These variable process conditions can be used to obtain the desired characteristics of pasta products, which can be classified to a group of convenience food (Singh and Smith, 1997). Processing simplicity of this type of pasta does not require high energy dryers, water or steam bath or frying during processing (Huber, 1998, Wang et al., 1999). To obtain instant or precooked products within a short preparation time they should be characterized by thin dimension in the shape of spaghetti or thin-walls in the case of tube-type pastas.

The aim of this study was to determine the specific mechanical energy consumption, process output and influence of these parameters on expansion ratio index of precooked whole wheat pasta products processed with variable extrusion-cooking parameters: moisture content of raw materials and different speed screw.

MATERIALS AND METHODS

Investigations of process output and SME consumption were performed during the extrusion-cooking process of precooked whole wheat pasta. The extrusion-cooking was carried out on a modified single screw extrusion-cooker TS-45 (Metalchem, Gliwice, Poland) with an elongated barrel section (L / D = 18:1, compression ratio 3:1) with the closed circuit glycol cooling system just before the die. The use of screw equipped with an additional mixing element allows better mixing of the dough in the latter barrel section. The prepared dough was processed by thermal-shearing treatment at the temperature ranging from 80°C in the first barrel section, 100°C in plasticizing barrel zone and 65-70°C just before the die. Pasta products were shaped on the forming open die with 12 outlets 0.8 mm in diameter, 20 mm in depth. Differential screw speed at the level of 60, 80, 100 and 120 rpm was applied during the processing.

The raw material was commercial whole wheat flour (Lubella S.A., Lublin, Poland), protein content 13,7% (Kjeldahl method), ash – 1,37% (AACC 08-01), carbohydrates – 65,4, fat – 2,3%, fiber – 6,7% (producer's data). The moisture content of whole wheat flour, tested according to AACC 44-19 in an air oven (in the 135°C for 1 hr.), was 10.5%. Whole wheat flour was moistened for planned dough moisture content varying from 28 to 36% by addition of a proper amount of water at 20°C by small streams of water through nozzles and a precise mixing. After mixing, the prepared whole wheat dough was rested for about 0.5 hours to achieve the uniform moisture content in the dough mass.

During the extrusion-cooking of whole wheat pasta the process output was measured by products sampling for 10 minutes of regular production for each batch processed at different conditions. The measurements were registered three times.

Based on the data collected during multiple trials the energy requirement of extrusion-cooking process was set at different screw speed and with different initial moisture content of the raw material. Power consumption was measured using standard register connected to extruder's motor during processing of each recipe and screw speed used. After the consideration of motor load and process output ($kg \cdot h^{-1}$), the SME (specific mechanical energy) values ($kWh \cdot kg^{-1}$) were calculated according to the method described by Ryu and Ng (2001):

$$SME = \frac{\text{rpm (test)}}{\text{rpm (rated)}} \times \frac{\text{\% motor load}}{100} \times \frac{\text{motor power (rated)}}{\text{feed rate}}. \quad (1)$$

The expansion ratio index of precooked whole wheat pasta was designated as the ratio of the diameter of the pasta thread to a diameter of forming die holes (0.8 mm) (Wójtowicz, 2005, 2007). Measurements the diameters of pasta were performed with a caliper with digital display with an accuracy of 0.01 mm. The measurements were made in 15 replications, as the final result the average of the measurements was taken into account.

The minimum time of preparation for consumption by pasta hydration in hot water was evaluated after each minute of soaking by mastication of single pasta thread (5 cm long) between two Plexiglas plates (Wójtowicz, 2005). The minimal preparation time for precooked pasta was defined as the moment of white internal core disappearance. Tests were performed in triplicate.

Results were analyzed using the statistical software Statistica 6.0, examining the relationships between the moisture content of raw materials and screw rpm to all the tested processing parameters, according to 3D. Analysis of variance was conducted at a confidence level of 95% ($p=0.05$), significance of differences was assessed by Duncan's range test.

