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INFLUENCE OF PROCESS PARAMETERS ON THE PHYSICAL PROPERTIES AND MICROSTRUCTURE OF EVERLASTING PEA (*LATHYRUS SATIVUS*) EXTRUDATE*

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A b s t r a c t. The research examines the feasibility of applying extrusion methods for hydrothermic processing of ground everlasting pea grains. In particular, the influence of process parameters and raw material properties on the process run, physical properties of the product, extrudate micro- and macrostructure, as well as product quality features were studied. The studies showed that by applying extrusion methods it is possible to obtain high quality products with excellent physical and organoleptic properties suitable for direct consumption such as: maize-everlasting pea, as well as high protein lunch concentrates.

K e y w o r d s: extrusion - cooking, everlasting pea, *Lathyrus sativus*, microstructure, physical properties

INTRODUCTION

Everlasting pea (*Lathyrus sativus*) has been grown in Poland for more than 200 years as a local vegetable, especially in the region of Podlasie. Its unique characteristics, and in particular, easy agrotechnology, resistance to ground frost, possibility of early sowing, early harvest, high protein content often exceeding 30%, high magnesium content, amino acid composition similar to lentil, low oligosacharides content, light coloured seed hull, light coloured cotyledons, and excellent taste predispose it to be the main protein plant in our climatic zone. The studies carried out so far [3], proved the high effectiveness of the extrusion method applied to the inactivation of the anti-nutritious factors in everlasting pea and showed a wide range of possible applications of everlasting pea in extrudate production. That is why we studied the influence of process parameters and raw material properties on the extrudate physical properties with special stress on those features that decide the organoleptic product properties and influence the temperature and moisture content of raw material on the extrudate macrostructure.

MATERIALS AND METHODS

Mixtures with everlasting pea content of 3, 6, 9, 12, 18, and 21% were prepared from maize semolina and ground everlasting pea (Table 1). The mixtures were then extruded on the single-screw extrusion-cooker S-45 (L: D =12:1, compression ratio 3:1). The influence of the mixture content, raw material moisture content, die diameter, rotation of the screw and temperature of the process run, physical properties and chemical transformations of the extrudate were investigated. Ground everlasting pea was also

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Table 1. Chemical composition of raw materials

Component	Corn semolina	Everlasting pea
Moisture cont.[%]	7.8	8.7
Ash [%]	1.5	3.0
Proteins [%]	8.1	32.5
Fat [%]	0.6	0.94
Fibre [%]	0.5	3.6
TI [TUI/mg]	1.98	32.4

extruded on a twin screw extrusion-cooker 2S-9/5. In particular, the influence of process temperature, raw material moisture content and die diameter on the process run, physical parameters and chemical transformations of the extrudate were analysed. The expansion ratio was determined as the ratio between the surface of extrudate cross-section to the surface of die cross-section. The structural components were determined according to the method of Goering *et al* [1]. The specific density of the extrudate was determined taking into consideration internal extrudate pores. The texture was determined as the amount of energy used for the destruction of 1 g sample [2]. Samples of unground extrudate were taken for the determination of extrudate macrostructure. Chosen fragments of the preparation were cut off and pasted onto preparation blocks by means of silver paste. The preparations were covered with carbon and gold in a vacuum sputter JEOL JEE 4X. Microscopic analysis was carried out on an electronic scanning microscope JSM 5200. Lipid extraction was carried out by means of hexane.

RESULTS AND DISCUSSION

The extrusion process of maize semolina and ground everlasting pea mixtures ran correctly in a wide range of parameters. Ground everlasting pea easily changed into melt in the extrusion-cooker and produced a homogenous mass with maize groats. No extrusion-cooker clotting, blocking of the mass flow or raw material sliding was observed. Stable working conditions allowed us to .obtain a high quality product with quality properties closely resembling maize extrudate. Introduction of as much as 20% of everlasting pea into the extrudate did not result in any significant changes in the extrusion-cooker efficiency. The light colour of everlasting pea seed cotyledons did not darken the product; hence everlasting pea inclusion could even exceed 20%. It was perfectly possible to obtain high quality extruded snacks with protein content as high as 15% from this mixture. Tripsine inhibitors were inactivated. The temperature of 160°C applied to the single-screw extrusion-cooker produced only 1.84 TUI/mg.

