Influence of process conditions and fillers addition on extrusion-cooking efficiency and SME of thermoplastic potato starch

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S u m m a r y. The aim of this paper is to present the results of the efficiency process and SME measurements during the extrusion-cooking of thermoplastic potato starch enriched with flax fibers, cellulose and ground bark.A modified single screw extrusion-cooker TS-45 with L/D = 18 and with an additional barrel cooling section was used in the experiments. The effect of the screw speed and the quantity and type of natural fillers added to the blends containing 20% of glycerol as plasticizer on the efficiency of the baro-thermal processing as well as energy consumption was the main concept of the investigation. It was proved that the increase of screw speed influences on higher process efficiency and SME values irrespective the type and amount of fillers, whereas additive level in the recipes had a slight effect on the tested characteristics.

K e y w o r d s: thermoplastic starch, fillers, extrusion-cooking, energy consumption – SME.

INTRODUCTION

Thermoplastic starch (TPS) based products are fully degradable and are successfully used in agricultural, horticultural and food sector for packaging of dry foods [3, 22, 23]. The production of TPS-based products is possible with commonly known machinery and equipment used by plastic manufacturers and these products may be complementary to alternative plastics, however they do not have a wide application because of the utility of certain defects [12, 23]. In recent years large-scale studies aimed the increased share of starch in high quality starch-plastic composites. The main reasons for such modifications are environmental regulations of EU requirements for the improvement of recyclable or biodegradable packaging materials. Most of plastic wastes are resistant to degradation, due to the content of polymers which remain in the environment for a long time. TPS may be an effective additive which accelerates the degradation process by shortening polymer chains and reducing decomposition time [4, 13]. The issue of using starch of different origins (mostly maize, wheat, potato, tapioca) for the production of TPS biodegradable packaging materials is discussed in numerous scientific papers. Unfortunately, mechanical properties of TPS-based materials are weaker than conventional plastics. In order to improve their physical properties or material strength as well as the elasticity of the obtained products, various fillers should be added to raw material blends in the amount ranging from 1 to even 50%, according to the type of additives used. Flax, hemp, jute, coir, cotton fibers and wastes from wood industry seem to be most commonly applied materials.

Due to the new trends in biopolymers, the investigations of TPS processing for packaging materials using different types of starches and additives [1, 2, 5, 15] were carried out at the Department of Food Process Engineering, University of Life Sciences in Lublin.

The aim of this work was to investigate the influence of process conditions and different fillers (i.e. flax fibers, cellulose and ground bark addition) on extrusion-cooking efficiency and SME of thermoplastic potato starch.

MATERIALS AND METHODS

Potato starch produced by AVEBE b.v. (NL), mixed with 20% of glycerol of 99% purity produced by Odczynniki Chemiczne – Lublin (PL) was used as the basic raw material. The additives: cellulose fibers vivapur type 102 of JRS GmbH (D), flax fibers and ground bark (Polish rural producers) were applied in the amount ranging from 10% to 30%. Potato starch (16% of the moisture content) and the additives were mixed in laboratory ribbon mixer for 20 minutes. Next, the blends of different compositions were stored for 24 hours in plastic bags before tests [9]. The share of fibers for the prepared blends was 10%, 20% and 30% of the sample mass. The prepared samples were again mixed for 10 minutes, prior to extrusion, which guaranteed getting loose structure of the compounds.

The study was performed using a modified single screw extrusion-cooker type TS 45 (Polish design) with L/D=18/1, equipped with an additional cooling section of the barrel and a forming die with a 3mm hole diameter. Granulates were produced using the extruder screw speed of 60 rpm, 80 rpm and 100 rpm. Extrusion-cooking process temperature was set in the range of 60°C - 110°C and maintained appropriately, adjusting the intensity of the flow of cooling liquid. The processing temperature was measured by thermocouples installed along the barrel; the results were recorded. Rotational speed of the screw was monitored using an electronic tachometer DM-223AR Wireless [9, 19, 20, 21].

The efficiency of TPS extrusion-cooking process according tothe screw speed and the addition of different types of fibers applied wasevaluated by setting the weight of TPS pellets obtained at a given time for all the mixtures according to following formula [17, 18]:

$$Q = \frac{m}{t}[\mathrm{kg \cdot h^{-1}}], \qquad (1)$$

where:

Q - process efficiency,

m – sample mass obtained during the measurement [kg],

t - measurement time [h].

Power measurement was performed using a standard wattmeter connected to the motor unit of the extruder. After consideration the motor load, screw speed and process efficiency the specific mechanical energy index (SME) according to the formula given in literature [2, 6, 7, 8, 9, 11, 14, 16] was evaluated:

$$SME = \frac{N \cdot O \cdot P}{N_m \cdot 100 \cdot Q}[\mathrm{kWh \cdot kg^{-1}}], \qquad (2)$$

where:

N - screw speed [min^{-1}],

N_m - the maximum screw speed [min^{-1}],

P - power [kW],

O - motor load [%],

Q –process efficiency [$kg{\cdot}h^{-1}$].

