Int. Agrophysics, 2009, 23, 287-293

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Changes in dietary fibre fractional composition of multi-cereal blends caused by extrusion

P. Zarzycki and Z. Rzedzicki*

Engineering and Cereals Technology Department, University of Life Sciences, Skromna 8, 20-704 Lublin, Poland

Received September 30, 2008; accepted March 25, 2009

A b s t r a c t. A study was conducted on the effect of the process of extrusion on changes in dietary fibre fractional composition. The material used in the study comprised a blend of corn grits, oat bran, everlasting pea wholemeal and powdered whole milk. The process of extrusion was conducted in a single-screw extruder, at the following parameters: L:D=12:1, screw compression ratio of 3:1, die diameter of 3.5 mm, screw speed of 110 rev. min^{-1}, cylinder temperature profile of 145/165/120°C. Raw material moisture content was adopted as 13.5%, and the relative share of oat bran, everlasting pea wholemeal and powdered whole milk was variable. The introduction of oat bran and everlasting pea wholemeal in the blends permitted obtainment of extrudates with increased content of dietary fibre, especially of its soluble fraction. The additives applied allowed also to obtain extrudates with low values of water solubility index. As a result of the process of extrusion, a lowering of the content of total dietary fibre and its insoluble fraction, and an increase in the content of the soluble fraction were observed in the extrudates. Changes in the fractional composition of dietary fibre were related primarily to the composition of the raw material blends.

K e y w o r d s: extrusion-cooking, oat bran, everlasting pea, dietary fibre

INTRODUCTION

In countries of the developed North, diseases of the circulatory system and neoplastic diseases are the cause of more than 80% of deaths (Jones, 2001). Pointed out as the primary causes of the pandemia of civilization diseases (circulatory system disorders, diabetes type II, cancer, obesity) are changes in dietary habits and in life style, and lack of physical activity in particular. The problem of rational diet has thus become the most essential element of prophylaxis of civilization diseases. A component of food that has a considerable prophylactic and medicinal significance in this respect is dietary fibre. Numerous studies have confirmed its favourable effect on, among other things, lowering the level of cholesterol in the blood, changes in the proportions of HDL to LDL cholesterol fractions (Friedrich, 2003; Gerhardt and Gallo, 1998), lowering of the post-meal concentration of glucose (Cavallero *et al*., 2002), and reducing the risk of neoplastic diseases, especially of the gastrointestinal tract.

The main source of dietary fibre in our diet is cereal products. They should supply adequate amounts of dietary fibre with required fractional composition. The content of dietary fibre in particular cereal products results not only from their raw material composition, but is also related to the kind of processing technologies applied. Commonly used technologies of intensive processing of raw materials *eg* thermoplastic treatment, result in products with high degree of transformation. Such products are frequently characterized by low protein content, low level of dietary fibre, and very often they have also very high values of the water solubility index, even exceeding 50% d.m. (Rzedzicki, 2005). In spite of its shortcomings, extrusion is widely used in food processing. It permits good incorporation of dietary fibre fractions in the composition of the product, and obtainment of products with very good sensory features (Rzedzicki and Zarzycki, 2005). It should be emphasised, however, that it is a technology that involves drastic processing of raw materials. As a result of extrusion, a notably large increase is observed in the values of the water solubility index (Rzedzicki, 2005), decrease in the content of total dietary fibre and insoluble fraction of dietary fibre, and simultaneous increase in the level of the soluble fraction (Larrea *et al*., 2005, Rzedzicki and Zarzycki, 2007; Vasanthan *et al*., 2002). Also observed is a decrease in protein content, and notable losses of certain amino-acids *eg* lysine (Björck *et al*., 1984, Rzedzicki *et al*.,

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

2004). The range of observed changes is related both to the process parameters applied and to the properties and composition of the raw materials processed. Therefore, it becomes of key importance to define a safe range of the process parameters, and to compose raw material blends in such a way as to minimize losses of valuable nu- trients and to compensate for predicted unavoidable losses of specially valuable components of food, and – at the same time – to ensure possibly high quality of the end product.