RESULTS AND DISCUSSION

Fiber-rich raw materials, which include whole wheat flour applied in the tests, used in the manufacture of healthy food, require specific conditions of heat treatment due to the presence of high quantity of dietary fiber. Determination of optimal parameters is particularly important in the extrusion-cooking, in which the integrated effects of temperature, pressure and shear forces are able to influence the processed materials by complex physicochemical changes (Camire et al. 1990, Mercier et al. 1998, Wójtowicz and Mościcki, 2009). The use of raw material moisture content above 30% allowed to obtain the process temperature not exceeding 100°C, which prevents bringing to the boil of water present in the dough during the extrusion-cooking and to avoid the formation of air bubbles inside pasta threads after evaporation of water from the hot product leaving the forming die. A similar range of moisture content was used by Salvadori and Olivier (2006) during the manufacture of lasagna based on wholegrain raw materials: the traditional semolina pasta dough

was moistened to 33.2% of moisture content, the dough from wholegrain raw materials – to 32.8% of moisture content, while organic raw materials used in research were moistened to 31.1% of moisture content. After cooking of these products the moisture content of cooked products ranged from 60.1 to 63.5% and didn't differ statistically.

During the extrusion-cooking of whole wheat pasta products it was observed that increasing the initial moisture content of raw materials slightly increased the process output (correlation coefficient r=0.18). In all the tested samples there was found a significant increase of the process output with increasing screw speed during whole wheat pasta processing (correlation coefficient r=0.93). Dependencies of whole wheat pasta output according to the process parameters are illustrated in Figure 1.

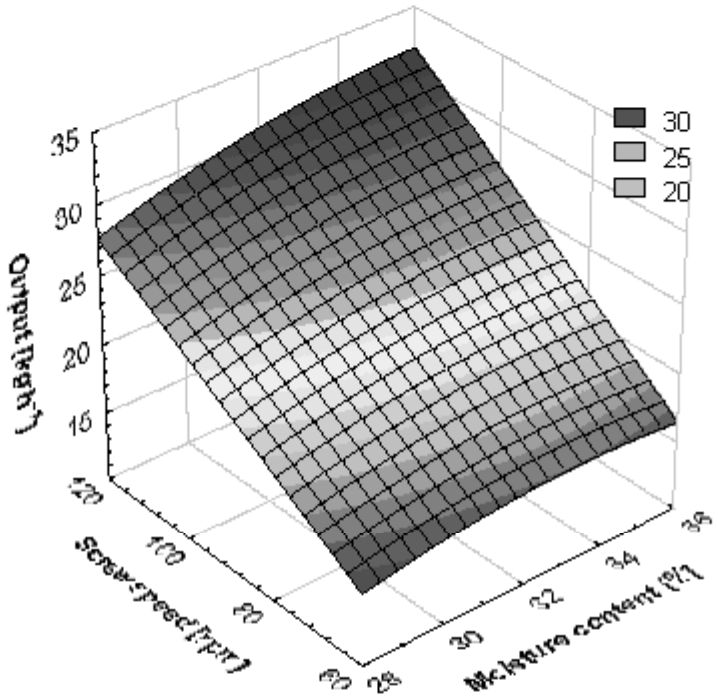

Fig. 1. The extrusion-cooking process output (kg h^{-1}) of whole wheat precooked pasta with different moisture content (%) and screw speed (rpm)

For the determination of specific mechanical energy, the power consumption, screw speed and output of the extrusion process were taken into account. It was observed that with increasing initial moisture content of raw materials, the values of SME decrease slightly (r=-0.15) during the whole wheat precooked pasta processing. The larger amount of water available during the extrusion-cooking of whole wheat products facilitates processing and results in lower motor load during extrusion, in spite of the presence of large quantity of fiber.

