*TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2011, 11, 430–440*

# INFLUENCE OF EXTRUSION-COOKING PROCESS PARAMETERS ON SELECTED MECHANICAL PROPERTIES OF PRECOOKED MAIZE PASTA PRODUCTS

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**Summary.** The paper presents the results of measurements of selected mechanical properties of precooked pasta made from maize flour using variable parameters of extrusion-cooking process. The different level of water addition to maize flour was used due to the moisture content from 30 to 34%. Processing of maize pasta products was performed at the temperature ranged 80-100°C on single-screw modified extrusion-cooker TS-45 with L/D = 18:1 using a differentiated screw speed: 60, 80, 100 and 120 rpm. Depending on the screw speed and the dough moisture content selected tensile properties and extension characteristics of hydrated products by elongation tests of precooked maize pasta products were determined. A higher screw speed and moisture content lowered load at tensile strength and increased extension at break during elongation tests. Similar tendencies were observed for tensile strain at break and tensile strain at tensile strength. Precooked maize pasta due to its acceptable texture and tensile properties may be an attractive product for consumers on a gluten-free diet.

**Key words:** extrusion-cooking, maize pasta, gluten-free pasta, extension, tensile.

## INTRODUCTION

In recent years, the world is constantly increasing the production of pasta products from raw materials other than flour and semolina flour such as rice, corn, barley, oats, fortified compound additives (Jurga, 2002). In the production of traditional pasta, the high level of addition of these raw materials to semolina or wheat flour results in deteriorating of gluten structure and decreases the physical properties of pasta products. It may occur that the reduction of the strength and plasticity of wet forms of pasta during pressing will industrially increase their stickiness and dry matter loss during cooking. Therefore, in conventional, industrially manufactured pasta, an acceptable addition of high-starchy raw materials to wheat flour or semolina pasta or noodles should not be higher than 10%. Application of extrusion-cooking to pasta processing give the possibilities to use many different raw materials, also gluten-free, for precooked or instant pasta (Huber 1998, Li Vasanthan 2003, Wang 1999, Wójtowicz 2008, 2010, Wójtowicz Mitrus 2010, Wójtowicz Mościcki 2009)

Preparation of gluten-free pasta is a challenging task for the food technologist, because of the lack of gluten which is formed when wheat is used as the starting material (Bryant et al., 2001). Gluten is the main contributor to dough development during mixing and extrusion, and thus prevents disaggregation of pasta during cooking in boiling water. It has been suggested that the lack of gluten can be overcome by blending pre-gelatinized starch or corn flour before adding water, or by gelatinizing some of the starch during mixing or extruding. Extrusion is a suitable process for producing snack foods for consumers with celiac disease, as starch is the main component providing the desirable expanded structure in the final product (Camire 1990, Ding 2005, Wójtowicz 2011). In the formulation of gluten-free pasta, it has been suggested that the production process should be altered, for example by pre-gelatinizing the gluten-free starch during mixing or extruding to denature the protein and protect the starch from rupturing during cooking (Charutigon 2008, Chillo 2007, Gallager 2008 Lai 2001).

The only effective way for treating celiac disease is a strict adherence to a gluten-free diet, the patients are not allowed to eat any bread, cereal or other food made with wheat, rye, barley, triticale and oat flour or ingredients, or by-products made from those grains, processed foods that contain wheat and gluten-derivatives as thickeners and fillers, for example hot dogs, salad dressings, canned soups/dried soup mixes, processed cheese, cream sauces, and medications that use gluten as pill or tablet binders (Niewinski 2008). Gluten removal results in major problems for processing and many gluten-free products available on the market are of low quality, exhibiting poor mouthfeel and flavor. This presents a major challenge to the cereal technologist to search for alternatives to gluten in the manufacture of gluten-free food products (Gallager 2004, Yoenyongbuddhagal, S., Noomhorm, A. 2002).

