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Application of oat whole-meal and protein components as modifiers of extrudates microstructure

P. Zarzycki[1]*, *Z. Rzedzicki*[1], *and W. Błaszczak*[2]

[1]Engineering and Cereals Technology Department, University of Life Sciences in Lublin, Skromna 8, 20-704 Lublin, Poland
[2]Division of Food Science, Institute of Animal Reproduction and Food Research, Polish Academy of Sciences, Olsztyn, Poland

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A b s t r a c t. A study was conducted on the application of oat whole-meal (5, 10, 15%) as a modifier of the structure of corn-oat extrudates. Material for comparison, constituting a point of reference, was oat bran. Additional structure modifiers applied were whole powdered milk, at the rate of 1%, and everlasting pea whole-meal in the amount of 10%. Results showed that oat whole-meal can be successfully applied as a modifier of the structure of extrudates, replacing in this respect the notably more expensive oat bran. The extrudates produced were characterized by microstructure very similar to that of extrudates with a content of oat bran. The extrudates had the characteristic 'honeycomb' pore structure. Over the whole range of process parameters applied, total liquefaction of raw material was observed, even at 15% content of oat whole-meal in the blends. Change in the moisture content of the material blends and in the process temperature had a notable effect on the microstructure of the products, causing changes in the thickness of walls of air pockets and in their dimensions, among other things. No deterioration of extrudate microstructure was observed following the application of the additional modifiers – whole powdered milk and everlasting pea whole-meal.

K e y w o r d s: extrusion-cooking, oat whole meal, everlasting pea, microstructure

INTRODUCTION

Extrusion is a technology commonly used in the production of various types of 'ready to eat' food products *eg* breakfast confectionery and snack-type products. The primary structural material in products of this type is corn grits. Due to its ease of liquefaction, it ensures the obtainment of suitable product structure, similar to that of honeycomb, which permits the production of well expanded products, with low density and very good crispness (Guy, 2001; Hashimoto and Grossmann 2003). The special interest in corn grits in the technology of extrusion results also from the fact that it can be processed within a broad range of process parameters. Corn grits is obtained from de-hulled and degermed corn grain, hence corn products are characterized by a poor chemical composition and by low nutritive value (Rampersad *et al.*, 2003). In order to retain proper quality of the product it is necessary to enrich the corn grits with components increasing its nutritive value. The introduction of pulse plant seeds or cereal bran into the recipe for extrudates increases not only their protein content, but primarily that of dietary fibre and minerals (Adrián *et al.*, 2008; Martin-Cebrejas *et al.*, 1999; Repo-Carrasco-Valencia *et al.*, 2009; Stojceska *et al.*, 2008; Vasanthan *et al.*, 2002).

Extruded corn grits is most frequently supplemented with sources of dietary fibre (Esposito *et al.*, 2005; Repo-Carrasco-Valencia *et al.,* 2009) which has a favourable effect on the human organism and reduces the risk of occurrence of many civilization diseases (Aldori *et al.*, 1997; Kahlon, 2001). Oat grain is one of the more valuable sources of dietary fibre. Clinical studies indicate that oat fibre reduces the concentration of total cholesterol in the blood, improves its fractional composition, especially the HDL to LDL ratio, stabilizes the level of glucose in the blood *etc* (Gerhardt and Gallo, 1998; Onning *et al.*, 1999).

The technology of extrusion, in which the raw material passes through a phase of liquefaction, permits very good incorporation of dietary fibre fractions into the structure of the product. With properly selected raw material composition and process parameters it is possible to create products with very good sensory traits (Zarzycki and Rzedzicki, 2008). In spite of the continual expansion of its application onto new areas of food processing, extrusion is still a process that is rather complex and difficult to master. Even slight changes in process parameters or in the chemical composition of the

*Corresponding author's e-mail: piotr.zarzycki@up.lublin.pl

raw materials processed may result in considerable changes in the process run and in the quality of the products, especially in the case of products with increased content of dietary fibre (Desrumaux *et al.*, 1999). The introduction of fibre components in extrudates causes changes in the degree of expansion, texture, density *etc* (Liu *et al.*, 2000; Veronica *et al.*, 2006). Among the fibre materials used, oat raw materials are among those whose application in extrusion encounters notable difficulties (Fornal *et al.*, 1995; Mendonça *et al.*, 2000). Their high content of fats, low content of starch, high content of (1→3) (1→4) β-D glucans make the selection of suitable process parameters difficult. Studies conducted to date indicate that in the case of single-screw extrusion the maximum content of oat components (whole-meal, bran) in the extruded blends may be approx. 18%; higher levels of oat components cause material slippage (Rzedzicki and Zarzycki, 2005). Obtaining corn extrudates of good quality requires also the enrichment of the raw material blend with high-protein components. Therefore it is necessary to perform research permitting the determination of optimum process parameters and the effect of the material blend composition on the properties of the products and on their microstructure. Studies conducted so far indicate that it is the microstructure that primarily creates the physical properties of the product (Błaszczak and Fornal, 2008; Rzedzicki and Błaszczak, 2005).