The specific mechanical energy SME requirements depending on the raw materials moisture content and the extrusion screw speed during the processing of whole wheat precooked pasta are summarized in Figure 2. The most important factor affecting the value of SME was an extrusion screw speed with high correlation coefficient (r=0.96). The higher screw speed was applied, the

higher the specific energy demand was. Wójtowicz and Mościcki (2008), for the determination of the rate of SME in common wheat flour precooked pasta extrusion, set this parameter in the range from 0.07 to 0.45 kWh kg^{-1}, an increase of screw speed during pasta processing resulted in an increase of SME values. Wójtowicz (2008), during the extrusion-cooking of instant pasta with the addition of legume seeds flour, has found that additive amount increasing will increase the demand of SME for protein-rich pasta in the application of low-speed extrusion, while applications of high screw speed reduced SME requirements with increasing share of legumes in a mixture of raw materials.

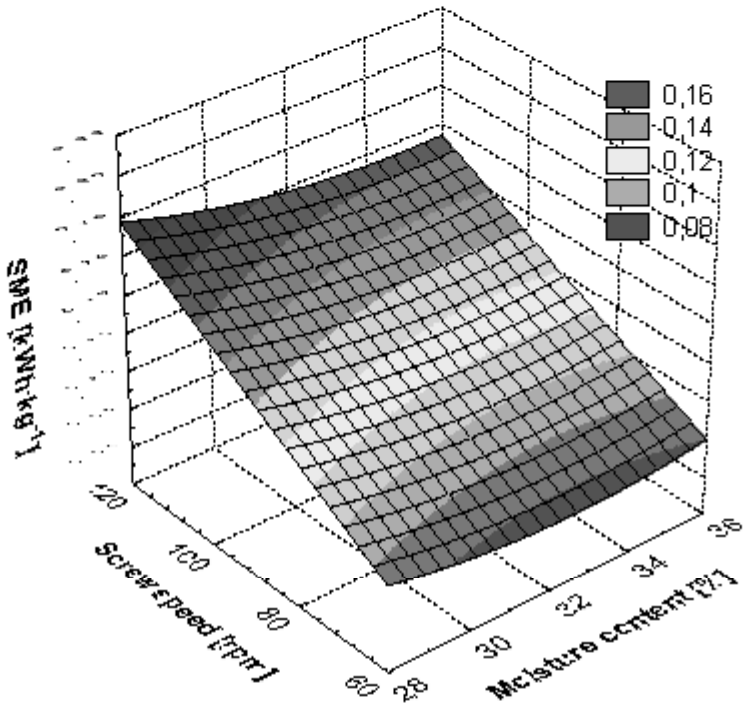

Fig. 2. Specific mechanical energy (kWh kg^{-1}) requirements during whole wheat precooked pasta processing from the raw materials with different initial moisture content (%) at different extrusion-cooking screw speed (rpm)

Yalla and Manthey (2006) tested pasta made from semolina with different yield and determined SME demand from 16 to 69 kJ kg^{-1} (0.004-0.017 kWh kg^{-1}) at the extrusion temperature range 44-47°C. SME decreased with increasing the amount of proteins and with stronger gluten, but decreased with increasing absorption level of raw materials. Singh and Smith (1997) during the high-temperature extrusion-cooking of whole wheat raw materials identified the SME demand for 0.09–0.13 kWh kg^{-1} in the application of temperature range from 30 to 175°C, while SME values increased for the application of low humidity raw materials (initial moisture content of the material ranged from 22 to 28%) and during lowering process temperature. High temperature extrusion-cooking, compared with traditional pasta pressing, generate at least 10-fold greater SME demand per kg of product. However, there should be taken into account the long-term drying process of traditional pasta, which improves the overall SME consumption. Abecassis et al. (1994) reported that during

conventional pasta pressing in a single screw pasta extruder at the temperatures not exceeding 50°C and up to 30 rpm, SME reached values from 0.03 to 0.12 kWh·kg^{-1}. Le Roux et al. (1995) achieved the SME values ranging 0.007-0.034 kWh·kg^{-1} during conventional durum semolina pasta pressing at 15-30 rpm when the dough moisture content 44-48% was used. Ryu and Ng (2001) ascertained higher SME values at higher screw rotational speed during the extrusion-cooking of wheat flour and corn meal, double screw speed escalation caused almost double SME consumption (from 0.155 to 0.293 kWh·kg^{-1} in processing duration of wheat flour at 120°C). Increasing the initial dough moisture content significantly decreased the SME (from 0.125 to 0.068 kWh·kg^{-1} during processing at 160°C). Della Valle et al. (1995) for extruded potato starch reported the SME consumption ranging 0.107-0.320 kWh·kg^{-1} depending on the process conditions and temperature used.

