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EXTRUSION-COOKING OF WHEAT STARCH

Marcin Mitrus, Agnieszka Wójtowicz

Department of Food Process Engineering, Faculty of Production Engineering,
University of Life Sciences, Doświadczalna 44, 20-280 Lublin, Poland,
marcin.mitrus@up.lublin.pl

Summary. During the study the impact of extrusion-cooking process parameters on the wheat starch physical properties changes was investigated. The process was characterized by small energy consumption within a range 270-1069 $kJkg^{-1}$. Extrusion-cooking technique allows creating the degree of gelatinization of processed starch. It is possible to achieve low or high level of gelatinization depending on the process parameters. Expansion index of the extrudates decreased with increase of wheat starch moisture content. It was found that the use of the extrusion process resulted in increase of water absorption and cold water solubility of starch. The highest value of WAI was 690% and WSI was 19%.

Key words: wheat starch, extrusion cooking, specific mechanical energy, gelatinization, solubility, water absorption.

INTRODUCTION

Starch plays an important role in many industries, especially in food and feed sector. In practice, native starches are not simply suitable for any specific application. Therefore, various starch modification techniques have been developed for food and non-food applications. The most popular methods of starch modification are chemical methods.

In recent years, it was found that in many cases, especially in the food industry, chemically modified starch can be replaced by extrusion-cooked starch. Food extrusion has been practiced for more than 50 years with early developments in the preparation of ready-to-eat cereals [8]. During the extrusion, physicochemical transformation of starch take place without any additional chemicals. Baro-thermal treatment causes gelatinisation of starch. This process is accompanied by rupture of intermolecular bonds, resulting in rupture of starch grains and significantly increase of water absorption [4, 9, 11, 12, 13, 14].

The degree of changes in starch depends on properly selected process parameters and the residence time of raw material in the extruder. This allows to affect on the properties of the obtained modified starches, including degree of gelatinization and viscosity of the gels [2, 18].

MATERIALS AND METHODS

Wheat starch Meritena 200 type was produced by SYRAL BELGIUM N.V. (Belgium). Its moisture content was 11,8 %. During the extrusion-cooking process the 4 levels of moisture content of raw material (17, 20, 25 and 30%) were used. In order to obtain expected moisture content, starch was mixed with sufficient amount of water and stored for 24h in air tight polyethylene bags at room temperature to make whole sample material homogeneous.

Extrusion-cooking of potato starch was carried out using a modified single screw extrusion-cooker TS-45 (Polish design) with L/D = 16. The die with one opening with a diameter of 3 mm was used. During the study three temperature of extrusion process (100, 120 and 140 °C) and a variable speed screw (60, 80, 100, 120 rpm) were used.

During the extrusion-cooking process energy consumption was measured with a wattmeter connected to the extruder and the specific mechanical energy (SME) input was calculated [7, 10, 20].

$$SME = \frac{n \cdot P \cdot O}{n_m \cdot Q} [kWhkg^{-1}], \qquad (1)$$

where: n - screw rotations [min^{-1}],

n_m - maximal screw rotations [min^{-1}],

P - power [kW],

O - engine loading [%],

Q - extruder output [kgh^{-1}].

Degree of starch gelatinization was measured by enzymatic method with diastase in accordance with Polish standard PN-A-79011-11:1998 [15].

Cross-sectional expansion index was determined as the diameter of extrudates divided by the diameter of the matrix opening [11]. Measurements were done in 10 repetitions.

Water absorption index was determined according to the method of Anderson et al. [1] with own modification. The extrudates were crushed using a laboratory mill to particles with a diameter less than 0.3 mm. A 0.7 g ground sample was suspended in 7 ml of distilled water at 20°C in a tared centrifuge tube, stirred intermittently over a 10 min period. The resulting suspension was centrifuged at rotational speeds 250 s^{-1} for 10 minutes in T24D type centrifuge. The supernatant liquid was poured into a tared evaporating dish. The remaining gel was weighted and the WAI was calculated as:

$$WAI \frac{m_g}{m_s} \cdot 100[\%], \qquad (2)$$

where: w_g - weight of gel [g],

w_s - weight of dry sample [g].

Measurements were performed in 3 replications.

Water solubility index was determined from the amount of dried solids recovered during evaporation of supernatant obtained from the WAI analysis according to the method of Harper [5]. Results were calculated from formula:

$$WSI = \frac{w_{ds}}{w_s} \cdot 100[\%], \qquad (3)$$

where: w_{ds} - weight of dry solids in supernatant [g],

w_s - weight of dry sample [g].