For the evaluation of mechanical properties of food products many tests may be performed according to instrumental measurements (Raina 2005, Ross 2006). There are several methods which have been used to measure the rheological properties of dough in extension: simple uniaxial extension, where dough is stretched in one direction; and biaxial extension, where the dough is stretched in two opposing directions. One of the oldest and most widely used test methods to measure material properties is the uniaxial tensile test. A strip of material is clamped at both ends and pulled apart at a fixed rate in a suitable testing machine, and the force measured at the same time as the displacement of the object. The force is generally plotted against the displacement (extension) to give a force–extension curve (Dobraszczyk 2003).

Mechanical and dynamic-mechanical properties of cereal-based products have been investigated by several research groups. Moreover, some model has been developed to study the relations between cooked pasta and mechanical properties. It is known that the evolution of mechanical parameters is related to the hydration process during cooking and overcooking as well as starch gelatinization. In particular, the mechanical behavior is described through the changes occurring in the elastic modulus and the tensile strength. (Cafieri et al. 2010). Elongation at break is the recorded strain at the moment of rupture of the sample and is expressed as the elongation percentage with respect to the original length. (Chillo 2009)

The aim of this work was an evaluation of processing parameters influence on selected mechanical properties of gluten-free maize precooked pasta.

## MATERIALS AND METHODS

Maize flour was used in the tests (protein - 5.13%, fat - 1.4%, ash - 0.45%, fiber - 2.0%). The raw material was moistened by proper water addition and mixed for a final dough moisture content 30, 32 and 34%. After mixing and resting compounds were processed using the modified

single screw TS-45 extrusion-cooker (Metalchem, Gliwice, Poland) with screw length to diameter ratio L/D=18:1, compression ratio - 3:1, equipped with additional glycol cooling section just before the die, at the temperature ranged from 80 to 105°C. Pasta products were shaped for threads with application of a forming die with 12 holes 0.8 mm in diameter. Gluten-free pasta products were processed at different screw speed at the level of 60, 80, 100 and 120 rpm. After a while, the drying samples were stored in plastic bags before testing.

Pasta elongation was tested with Tensile Kiefer Dough and Gluten Extensibility Rig equipment of Instron 5564 apparatus with head 50N (Stable Micro Systems Ltd., UK). Tests were performed in Food and Bioprocess Engineering Group, Wageningen University (the Netherlands). Tension test speed 3.3 $mm \cdot s^{-1}$ was set. Single pasta tread after 5 minutes of hot water hydration was placed on the testing table and held under plastic cover during the test. During the tensile tests load at break, extension at break, tensile stress at break, tensile strain at break, tensile stress at tensile strength, and true stress at tensile strength were evaluated using computer program. Values on curves are means of five replications.

The 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. Analysis of variance was conducted at the confidence level of 95% (p=0.05), significance of differences was assessed by Duncan's range test.

## RESULTS

The results of measurements of strength characteristics of gluten-free pasta processed at varied screw speed and different moisture content of maize flour dough (30-34%) showed dependency on both the moisture content of raw materials and screw rotations applied during the extrusion. It was observed that increasing the moisture content of maize flour causes a significant increase in the value of extension at break, elongation at break, and to reduce stress during stretching. In this case, little effect was used during extrusion screw rotation of maize precooked pasta on rheological properties determined in tensile tests. Correlation coefficients for these dependencies are shown in Table 1.

Table 1. Correlation coefficients of rheological parameters of maize pasta, depending on the moisture content ranged 30-34% of raw materials and the screw speed of 60-120 rpm.

| Parameter | Tensile strain at break [mm·mm$^{-1}$] | Tensile stress at break [MPa] | Extension at break [mm] | Load at tensile strength [N] | Tensile strain at tensile strength [mm·mm$^{-1}$] | Tensile stress at tensile strength [MPa] | True stress at tensile strain [kPa] |
|---|---|---|---|---|---|---|---|
| Moisture content [%] | 0,554 | -0,173 | 0,534 | -0,475 | 0,418 | -0,605 | 0,253 |
| Screw speed [rpm] | 0,284 | 0,362 | 0,173 | -0,309 | 0,217 | -0,243 | -0,182 |

The values of tensile strain at break increased with increasing screw speed applied during extrusion-cooking of maize pasta. Similarly, the increased initial moisture content of maize flour

resulted in the increase of the value of this parameter. Relationships between processing parameters and tensile strain at break of maize precooked pasta are shown in Fig. 1.

