Int. Agrophysics, 2008, 22, 339-347

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Application of everlasting pea wholemeal in extrusion-cooking technology

M. Kasprzak and Z. Rzedzicki*

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

Received May 8, 2008; accepted July 10, 2008

A b s t r a c t. In the study the authors investigated the possibility of applying seeds of everlasting pea (*Lathyrus sativus*) in the extrusion-cooking technology. Extrudates were used to analyse the effect of an addition of everlasting pea wholegrain meal on the content of ash, fat, protein, and dietary fibre. The share of everlasting pea wholegrain meal in the raw material mixture varied from 3 to 21%. Corn semolina was used as the structure-forming component. The process of extrusion was conducted using a single-screw extrusion-cooker (L:D = 12:1, D = 45 mm) at raw material moisture content of 12-16% and at barrel temperature distribution profiles from 115/135/120 to 155/175/120ºC. As a result of the process of extrusion, a reduction was observed in the content of fat, protein, raw fibre, neutral-detergent fibre (NDF), acid-detergent fibre (ADF), hemicellulose (HCEL), cellulose (CEL), total dietary fibre (TDF) and insoluble dietary fibre (IDF). At the same time an increase was recorded in the content of soluble dietary fibre (SDF) and lignin (ADL).

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

INTRODUCTION

The market of breakfast cereals, snacks and various crisps has become dominated by high-processed corn products, produced of corn semolina. Corn semolina is obtained from hulled and de-germed corn grain, hence such extrudates are characterized by a low content of protein and a very low content of dietary fibre (Rzedzicki and Wirkijowska, 2006). As the primary consumers of that group of food products are mainly children, such a poor chemical composition assumes a special significance. Therefore, every enrichment of such products with proteins and dietary fibre is greatly desirable and notably improves their chemical composition and nutritional value. A special role can be played here by seeds of leguminous plants. As cereal confectionery is produced with the use of the extrusion technology, such enriching protein-fibre leguminous components must easily undergo liquefaction in extrusion-cooking. Special features of seeds of everlasting pea, including their light-colour seed cover and cotyledons that do not darken under thermal treatment, predispose them for extensive application in the extrusion technology (Kasprzak and Rzedzicki, 2007; Lambein and Kuo, 1997). Common utilisation of that raw material in extrusion technology is also supported by its rich chemical composition. Seeds of everlasting pea contain even up to 28% protein, 33% dietary fibre (Tables 1 and 2), and are an especially valuable source of biologically active compounds (Kozłowska and Troszyńska, 1995; Troszyńska *et al*., 1997a, b).

During thermoplastic treatment, raw material fed into the extrusion-cooker barrel is mixed, compressed, plasticized up to liquefaction of the mass, boiled, and extruded through a die. Such baking conditions permit homogenization of the raw material and uniform distribution of various admixtures in the continuous phase. The technology is used to obtain products with any desired properties, varied in terms of form, shape, texture, and sensory and quality features (Fornal *et al.,* 1998; Huber, 2001; Pansawat *et al.,* 2008).

It should be kept in mind that the processed material is strongly affected by high temperature, pressure, and tangential stress. The total time that the material stays in the extruder is usually from a few dozen seconds to about 2 min (Harper, 1989; Huber, 2001), but the time of its being subjected to the effect of high temperature and pressure is less than twenty seconds. Due to the simultaneous effect of those factors deep structural changes occur within the material processed, that permit the obtainment of products with new quality features, interesting in form, totally different from the original raw material. Apart from the structural changes, in the extruded material there occur also deep

*Corresponding author's e-mail: malgorzata.kasprzak@up.lublin.pl

T a b l e 1. Chemical composition of the raw materials (Kozłowska and Troszyńska, 1995; Troszyńska *et al*., 1997b)

Raw material	Ash	Crude protein	Crude fat	Crude fiber
	(% d.m.)			
Everlasting pea meal	3.32±0.202	27.92±0.480	1.03±0.092	5.86±0.113
Corn semolina	0.58±0.16	7.64±0.627	0.83±0.113	0.52±0.106

± standard deviation.

