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Study on the process of single-screw extrusion-cooking of mixtures with a content of pea hulls

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A b s t r a c t. A study was conducted on the possibility of application of pea hulls as a valuable source of dietary fibre and of biologically active compounds for the production of cereal extrudates. The research was performed using a single-screw extrusion-cooker with a compression ratio of 3:1 and L:D=12:1, using the following cereal materials: commercially available corn grits, pea hulls of cv. Opal, and oats bran. The aim of the study was to examine the effect of the leguminous material and of the process parameters (profile of barrel temperature distribution and raw material moisture) on the possibility of stabilization of extrusion conditions, physical properties of the extrudates, and on the sensory features of the product. The study showed that the technology of single-screw extrusion-cooking can be applied to process mixtures containing maximum 15% of pea hulls; higher levels of the pea hulls content caused a disturbance of the stability of the process and so-called 'material slippage'. Increase of the pea hulls content in the mixture above 10% caused a decrease in radial expansion and an increase in specific density even up to 140 kg m^{-3}. Moderate introduction of pea hulls did not result in any deterioration in the texture of the extrudates. The physical properties of the extrudates were significantly affected by the temperature of extrusion and by the raw material moisture content. Increased process temperature resulted in a decrease in radial expansion with simultaneous decrease in specific density of products, increase in crispness and decrease in the WAI of the extrudates. Increase in the moisture of the processed material, on the other hand, resulted in lower radial expansion, increased specific density, and increased water absorption index (WAI) of grinded extrudates. Admixture of pea hulls in amounts up to 7.5% did not cause any deterioration in the sensory features of the extrudate.

K e y w o r d s: extrusion-cooking, pea hulls, cereals, physical properties, dietary fibre

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INTRODUCTION

In spite of the health-promoting effect of dietary fibre, demonstrated beyond any doubt by numerous research centres, its consumption in the countries of the rich North is still too low (Van der Kamp, 2004). In the face of the violent increase in the rate of incidence of such diseases as obesity and type II diabetes, increase in the consumption of high-fibre foods becomes extremely important and makes food process engineers engage in the search for new sources of dietary fibre and in the creation of new high-fibre food products. The most popular and most extensively used so far high-fibre components are cereal products – oats bran and wheat bran. Studies conducted by Rzedzicki *et al*. (2004a) and by Troszyńska and Bałasińska (2002); Troszyńska *et al*. (1997; 2002) showed that also pea hulls, a by-product of pea husking, is a high-fibre material worthy of attention. Pea hulls contain 67.64% d.m. of total dietary fibre (TDF), but the dominant fraction here is insoluble dietary fibre (IDF), constituting 61.84% d.m.; soluble dietary fibre (SDF) is present only in the amount of 5.81% d.m. (Rzedzicki *et al*., 2004a). Apart from the high content of dietary fibre, pea hulls are a valuable source of mineral compounds and of biologically active compounds, such as polyphenols, phytinians, tocochromanols, oligosaccharides, and trypsin inhibitors – among others. At present, an important role is attributed to those compounds in the prophylactics and treatment of numerous civilisation diseases. Studies in vivo and in vitro conducted by Troszyńska and Bałasińska (2002); Troszyńska *et al*. (1997; 2002) showed that polyphenols and tocochromanols, present in pea hulls, are characterized by strong antioxidative activity and have a favourable effect on the level of total cholesterol and of the it's LDL fraction. Studies conducted so far (Rzedzicki *et al*., 2004b) showed that pea hulls can be successfully applied at rates of even up to 80% in the technology of twin-screw extrusion-cooking. However, the range of application of extrudates of that type is limited, hence a study was undertaken on the possibility of application of that raw material in the production of snacks for direct consumption in the high popular technology of single-screw extrusion-cooking. Introduction of the high-fibre raw material for products of that type is extremely significant, as the basic raw material here is corn semolina, a component with very poor chemical composition and very low content of dietary fibre (Table 1). Every instance of enriching products of this type in nutrients and dietary fibre assumes special importance as such products are particularly favoured and consumed by children.

MATERIALS AND METHODS

Raw materials used in the study were commercially available corn grits, oats bran, and pea hulls of cv. Opal. The chemical composition of the raw materials (Table 1) was determined according to AACC–Approved Methods (2000). Pea hulls were grinded until obtaining equivalent diameter of about 0.89 mm (Table 2). The process of pea hulls grinding was conducted so that the share of mealy fractions <0.5 mm was not less than 20%. At the same time care was taken to retain a fairly high content of fraction above 1 mm, so as to ensure that the product would have the 'physiological brush effect'. The fractional composition of the raw materials and the equivalent diameter were determined according to Rzedzicki (1996). The raw materials mentioned above were used to prepare mixtures in accordance with the assumed model of the experiment (Table 3). To improve the physical properties of the extrudates and to modify the fractional composition of the dietary fibre, admixture of oats bran was applied, at the rates of 3.5 and 5%. Additionally, whole powdered milk was introduced in the mixtures, at the rate of 0.5%. The mixtures were wetted, stirred thoroughly, and conditioned for 12 h at room temperature. The process of extrusion cooking was performed using a single-screw extrusion-cooker with compression ratio of 3:1 and L:D=12:1. Variable process parameters included the profile of temperature distribution in the extrusion-cooker barrel and the moisture content of the raw material. The process parameter ranges applied in the study and the composition of

T a b l e 1. Chemical composition of the raw materials (% d.b.)