The aim of this study was to identify the possibility of creating the corn extrudates microstructure through changes in the moisture of the material, temperature, and varied levels of oat components.

MATERIALS AND METHODS

The study was conducted on corn-oat extrudates containing also 5, 10 and 15% admixtures of at components (whole-meal of hulled or hull-less oat cultivars Akt, STH 3997, STH 4097, oat bran). In earlier studies (Rzedzicki and Zarzycki, 2005; Zarzycki and Rzedzicki, 2009) such a level of oat components ensured the possibility of obtaining products with a high degree of expansion, low density and crispness. Some of the raw material blends with 10% content of oat components (oat whole-meal) were supplemented with whole powdered milk (1%) and everlasting whole-meal (10%). Extrusion was conducted in a single-screw extruder (L:D=12:1; screw compression ratio 3:1, die diameter 3.5 mm, screw speed 110 rev min^{-1}) using 3 profiles of cylinder temperature distribution – 125/145/120°C, 145/165/120°C and 160/180/120°C, and two levels of moisture of the raw materials – 13 and 16%.

The studies on microstructure were conducted at the Institute of Animal Reproduction and Food Research of PAN in Olsztyn. Selected samples were used to slice off fragments of extrudates that were then glued with silver paste onto specimen circles, and sprayed with carbon and gold in a vacuum sprayer type JOEL JEE 4X. Microscope analyses were made with the help of electron microscope type JSM 5200.

In the extrudates obtained the degree of expansion was determined as the ratio of the extrudate cross section area to the area of the die aperture. The measure of texture was adopted as the amount of energy required for multi-plane shearing of sample as converted to a value per 1 g of extrudate sample. The measurements were made using an apparatus for multi-plane shearing (Rzedzicki, 1994). Specific density of the extrudates was determined as the ratio of the mass of the extrudates to their volume. Other determinations performed included the water solubility index (WAI) and water solubility of the extrudates (WSI), with the centrifuge method (AACC, 2000), using load value of 5 000 g and separation time of 15 min.

RESULTS AND DISCUSSION

The extrudates obtained, irrespective of their content of oat components, oat cultivar, raw material moisture level and cylinder temperature, were characterized by a specific porous structure, similar to that of honeycomb, with visible numerous air cells with sizes of several hundred μm, ruptured due to the instantaneous boiling of water during the expansion. Such a structure of the product ensures excellent water absorption that may reach even 1 000% d.m., excellent crispness and texture (Table 1). These extremely good physical properties appear to support the thesis Rzedzicki and Błaszczak (2005) that it is the microstructure that creates the physical properties of extrudates. All samples tested, within the studied ranges of the process parameters and raw material features, indicated total liquefaction of the extruded mass. Therefore the information about inhibition of oat starch liquefaction in an environment with increased content of fat and soluble fractions of dietary fibre is not true. This applies also to samples with oat whole-meal content at the level of 15%. Thus, increased content of fats and soluble fractions of dietary fibre did not interfere with the conditions of extrusion and did not negatively affect the quality of the product. Deterioration of the quality of product with increased level of oat component takes place, therefore, as a result of material slippage and disturbed conditions of extrusion and not as a result of improper microstructure.

The study included the determination of the effect of the oat cultivars applied (Akt, STH 3997 and STH 4097) on the microstructure of the extrudates (oat whole-meal admixture at 10%) (Fig. 1). No significant differences were observed in the microstructure of the extrudates related to the oat cultivars. All samples were characterized by thin walls of air cells ruptured through the instantaneous boiling of water during expansion. The air cells were several hundred micrometers in diameter. The most delicate structure was observed in the extrudate with a content of oat cv. Akt. The air cell walls of extrudates with all of the oat cultivars tested had a scaly structure. In the samples tested there were no molten protein fibres, protein bodies or molten protein mass encasing a starch skeleton, so characteristic of lupine or everlasting pea extrudates (Rzedzicki and Fornal, 1998).

T a b l e 1. Model of the experiment and physical properties of the extrudates

Sample No.	Mixture composition (%)								Process parameter		Physical properties of extrudates				
	Maize grits	Hulled oat*	Hull-less oat Akt*	Hull-less oat STH 3997*	Hull-less oat STH 4097*	Whole milk powder	Everlasting pea*	Oat bran	Moisture content (%)	Temperature (°C)	Expansion ratio	Specific density (kg m^{-3})	Texture (J g^{-1})	WAI (% d.b.)	WSI (% d.b.)
1	95	5							13	145/165/120	17.96	73.10	0.43	750.50	22.35
2	90	10							13	125/145/120	17.10	73.60	0.4	770.05	25.95
3	90	10							13	145/165/120	16.05	74.65	0.37	830.41	15.55
4	90	10							13	160/180/120	14.50	74.90	0.32	689.72	21.95
5	90	10							16	145/165/120	14.68	76.75	0.25	884.23	22.04
6	85	15							13	145/165/120	14.32	76.41	0.36	955.20	13.90
7	89	10				1			13	145/165/120	19.05	60.12	0.32	1040.25	43.95
8	80	10					10		13	145/165/120	16.04	67.80	0.29	1020.11	43.06
9	90		10						13	145/165/120	20.35	75.95	0.37	1012.05	27.65
10	90			10					13	145/165/120	19.96	86.01	0.31	870.13	18.20
11	90				10				13	145/165/120	18.03	86.65	0.33	915.21	20.02
12	90							10	13	145/165/120	16.09	63.85	0.31	830.71	40.31

*whole grain meal.