T a b l e 2. Fiber fraction content of the raw materials (Kozłowska and Troszyńska, 1995; Troszyńska *et al*., 1997b)

Raw material	Fiber fraction							
	NDF*	ADF	HCEL	CEL	ADL	SDF	IDF	TDF
	(% d.m.)							
Everlasting pea meal	22.05±0.276	7.85±0.267	14.2	7.75	0.10±0.014	4.26±0.194	28.88±0.085	33.14
Corn semolina	3.7±0.014	0.75±0.049	2.95	0.60	0.15±0.016	1.07±0.131	5.33±0.064	6.40

± standard deviation; *NDF – neutral-detergent fibre, ADF – acid detergent fibre, HCEL – hemicellulose, CEL– cellulose, ADL – acid detergent lignin, SDF – soluble dietary fibre, IDF – insoluble dietary fibre, TDF – content of total dietary fibre.

chemical transformations. The intensity of those transformations depends on the conditions of the process and on the features of the material processed (Pansawat *et al.,* 2008; Singh *et al*., 2007). The intensity of the transformations can be modelled through altering the process parameters and the composition o the material subjected to the treatment.

The objective of the study was to investigate the possibilities of modifying the chemical composition of cereal extrudates produced on the basis of corn grits, and in particular of the possibility of increasing the content of proteins and dietary fibre through the introduction of everlasting pea wholemeal in the extruded composition, and to determine the effect of variable parameters of extrusion *ie* raw material moisture, process temperature and material composition on the chemical composition of the extrudates produced.

MATERIAL AND METHODS

As the structure-forming material in the study corn semolina was used, originating from grinding of hulled and de-germed grain of vitreous corn. For the modification of chemical composition, and especially of the content of proteins and dietary fibre, seeds of everlasting pea (*Lathyrus sativus*) cv. Derek were used. The process of fragmentation of the raw materials was performed in an impact grinder (type H-111/3) until the required equivalent diameter was obtained and the required share of mealy fractions <0.5 mm (Table 3). The process of extrusion was conducted in an S-45 single-screw extrusion-cooker with compression ratio of 3:1, L/D = 12:1, die diameter of 3.5 mm and screw rotation speed of 100 min^{-1}.

The study included variable share of everlasting pea wholemeal (3-21%) and corn semolina (79-97%). The moisture of the composition fed into the extruder varied within the range from 12 to 16%. The process of extrusion was conducted at barrel temperature distribution profiles from 115/135/120 to 155/175/120ºC. Mixtures for extrusion were prepared in accordance with the model of the experiment (Table 4), moistened, stirred, and conditioned at a temperature of approx. 20ºC for 24 h to achieve uniform water diffusion within the material. Compositions prepared in this manner were subjected to thermoplastic processing in the extruder. The model of the experiment included process parameters and material properties resulting from pilot tests, ensuring the obtainment of extrudates with the features of a high-quality food product.

Determinations made for the raw materials and the extrudates included the content of crude ash (AACC, Method 08-01), total protein (AACC, Method 46-08), free fat (AACC, Method 30-10), crude fibre (AACC, Method 32-10), and dietary fibre. Determination of dietary fibre fractions was performed with the detergent method, determining the neutral-detergent fibre (NDF), acid detergent fibre (ADF), hemicellulose (HCEL), cellulose (CEL), and acid detergent lignin (ADL) (Van Soest, 1963 a, b). Analysis of fractional composition of dietary fibre with the enzymatic method was conducted in accordance with the following methods: AACC Method 991.43, AACC Method 32-07, AACC Method 32-21, AOAC Method 985.29, AACC Method 32-05. Also determined were the content of total dietary fibre (TDF), insoluble dietary fibre (IDF) and soluble