The introduction of everlasting pea into the mixture resulted in only a slight decrease in radial extrudate expansion. The addition of another 10% of oat bran changed the decreasing tendency of radial expansion. The curves obtained shows high values of the determination coefficient, which show that it is a standing tendency that can be expected at the initial stages of production. The coefficient of radial expansion ranging from 12 to 15 was very satisfactory for the extrudate produced with the maize semolina base. During extrusion of the maize-everlasting pea mixture a uniform outflow of the material from the extrusion-cooker die was observed. It influenced the outlook of crisps, their shape and the values of the radial expansion ratio coefficient very favourably.

A decrease in radial expansion is always accompanied by a slight increase in the extrudate specific density. The highest values observed did not exceed 68 kg/m^3. The above values do not differ from the parameters of maize extrudate. An increase in the specific density was observed when 10% of oat bran was added to the mixture. However, the maximum value did not exceed 76 kg/m^3. These parameters are also very good for this type of product.

Inclusion of everlasting pea in the mixture improved the hygroscopic properties of the product. The water absorption index determined by the effluent method increased from 240 to 320%. A significant improvement in the WAI level was observed in the samples with 10% inclusion of additional oat bran. The values observed ranged from 320 to 440%.

The texture of the extrudate with everlasting pea inclusion is particularly interesting. With the increase in the everlasting pea inclusion level in the mixture a slight increase in the destruction energy was observed but its maximum value did not exceed 0.4 J/g. These parameters are very good for this type of produce. Totally unexpectedly, inclusion of 10% of bran in the mixture improved its texture. The values of destruction energy obtained did not exceed 0.35 J/g. No increase in this value was observed with the increase of everlasting pea inclusion in the mixture.

During the extrusion process of the maize-everlasting pea mixture a non-typical behaviour of the mass in the extrusion-cooker was noticed. With the increase in the raw material moisture content a decrease in the extrusion-cooker efficiency was observed. The coefficient of determination exceeded the level of 0.95. In the case of other raw materials, increase in the moisture level was usually accompanied by a decrease in viscosity and an increase in the outflow speed, and hence an increases in the extrusion-cooker efficiency. Changes in the process temperature influenced the mixture with everlasting pea inclusion in a different way. An increase in the temperature of the cylinder was accompanied by a decrease of the radial extrudate expansion.

However, a decrease in the radial extrudate expansion did not mean any decrease in the extrudate quality. An increase of the cylinder temperature was accompanied by a decrease of extrudate specific density. It meant that an increase of temperature was necessarily connected with a decrease in viscosity and increase of longitudinal expansion.

In the studied range of moisture levels of the mixture a decrease in destruction energy with an increase in moisture was observed. In the case of other raw leguminous materials, i.e., broad beans, the reverse tendency was observed. The increase in the raw material moisture level was always accompanied by an increase in destruction energy. In practice it meant that at higher temperatures everlasting pea was liquefied easier in the extrusion-cooker and formed a less compact structure.

Texture was also conditioned by the temperature of the barrel. With a temperature increase the value of destruction energy also increased. In the case of other raw materials the reverse tendency was observed. Hence, with everlasting pea inclusion it was possible to run processing with lower barrel temperatures.

Maize-everlasting pea extrudate was subjected to broad range organoleptic studies. Each time the results obtained were close to those of maize crisps or even better. In the case of moisture evaluations of raw material, consumers evaluated the samples extruded at 13% moisture as best. While evaluating the influence of temperature, the highest grade was given to the samples extruded at 165°C. When the composition of the mixture was evaluated, the samples with the highest grades were those with 9-12% of everlasting pea inclusion. The samples with everlasting pea and 10% of oat bran were also very favourably received by consumers.

Studies on the ground everlasting pea were also carried out on the twin screw extrusion-cooker 2S-9/5. Contrary to other raw materials, the range of raw material moisture was very limited. In practice, everlasting pea with a moisture content of above 25% could not be extruded. The viscosity of raw material was so high that it was not possible for the screws to pick it up. With an increase in the moisture content extrusion-cooker efficiency decreased, radial extrudate expansion increased and specific density decreased. This atypical behaviour of everlasting pea in the extrusion process requires more precise studies in order to learn about discrepancies and establish correct conditions for extrusion. However, the parameters of radial expansion observed did not exceed 2.5. At the same time a very high specific density of the extrudate that exceeded 1000 kg/m^3 was noted.