Load at tensile strength measured with the use of the Kiefer Dough and Gluten Extensibility Rig showed the lowest value of the load during extension for gluten-free pasta processed using high-moisture dough and high screw rotational speed. However, low screw speed and the highest moisture applied during the extrusion-cooking of maize pasta resulted in the highest value of load at tensile strength. A similar range of results was obtained for maize pasta extruded at the highest speed and lowest initial moisture content of maize flour. The results of measurements of load at tensile strength are summarized in Fig. 2.

Carini et al. 2009 tested extruded and laminated pasta products. Force at rupture (maximum force (N) required to shear the sample) in the range from 10 till 14 N were obtained for extruded and laminated fresh pasta and extensibility (deformation at breakage (mm)) in the range from 9 ot 11 mm were obtained. The extruded pasta was characterized by higher extensibility and force at rupture. They also tested an influence of mixing system on mechanical properties of pasta. Different mixers affecting the physicochemical properties were observed more markedly in the extruded than in laminated products. Fresh extruded pasta was less extensible and harder than the laminated one (carini 2010)

Li and others (2008) tested mechanical properties of wheat protein dough and they assumed that extensibility at rupture decreased when the glutenin, insoluble glutenin, soluble glutenin, and glutenin macropolymer were added, and decreased systematically with increasing levels of these fractions. However, extensibility at rupture increased when the monomeric protein, albumin-globulin, and gliadin were added, and increased systematically with increasing levels of these fractions.

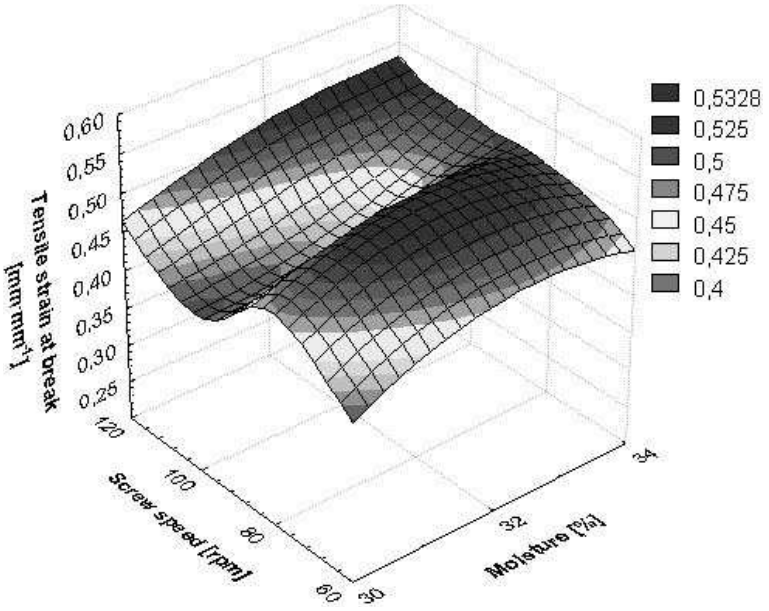


Fig. 1. Tensile strain at break during elongation test of precooked maize pasta processed at different screw speed and initial moisture content