The aim of this study was to examine the possibilities of introduction of oat bran, powdered whole milk and everlasting pea wholemeal in mixtures with corn grits, and to determine the effect of the blends composition on changes in the fractional composition of dietary fibre.

MATERIALS AND METHODS

The materials used in the study included commercially available corn grits, oat bran, everlasting pea wholemeal (cv. Derek), and powdered whole milk (protein content – 27%). Everlasting pea seeds were fragmented using a type H-111/3 impact grinder to achieve equivalent diameter of Φ=0.63 mm. The chemical composition of the raw materials is given in Table 1, and their water absorption index (WAI) and water solubility index (WSI) in Table 2. Blends for extrusion were prepared in accordance with the adopted model of the experiment (Table 3). Based on earlier studies and a pilot experiment, the blends were moistened to a moisture content of 13.5% and conditioned for 24 h (Rzedzicki and Zarzycki, 2005). Processing of the materials was done using a single-screw extruder, at the following process parameters – L:D=12:1, compression ratio of the screw 3:1, die diameter 3.5 mm, screw speed 110 rev. min^{-1}, and profile of cylinder temperature distribution 145/165/120°C (temperatures of particular sections of extruder cylinder).

Determinations performed for the raw materials and for the extrudates included ash content (AACC, Method 08-01), protein content (AACC, Method 46-08), crude fibre (AACC, Method 32-10), free fats content (AACC, Method 30-26), and the level of total dietary fibre (TDF), insoluble fraction (IDF) and soluble fraction (SDF). Determinations of the level of dietary fibre were made in accordance with AOAC and AACC methods (Method 991.43; AOAC Method 985.29; AACC, Method 32-07; AACC, Method 32-21; AACC, Method 32-05). Also determined was the water absorption index (WAI) and the index of dry matter solubility (WSI) (AACC, Method 56-20).

The particular determinations were made in three replications, and mean values, standard deviation and coefficient of variation were calculated. If the values of the coefficient of variation exceeded adopted limits of error for a given method, the results were rejected and the determinations were repeated. For continuous variables, analysis of regression was performed, and regression equations and coefficients of determination R^2 were determined.

RESULTS AND DISCUSSION

The operation parameters of the single-screw extruder used in the study (profile of cylinder temperature distribution 145/165/120°C, raw material moisture 13.5%, die diameter 3.5 mm) permitted processing of blends with maximum share of oat bran up to 18%. At higher content of that component there appeared a lack of backflow of material in the extruder cylinder, resulting in 'slippage' of the material. This precluded correct stabilization of extrusion conditions and continuation of the process. The value given above is the limit for the share of oat bran at such a configuration of single-screw extruder; similar values of the share limit were also observed in earlier studies on blends with a content of oat wholemeal (Rzedzicki and Zarzycki, 2005).

Thermoplastic treatment caused a notable increase in the water solubility index (WSI) of the processed material. WSI values of extrudates (Fig. 1) were considerably higher than those determined in the raw materials (Table 2). Thus it was confirmed that extrusion is a process with very strong effect on the raw material processed. A similar orientation of changes in the value of WSI was observed in an earlier study for oar wholemeal (Rzedzicki and Zarzycki, 2005). The study reported herein confirmed also the effect of raw material composition on WSI, and the possibility of its modification. With 3% share of oat bran, the WSI of extrudates was 43.22%d.b; increase in the content of oat bran to 18% permitted to reduce the value of WSI to the level of 39.39% d.b. For comparison, in certain extruded corn breakfast cereals dry matter solubility exceeded even 50% (Rzedzicki, 2005).

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

Component	N-free extract	Protein	Fat	Crude fibre	Ash	TDF	SDF	IDF
		x ± SD					x ± SD	
Corn semolina	88.57	8.39±0.15	1.20±0.25	0.43±0.10	1.41±0.20	6.28	0.97±0.20	5.31±0.17
Everlasting pea	62.21	27.59±0.10	1.12±0.15	5.70±0.20	3.38±0.15	34.26	5.34±0.10	28.92±0.09
Oat bran	69.97	16.63±0.16	7.23±0.05	2.88±0.02	3.28±0.09	23.75	9.81±0.08	13.94±0.12

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

T a b l e 2. WSI and WAI of the raw materials used in experiments (% d.b.)