The course of the extrusion process conditioned also the intensity of chemical transformations in the extruded materials. With an increase of raw material moisture level a clear increase in the content of raw fibre was observed (Fig.1).

A similar tendency was also observed in the case of NDF fibre determined by means of the

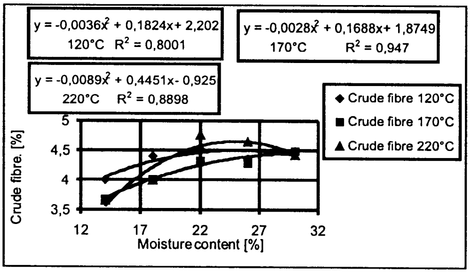


Fig. 1. Influence of process parameters on the transformations of raw fibre in the everlasting pea extrudate.

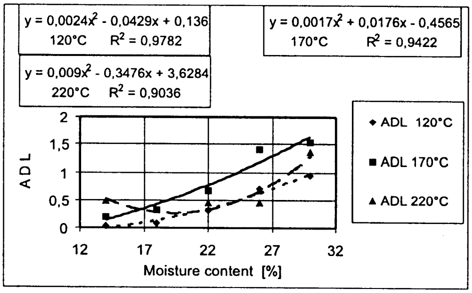
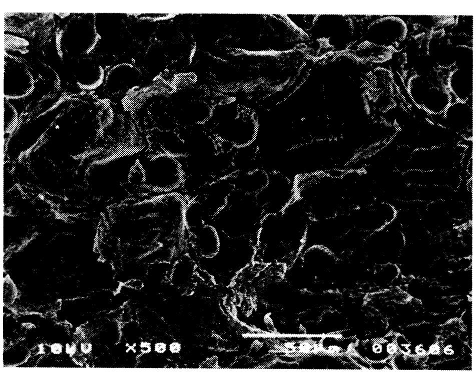


Fig. 2. Influence of process parameters on the changes in the acidic-detergent lignin content of everlasting pea extrudate.

detergent method and ADL lignin (Fig. 2). An increase in the content of ADL lignin seemed to explain the above tendency. With an increase in moisture content the viscosity of ground everlasting pea increased. Whereas a decrease in the efficiency prolonged the time the processed material remained in the extrusion-cooker, which in turn, not only increased the intensity of Maillard's reaction, but also created lipid-starch and lipid-protein complexes, and could result in the formation of resistant starch structures. The observed intensification of transformations in NDF and ADL at a moisture level of above 22% pointed to the fact that in practice the moisture level of ground everlasting pea should not exceed this limit due to the high risk of poorer product quality. This moisture limit of the everlasting pea undergoing extrusion also should not be exceeded because of the working efficiency of auxiliary equipment.

Despite very low radial expansion and very high specific density, the extrudate obtained in the studied moisture and temperature ranges was very well processed. It was confirmed by the microstructure studies also carried out. Photographs 1a and 1b present the microstructure of the initial raw material, i.e., ground everlasting pea meal. The cell structure of the everlasting pea cotyledons resemble the structure of other leguminous plants such as broad beans, beans and lentil. Cotyledons cells covered with central lamella are separated from one another by clearly marked intercellular spaces (Photo 1b). In the open cells compact packing of the two basic storage components: protein and starch (Photo 1a) can be seen. Starch granules with a diameter of 5-30 μm are merged in the protein part that consists mainly of globular protein bodies joined by an amorphous matrix. Transformations of these two components in the extrusion process decided on the structure and texture of the produce obtained.

a



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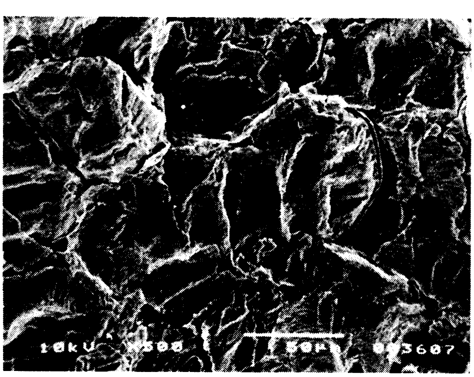

Photo 1. The microstructure of everlasting pea meal.