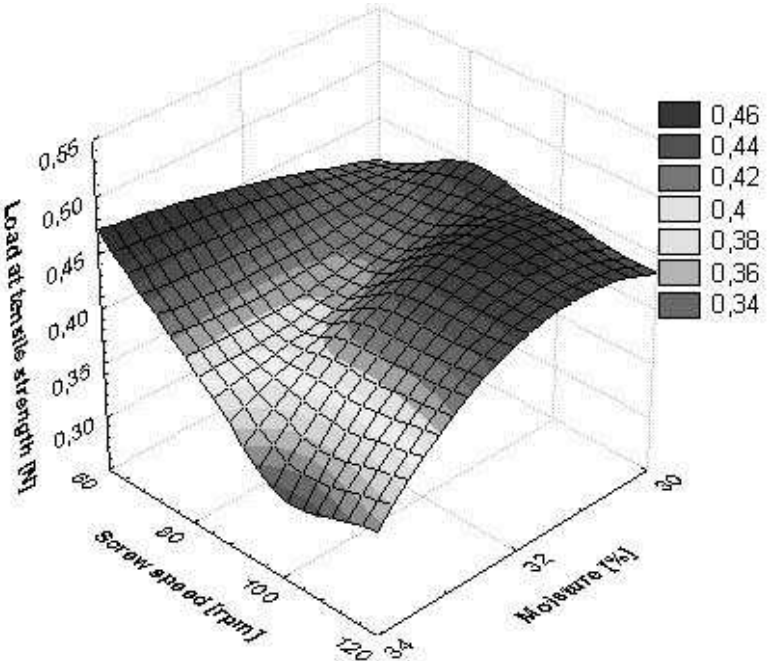


Fig. 2. Load at tensile strength of precooked maize pasta processed at different screw speed and initial moisture content during elongation test

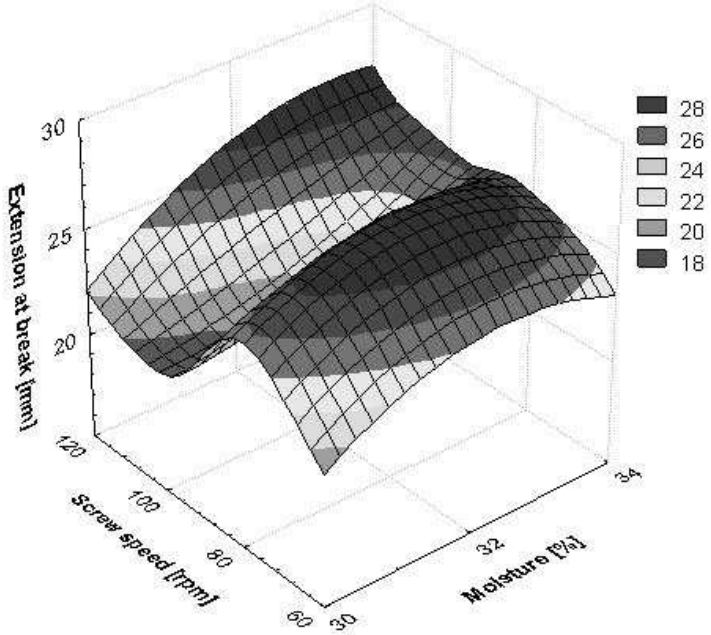


Fig. 3. Extension at break during elongation test of precooked maize pasta processed at different screw speed and initial moisture content

The values of extension at break indicate a diverse flexibility of maize pasta during the tensile test. Extension at break was dependent on the screw speed used during the extrusion-cooking, the higher the extrusion screw speed used for pasta processing, the greater extension until rupture (Fig. 3). The smallest differences between the measurements were determined for examining of extruded maize pasta with initial moisture content of 30%, the higher the moisture content of maize flour was set, the greater differences in flexibility – products prepared with the highest screw speed used during extrusion at the highest moisture content of raw materials showed the highest values of extension, which suggested that they were the most flexible.

During the test, the true stress at tensile strain indicated the effects of extrusion screw speed and moisture content of raw materials on the value of true stress of maize pasta - stress underwent reduction using the low speed screw extrusion at low initial moisture content of raw materials and at the highest screw speed and high moisture content of maize flour (Fig. 4). The most stable results, about 1300 kPa, in assessing of this parameter, were obtained for extruded precooked maize pasta processed with the initial moisture content of 32% - in this case there was no significant effect of screw speed on true stress at tensile strain values.