Component	Corn semolina	Everlasting pea	Oat bran
		x ± SD	
WSI	5.8±0.15	22.65±0.2	3.07±0.14
WAI	248±0.30	213±0.5	217±0.10

WSI – water solubility index, WAI – water absorption index.

Reduction of the value of WSI was achieved also thanks to the introduction in the blend of a small admixture of powdered whole milk (0.5%). The effect of that component was evident especially in extrudates with low (3%) content of oat bran. The application of 0.5% addition of powdered milk in extrudates with 3% content of oat bran permitted a reduction in dry matter solubility from 43.22 to 35.54% d.b. At higher levels of oat bran content, the effect of powdered milk was notably weaker (Fig. 1). Considerable reduction of dry matter solubility was obtained also through the introduction of everlasting pea wholemeal in the raw material blends. The effect of the addition of everlasting pea was notable especially at oat bran content above 6%. For example, the addition of 5% admixture of everlasting pea, at 18% content of oat bran, resulted in a decrease in WSI value from 39.39 to 31.88% d.b.

T a b l e 3. Model of the experiment and protein content of the extrudates

Sample No.	Mixture composition (%)				Protein	Protein*
	Corn semolina	Oat bran	Everlasting pea	Milk powder	(% d.b.) x ± SD	
1	97.0	3	0	0	8.49±0.12	8.64
2	94.0	6			8.50±0.15	8.88
3	91.0	9			8.64±0.10	9.13
4	88.0	12			8.92±0.08	9.38
5	85.0	15			9.22±0.05	9.63
6	82.0	18			9.34±0.20	9.87
7	96.5	3	0	0.5	8.75±0.12	8.73
8	93.5	6			8.98±0.15	8.98
9	90.5	9			9.21±0.09	9.22
10	87.5	12			9.40±0.01	9.47
11	84.5	15			9.80±0.20	9.72
12	81.5	18			10.04±0.20	9.97
13	92.0	3	5	0	8.78±0.01	9.60
14	89.0	6			8.81±0.30	9.84
15	86.0	9			9.11±0.15	10.09
16	83.0	12			9.26±0.08	10.34
17	80.0	15			9.45±0.07	10.59
18	77.0	18			9.83±0.12	10.83
19	91.5	3	5	0.5	8.99±0.13	9.69
20	88.5	6			9.32±0.20	9.94
21	85.5	9			9.51±0.06	10.18
22	82.5	12			9.68±0.06	10.43
23	79.5	15			9.91±0.08	10.68
24	76.5	18			10.22±0.10	10.93

*expected value.