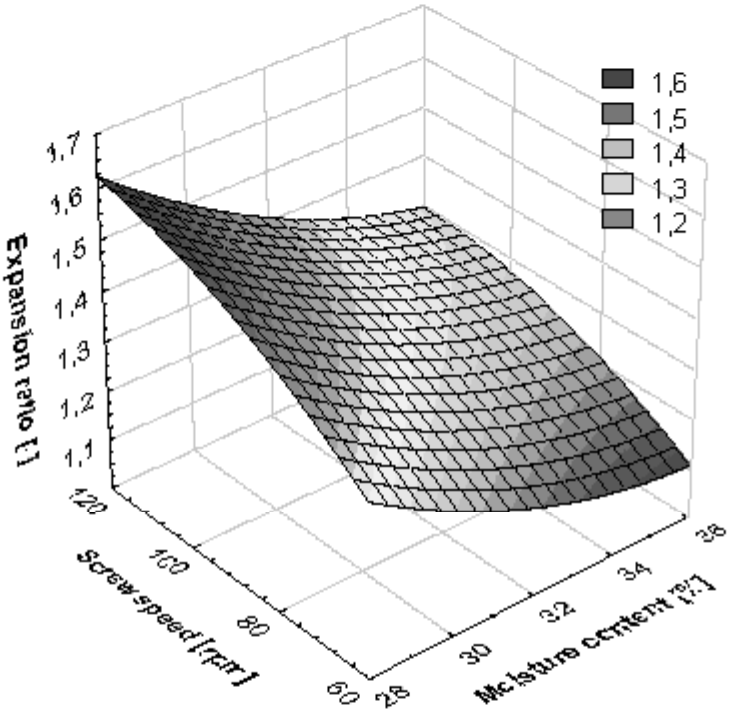

Fig. 3. The expansion ratio (-) of whole wheat precooked pasta processed with different dough moisture content (%) under different screw speed (rpm)

Figure 3 presents the results of the radial expansion ratio index measurements of precooked pasta made from whole wheat flour, depending on the screw rotation speed and dough moisture content. The whole wheat precooked pasta was characterized by low rate of the results differentiation defined in the application of different rpm during extrusion but increase of expansion ratio with increasing screw speed during extrusion was noted (r=0.57). There was also a significant influence of dough moistening on precooked pasta expansion ratio; higher moisture content of raw materials has to limit the expansion ratio of whole wheat pasta products (r=-0.67). Similar observations were noted by Wójtowicz and Mościcki (2009) for common wheat precooked pasta: higher expansion ratio was noted with higher screw speed used and lower dough moisture content. Singh and Smith

(1997) appointed for whole grain extrudates the expansion ratio values within 3-6 using a 22-28% moisture content of raw materials and extrusion temperature up to 175°C, an increase of process temperature and decrease of raw materials humidity affected the reduction of products expansion.

Minimal preparation time was similar for all the tested samples of precooked whole wheat pasta and ranged from 3 to 5 minutes of hot water hydration for the preparation of adequate consistency. There were no significant differences between the tested samples. The traditional cooking process was unnecessary for these types of products processed by extrusion-cooking. A longer hydration time (6 - 7 minutes) was observed for pasta processed at 120 rpm and 28 - 30% of dough moisture content, but it was mostly connected to a higher expansion ratio of pasta threads.