Figure 5 presents the results of tensile stress at tensile strength evaluated for maize pasta extruded at different extrusion screw speeds and moisture content of raw materials. It was found that for this parameter the lowest tensile stress values were obtained for maize pasta processed at the highest speed screw and high-moisture maize flour - 34%. Other measurements showed no significant difference, tensile stress at tensile strength ranged from 0.53 to 0.58 MPa. This shows a similar resistance to the stretching of maize precooked pasta.

Zardetto and others (2009) tested extruded and sheeted pasta and they observed the extruded pasta samples were tougher than the sheet-rolled pasta. Cooking the pasta resulted in less toughness and more hardness, and a significant increase in the extensibility of both samples.

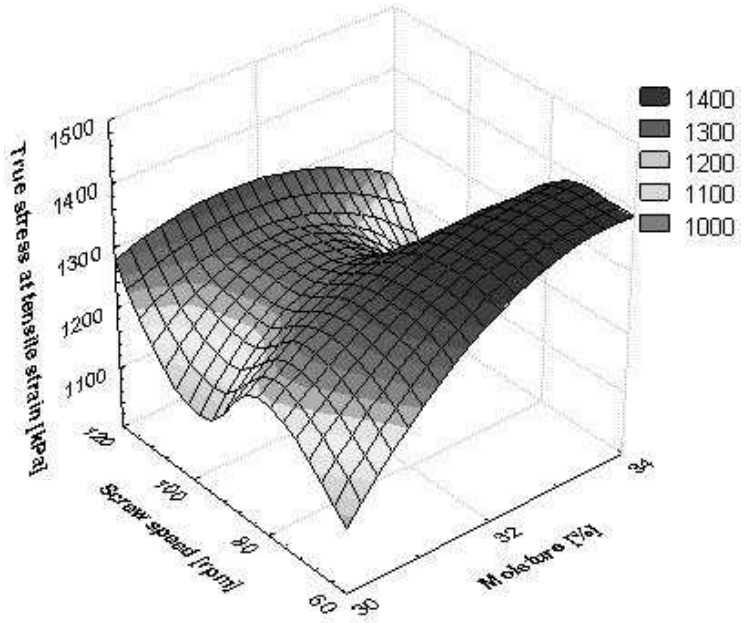


Fig. 4. True stress at tensile strain during elongation test of precooked maize pasta processed at different screw speed and initial moisture content

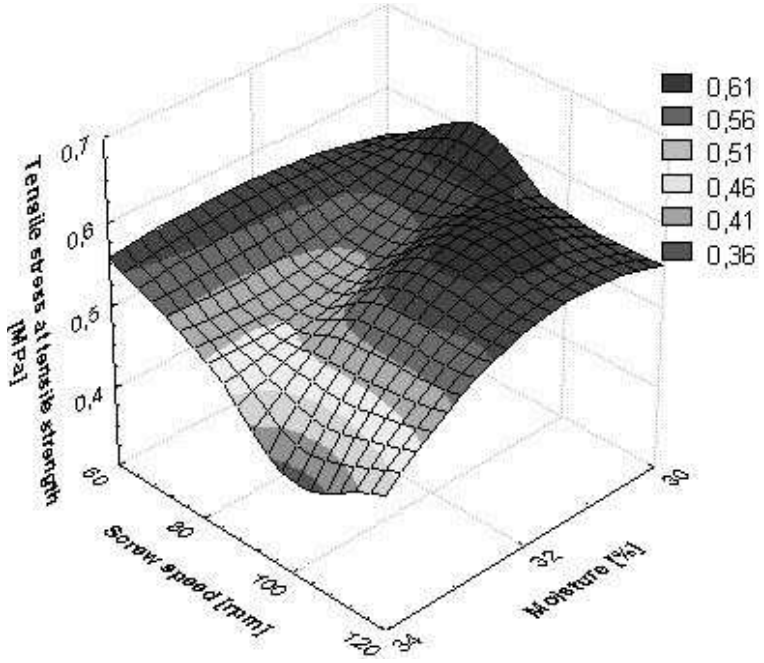


Fig. 5. Tensile stress at tensile strength of precooked maize pasta processed at different screw speed and initial moisture content during elongation test