T a b l e 3. Sieve analysis of the raw materials

Fraction (mm)	Everlasting pea meal	Corn semolina
	(%)	
> 1.6	0	0
1.6 - 1.2	1.5	0.22
1.2 - 1	8.67	5.58
1- 0.8	21.45	26.57
0.8 - 0.5	27.69	42.38
0.5 - 0.265	22.36	19.23
< 0.265	18.33	6.02
Sum of fractions <0.5	40.69	25.25
Mean diameter (mm)	0.624	0.669

T a b l e 4. Model of experiments

Sample No.	Share rate of component (%)			Moisture content (%)	Barrel temperature (°C)
	Ever-lasting pea meal	Corn semolina	NaCl		
1	3	97			140/160/120
2	6	94			
3	9	91			
4	12	88		13	
5	15	85			
6	18	82			
7	21	79			
8				12	
9			1	13	
10				14	
11				15	
12				16	
13	10	90			115/135/120
14					125/145/120
15				13	135/155/120
16					145/165/120
17					155/175/120

dietary fibre (SDF). In the enzymatic method Megazyme enzymes and methodological procedures were applied. The correctness of determinations with the enzymatic method was verified with the use of Megazyme control tests. Additionally, for every series of samples control samples of casein and starch were introduced. The content of selected mineral elements (iron, manganese, nickel) in the raw material and the extrudates was determined with the method of atom absorption spectrophotometry (ASA) using the Unicam 939 apparatus (AOAC, Method 975.03). The determinations were made at the Central Analytical Laboratory of the Lublin University of Life Sciences in Lublin.

All the chemical analyses were made in three replications. The results were subjected to statistical analysis using Microsoft Excel (Microsoft Office XP software).

Calculations were made of the mean values, standard deviations, and coefficient of variability. For continuous variables regression equations and coefficients of determination (R^2) were determined. If the values of the coefficient of variability exceeded the limits of error adopted for a given method, analyses were repeated until correct distribution of results was obtained.

RESULTS AND DISCUSSION

Within the ranges of process parameters and material features defined by the model of the experiment the process of extrusion of corn-everlasting pea mixtures ran with a high degree of correctness. No slippage of extruded mass was observed, nor any burning of the material. The obtained extrudates displayed features of high-quality snacks and were acceptable for direct consumption. Within this range the obtained results were in conformance with those of earlier studies (Rzedzicki, 1997), performed for a different batch of raw material and another everlasting pea cultivar, confirming also the high applicability of everlasting pea in the extrusion technology. The obtained extrudates were characterised by very good sensory features and very good physical properties that determine the acceptability and attractiveness of products of this type.

The study showed that changes in the process parameters (moisture and temperature) and in the share of everlasting pea wholegrain meal in the mixture with corn grits led to significant differences in the chemical composition of the extrudates produced. With increase in the share of everlasting pea wholegrain meal there was an increase in the content of the basic components in the extrudates-ash, protein and crude fibre (Table 5). It should be emphasized that the everlasting pea contained 27.92% of proteins and its introduction to the corn grits, containing only 7.64% of protein, permitted a notable improvement of the content of that component in the extrudates (Table 1). With a 21% share of everlasting pea in the composition it was already possible to obtain extrudates with protein content of 11.81% (Table 5).