Measurements were performed in 3 replications.

RESULTS

Application of extrusion cooking technique for plant starch needs a determination of specific mechanical energy (SME) necessary to obtain product mass unit. As Bindzus et al. [3] hold when wheat, maize and rice starch was processed at twin screw extruder the SME values changed in the range 0,081–0,365 $kWhkg^{-1}$. Wiedmann and Strobel [19] in their investigations on the extrusion of wheat TPS recorded the SME ranging from 0,1 to 0,55 $kWhkg^{-1}$ depending on material moisture.

The use of extrusion-cooker TS-45 equipped with additional cooling system allowed to keep a stable conditions during wheat starch modification. Extrusion-cooking of the wheat starch was characterised by low mechanical energy consumption (SME) within a range 270-1069.2 $kJkg^{-1}$ (0.075-0.297 $kWhkg^{-1}$). Changes in SME depended mainly on the extruder screw speed and starch moisture content, less on process temperature (fig. 1).

Screw rotational speed increase caused rise in mechanical energy consumption, independently of the process temperature. Effect of moisture content on the SME was inconclusive. When carrying out the process at 100 °C and 120 °C the higher moisture content of the starch caused SME increase. During wheat starch extrusion-cooking at 140 °C the higher moisture content of the starch caused SME decrease.

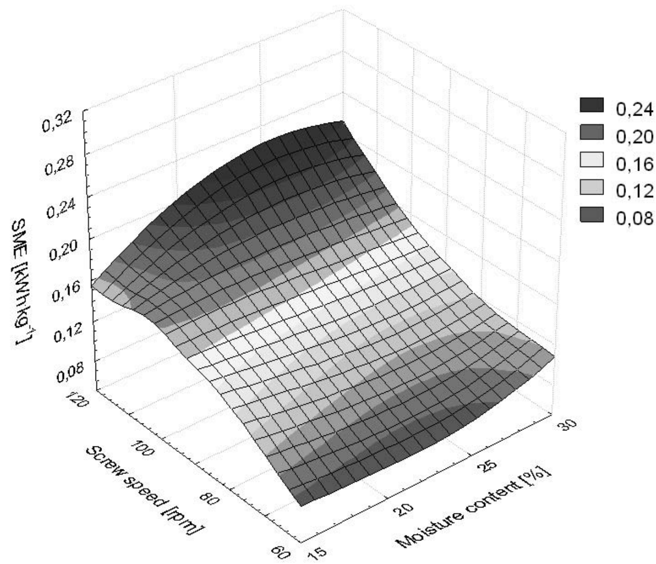

Fig. 1. SME changes during wheat starch extrusion-cooking at 100 °C

The highest degree of gelatinization (100%) was recorded for starch extruded at 100 °C at the moisture content 17%. The lowest degree of gelatinization (69.8%) was recorded for starch extruded at 120 °C at the moisture content 30%. During the studies, independent of the extrusion process parameters, decrease of the degree of starch gelatinization with starch moisture content increase was observed. The research reviled that the degree of starch gelatinization increased with increase extruder screw speed for wheat starch processed at temperature 100 and 140 °C. When carrying out the process at 120 °C the higher extruder screw speed caused decrease in degree of gelatinisation (fig. 2).

Measurements of the expansion index of extruded wheat starch showed that its value decreases with moisture content increase (fig. 3). Extruder screw speed increase caused increase of expansion index. This is a common phenomenon for the most of the extrudates. Extrudates were characterized by a typical structure, resembling a honeycomb structure. Values of the expansion index ranged between 2.7 and 6.2.

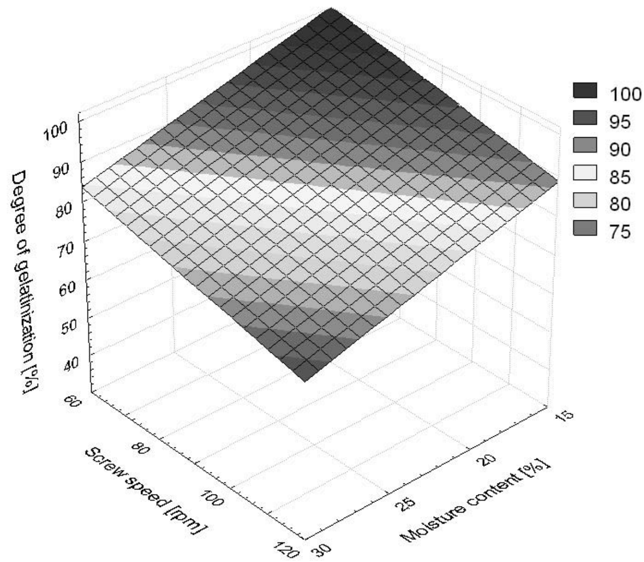

Fig. 2. Degree of gelatinisation changes for wheat starch extrusion-cooked at 120 °C