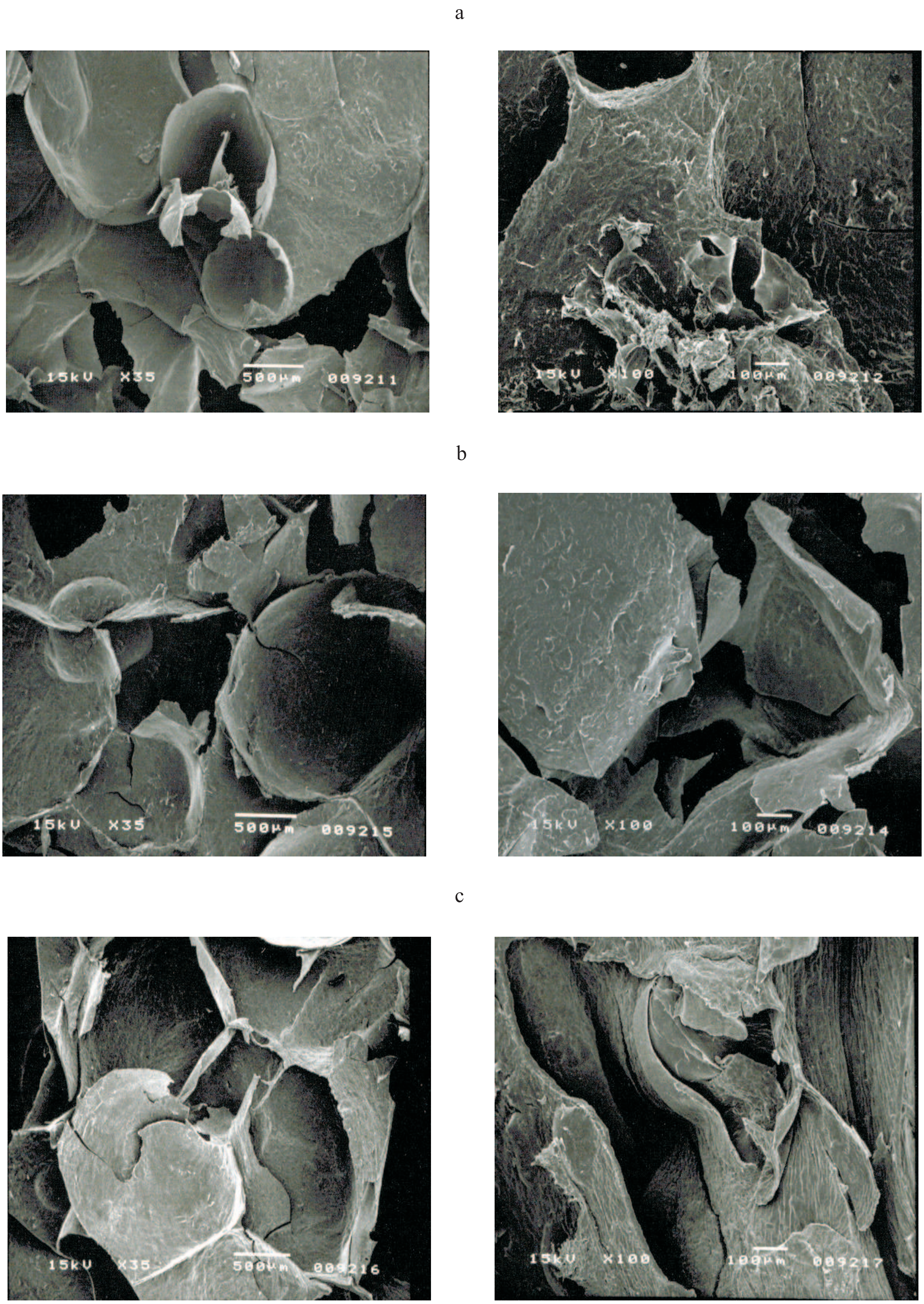


Fig. 1. The effect of the hull-less oat cultivars applied: a – Akt, b – STH 3997 and c – STH 4097 on the microstructure of the extrudates – oat whole-meal admixture at 10%, moisture content 13%, profiles of cylinder temperature distribution 145/165/120°C.