T a b l e 5. Chemical composition of the extrudates

Sample No.	Ash	Crude protein	Crude protein*	Crude fat	Crude fat*	Crude fiber	Crude fiber*
				(% d.m.)			
1	0.90±0.057	8.07±0.021	8.25	0.09±0.014	0.84	0.16±0.016	0.68
2	1.05±0.037	8.52±0.094	8.86	0.09±0.012	0.84	0.19±0.011	0.84
3	1.10±0.032	9.26±0.036	9.47	0.07±0.002	0.85	0.29±0.005	1.00
4	1.16±0.045	10.02±0.005	10.07	1.18±0.788	0.85	0.42±0.044	1.16
5	1.27±0.039	10.60±0.043	10.68	0.09±0.012	0.87	0.52±0.002	1.32
6	1.37±0.021	11.30±0.036	11.61	0.16±0.067	0.87	0.77±0.036	1.48
7	1.41±0.060	11.81±0.084	11.90	0.16±0.041	0.87	0.84±0.090	1.64
8	0.99±0.040	9.89±0.003		0.44±0.029		0.25±0.074	
9	1.03±0.073	9.86±0.018		0.40±0.053		0.34±0.011	
10	1.05±0.074	9.99±0.002		0.07±0.042		0.35±0.015	
11	1.06±0.053	9.93±0.025		0.07±0.028		0.35±0.026	
12	1.00±0.052	9.84±0.013	9.67	0.07±0.012	0.85	0.39±0.014	1.05
13	0.93±0.038	9.85±0.012		0.18±0.052		0.37±0.026	
14	1.00±0.087	9.73±0.033		0.15±0.012		0.39±0.004	
15	1.02±0.058	9.86±0.133		0.4±0.031		0.36±0.025	
16	1.03±0.050	9.88±0.076		0.24±0.036		0.35±0.007	
17	1.02±0.072	9.62±0.107		0.07±0.002		0.33±0.030	

*calculated value of component, based on the composition of the raw material, ±standard deviation.

In all the tested samples of corn-legume extrudates a lower protein content was determined relative to the expected values resulting from the raw material composition (Table 5). Although the scale of the changes was small, the regularity of nitrogen reduction as a result of the process of extrusion was confirmed. Increased reduction in the content of nitrogen in the extrudates was facilitated by higher process temperatures, hence the greatest rates of the decrease were recorded with the temperature distribution profile of 155/175/120ºC (Table 5). Increase in the moisture content of the mixture limited the loss of that component. Similar tendencies were also observed in other studies (Alonso *et al*., 2001; González and Pérez, 2002; Leontowicz *et al*., 1999). Stanley (1989) demonstrates that nitrogen losses in the course of extrusion are caused by the formation of isopeptide bonds with simultaneous emission of ammonia.

The introduction of everlasting pea wholemeal to the mixtures permitted also a notable increase of the content of mineral compounds in the extrudates. Samples with 21% share of everlasting pea contained 1.41% of ash (Table 5), while the corn grits contained only 0.58% of the component (Table 1). As it was to be expected, the process of extrusion did not affect the content of that component in the extrudates with relation to the initial composition subjected to the treatment (Table 5).

Analysis of fat content in the mixtures prior to the thermoplastic treatment and in the extrudates (Table 5) revealed very strong binding of fat in the course of extrusion. In the extrudates several-fold lower content of that component was observed than in the raw material compositions. The difference between fat content in raw materials and in extrudates is accepted as the measure of the intensity of fat binding in the course of thermoplastic treatment (Guzman *et al*., 1992). According to numerous authors, lowering of fat content due to extrusion is caused by the formation of starch-lipid and protein-lipid complexes that are resistant to the effect of apolar solvents (Camire, 2001; Fornal *et al*., 1995; Ho and Izzo, 1992). Many researchers observed decrease of fat determinability by as much as 70% (Bhatnagar and Hanna 1994 a, b, 1996; Guzman *et al*., 1992; Ho and Izzo, 1992). The intensity of fat binding is significantly affected by the kind of raw material used and by the process parameters. Reduction of fat-complex formation can be achieved through shortening the time of raw materials being subjected to the effect of high temperatures (Guzman *et al*., 1992; Ho and Izzo, 1992). According to research by Wang *et al*. (1993), lowering of the content of starch in material is conducive also to reduced fat-complex formation.