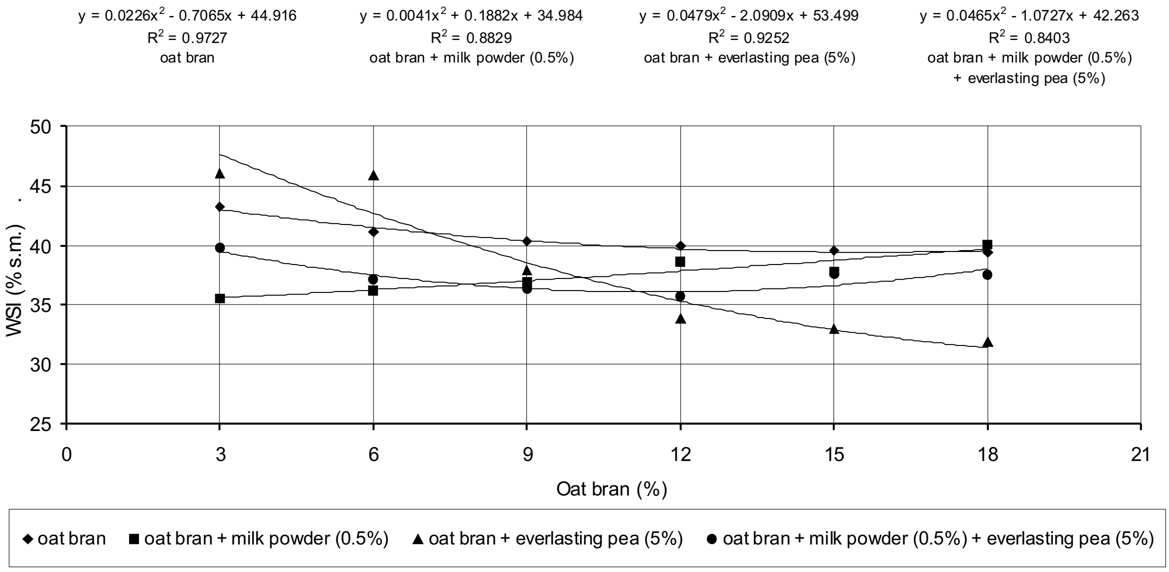

Fig. 1. Water Solubility Index (WSI) of extrudates: ◆ – oat bran, ■ – oat bran + milk powder (0.5%), ▲ – oat bran + everlasting pea (5%), ● – oat bran + milk powder (0.5%) + everlasting pea (5%).

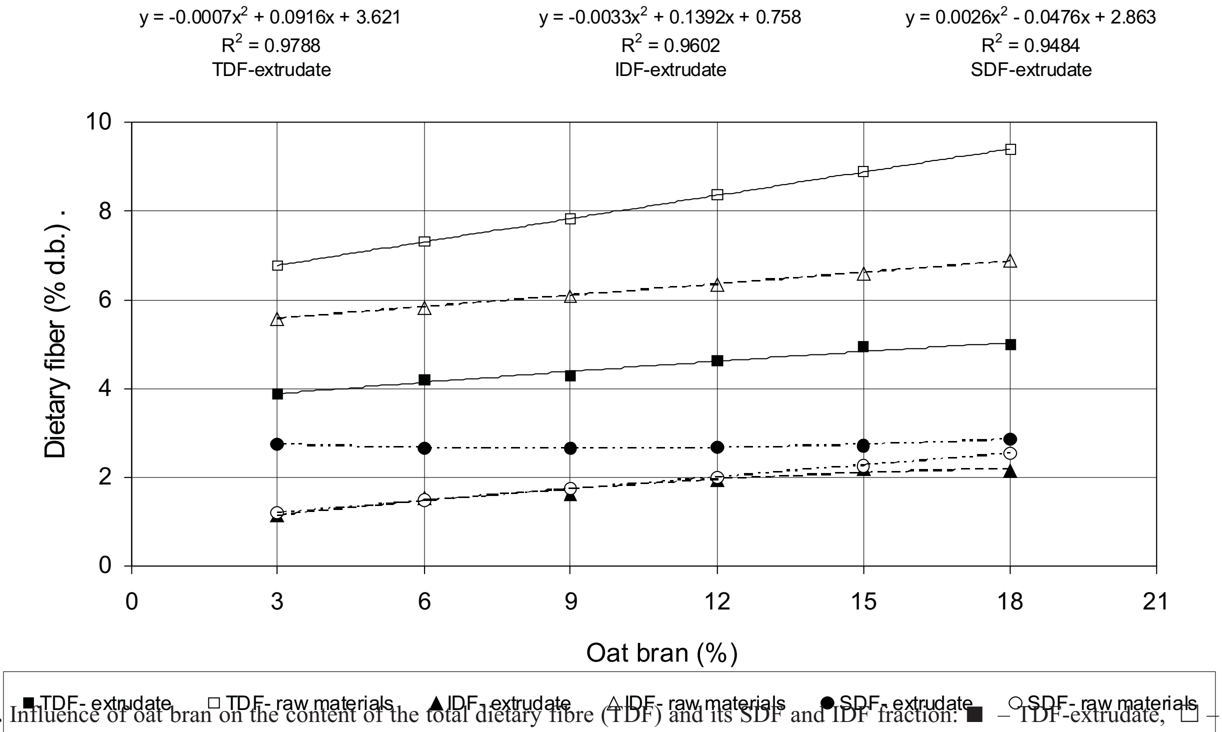

Fig. 2. Influence of oat bran on the content of the total dietary fibre (TDF) and its SDF and IDF fraction: ■ – TDF-extrudate, □ – TDF-raw materials, ▲ – IDF-extrudate, Δ – IDF-raw materials, ● – SDF-extrudate, ○ – SDF-raw materials.