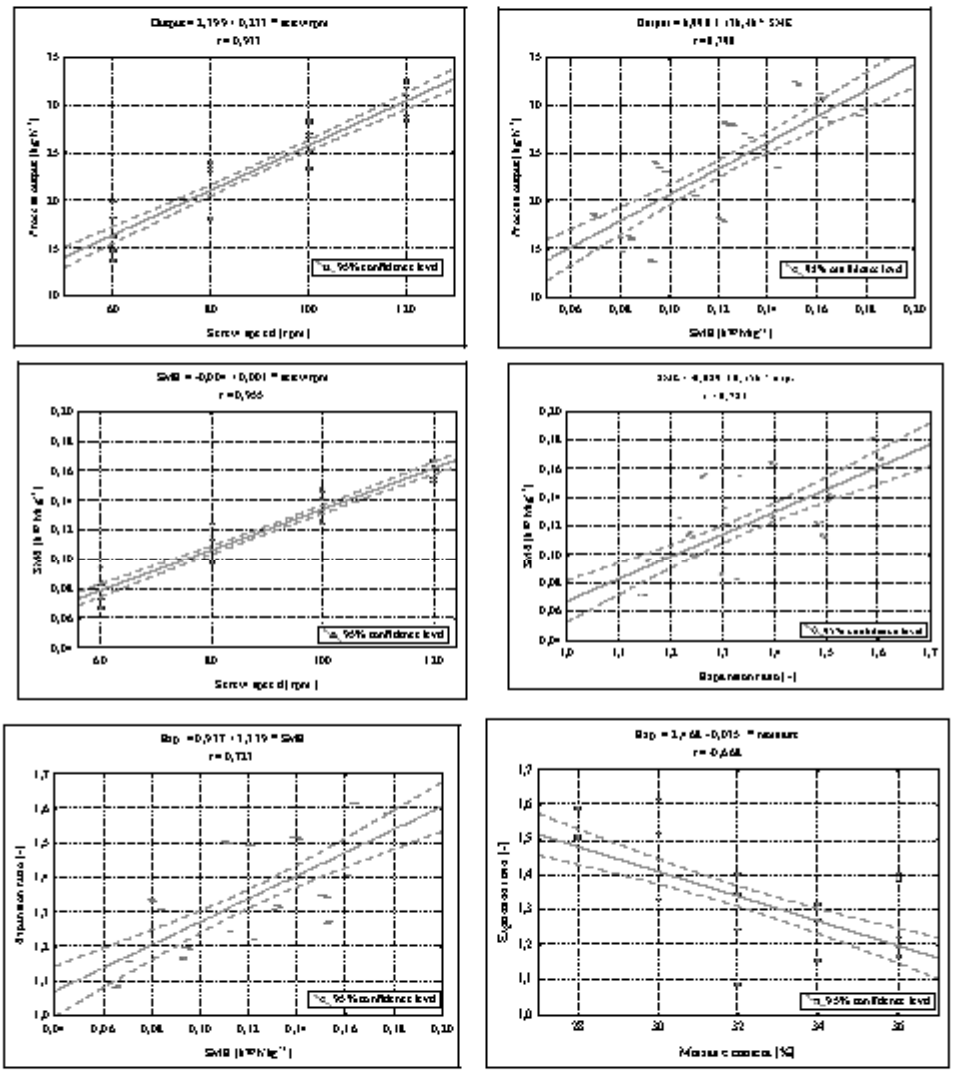

Fig. 4. Relationships of process output, SME values and expansion ratio of precooked whole wheat pasta with linear correlation coefficients in the 95% of confidence level.

The statistical analysis of the correlation matrix also showed the relationships between the tested characteristics. Process output increased at a higher SME values observed during the extrusion-cooking (r=0.79), while the expansion ratio was significantly dependant on the SME values (r=0.72). There are no significant interactions of expansion ratio and process output (r=0.32). Mutual dependencies of individual characteristics corresponding to each other are summarized in Figure 4, allowing 95% of confidence level. Correlation coefficients determined for these relationships indicate strong interdependencies of the evaluated parameters and characteristics of whole wheat precooked pasta products. The analysis of variance revealed significant differences between the averages of both the moisture content, and the screw speed during the extrusion-cooking at the 0.05 significance level.