Extrudate obtained from ground everlasting pea with a moisture content of 14% and a barrel temperature of 100°C have a compact macrostructure with irregular air spaces and no clearly defined air cell walls (Photo 2a). In some places of the preparation fragments of seed hulls could be observed. Despite the low moisture content of the initial ground everlasting pea and the low process temperature, significant changes of the microscopic picture of protein and starch could be observed in the microstructure of the studied extrudate. The proteins lost their globular shape due to the combined action of the shearing forces, temperature and moisture and formed fibrous and amorphous structures entwining starch granules (Photo 2b). Starch granules underwent a high degree of deformation due to radial swelling. Part of the starch granules, however, survived the extrusion process in an unchanged state and maintained their original shape and smooth surface. An increase in the raw material moisture content up to 22% did not cause any significant changes in the extrudate macrostructure (Photo 2c). In the picture of the microstructure a tendency towards more intense complexing of proteins with starch and progressing contiguous swells of starch granules (Photo 2d) was found. It was manifested by a stronger corrugation of their structure. The most progressed changes in the macro- and microstructure were observed in the extrudate samples obtained at raw material moisture level of 30%. In its macrostructure the extrudate was built of thick-walled air vesicles (Photo 2e). Granular starch and protein microstructure disappeared already and the material looked like an amorphous mass consisting of starch mash and denatured protein (Photo 2f).

Increasing the process temperature up to 150°C had a significant influence on the extrudate micro- and macrostructure. Already at the raw material moisture content of 14% an increased porosity of the produce and initial stages of air vesicles formation were observed (Photo 3a). In the picture fibrous microstructure of the produce is observed, similarly as in the Photos 2b and 2c.

Starch granules complexed more and more with protein forming starch-protein fibres (Photo 3b). Changes in the raw material moisture content up to 22% caused a significant increase in the extrudate porosity in the picture of the macrostructure (Photo 3c). Melted protein mass covered starch granules almost completely (Photo 3d). Only very few starch granules were not completely covered by the protein mass. This phenomenon observed in several cases confirmed that the basic mechanism of starch and protein interaction in the extrusion process consisted in forming bridges between protein films on single starch granules, their total smear or, in the most drastic conditions of the process, formation of a mixed, amorphous mass. At the raw material moisture level of 30% the produce obtained had a macrostructure that resembled the samples obtained at the temperature of 100°C (Photo 3e), similar to the one in Photo 2e. In the picture of the microstructure further disappearance of the granular structure of the produce was observed. The extrudate walls were built of smeared starch and denatured protein that took on the look of melted, amorphous, glassy mass (Photo 3f). A similar structure was already observed in the samples extruded at the temperature of 100°C and moisture level of 30%.

An increase in the process temperature up to 200°C caused further deepening of changes in the micro- and macrostructures. In the macrostructure there was an increase in the produce porosity (Photos 4a, 4c, 4e) which explained changes in the radial expanding and specific density discussed above. Very intense changes were observed in the microstructure. In the case of all the studied moisture ranges total disappearance of the granular structure was observed. No fibrous structure of the produce was observed either (Photos 4b, 4d, 4f). On the other hand deformation of the remnants of starch granules could be observed (Photo 4d). The central part of granules caved in as a result of outflow of amylases. These granules took on the form of pontoons before they fell into fragments. Similarly to lower temperatures, very intense changes in the samples obtained from