Figure 2 present extrudates with varied content of oat whole-meal. Increase in the oat whole-meal level from 5% (Fig. 2a) to 10% (Fig. 2b) and then to 15% (Fig. 2c) did not cause any observable changes in the microstructure of the extrudates. Air cells in all samples are similar in size, and no increase in cell wall thickness is observed with increase in the level of oat whole-meal addition. It should be kept in mind that increase in the amount of oat whole-meal means also an increase in the content of fat and of the soluble fraction of dietary fibre. It can, therefore, be stated that over a fairly broad range of oat whole-meal content (even up to 15%) it is possible to obtain extrudates with very good quality, very well expanded, and with very good physical properties as determined by their microstructure. A rapid deterioration of microstructure is observed due to 'material slippage' caused by sudden disturbance of the conditions of extrusion, which means the interruption of the process. Such an extrudate cannot even be considered as a product, but as a waste product.

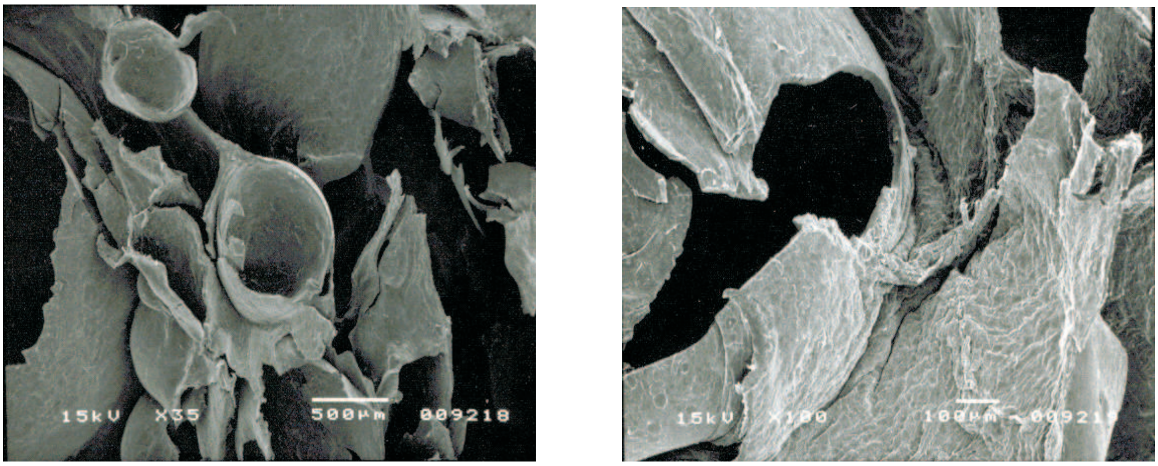
Samples with 10% content of the oat component were also extruded at two levels of raw material moisture content - 13 and 16%, applying a constant profile of extruder cylinder temperature of 145/165/120°C (Fig. 3a, b). Both in the case of extrudates obtained at raw material moisture of 13 and of 16% the characteristic honeycomb structure was obtained, with visible numerous air cells. Careful analysis of the photographs, however, reveals certain small differences in the size of the air cells and in the cell wall thickness. Increase in the raw materials moisture caused a decrease in the air cell diameters, though no proportionally increased thickness of air cell walls was observed, responsible for so-called vitreosity of extrudate. Such microstructure of extrudates indicates clearly that the corn-oat blend has a relatively broad range of tolerance with respect to the raw material moisture levels at which it is possible to obtain extrudates of very good quality. The authors of an earlier study (Rzedzicki and Fornal, 1998) demonstrated that changes in the microstructure may be responsible for an increase in the specific density of extrudates, reduction of expansion, and deterioration of texture. Samples extruded at higher raw material moisture were characterized by a lower degree of expansion and greater density. No such relations were observed in this case.

The study comprised also determination of the effect of temperature on the microstructure of extrudates. For those determinations samples with 10% level of oat whole-meal (dehulled oat) were selected, obtained at a constant raw material moisture level (13%) and at various profiles of cylinder temperature distribution (125/145/120, 145/165/120, and 160/180/120°C) (Fig. 4). It might appear that the changes in cylinder temperature had no significant effect on the microstructure of the extrudate, as no notable changes were observed in the size of the air cells nor in their wall thickness. However, careful analysis of the images at greater magnification indicates something different. In samples extruded at the lowest temperature (145°C – centre section temp.) one can observe a totally enclosed spherical mass form. It might be concluded that it could be a fragment of non-liquefied mass or that the vapour pressure was too low to disrupt the air cell walls. Both at the temperature of 145 and 165°C continuous air cell walls are observed. In this case, the air cell walls are built of thin 'scales' adhering to one another, which imparts to the products a delicate and crispy character. Similar observations were also made in earlier research (Rzedzicki and Błaszczak, 2005). Temperature increase to 180°C caused notable changes in the air cell wall structure – they became fuzzy and very porous, with the pore sizes varying from several to over a dozen μm (Fig. 4c). This kind of structure will guarantee excellent crispness of the product, but at the same time it will result in very large specific surface area. Excessive development of product surface area may be conducive to the processes of oxidation of fats and cause deterioration in the shelf life of the product. Therefore, this kind of structure should be considered as undesirable, even though the product will have an excellent texture.