Raw material	N-free extract	Protein N x 6.25	Fat	Crude fiber	Ash	TDF*	IDF*	SDF*
	(%)							
Maize semolina	85.95	11.18	1.12	0.48	1.27	6.43	5.31	1.12
Pea hulls	44.93	15.48	1.77	32.98	4.84	67.45	62.05	5.40
Oat bran	69.28	17.16	7.81	2.62	3.13	24.39	14.34	10.05

*TDF – total dietary fibre, IDF – insoluble dietary fibre, SDF – soluble dietary fibre.

T a b l e 2. Sieve analysis of components

Fraction (mm)	Corn semolina	Pea hulls	Oat bran
	(%)		
>1.6	-	1.6	2.25
1.6-1.2	4.1	21.4	12.37
1.2-1.0	22.5	17.1	16.98
1.0-0.8	27.1	18.7	24.44
0.8-0.5	29.2	19.7	25.24
0.5-0.265	14.3	11.1	9.36
0.265-0.1	1.5	7.1	7.76
<0.1	1.3	3.3	1.60
Sum of fractions <0.5	17.1	21.5	18.72
Mean diameter (mm)	0.80	0.89	0.83

T a b l e 3. Model of the experiments

Sample	Component (%)				Moisture (%)	Temperature (°C)
	Corn semolina	Pea hulls	Oat bran	Milk powder		
1	94	2.5	3.5	0	13.5	130/145/125
2	91.5	5	3.5	0	13.5	130/145/125
3	89	7.5	3.5	0	13.5	130/145/125
4	86.5	10	3.5	0	13.5	130/145/125
5	84	12.5	3.5	0	13.5	130/145/125
6	81.5	15	3.5	0	13.5	130/145/125
7	92	2.5	5	0.5	13.5	130/145/125
8	89.5	5	5	0.5	13.5	130/145/125
9	87	7.5	5	0.5	13.5	130/145/125
10	84.5	10	5	0.5	13.5	130/145/125
11	82	12.5	5	0.5	13.5	130/145/125
12	90	10	0	0	13.5	130/145/125
13	90	10	0	0	14.0	130/145/125
14	90	10	0	0	14.5	130/145/125
15	90	10	0	0	15.0	130/145/125
16	90	10	0	0	15.5	130/145/125
17	90	10	0	0	16.0	130/145/125
18	90	10	0	0	16.5	130/145/125
19	90	10	0	0	13.5	110/125/125
20	90	10	0	0	13.5	120/135/125
21	90	10	0	0	13.5	130/145/125
22	90	10	0	0	13.5	140/155/125
23	90	10	0	0	13.5	150/165/125
24	90	10	0	0	13.5	160/175/125

the mixture were determined on the basis of pilot experiments. Only such parameters ranges were adopted that guaranteed correct and stable run of the process, extrudate quality corresponding to that of snacks products of the type on the market, and sensory similarity of the snacks to corn crisps, hence only the 3.5 mm die diameter was adopted in the study. The extrudates obtained were subjected to determinations of their physical properties. Radial expansion ratio was determined as the relation between the cross-sectional of area of the extrudate and that of the die (Rzedzicki *et al*., 1997). Specific density of the extrudate was established in relation to its inner pores according to the method described by Rzedzicki (1996). Texture of the extrudate was measured as the amount of energy used for the destruction of 1 g sample (Rzedzicki, 1994). Water absorption index was analysed by means of the reflux method (Jao *et al*., 1985) and centrifugal method (AACC, 2000). Sensory evaluation was carried out using 9 points hedonic scale. Also the microstructure of the extrudates was studied, with the help of a scanning electron microscope. Measurements of radial expansion ratio and of texture were made in 52 replications, discarding two extreme results. Water absorption with the reflux and the centrifuge methods was measured in six replications. Chemical composition was determined in three replications. Mean values, standard deviations and coefficients of variability were calculated. If the values of the coefficient of variability exceeded the adopted error level for a given method, the experiments were repeated. For continuous variables analysis of regression was performed. Equations of regression and coefficients of determination R^2 were determined.