Values of tensile stress at break, evaluated in a tensile test varied depending on the screw speed during extrusion-cooking of maize pasta and the initial moisture content of flour. Tensile stress at break was about 6-fold higher than the tensile stress at tensile strength, the results obtained in the study of this parameter ranged from 2.1 to 3.2 MPa. This demonstrates the high resistance of extruded maize pasta at break. The measurement results are presented in graphical form in Figure 6. Low resistance to breaking pasta products were only recorded for products processed at the lowest screw speed during extrusion-cooking. The most resistant to rupture were gluten-free maize pasta produced using 100 and 120 rpm with the initial moisture content of flour 30-32%. Low values of tensile stress at break were observed for pasta with low tensile strain at tensile strength during extension tests.

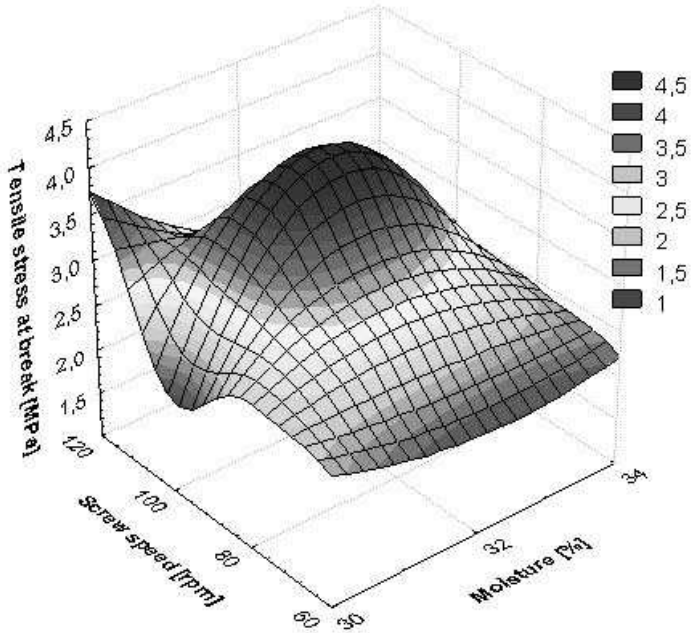


Fig. 6. Tensile stress at break of precooked maize pasta processed at different screw speed and initial moisture content during elongation test