T a b l e 6. Fractional composition of detergent fiber components of the extrudates

Sample No.	NDF	NDF*	ADF	ADF*	HCEL	HCEL*	CEL	CEL*	ADL	ADL*
	(% d.m.)									
1	2.49±0.110	4.25	0.51±0.027	0.96	1.98±0.137	3.29	0.25±0.016	0.82	0.26±0.011	0.15
2	2.52±0.037	4.8	0.77±0.103	1.18	1.75±0.066	3.63	0.52±0.090	1.03	0.25±0.012	0.15
3	3±0.218	5.35	0.83±0.036	1.139	2.17±0.254	3.96	0.63±0.023	1.24	0.2±0.013	0.15
4	3.8±0.282	5.9	1±0.023	1.6	2.8±0.259	4.3	0.85±0.013	1.46	0.15±0.011	0.14
5	4.44±0.290	6.45	1.16±0.043	1.82	3.28±0.332	4.64	1±0.053	1.67	0.16±0.011	0.14
6	4.43±0.003	7	1.26±0.054	2.03	3.17±0.050	4.98	1.1±0.041	1.89	0.16±0.012	0.14
7	4.84±0.060	7.55	1.65±0.073	2.24	3.19±0.133	5.31	1.43±0.061	2.1	0.22±0.012	0.14
8	3.63±0.013	5.54	1.03±0.153	1.46	2.6±0.139	4.08	0.85±0.140	1.46	0.18±0.012	0.15
9	3.48±0.388		0.94±0.069		2.54±0.319		0.75±0.054		0.19±0.015	
10	3.56±0.409		1.01±0.033		2.55±0.442		0.82±0.019		0.19±0.014	
11	3.54±0.217		1.08±0.066		2.46±0.283		0.88±0.051		0.2±0.015	
12	3.85±0.358		1.15±0.162		2.7±0.196		0.92±0.144		0.23±0.018	
13	3.06±0.106		0.86±0.042		2.2±0.064		0.75±0.032		0.11±0.010	
14	3.66±0.090		0.84±0.047		2.82±0.043		0.71±0.035		0.13±0.012	
15	3.48±0.218		0.94±0.042		2.54±0.261		0.75±0.032		0.19±0.011	
16	3.95±0.067		0.92±0.043		3.03±0.025		0.7±0.029		0.22±0.014	
17	3.55±0.233		0.81±0.052		2.74±0.180		0.58±0.038		0.23±0.014	

Explanations as in Tables 2 and 5.

Introduction of everlasting pea wholemeal in compositions with corn semolina led to increase in the content of structural components of cell walls in extrudates. This regularity was observed every time in the three methods applied for the determination of those components: the traditional crude fibre method (Table 5), the detergent method (Table 6) and the enzymatic method (Fig. 1). According to studies by Fornal *et al*. (1993) the level of the changes is affected both by the raw material composition subjected to thermoplastic treatment and by the process parameters applied.

The greatest changes in the content of structural components were observed as a result of changes in the raw material composition and the introduction of the leguminous material into the mixture. Increase in the share of everlasting pea wholemeal in the raw materials mixture from 3 to 21% resulted in increase in crude fibre content from 0.68 to 1.64% d.m. (Table 5), of neutral-detergent fibre (NDF) from 4.25 to 7.55% d.m. (Table 6), of acid-detergent fibre (ADF) from 0.96 to 2.24% d.m., hemicellulose (HCEL) from 3.29 to 5.31% d.m., and of cellulose (CEL) – from 0.82 to 2.1% d.m. Within a small range changes were also observed in the content of acid-detergent lignin (ADL).

Comparing the content of crude fibre, neutral-detergent fibre, acid-detergent fibre, hemicellulose and cellulose in the raw materials and in corn-everlasting pea extrudates one can explicitly state that extrusion-cooking leads to strong degradation and reduction of the content of structural components in the products (Tables 5 and 6). Decrease in the content of structural components was also observed by other researchers (Alonso *et al*., 2001; Fornal *et al*., 1993; González and Pérez, 2002).

In all of the studied crisps, on the other hand, a slight increase was observed in the content of acid-detergent lignin (ADL) (Table 6). The ADL content determined in the corn-everlasting pea extrudates varied within the range from 0.15 to 0.26% d.m., while in the raw material mixture its level was much lower (Table 6). Increase in the content of acid-detergent lignin in extrudates was also noted by Fornal *et al*. (1993). According to many authors drastic parameters of the process of extrusion may lead to the formation of Mailard reaction products, increasing the level of that lignin fraction (ADL) (Fornal *et al*., 1993; Singh *et al*., 2007).