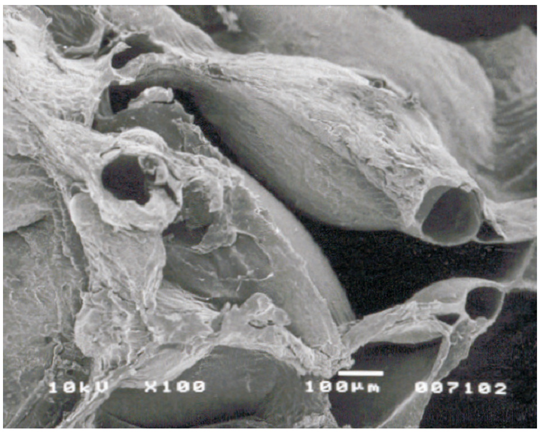
RESULTS AND DISCUSSION

Single-screw extrusion cooking of corn grits with an admixture of pea hulls proceeds correctly at pea hulls addition rates of up to 15%. Attempts at introducing greater amounts of pea hulls caused the disappearance of reverse flow, resulting in a disturbance of the stability of the process; the processed material was not suitably liquefied and flowed through the extrusion-cooker's barrel in an uncontrolled manner, which is referred to as 'material slippage'. Increase in the share of oats bran in the processed mixtures from 3.5 to 5% limited the possible level of pea hulls admixture to 12.5%; at that level of oats bran content, 15% admixture of the leguminous material was too high and already caused 'material slippage'. Material slippage was also observed when exceeding barrel temperatures of 160/175/125°C. Additionally, whole powder milk was introduced in the mixtures. Even a slight admixture of that component performs in the technology of extrusion cooking the function of an indicator of product overheating. Every instance of exceeded temperature is immediately signalled by darkening of the extrudate. It should be emphasized that the introduction of pea hulls did not significantly alter the efficiency of the extrusion-cooker.

In accordance with the methodological assumptions, all the products obtained, analysed in the study, had to have the features of a food product with parameters acceptable in sensory tests. Samples falling outside of the adopted assumptions were excluded from the model of the experiment, hence only extrudates having fully acceptable porous and crunchy structure, similar to the structure of honeycomb (Figs 1a, 1b), were approved for subsequent testing. The photos present examples of extrudates with 10% content of pea hulls. The numerous air pores visible in Fig. 1a, with dimensions of the order of several hundred μm, have a specific baggy shape with distinct venting holes. In comparison to other starch extrudates (Rzedzicki and Błaszczak; 2005), relatively thick air cell walls can be observed, resulting in increased density of the extrudate. In spite of the 10% content of pea hulls, no big fragments of non-liquefied mass are observed. It is to be assumed that the applied degree of grinding and the adopted process parameters ensured complete blending of pea hull fragments in the structure-forming binding agent of corn grits.

In studies performed to date it has been shown that the microstructure of the extrudate is the creator of its physical properties (Rzedzicki and Błaszczak; 2005). Therefore, it was to be expected that extrudates with a content of pea hulls, having relatively thick air cell walls and baggy pore shapes, would differ considerably from other cereal extrudates. That was not the case with expansion – the studied extrudates were very well expanded, reaching even the level of radial expansion ratio of 22. In accordance with the expectations, a notable decrease in the radial expansion was observed with increasing share of pea hulls admixture (Fig. 2). Opposite to changes in radial expansion were the changes in the values of specific density. With increasing percentage of pea hulls admixture in the extruded mixture there was a significant increase in the specific density of the product, reaching even the level of 140 kg m^{-3}, while in other cases of extruded snacks values of the order of 50 kg m^{-3} were

a



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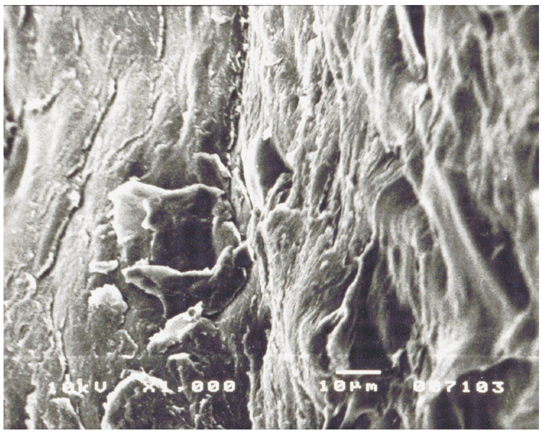

Fig. 1. Microstructure of the extrudate: rate of pea hulls – 10%, die – 3.5 mm, temperature – 130/145/125°C, moisture – 13.5%; a – magnification x100, b – magnification x1000.