As expected, increase in the content of oat bran and addition of fragmented seeds of everlasting pea resulted every time in increased protein content in the extrudates produced. Comparison of the expected values, resulting from the raw material composition, with values obtained analytically, showed a slight reduction of the content of the component as a result of the thermoplastic treatment. This is in agreement with the results obtained by other authors (Rzedzicki *et al.*, 2004). It is commonly accepted that nitrogen losses are caused by the formation of isopeptide bonds in the course of the process of extrusion, resulting in emission of free ammonia (Stanley, 1989).

As a result of the thermoplastic treatment, notable changes were observed in the content of the particular fractions of dietary fibre. There was a reduction in the content of total

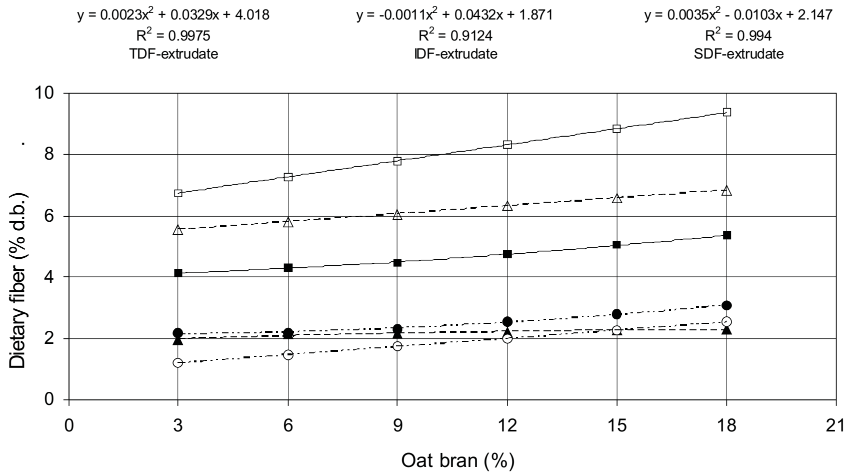

Fig. 3. Influence of the powdered milk (0.5%) on the content of the total dietary fibre (TDF) and its SDF and IDF fraction. Explanations as in Fig. 2.

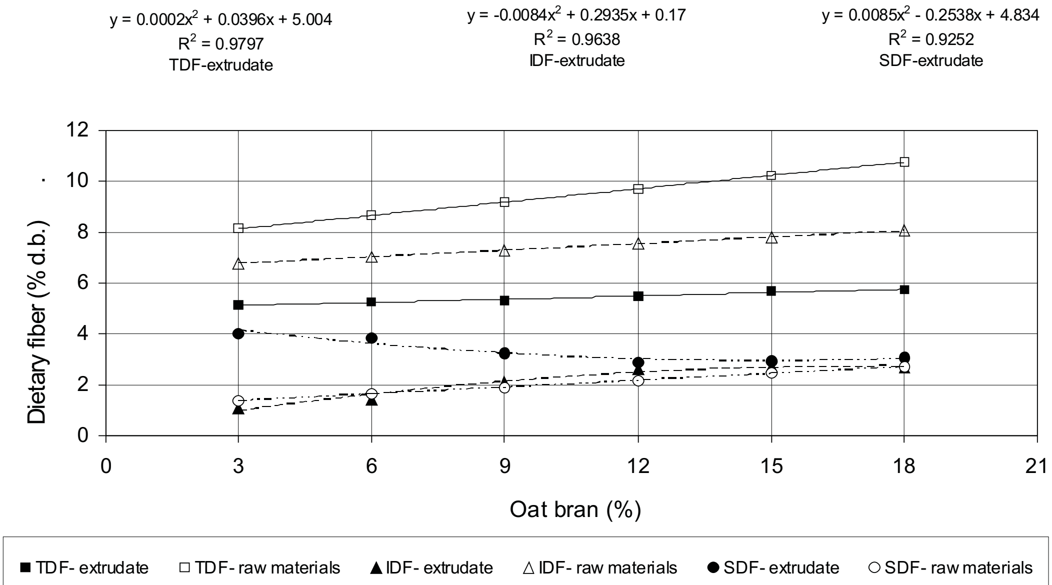

Fig. 4. Influence of the everlasting pea meal (5%) on the content of the total dietary fibre (TDF) and its SDF and IDF fraction. Explanations as in Fig. 2.