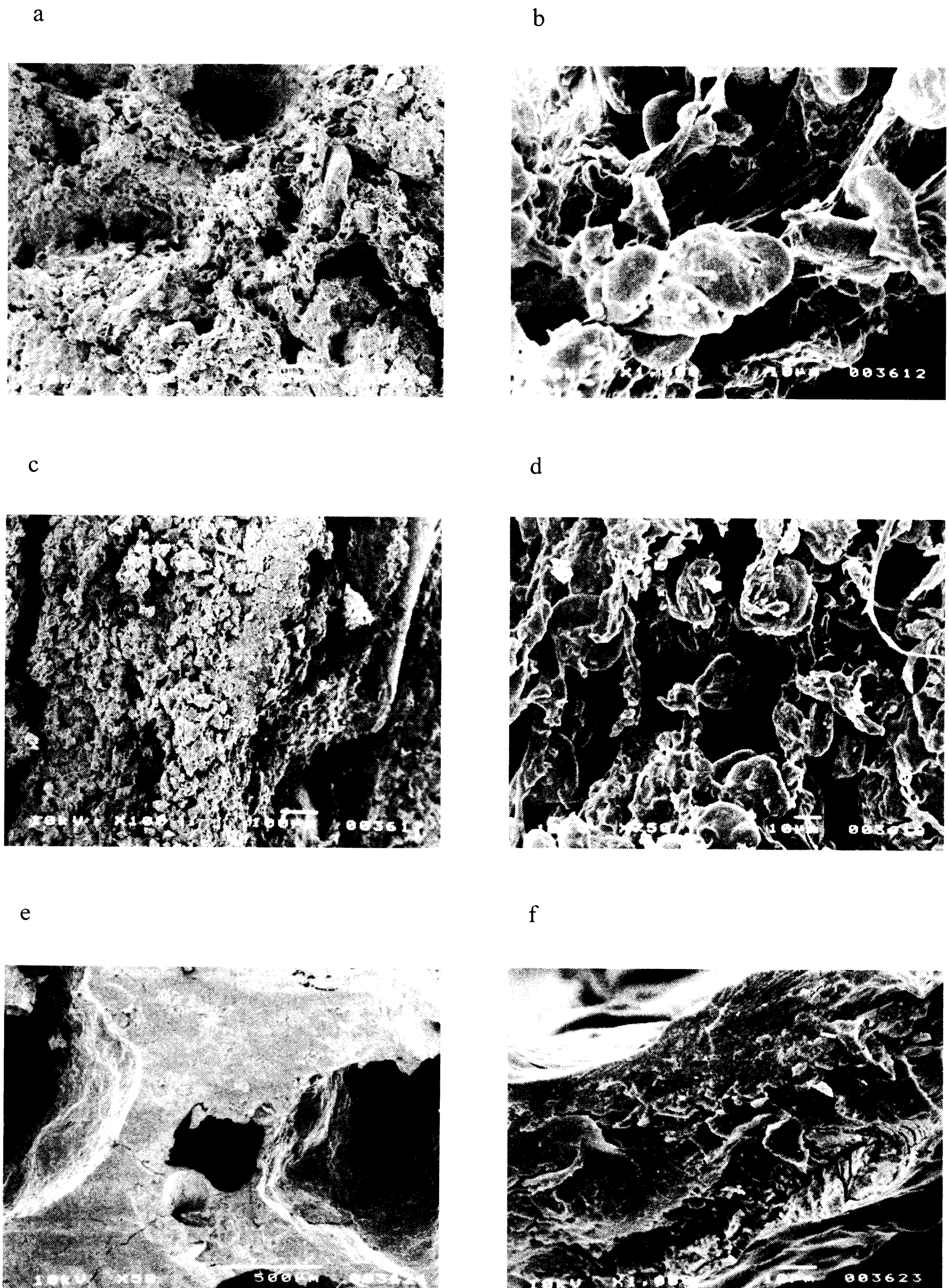

Photo 2. The macro- and microstructure of everlasting pea extrudate. Extrusion temperature 80/100/100/100/100°C. Raw material moisture content: a,b - 14%, c,d - 22%, e,f - 30%.