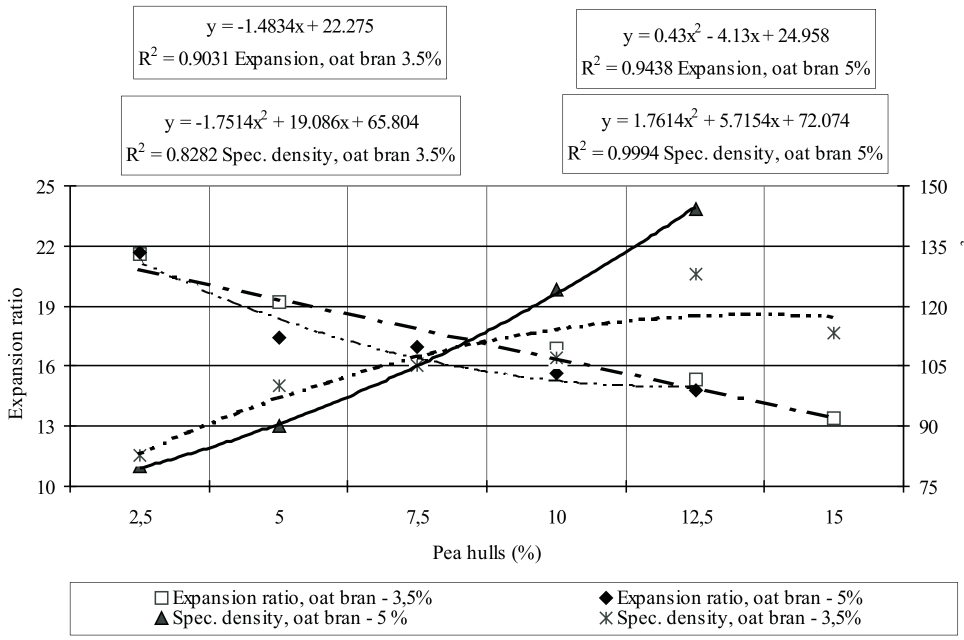

Fig. 2. Influence of the pea hulls share rate on the expansion ratio and the specific density of the extrudate (die – 3.5 mm, temperature – 130/145/125°C, moisture content – 13.5%).

observed (Rzedzicki *et al*., 2000). Such high values of density find no support or justification in the microstructure (Figs 1a, 1b) nor in the values of radial expansion. Regularities of this type are observed in cases when the extruded mass, pressed out of the die, is strongly adhesive to the die surface, which results in strongly restricted longitudinal expansion.

In spite of the recorded high values of specific density, the structure of the obtained extrudates is delicate and crunchy. This is supported by results of texture determinations. The admixture of pea hulls in amounts of up to 10% caused a loosening of the structure, a notable improvement in the crunchiness of the products, and a decrease in the values of destructive energy (Fig. 3). The best texture was characteristic of snacks containing 7.5- 10% of pea hulls, for which the values of destructive energy, necessary for multiplane sample shearing, fell within the range of 0.33-0.34 J g^{-1}. Varied admixture of oats bran, in the amounts of 3.5 and 5%, had no effect on the values of the energy nor caused a deterioration in the texture of the products. An effect of bran admixture was observed only in samples containing more than 10% of the leguminous raw material.

The content of pea hulls in the extruded mixture had a significant effect on the absorption characteristics of the products. A differentiated effect of the content of the leguminous raw material on the water absorption capacity was observed, especially in the centrifuge method. Grinded extrudates (centrifuge method) had a water absorption capacity of even 640%, while the extruded product (reflux method) could absorb water in amounts up to 460% (Fig. 4). The centrifuge method permits the determination of the capacity of a product for water binding by the grinded and therefore easy-to-hydrate extrudate. In the reflux method, determining the water absorption of non-grinded extrudate, the applied 15 min time of soaking appears to be too short for complete hydration Rzedzicki and Sobota (1999). Therefore, the study of water absorption capacity with the reflux method permits the determination of the amount of water a product has managed to absorb during the hydration time (15 min.), wile water absorption examined with the centrifuge method on grinded product determined the total amount of water that the product is capable of absorbing. The results of studies on the water absorption of extrudates and shape of curves, as a fun- ction of pea hulls content, especially that of centrifuge method, find support in the macro- and microstructure of the extrudates and in the notable increasing values of specific density (Fig. 2). WAI is increasing when pea hulls content increase from 2.5% to 5-7.5%. In those facilities snacks are very porous and increase of WAI is associated with protein increase. At 10% pea hulls content minimum extreme is observed, because of very compact microstructure. Higher content of pea hulls in connected with loosing microstructure and better facilities of product moistening.

Another significant factor affecting the physical properties of extrudates is extrusion parameters, including the process temperature and the raw material moisture content. Within the studied range, increase in extrusion-cooking temperature from 110/125/125°C to 160/175/125°C