dietary fibre (TDF) and of the insoluble fraction (IDF), with simultaneous increase in the content of the soluble fraction (SDF) (Figs 2-5). Similar changes were observed in their studies by Vasanthan *et al*., (2002), Larrea *et al*., (2005) and Rzedzicki and Zarzycki (2007). As a result of intensive thermoplastic treatment, and especially due to considerable static stress, there takes place breaking up of the long molecular chains of the IDF fraction into smaller fragments, soluble in water. The artificial fraction of 'soluble' dietary fibre formed in this manner, however, still has the chemical structure of the insoluble fraction. It does, nevertheless, lose some of its sorptive properties *eg* the ability of bonding bile acids (Camire *et al*., 1993). The soluble fraction of dietary fibre artificially formed as a result of extrusion does not possess properties that are characteristic for native forms of soluble dietary fibre occurring in food.

Also, one cannot speak of total conversion of insoluble fraction of dietary fibre to the soluble fraction. In the course of thermoplastic treatment not only transformations take place in the particular fractions of dietary fibre, but it is also possible for resistant starch to be formed (Huth *et al*., 2000), increasing the content of IDF fraction. The share of the particular dietary fibre fractions is thus a resultant of the above processes.

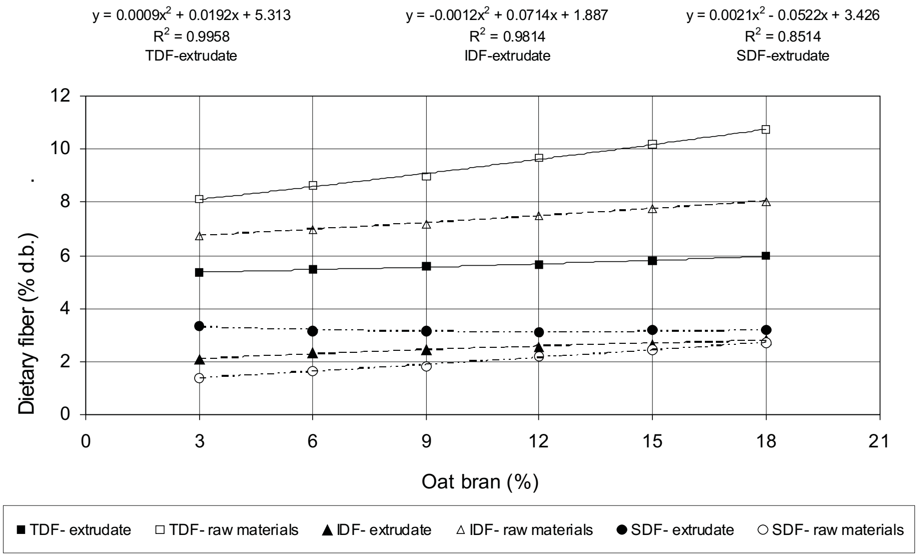

Fig. 5. Influence of the everlasting pea meal (5%) and powdered milk (0.5%) on the content of the total dietary fibre (TDF) and its SDF and IDF fraction. Explanations as in Fig. 2.

The application of a small addition of powdered whole milk (0.5%) had only a slight protective effect on dietary fibre. Only a slightly higher content of total dietary fibre and of the insoluble fraction was observed in extrudates with an addition of powdered milk, compared to extrudates without milk addition. At the same time also a lower increase was observed in the content of the soluble fraction (Figs 2, 3). The application of powdered milk in extruded blends had also another extremely important function. Powdered milk is an excellent indicator of overheating of products, and immediately provides a warning to the operator that the cylinder temperature must be reduced. In this study, exceeding of the temperature of 160°C in zone II of the cylinder was indicated by darkening of the extrudate, resulting from the formation of products of the Maillard reaction.