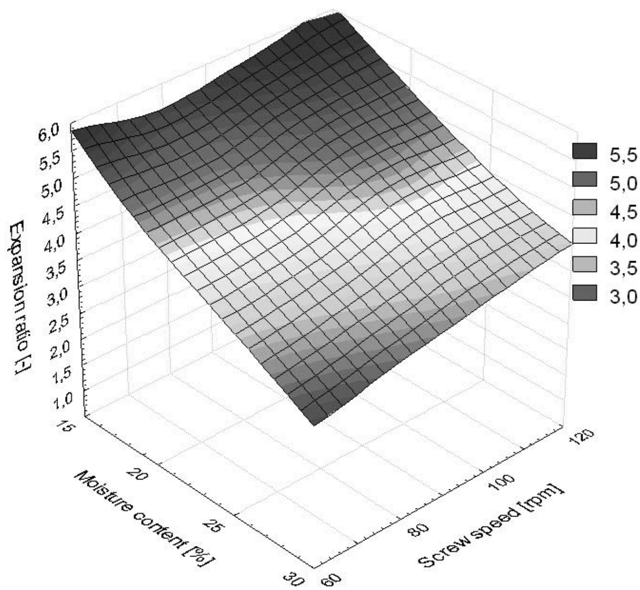

Fig. 3. Expansion index changes during wheat starch extrusion-cooking at 120 °C

According to Ryu and Ng [17] the moisture content in the feed material influences the rheological properties of the melt and builds up the vapor pressure. This causes extensive flash-off of internal moisture when the melt exits the die. However, the viscosity of the melt affects bubble growth as well as shrinkage of generated bubbles. The viscosity of the melt at higher moisture content is lower, thus bubble shrinkage and collapse are increased when steam is flashing at the exit. The viscosity of the melt and the glass transition temperature during the setting of air bubble inside extrudates influenced bubble collapse. Bubble collapse during bubble setting was increased with higher moisture of melt, since melt with higher moisture or lower viscosity had a lower glass transition temperature. Thus, the expansion was decreased in a melt with higher moisture content.

Native wheat starch has WAI approximately 184% and WSI approximately 0.24%. The study showed that the baro-thermal modification of starch significantly effects on its water absorption and solubility in cold water.

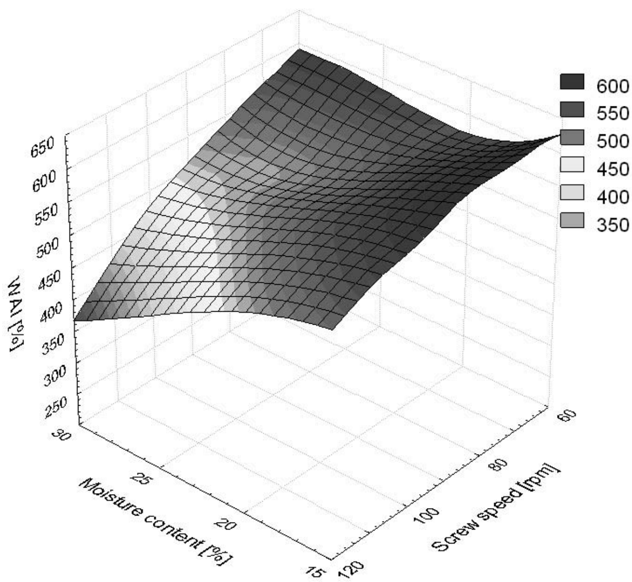

Fig. 4. Wheat starch WAI changes during extrusion-cooking at 100 °C

With the increase in moisture content of processed wheat starch the decrease of water absorption was observed (fig. 4). During extrusion-cooking at 100 and 120 °C the higher extruder screw speed caused WAI decrease. The researches carried out at temperature 140 °C revealed that extruder screw speed increase caused an initial increase (60-80 rpm) and than decrease (100-120 rpm) in modified starch water absorption. WAI values of the extruded wheat starch ranged from 369 to 690% and generally did not deviate from the values obtained for a typical starch extrudates [8].