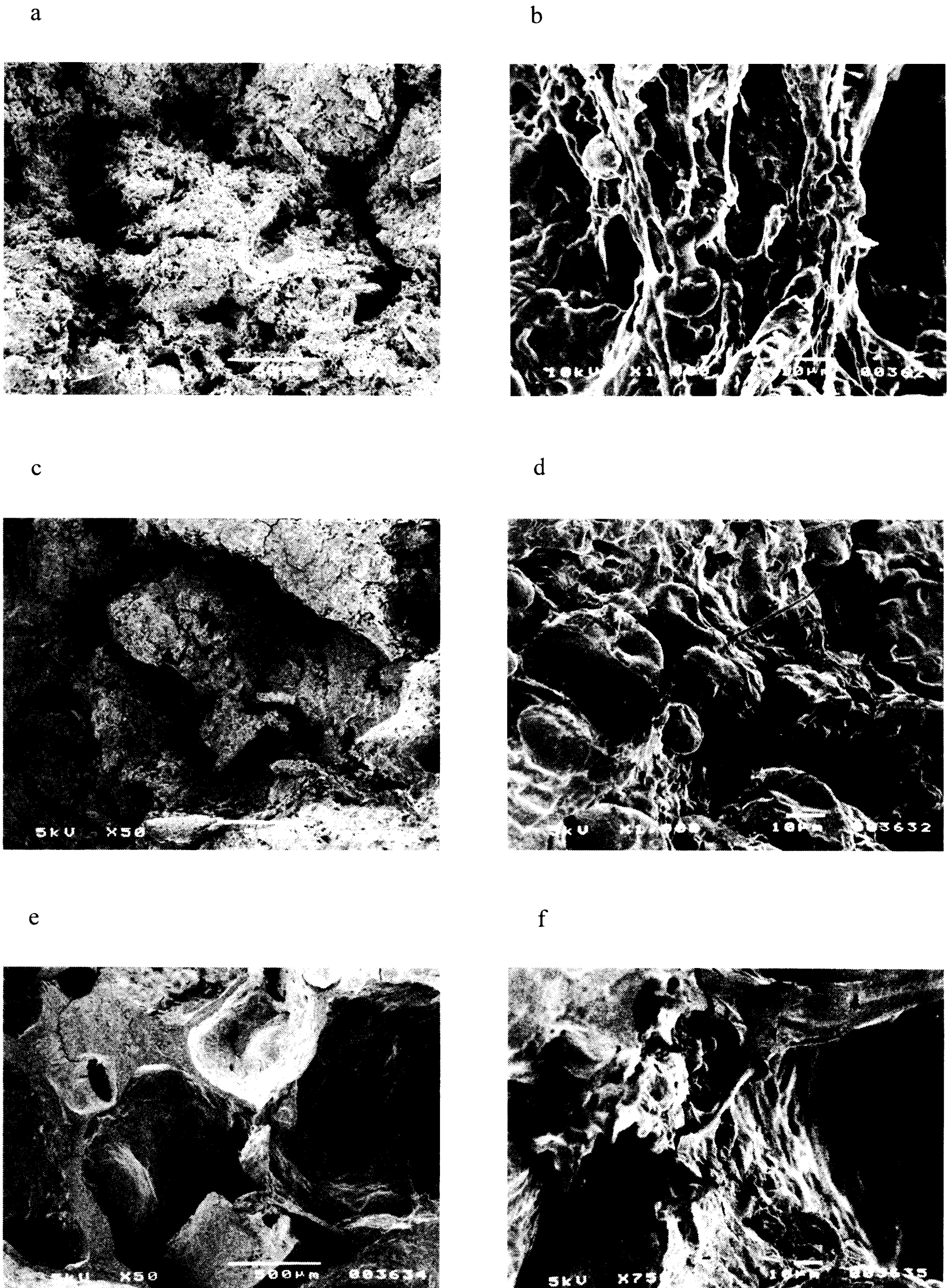

Photo 3. The macro- and microstructure of everlasting pea extrudate. Extrusion temperature 120/140/150/150/120°C. Raw material moisture content: a,b - 14%, c,d - 22%, e,f - 30%.