The study presented herein confirmed the relationships between the content of the particular dietary fibre fractions and the solubility of dry matter (WSI). Increased intensity of the process resulted both in an increase in the water solubility index and in deeper changes in the particular fractions of dietary fibre (Figs 1-5). Changes in the values of the WSI may be, therefore, a valuable indicator of the intensity of the process and of degradation of the product, and especially of insoluble fractions of dietary fibre.

CONCLUSIONS

1. Application of corn grits, oat bran, everlasting pea wholemeal and powdered whole milk considerably improved the chemical composition of extrudates.

2. The applied protein-fibre components had a favourable effect on lowering dry matter solubility.

3. Extrusion caused significant changes in the content of the particular fractions of dietary fibre. A decrease was observed in the content of total dietary fibre and of the insoluble fraction, with simultaneous increase in the content of the soluble fraction, compared to the expected values resulting from the raw material composition.

4. Every time the increases in the content of the soluble fraction fraction were lower than the reduction in the insoluble fraction.

5. Changes in the values of water solubility index were proportional to changes in the fractional composition of dietary fibre.

REFERENCES

Approved Methods of the American Association of Cereal Chemists (AACC), **2000**. St. Paul, MI, USA.

Björck I., Asp N-G., Brikhed D., and Lundquist I., 1984. Effects on processing on availability of starch for digestion *in vitro* and *in vivo*. I. Extrusion cooking of wheat flour starch. J. Cereal Sci., 2, 91-103.

Camire M., Zhao J., and Violette D.A., 1993. *In vitro* binding of bile acids by extruded potato peels. J. Agric. Food Chem., 41, 2391-2394.

Cavallero A., Empillit S., Brighenti F., and Stanca A.M., 2002. High (1-3, 1-4) β glucan barley fraction in bred making and their effects on human glycemic response. J. Cereal Sci., 36, 59-66.

Friedrich M., 2003. The effects of diet enrichment with hull-less oat cultivar on glucose, lipid, lipoproteid, fibrinogen, and estradiol contents in the blood of post-mastectomy women. Polish J. Food Nutr. Sci., 12/53, 4, 69-74.

Gerhardt A.L. and Gallo N.G., 1998. Full-fat rice bran and oat bran similarly reduce hypercholesterolemia in humans. J. Nutr., 128, 865-869.

Huth M., Dongowski G., Gebhardt E., and Flamme W., 2000. Functional properties of dietary fibre enriched extrudates from barley. J. Cereal Sci., 32, 115-128.

Jones J.M., 2001. Dietary advice in North America: the good, the bad and the unheeded. In: Advanced Dietary Fibre Technology. Blackwell Press, London, UK.

Larrea M.A., Chang Y.K., and Martinez Bustos F., 2005. Effect of some operational extrusion parameters on the constituents of orange pulp. Food Chemistry, 89, 301-308.

Rzedzicki Z., 2005. Analysis of the chemical composition of selected hot breakfast cereals (in Polish). Bromatologia i Chemia Toksykologiczna, 37S, 141-146.

Rzedzicki Z., Kozłowska H., and Troszyńska A., 2004. Application of pea hulls for extrudate production. Polish J. Food Nutr. Sci., 13/54(4), 363-368.

Rzedzicki Z. and Zarzycki P., 2005. A study on the technology of extrusion cooking of mixtures with a share of everlasting pea and oat meal (in Polish). Acta Agrophysica, 6(2), 515-528.

Rzedzicki Z. and Zarzycki P., 2007. Influence of extrusion cooking of maize-oat meal mixtures on the changes of fractional composition of dietary fibre (in Polish). Żywność, 1(50), 84-93

Stanley D.W., 1989. Protein reactions during extrusion cooking, In: Extrusion Cooking. AACC Press, St. Paul, MI, USA.

Vasanthan T., Jiang G., Yeung J., and Li J., 2002. Dietary fiber profile of barley flour as effect by extrusion cooking. Food Chem., 77, 35-40.