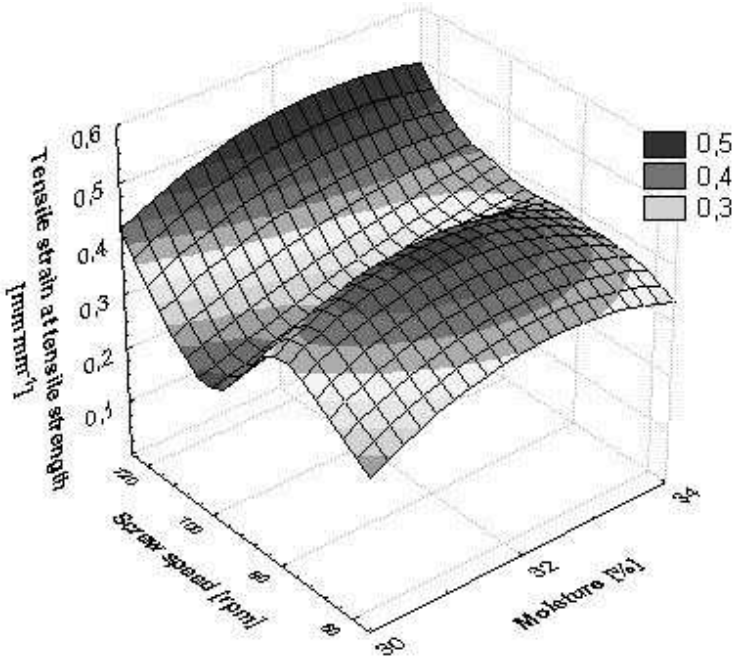


Fig. 7. Tensile strain at tensile strength of precooked maize pasta processed at different screw speed and initial moisture content during elongation test

The values of tensile strain at tensile strength of maize gluten-free pasta are illustrated in Fig. 7. Within the results of this parameter significant differences depending on the moisture content of raw materials and the screw speed during the extrusion-cooking of maize pasta were observed. Smallest deformation was observed for pasta processed at the lowest moisture content of maize flour, independently on the screw rotation, which may prove too low moisturizing of raw materials to obtain stable structure of pasta under tension and these pasta products underwent rupture very easy. Increasing humidity of raw materials to 32% resulted in the occurrence of larger tensile strain depending on the extrusion speed - the higher screw speed used during the extrusion-cooking, the higher values of tensile strain at tensile strength were obtained. The most significant differences were observed during testing pasta processed with initial moisture of maize flour 34%, in these products an influence of screw speed on tensile stress at tensile strength was very important.

## CONCLUSIONS

The mechanical properties of precooked maize pasta processed by extrusion-cooking using modified single screw extruder TS-45 varied, according to the processing conditions: resistance for elongation and tensile of pasta increased with increasing screw speed during processing. It was observed that increasing the moisture content of maize flour causes a significant increase in the value of extension at break and tensile strain at break, and reduction of tensile stress at tensile strength and tensile stress at break. In this case, little effect of varied screw rotations was noted on the mechanical properties of maize precooked pasta determined in tensile tests. Precooked maize pasta, due to its acceptable texture and tensile properties, may be an attractive product for producers and consumers on a gluten-free diet.

**Acknowledgements**

***This scientific work was supported by Polish Ministry of Science and Higher Education founds on science in the years 2008-2010 as a research project N N312 162334.***

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## WPŁYW PARAMETRÓW PROCESU EKSTRUZJI NA WYBRANE WŁAŚCIWOŚCI MECHANICZNE PODGOTOWANYCH MAKARONÓW KUKURYDZIANYCH

**Streszczenie.** W artykule przedstawiono wyniki pomiarów wybranych właściwości mechanicznych makaronów błyskawicznych z mąki kukurydzianej przy zmiennych parametrach procesu ekstruzji. Zastosowano zróżnicowany dowilżania mąki kukurydzianej do zawartości wilgoci od 30 do 34%. Ekstruzję produktów makaronowych z kukurydzy przeprowadzano w temperaturze 80-100 ° C, na ekstruderze jednoślimakowym TS-45 z L / D = 18:1, przy użyciu zróżnicowanych prędkość ślimaka: 60, 80, 100 i 120 obr. / min. W zależności od szybkości ślimaka i wilgotności ciasta ustalono wybrane właściwości wytrzymałościowe i właściwości rozciągania uwodnionych produktów makaronowych z kukurydzy. Wyższa prędkość ślimaka i wilgotność obniża wytrzymałość na obciążenia i zwiększa ilość przerwań podczas badań rozciągania. Podobne tendencje zaobserwowano dla napięcia przy obciążaniu i wydłużaniu. Wstępnie gotowany makaron z maki kukurydzianej, ze względu na właściwą strukturę i elastyczność, może być atrakcyjnym produktem dla konsumentów na diecie bezglutenowej.

**Słowa kluczowe:** ekstruzja, makaron kukurydziany, makaron bezglutenowy, wydłużanie, rozciąganie.