CONCLUSIONS

A study of the influence of processing parameters like screw speed and dough moisture content during the extrusion-cooking of precooked whole wheat pasta allowed to establish the relationships between process parameters and product characteristics. The use of the proper moisture content of raw materials and processing intensity for the manufacture of whole wheat precooked pasta using modified single screw extruder TS-45 influenced the low expansion ratio which decreased following an increase of the moisture content of the material. The SME requirements increased with an increase of extrusion screw speed, which increased the expansion of pasta products. The output of the process increased with an increase of screw speed and it was connected with higher specific mechanical energy during the extrusion-cooking of precooked whole wheat pasta products.

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REFERENCES

AACC. (1995).: Approved methods of the American Association of Cereal Chemists (9th ed.). St. Paul: *American Association of Cereal Chemists.*

Abecassis J., Abbou R., Chaurand M., Morel M. H., Vernoux P. 1994.: Influence of extrusion conditions on extrusion speed, temperature and pressure in the extruder and on pasta quality. Cereal Chemistry, 71(3), 247-253.

Camire M., Camire A., Krumhar, K. 1990.: Chemical and nutritional changes in foods during extrusion. Food Science and Nutrition, 29(1), 35-57.

Chillo S., Laverse J., Falcone P.M., Protopapa A., Del Nobile M.A.: 2008. Influence of the addition of buckwheat flour and durum wheat bran on spaghetti quality. Journal of Cereal Science, 47, 144-152.

Franz M., Sampson L. 2006.: Challenges in developing a whole grain database: Definitions, methods and quantification. Journal of Food Composition and Analysis, 19, S38–S44.

Huber G. R. 1998.: Extrusion cooking applications for precooked pasta production. Northern Crops Institute. Fargo, N. Dak.: Wenger Manufacturing Inc.

Jacobs Jr., D.R., Meyer K.A., Kushi L.H., Folsom, A.R. 1998.: Wholegrain intake may reduce the risk of ischemic heart disease death in postmenopausal women: the Iowa Women's Health Study. American Journal of Clinical Nutrition, 68, 248–257.

Le Roux D., Vergnes B. 1995.: A thermomechanical approach to pasta extrusion. Journal of Food Engineering, 26, 351-368.

Marquart L., Pham A.T., Lautenschlager L., Croy M., Sobal, J. 2006.: Beliefs about whole-grain foods by food and nutrition professionals, health club members, and special supplemental nutrition program for women, infants, and children participants/state fair attendees. Journal of American Dietetic Association, 106, 1856-1860.

McKeown N.M., Meigs J.B., Liu S.M., Wilson P.W., Jacques P.F. 2002.: Whole-grain intake is favorably associated with metabolic risk factors for type 2 diabetes and cardiovascular disease in the Framingham Offspring Study. American Journal of Clinical Nutrition, 76(2), 390–398.

Olivera D., Salvadori V. 2006.: Textural characterisation of lasagna made from organic whole wheat. International Journal of Food Science and Technology, 41 (Supplement 2), 63-69.

Pınarlı I., İbanoğlu S., Öner M. 2004.: Effect of storage on the selected properties of macaroni enriched with wheat germ. Journal of Food Engineering, 64, 249–256.

Ross A. 2006.: Instrumental measurement of physical properties of cooked Asian wheat flour noodles. Cereal Chemistry, 83(1), 42–51.

Ryu G. H., Ng P. K. 2001.: Effect of selected process parameters on expansion and mechanical properties of wheat flour and whole commeal extrudates. Starch/Starke, 53, 147-154.

Schneeman B. 1998.: Dietary fiber and gastrointestinal function. Nutrition Research, 18(4), 625-632.

Singh N., Smith A. 1997.: A comparison of wheat starch, whole wheat meal and oat flour in the extrusion cooking process. Journal of Food Engineering, 34, 15-32.

Slavin J., Jacobs D., Marquart L., Wiemer K. 2001.: The role of whole grains in disease prevention. Journal of the American Dietetic Association, 101, 780-785.