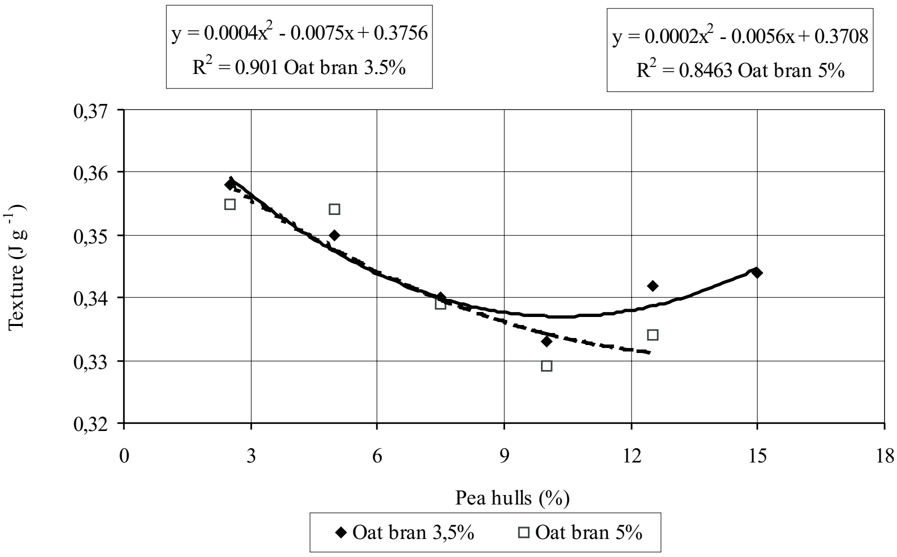

Fig. 3. Influence of the pea hulls share rate on the texture of the extrudate. Explanations as in Fig. 2.

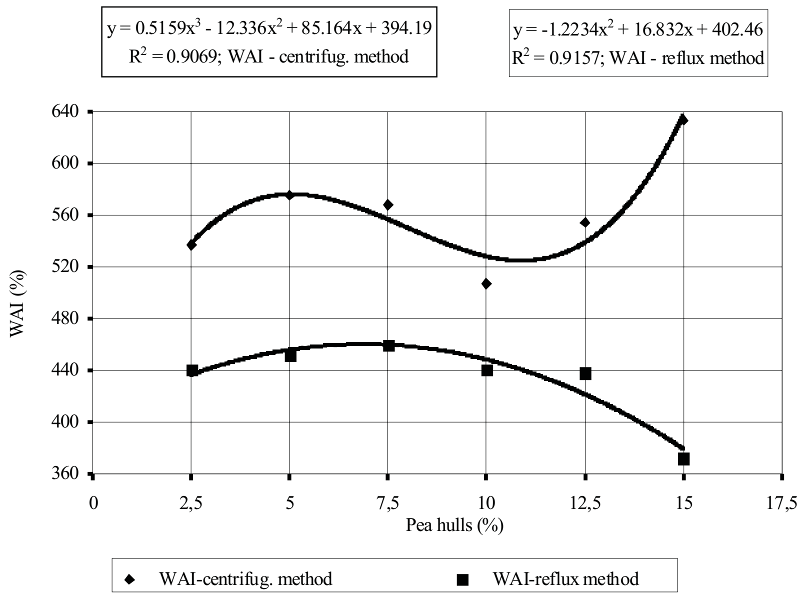

Fig. 4. Influence of the pea hulls share rate on the water absorption index (WAI) of the extrudate. Explanations as in Fig. 2.

caused a slight reduction in the radial expansion ratio, from 17 to approx. 16, with simultaneous reduction in the density of the products from 111.6 kg m^{-3} to 102.81 kg m^{-3} (Fig. 5). Simultaneous reduction in the radial expansion ratio and in the specific density of extrudates is a rare phenomenon that is observable under conditions of domination of longitudinal expansion over radial expansion. Similar behaviour of extruded mass was also observed by Colonna *et al*. (1989) and by Rzedzicki *et al*. (2004b).

The process temperature had an effect also on the texture of the extrudate; within the range studied, increase in the barrel temperature was accompanied by a decrease in the value of destructive energy necessary for multi-plane shearing of the product. The recorded values of destructive energy fell within the range from 0.391 J g^{-1} for temperatures of 110/125/125°C to 0.339 J g^{-1} for temperatures of 160/175/125°C (Fig. 6).

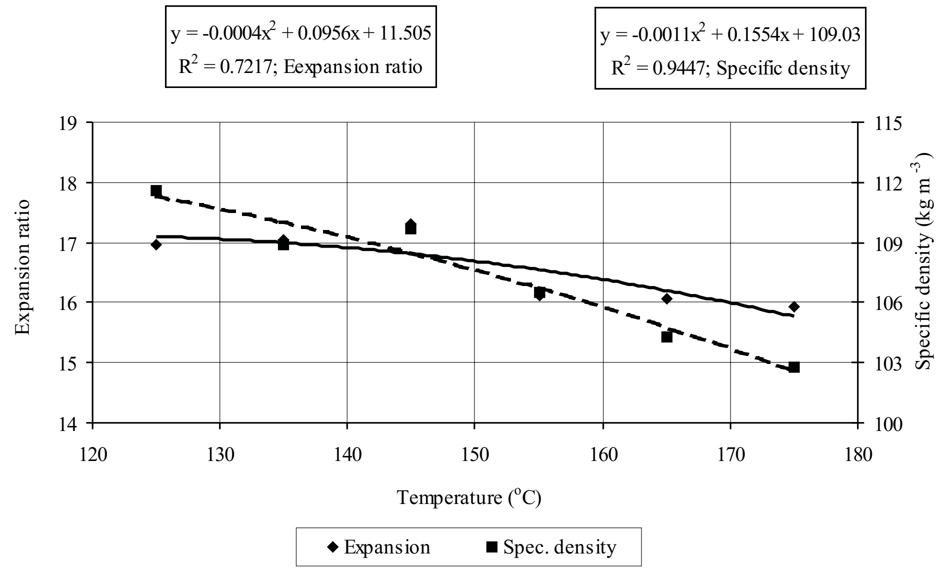

Fig. 5. Influence of the barrel temperature on the expansion ratio and the specific density of the extrudate (rate of pea hulls - 10%, die – 3.5 mm, moisture content – 13.5%).