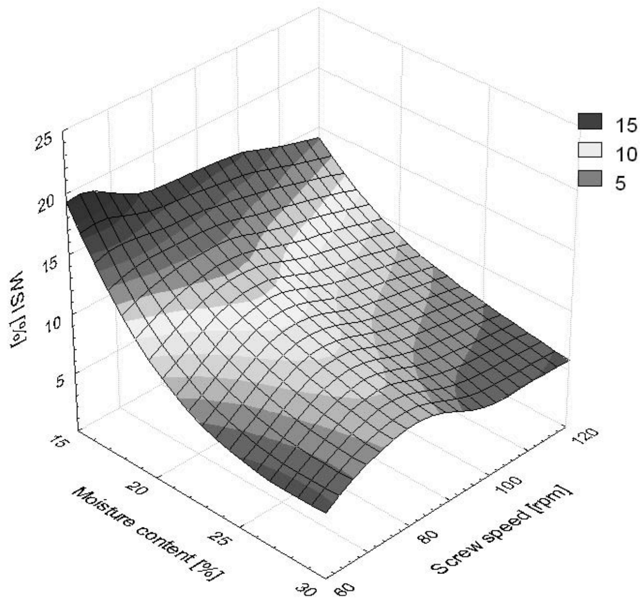

Fig. 5. Wheat starch WSI changes during extrusion-cooking at 140 °C

The research showed that the starch moisture content increase caused reduction of extruded starch WSI (fig. 5). Similar effects of decreasing moisture on WSI have been reported earlier for starch, maize grits and wheat flour [16]. During the studies initial increase (60-80 rpm) and than decrease (100-120 rpm) in modified starch solubility with extruder screw speed increase was observe. WSI values of the extruded wheat starch ranged from 3.8 to 19%. The changes of the solubility of starch were related with changes in the process of gelatinization and starch degradation due to starch moisture content increase. At low to intermediate moisture content and high temperature, the water contained in starch might behave like a lubricant [6]. Degradation of starch progressed by increasing extruder screw speed at low moisture content because less lubricant (water) was available.

CONCLUSIONS

In the light of obtained results following conclusions can be overtaking:

1. Modification of wheat starch by extrusion-cooking technique is characterized by relatively low specific mechanical energy consumption, ranged from 270 to 1069.2 $kJkg^{-1}$ (0.075-0.297 $kWhkg^{-1}$). Significant impact on the values of the SME had a screw speed and a moisture content of the raw material.
2. Extrusion-cooking technique allows creating the degree of gelatinization of processed starch. It was possible to achieve low or high level of gelatinization depending on the process parameters. This is especially important for food and feed applications.
3. Expansion index of wheat starch largely depended on the parameters of the extrusion process. Its value decreased with moisture content increase while increased with screw speed increase.

4. The extrusion process of starch increased the water absorption and cold water solubility. WAI values of the extruded wheat starch ranged from 369 to 690% while WSI ranged from 3.8 to 19%. These changes were closely related to the course of the process of starch gelatinization and degradation and their extent depends on the extrusion parameters used.

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EKSTRUZJA SKROBI PSZENNEJ

Streszczenie. W trakcie badań określano wpływ parametrów procesu ekstruzji na zmiany fizycznych właściwości skrobi pszennej. Proces ten charakteryzuje się niską energochłonnością w zakresie 270-1069 $kJkg^{-1}$. Technika ekstruzji umożliwia kreowanie stopnia skleikowania przetwarzanej skrobi. Możliwe jest uzyskanie niskiego lub wysokiego stopnia skleikowania skrobi w zależności od zastosowanych parametrów procesu. Stopień ekspandowania ekstrudatów malał wraz ze wzrostem wilgotności skrobi pszennej. Stwierdzono, że zastosowanie procesu ekstruzji powoduje wzrost absorpcji wody i rozpuszczalności skrobi w zimnej wodzie. Najwyższa wartość WAI wynosiła 690% a WSI 19%.

Słowa kluczowe: skrobia pszenna, ekstruzja, energochłonność, kleikowanie, rozpuszczalność, absorpcja wody.