The introduction in the recipe of up to 15% of oat component admixture notably increases the content of dietary fibre in the extrudate, while increasing the protein content in an insufficient degree and permitting only a slight modification of the amino acid composition. Protein content in products of this type can be significantly modified by the application of additional high-protein components such as whole powdered milk or everlasting pea whole-meal. The study of microstructure (Fig. 5) did not reveal any deterioration in the structure of corn-oat extrudates (10% share of oat whole-meal) both in the case of application of everlasting pea whole-meal (10%) and of powdered whole milk (1%). The structure of the extrudates obtained is comparable with that of extrudates produced without any addition of those components. In both cases there are visible numerous air cells determining the structure and crispness of the extrudates produced. The addition of powdered milk, however, caused the appearance of air cells with sizes of several hundred μm as well as of a notable number of cells with dimensions of several dozen μm. The walls of the extrudates are relatively thin and non-fuzzed (Fig. 5a) and characterized by a coherent scaly structure. The application of everlasting pea whole-meal in the corn-oat blends resulted in a slight decrease in the dimensions of the air cells. As in the case of the powdered milk admixture, there are cells of several hundred μm and a notable number of cells of several dozen μm in size. The cell walls, however, are somewhat thicker and have a compact structure. Such a structure of the product will cause a significant decrease in specific surface area and permit oxidable compounds encasing in protein-starch matrix, ensuring extended shelf-life of the product.

a

b



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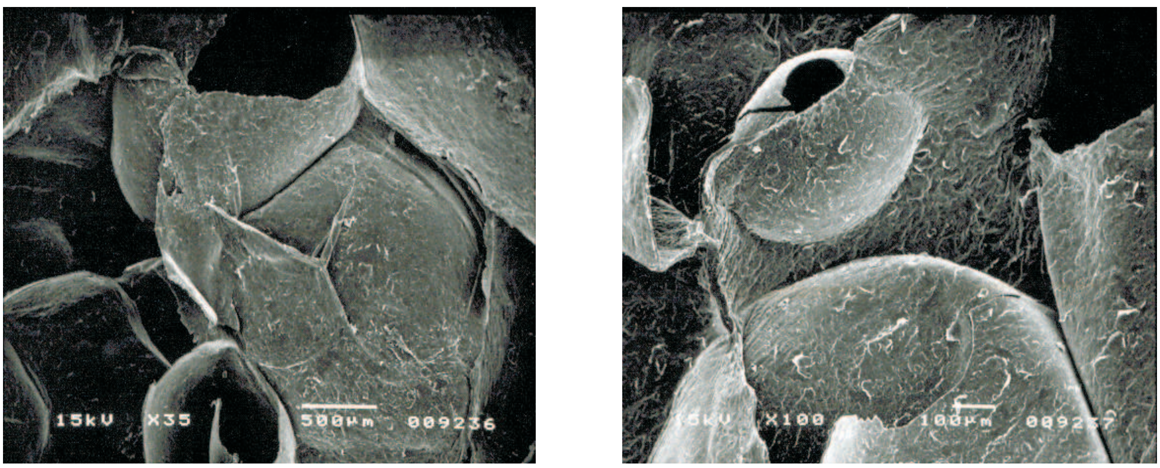


Fig. 2. The effect of varied content: a – 5%, b – 10%, c – 15% of oat whole-meal (hulled oat) on the microstructure of the extrudates – moisture content 13%, profiles of cylinder temperature distribution 145/165/120°C.