The process moisture and temperature also affect the content of structural components in extrudates. It was noted that increasing the moisture of mixtures subjected to extrusion limited the destructive effect of the process and resulted in an increased content of dietary fibre. Moisture increase by 4% led to crude fibre content increase from 0.25 to 0.39% d.m. (Table 5). In the case of the detergent fibre fraction a varied directionality of changes in the content of those components was observed (Table 6). Also Lipiec *et al*., (1997) recorded similar changes in the fractional composition of detergent fibre.

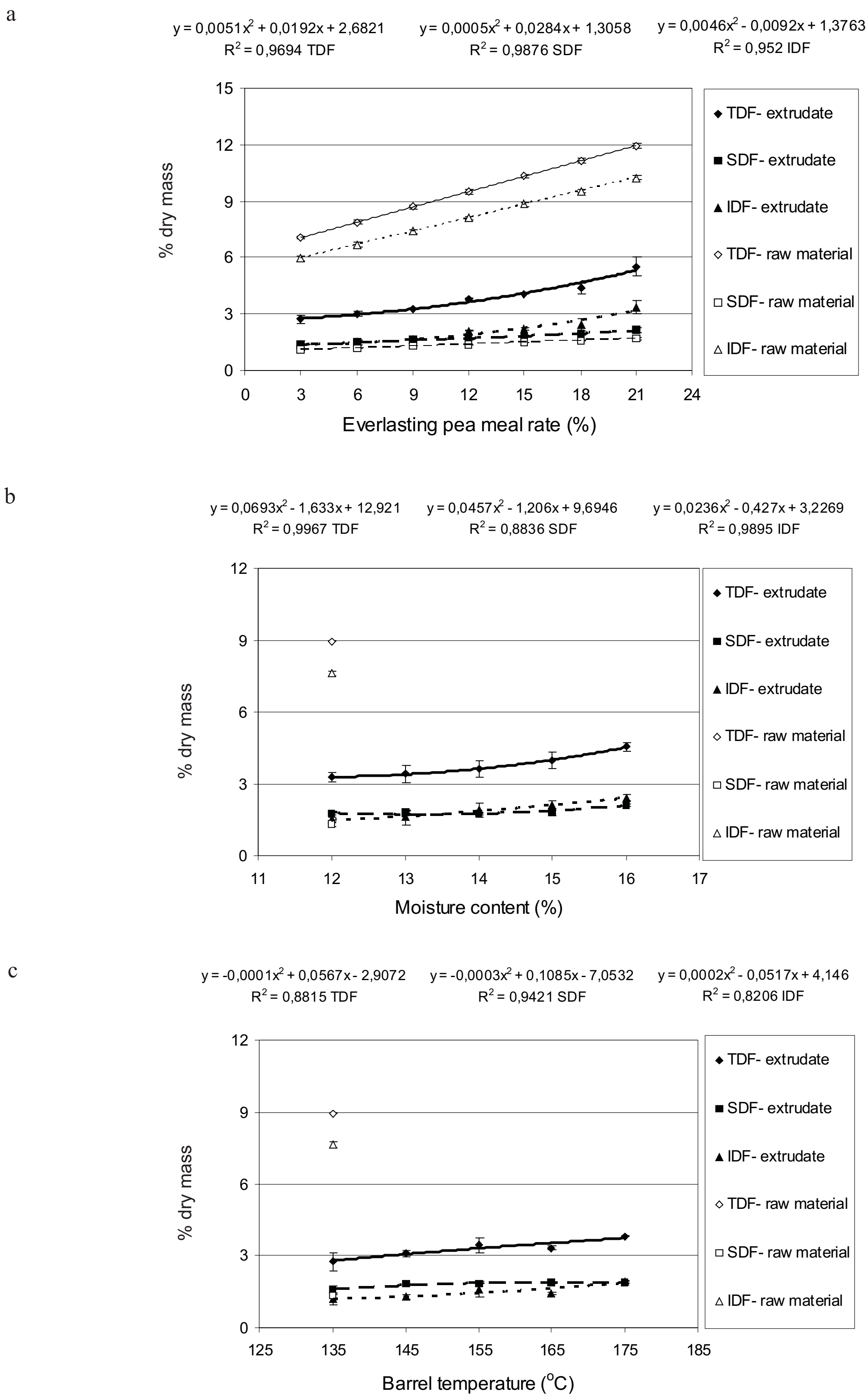

Fig. 1. The influence of: a – everlasting pea meal rate, b – moisture content, and c – barrel temperature on the content of the TDF, SDF and IDF in the extrudates.