The measurements were made in six repetitions for each series of tests. Correlation coefficients were determined according to the influence of screw speed and the amount of fillers on efficiency process and SME values. Trend lines and regression equations were designated.

RESULTS

The efficiency of TPS extrusion-cooking process was directly correlatedwith the screw speed; the higher the screw speed applied, the higher the efficiency process was obtained, with correlation coefficients ranging from 0.99 for samples without the additive to 0.93 with addition of 30% cellulose fibers. The increasing content of cellulose fibers in the formulations for the sample processed at 60 rpm caused a slight increase of efficiency process (cor. coefficientof 0.82).The opposite tendencies to lower the efficiency with the increased level of cellulose fibers were observed for the screw speed of 80 and 100 rpm (-0.86 and -0.82, respectively). The highest process efficiency of 37.4 $kg{\cdot}h^{-1}$ was determined during the extrusion of potato TPS pellets contained 10% of cellulose fibers processed at the highest screw speed of 100 rpm (Fig. 1). The lowest efficiency (23.3 $kg{\cdot}h^{-1}$) was observed for blends without and with the content of 10% of cellulose fibers, processed at 60 rpm screw speed.

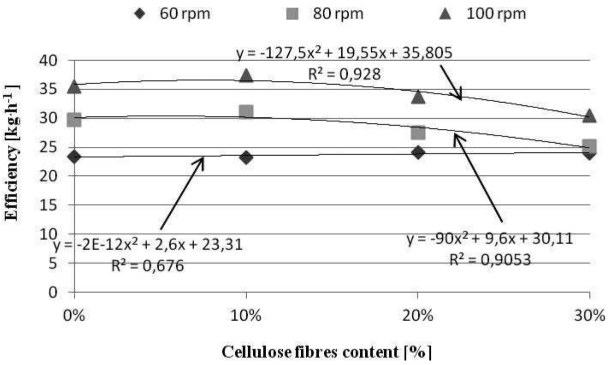

Fig. 1. Effect of screw speed and cellulose fibers content on the efficiency process of potato TPS pellets

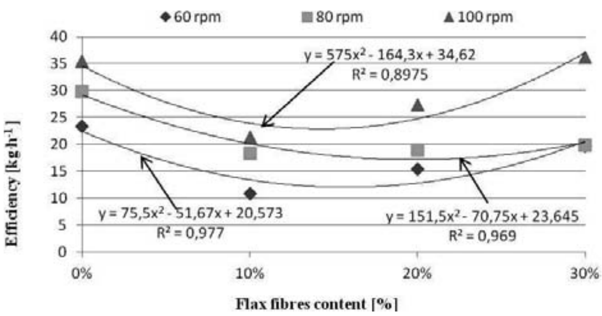

Fig. 2. The influence of the screw speed and flax fibers content on the efficiency of the extrusion-cooking of potato thermoplastic pellets

The results of process efficiency for blends with flax fibers are presented in Fig. 2. A bit similar effect was observed for samples with addition of flax fibers. The efficiency of process increased when increasing screw speed was applied (cor. coefficients ranging from 0.86 at 30% of flax fibers to 0.99 without the additive).The lowest efficiency of extruded blends was registered for the samples with the content of 10% of flax fibers.

The application of ground bark to all kinds of mixtures resulted in the decrease of efficiency of the extrusion-cooking (correlation coefficients -0.77, -0.96 and -0.83 for 60 rpm, 80 rpm and 100 rpm, respectively). Differences between trials were small and calculated to the value of 1,0 $kg{\cdot}h^{-1}$. The results are presented on the Fig. 3. A strong impact of screw speed applied during processing onthe process efficiencywas observed, with correlation coefficients varying from 0.99 for samples without additives to 0.95 for samples with 30% of bark.

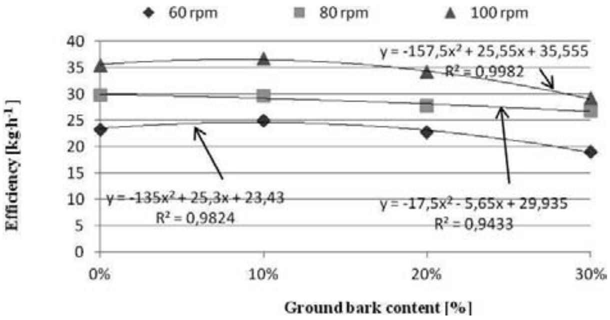

Fig. 3. The influence of the screw speed and ground barkcontent on the efficiency of the extrusion-cooking of TPS pellets

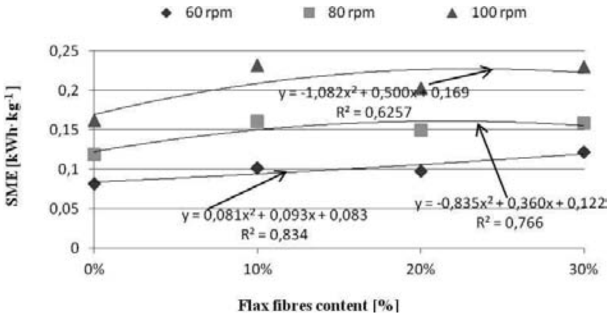

Fig. 5. The influence of the addition of flax fibers and the screw speedused on SME values