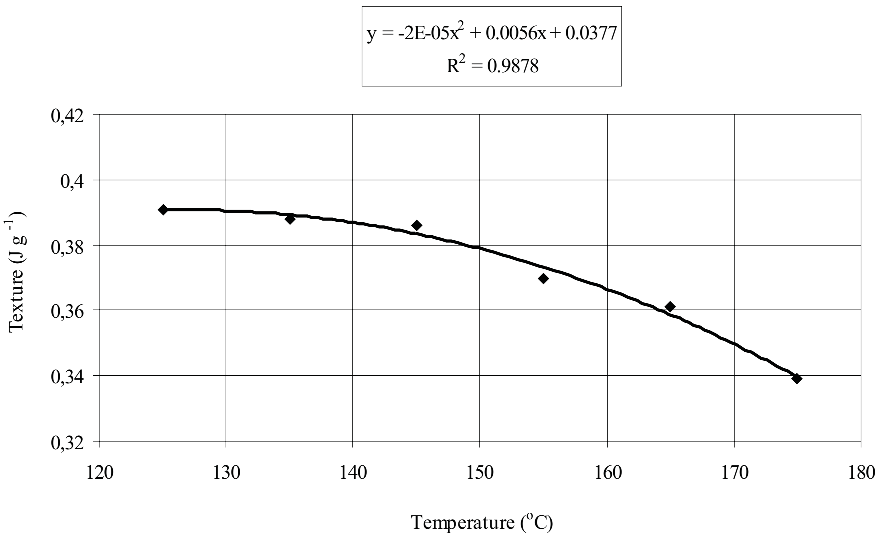

Fig. 6. Influence of the barrel temperature on the texture of the extrudate. Explanations as in Fig. 5.

Another effect of the process temperature was that on the capacity of the extrudate to absorb water. A negative correlation was demonstrated between the temperature of extrusion cooking and the water absorption index (WAI) of the extrudates (Fig. 7), both in the case of the reflux method and of the centrifuge method. Interest may be drawn by the similarity in the shapes of WAI curves as determined with the centrifuge and reflux methods. With increase in the process temperature from 110/125/125°C to 160/175/125°C the values of WAI determined with the centrifuge and reflux methods decreased by 44 and 67%, respectively. Such a layout of the WAI lines should be related with similar shapes of the curves of expansion and of density. The very high WAI recorded for extrudates obtained at temperatures of 160/175/125°C, divergent from the trend line, signals the beginning of material slippage in the extruder barrel. The capacity of the extrudates to absorb water is determined by the degree of their processing. Increase in the extrusion cooking temperature to a level at which starch becomes completely gruelled leads to an increase in the WAI of the extrudates. Further increase in temperature leads to depolymerisation of amylose and amylopectin and to reduced water absorption capacity of the products (Smith, 1992; Colona *et al*., 1989).

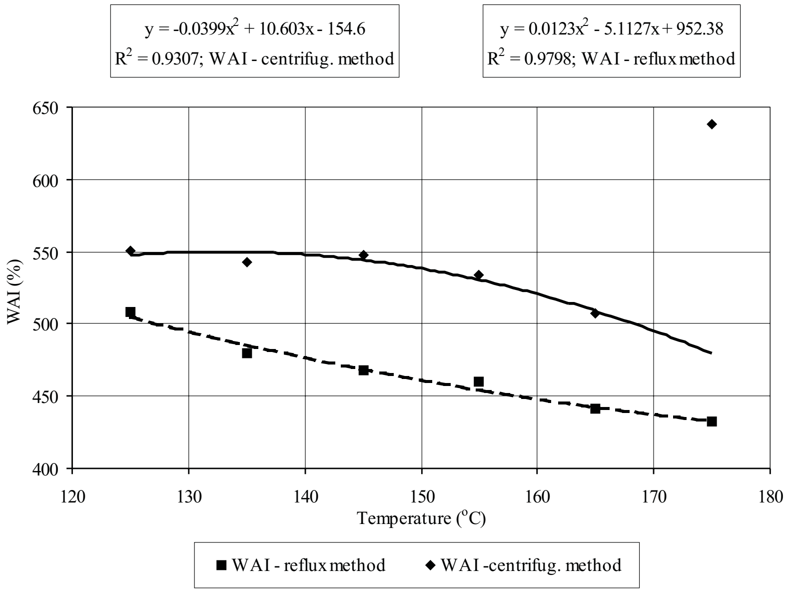

Fig. 7. Influence of the extrusion temperature on the water absorption index (WAI) of the extrudate. Explanations as in Fig. 5.