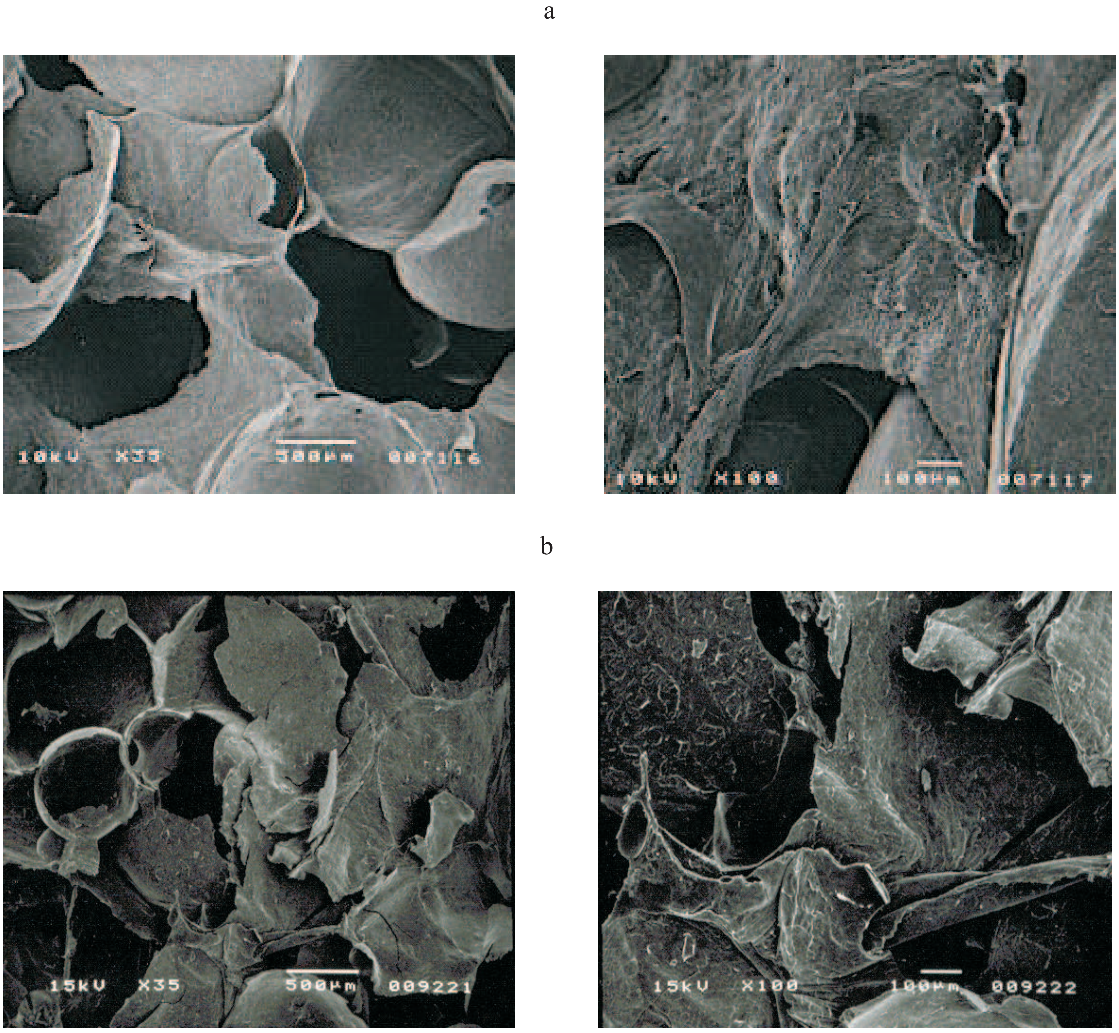


Fig. 3. The effect of moisture content: a – 13%, b – 16% on the microstructure of the extrudates - oat whole-meal admixture at 10%, profiles of cylinder temperature distribution 145/165/120°C.

For comparison, structure examination was also performed for extrudates with 10% content of oat bran (Fig. 6). Comparison of their microstructure with that of samples with 10% content of oat whole-meal (Fig. 2b), extruded at the same process parameters, indicates very high similarity of the products in terms of the size of the air cells, cell wall thickness, and the scaly structure of the cell walls. Those similarities indicate clearly that oat whole-meal can be successfully applied to produce extrudates analogous to those with a content of oat bran, as their similar microstructure will create highly similar physical and functional properties of the products. It is also to be expected that the micro-structural similarity will create highly similar sensory features of the products. This conclusion appears to be supported by research performed previously (Rzedzicki and Błaszczak, 2005; Rzedzicki and Fornal, 1998).

CONCLUSIONS

1. Application of oat whole-meal in single-screw extrusion, at rates of up to 15%, permits stable operation of the extruder and obtainment of very good microstructure of the product.

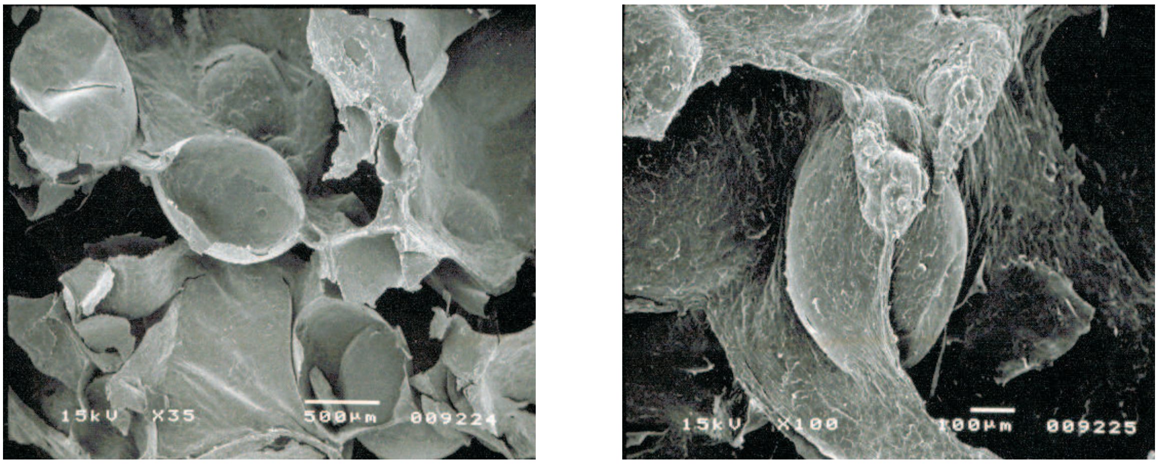
2. Extrudates with the same levels of oat whole-meal and oat bran admixture displayed highly similar microstructure.