Sozer N., Dalgıc A.C., Kaya A. 2007.: Thermal, textural and cooking properties of spaghetti enriched with resistant starch. Journal of Food Engineering, 81, 476–484.

Vasanthan J. 2003.: Hypochlorite oxidation of field pea starch and its suitability for noodle making using an extrusion cooker. Food Research International, 36, 381–386.

Wang N., Bhirud P., Sosulski F., Tyler R. 1999.: Pasta – like product from pea flour by twin- screw extrusion. Journal of Food Science, 4, 671- 678.

Wójtowicz A. 2005.: Influence of some functional components addition on microstructure of precooked pasta. Polish Journal of Food and Nutritional Science, 55(4), 417–422.

Wójtowicz A. 2007.: Influence of monoglyceride and lecithin addition on cooking quality of precooked pasta. Polish Journal of Food and Nutritional Science, 57(3A), 157–62.

Wójtowicz A. 2008.: Influence of legumes addition on proceeding of ekstrusion-cooking process of precooked pasta. TEKA Commision of Motorization and Power Industry in Agriculture, 8a, 209-216

Wójtowicz A., Mościcki L. 2008.: Energy consumption during extrusion-cooking of precooked pasta. TEKA Commision of Motorization and Power Industry in Agriculture, 8, 311-318.

Wójtowicz A., Mościcki L. 2009.: Influence of extrusion-cooking parameters on some quality aspects of precooked pasta-like products, Journal of Food Science, 74(5), E226-233.

Yalla S., Manthey F. 2006.: Effect of semolina and absorption level on extrusion of spaghetti containing non-traditional ingredients. Journal of the Science of Food and Agriculture, 86, 841–848.

WPŁYW NAWILŻENIA MĄKI PSZENNEJ PEŁNOZIARNISTEJ ORAZ PRĘDKOŚCI WYTŁACZANIA NA ENERGOCHŁONNOŚĆ PROCESU I EKSPANDOWANIE EKSTRUDOWANYCH WYROBÓW MAKARONOWYCH BŁYSKAWICZNYCH

Streszczenie. W pracy przedstawiono wyniki pomiarów energochłonności procesu ekstruzji oraz ekspandowania ekstrudowanych makaronów błyskawicznych wytwarzanych z mąki pszennej pełnoziarnistej. W badaniach zastosowano różny stopień nawilżenia mąki pełnoziarnistej w zakresie wilgotności od 28 do 36%. Ekstruzję wyrobów makaronowych prowadzono w jednoślimakowym zmodyfikowanym ekstruderze TS-45 o L/D=18:1 przy zastosowaniu zróżnicowanej prędkości obrotowej ślimaka 60, 80, 100 i 120 obr·min^{-1}. Ekstruzję wyrobów makaronowych prowadzono w zakresie temperatur 80-100°C, wytłaczając makarony w formie nitek przez matrycę z 12 otworami o średnicy 0,8 mm. W zależności od zastosowanych obrotów ślimaka oraz wilgotności surowców wyznaczano wydajność procesu, jednostkowe zapotrzebowanie energii mechanicznej SME oraz wskaźnik ekspandowania promieniowego makaronów. Wydajność procesu ekstruzji podczas wytwarzania makaronów pełnoziarnistych zwiększała się wraz ze wzrostem zastosowanych obrotów ślimaka roboczego, zwiększanie wilgotności surowców wpłynęło na obniżenie wydajności procesu. Wartości SME wynosiły od 0,07 do 0,84 kWh·kg^{-1} i uzależnione były zarówno od wilgotności surowców, jak i od prędkości wytłaczania makaronów. Wskaźnik ekspandowania promieniowego makaronów zwiększał się wraz z zastosowanymi obrotami podczas wytłaczania, stosowanie wyższych wilgotności surowców wpływało na ograniczanie ekspandowania wyrobów makaronowych pełnoziarnistych.

Słowa kluczowe: ekstruzja, makaron błyskawiczny, mąka pełnoziarnista, SME, ekspandowanie