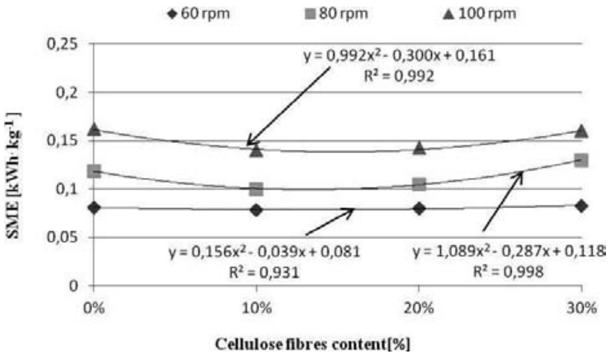

Fig. 4. The influence of cellulose fibers addition and the screw speedon the energy consumption

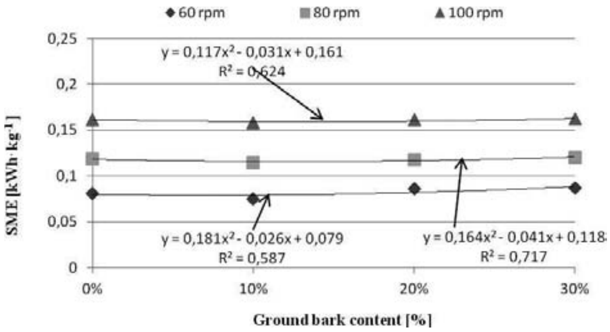

Fig. 6. The influence of the addition of ground bark and screw speed on the SME values

The application of the extrusion-cooking technology to produce TPS pellets takes into account another important factor - the specific mechanical energy SME required to obtain the unit of final product [18]. During the measurements it was found out that the consumption of energy strongly depended on the screw speed used during processing. SME values were higher with increasing screw rotations (0.98-0.99), irrespective of the type of additive applied.

Fig. 4 presents the results of SME for samples with the addition of cellulose fibers. For samples processed at 60 rpm there was no impact of additive level on SME values. For higher rpm applied, the addition of cellulose fiber in amount of 10% lowered SME, but a higher level of the additive slightly increased SME during processing.

For TPS samples contained flax fibers, the increase of SME with a higher level of additive in the recipe with correlation coefficients 0.91, 0.72 and 0.69 for 60, 80 and 100 rpm, respectively was observed (Fig. 5). A higher SME in these samples may be affected by the filamentous nature of flax fibers and due to its greater length; samples with this additive display greater resistance during processing. The highest SME values of 0.23 $kWh \cdot kg^{-1}$ were noticed for the sample containing 30% of flax fibers processed at 100 rpm of the screw.

It was noticed that SME values were similar during processing of biopolymers containing cellulose fibers and ground bark. The addition of ground bark as a filler had no significant impact on the energy consumption (Fig. 6). Higher values of SME were recorded during processing of potato TPS pellets containing ground bark at higher screw rpm, with 0.99 correlation coefficient evaluated for each level of additive in the recipe.

CONCLUSIONS

The efficiency of the extrusion-cooking of potato thermoplastic starchwas directly correlated to the screw speed applied; the higher the screw rotation, the higher the efficiency was obtained. The addition of natural fillers decreased the process efficiency.

The values of SME were strongly affected by the screw speed during extrusion-cooking, where a higher rpm resulted in higher SME.

The obtained SME results were similar during processing of biopolymers containing cellulose fibers and ground bark.

The increased level of additive resulted in higher SME during processingonly for samples with flax fibers. The highest energy consumption of 0.23 $kWh \cdot kg^{-1}$ was noticed during the production of potato TPS pellets containing 30% of flax fibers, processed at 100 rpm of the screw.

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WPŁYW PARAMETRÓW PROCESU I DODATKU WYPEŁNIACZY NA WYDAJNOŚĆ I ENERGOCHŁONNOŚĆ EKSTRUZJI TERMOPLASTYCZNEJ SKROBI ZIEMNIACZANEJ

Streszczenie. W pracy przedstawiono rezultaty badań wydajności i energochłonności procesu ekstruzji termoplastycznej skrobi ziemniaczanej z dodatkiem wypełniaczy w postaci włókien celulozowych,lnianych oraz mielonej kory. W badaniach zastosowano zmodyfikowany ekstruder jednoślimakowy TS-45 o L/D=18 z dodatkowym chłodzeniem końcowej części cylindra urządzenia. Badano wpływ prędkości obrotowej ślimaka ekstrudera oraz ilości i rodzaju stosowanego wypełniacza w mieszance zawierającej 20% gliceryny jako plastyfikatora na wydajność oraz energochłonność procesu ekstruzji mieszanek skrobi termoplastycznej. Wraz ze wzrostem prędkości obrotowej ślimaka ekstrudera rosła energochłonność oraz wydajność procesu ekstruzji w przypadku wszystkich rodzajów zastosowanych mieszanek surowcowych.

Słowa kluczowe: skrobia termoplastyczna, wypełniacze, ekstruder, energochłonność.