3. Within the process parameter ranges applied in the study the most favourable microstructure was obtained for extrudates produced at cylinder temperature profile of 120/145/165°C and raw material moisture of 13%.

4. No effect of the oat cultivars on the microstructure of extrudate was observed.

5. Application of an admixture of whole powdered milk at the rate of 1% and of everlasting pea whole-meal at the level of 10% did not cause any deterioration of the microstructure of the product.

a



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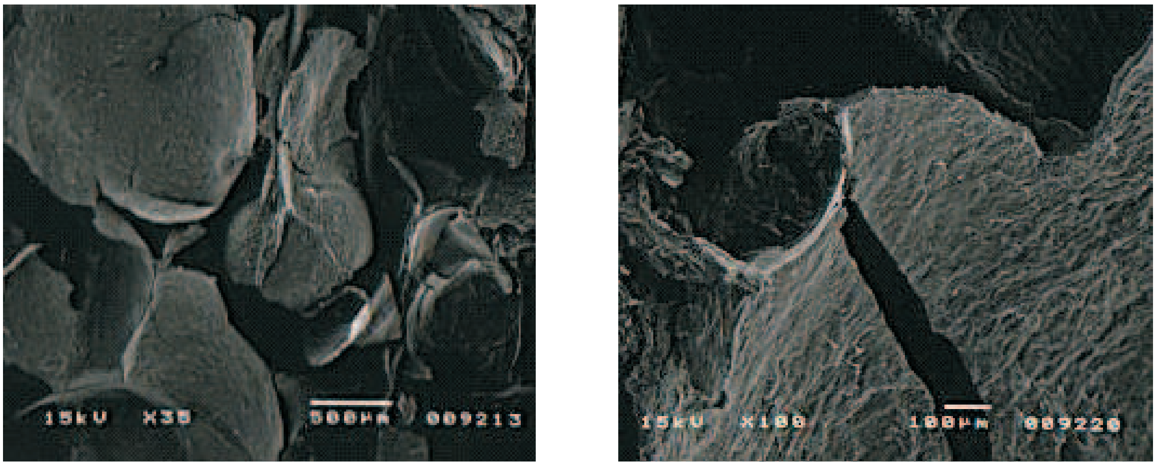

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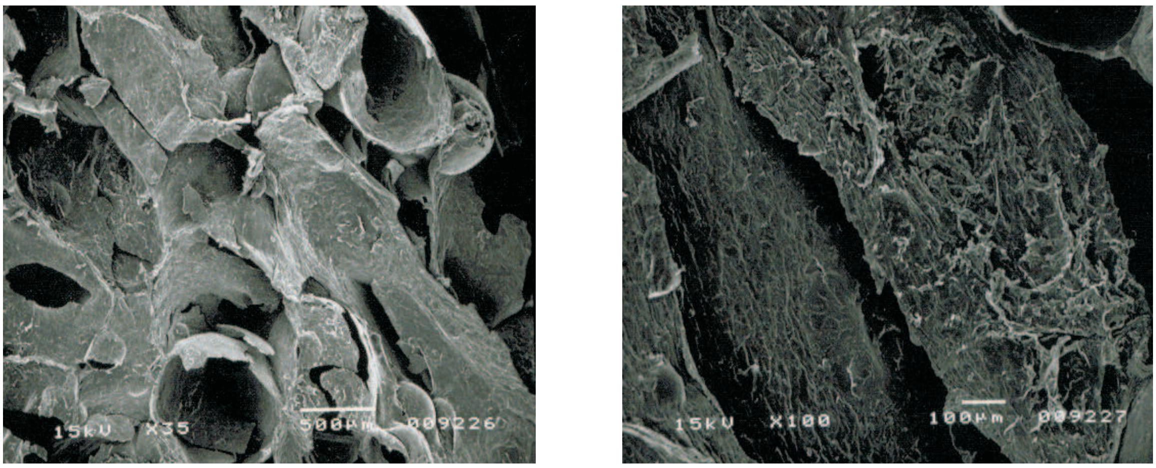
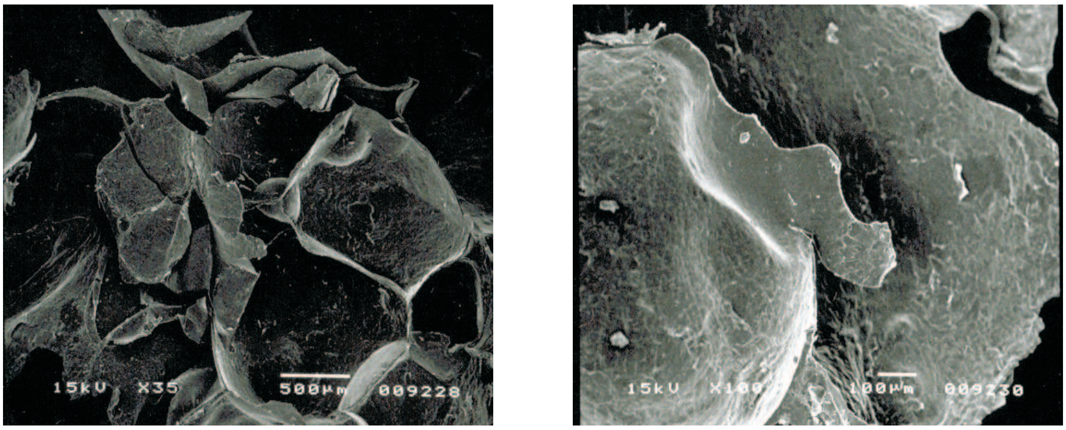