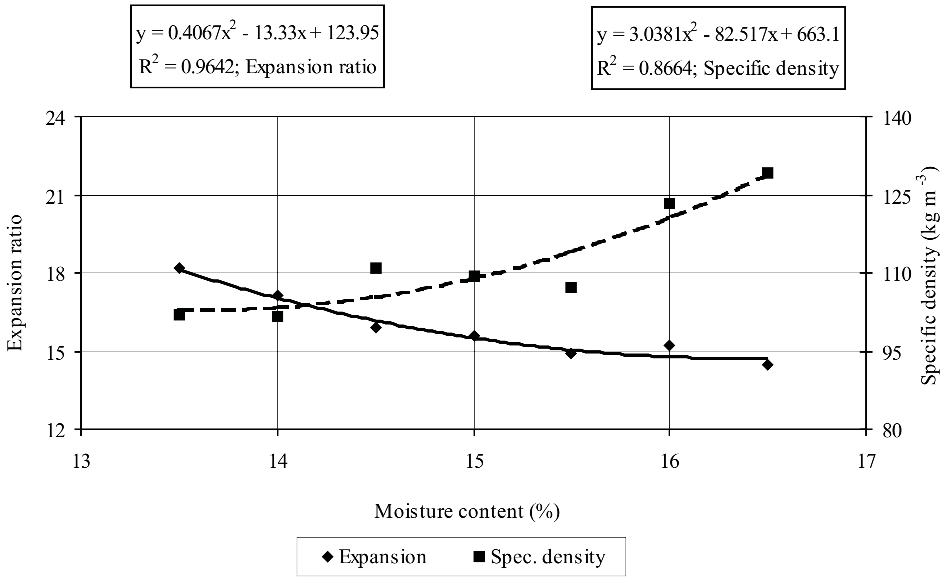

Fig. 8. Influence of the moisture content on the expansion ratio and the specific density of the extrudate (rate of pea hulls - 10%, die – 3.5 mm, temperature – 130/145/125°C).

The physical properties of the extrudates were also affected by the moisture content of the material processed. Within the studied range, increase in the material moisture was accompanied by a decrease in the radial expansion and an increase in the specific density (Fig. 8), hence products with the best expansion and the lowest specific density were obtained with the application of material moisture of 13.5%.

Interesting relations were noted when analysing the effect of raw material moisture on the texture of the products. For many raw materials an increase in the material moisture is accompanied by an increase in specific density, a decrease in expansion, and a deterioration of texture. In this study reverse relations were observed – increase in mixture moisture was initially accompanied by a slight increase in the destructive energy, reaching a maximum at moisture content of about 14.5%, and then by a decrease as the moisture content continued to increase (Fig. 9). It is to be supposed that, within the studied ranges, raw material moisture increase above 14.5% reduces the intensity of thermoplastic processing through a decrease in tangential stresses, which in combination with increasing content of dietary fibre produces a less compacted extrudate.

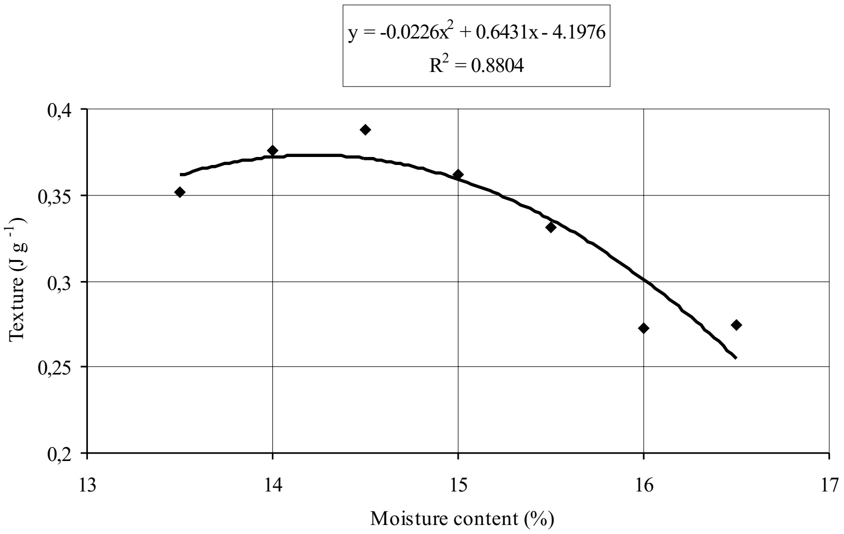

Fig. 9. Influence of the moisture content on the texture of the extrudate. Explanations as in Fig. 8.