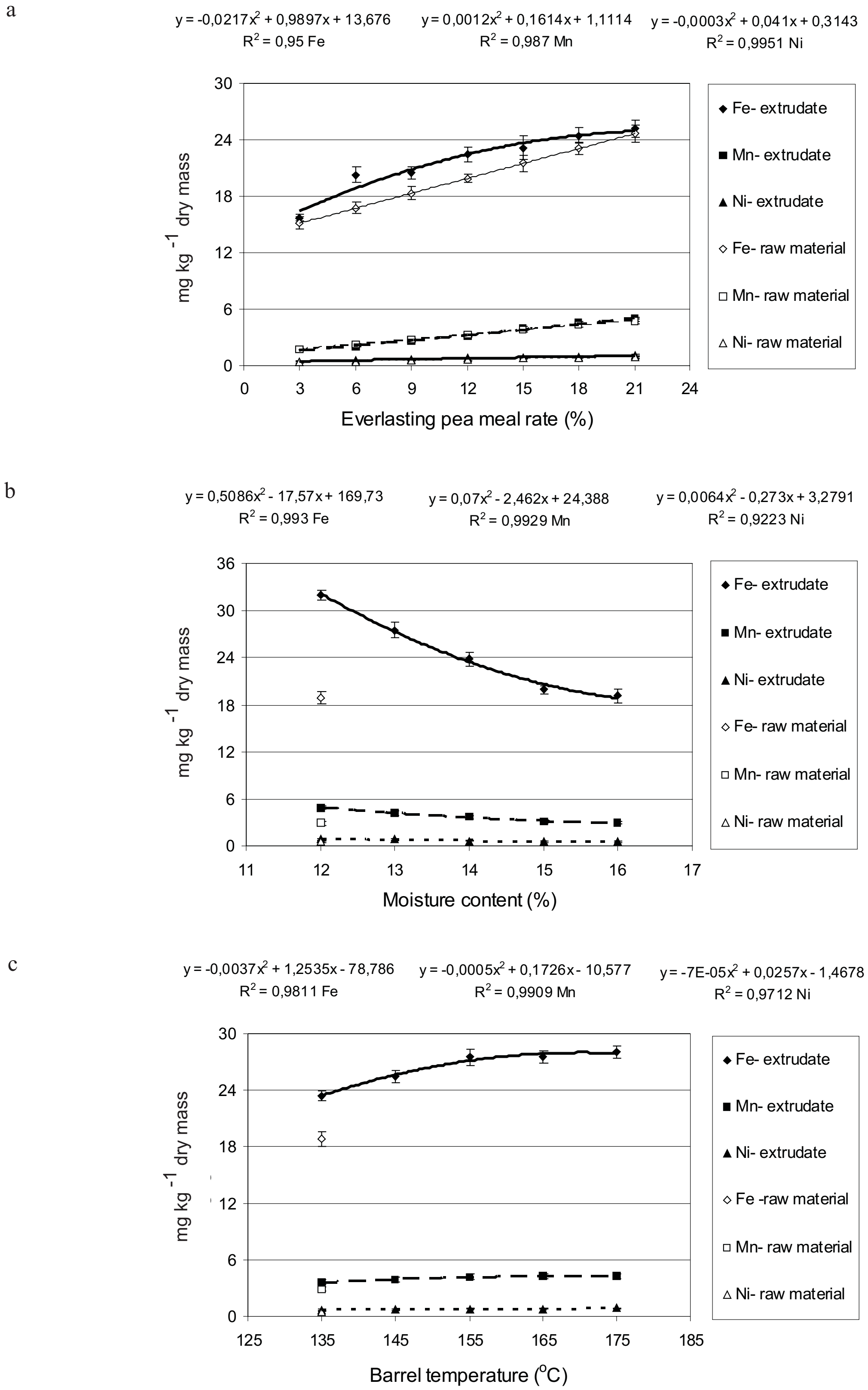

Fig. 2. The influence of: a – everlasting pea meal rate, b – moisture conent, and c – barrel temperature on the content of the Fe, Mn, and Ni in the extrudates.

The authors analysed also the effect of change in the barrel temperature distribution profile on the content of dietary fibre. Increase in the temperature caused a decrease in the content of crude fibre from 0.37 to 0.33% d.m. (Table 5) and of cellulose from 0.75 to 0.58% d.m., and an increase in the content of acid-detergent lignin from 0.11 to 0.23% d.m. (Table 6). The obtained values of ADL content were higher than the expected values resulting from the raw material composition (Table 6).

It was also observed that the crude fibre content, both in the extrudates and in the raw materials, was lower than the content of acid-detergent fibre that, by definition, should be the sum of cellulose and lignin fractions, so the Wendee method for determination of structural components is definitely unsuitable for high-processed products, such as extruded cereal products.

The content of dietary fibre was also studied with the enzymatic method. Compared to the expected values, resulting from the raw material composition, for each of the analysed samples a decrease was recorded in the content of total dietary fibre (TDF) and of insoluble dietary fibre (IDF). At the same time an increase was observed in the content of soluble dietary fibre (SDF) (Fig. 1). As a result of break-up of insoluble fibre fractions a part of them is determined as soluble fibre. It should be emphasized, however, that increased determinability of the soluble fraction is still decidedly lower than the losses of the insoluble fraction.