Fig. 4. The effect of profiles of cylinder temperature distributions: a – 125/145/120°C, b – 145/165/120°C, c – 160/180/120°C on the microstructure of extrudates – oat whole-meal admixture at 10%, moisture content 13%.

a



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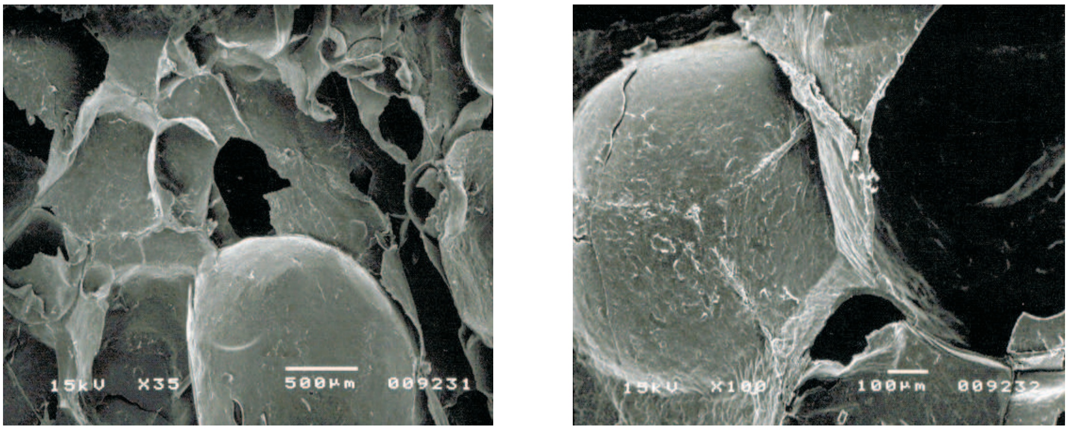

Fig. 5. The effect of addition protein components: a – whole milk powder 1%, b – everlasting pea 10% on the microstructure of extrudates – moisture content 13%, oat whole-meal admixture at 10%, profiles of cylinder temperature distribution 145/165/120°C.

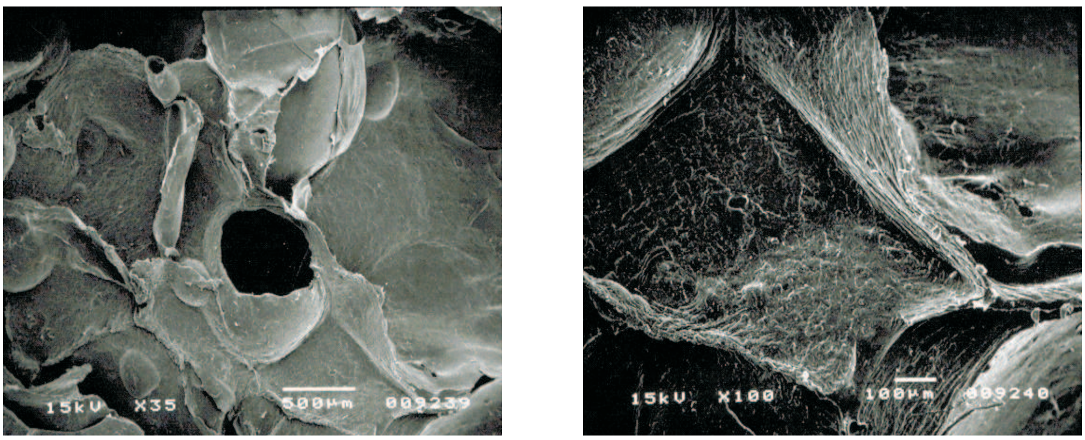

Fig. 6. Microstructure of oat bran extrudates – oat bran 10%, moisture content 13%, profiles of cylinder temperature distribution 145/165/120°C.

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