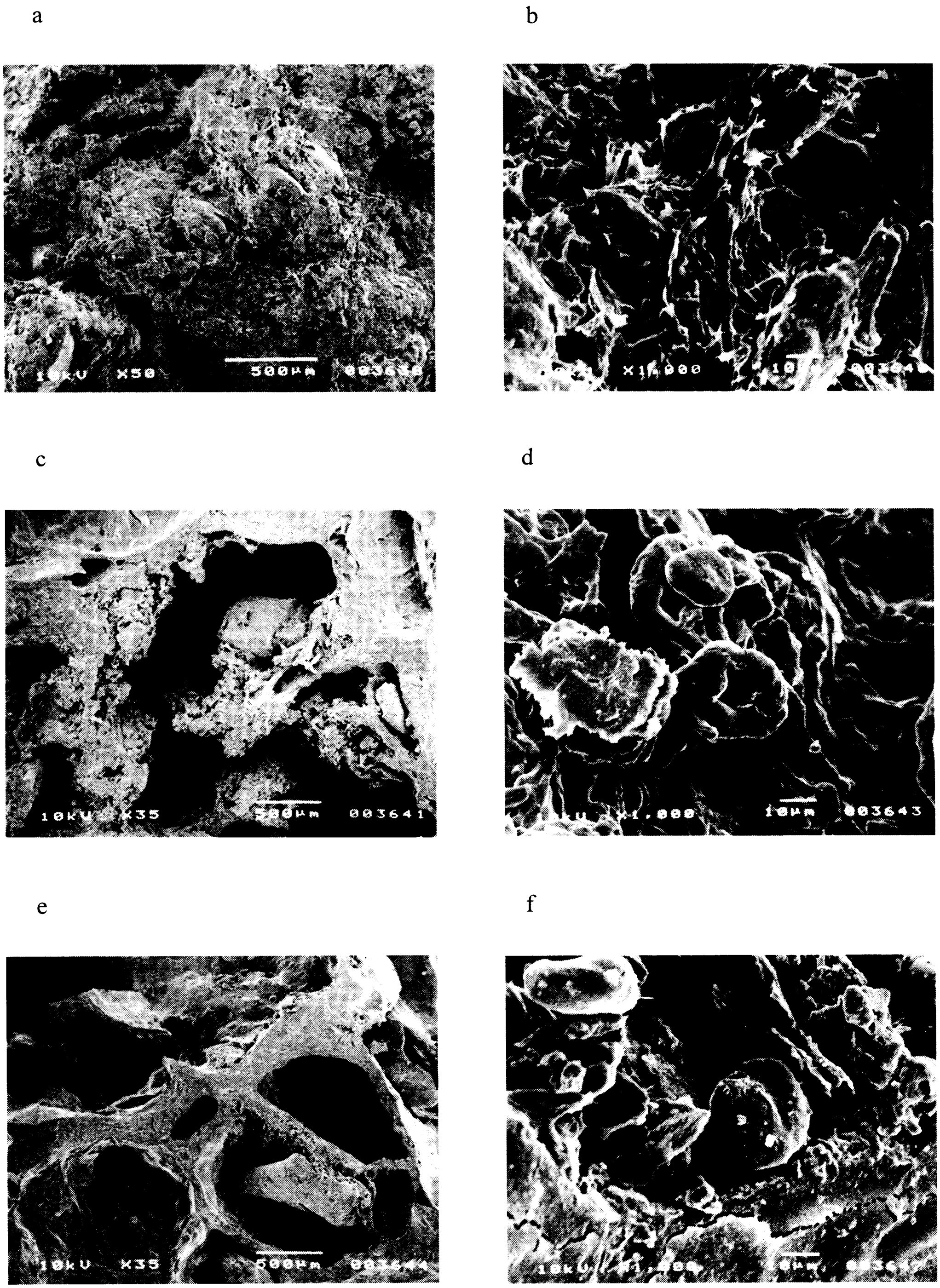

Photo 4. The macro- and microstructure of everlasting pea extrudate. Extrusion temperature 140/180/200/180/130°C. Raw material moisture content: a,b - 14%, c,d - 22%, e,f - 30%.

the raw material with the moisture level of 30% were observed. Confronting the photographs discussed above a certain regularity was noticed. The intensity of changes increased to a far higher degree with the increase in the raw material moisture level than with the increase in the process temperature. Total disappearance of fibrous and granular structures was observed in the samples extruded at the temperature of 100°C and moisture level of 30%. This kind of changes was not observed in the samples extruded at the temperature of 150°C but with the moisture content of 14 and 22%. The above observations could prove to be very significant for the optimum chöice of process parameters.

CONCLUSIONS

1. Application of extrusion method allows for the production of high quality maize snacks with up to 20% inclusion of everlasting pea.

2. Inclusion of everlasting pea does not make radial expansion or proper extrudate density any worse.

3. The increase in the content of raw fibre and ADL fraction observed at a raw material moisture content of above 25%, points to the intensification of product degradation.

4. Extrudate microstructure is conditioned by the moisture content of the processed raw material to a greater extend than by the temperature of the process.

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