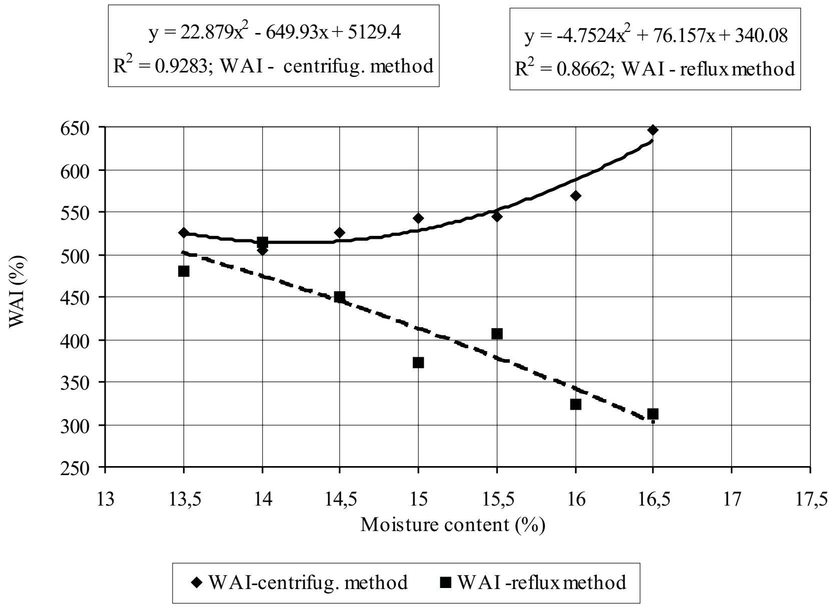

Fig. 10. Influence of the moisture content on the water absorption index (WAI) of the extrudate. Explanations as in Fig. 8.

Analysing the WAI of extrudates as a function of variable moisture of raw material, it was also observed that the determined trend lines differed with relation to the different methods of determination (Fig. 10). The results of WAI determinations with the centrifuge method showed an increase in the water absorption of products from 526 to 646% with raw material moisture increase from 13.5 to 16.5%. In the reflux method, the values of WAI decreased from 480 to 311%, respectively.

The extrudates were also subjected to sensory examinations. Sensory features examined included the appearance, taste, aroma, crunchiness, vitreousness, and stickiness of the product. A summary assessment of the sensory examinations is presented in Fig. 11. Introduction of pea hulls at rates above 7.5% had a slight deteriorating effect on the quality of the product; increasing vitreousness and stickiness of the extrudate was observed with increasing content of pea hulls. Pea hulls admixture at rates up to 7.5% permitted the obtaining of crisps of qualities similar to those of corn crisps. Higher percentage content of pea hulls up to 12.5% did not necessarily mean a worse product; that product was only different from corn crisps and requires consumers acceptations.

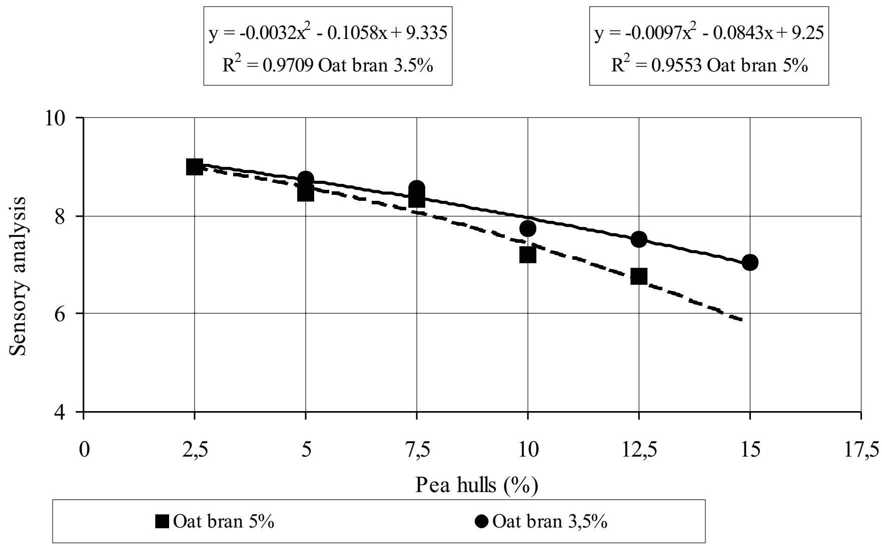

Fig. 11. Influence of the pea hulls share rate on sensory analysis of the extrudate. Explanations as in Fig. 4.

CONCLUSIONS

1. Single-screw extrusion-cooking permits the processing of mixtures containing maximum 15% of pea hulls.

2. Optimum parameters of extrusion of snack-type products with an admixture of pea hulls are as follows: pea hulls content up to 7.5%, process temperature of 130/145/125°C, raw material moisture content of 13-13.5%, and whole powder milk content 0.5%.

3. Increase in the content of the leguminous raw material in the processed material caused a decrease in the radial expansion and an increase in the specific density of the products.

4. A small (7.5-10%) admixture of pea hulls caused an improvement in the crunchiness of the extrudates.

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