Changes in raw material moisture have a significant effect on the fractional composition of enzymatic fibre. For samples with 9% content of everlasting pea wholemeal, increase in raw material moisture by 4% resulted in an increase in IDF content from 1.52 to 2.42% d.m., SDF- from 1.77 to 2.13% d.m., and TDF- from 3.29 to 4.55% d.m. (Fig. 1b). In spite of the observed increasing tendency, the obtained values of TDF and IDF content in the extrudates were still decidedly lower that the expected values calculated from the raw material composition. At the same time, an increase was recorded in the content of soluble dietary fibre, SDF, from 0.44% for the raw material mixture to 0.80% d.m. in the extrudate. A similar directionality of changes was noted also by Rzedzicki *et al*. (2004) and Singh *et al*. (2007).

The study included also investigation of the effect of barrel temperature distribution profile on the content of particular dietary fibre fractions. Tests were performed for samples with 9% content of everlasting pea wholemeal. Increasing the process temperature by 40ºC an increase was obtained in the content of IDF by 0.76% d.m., SDF by 0.30% d.m., and TDF by 1.06% d.m. (Fig. 1c).

Also analysed was the effect of the material mixture composition and of the process parameters on the level of metallic contamination of extrudates, resulting from the wear of the working elements of the extrusion-cooker. As a result of the process of extrusion, a slight increase in the content of iron in the extrudate was recorded with relation to the expected values resulting from the composition of the input mixture (Fig. 2a). The differences, however, were very small. Similar proportions were obtained for the content of two other mineral components (Mn and Ni). Somewhat higher levels of metallic contamination were obtained by Alonso *et al*. (2001) in their research.

The content of mineral components in the extrudates was also affected by the moisture level of the material mixture. Higher levels of Fe, Mn and Ni were recorded in the extrudates than in the raw material compositions (Fig. 2b). Increase in raw material moisture from 12 to 16% resulted in reduced wear of the working elements of the extruder, and thus also in lower content of Fe- from 31.96 to 19.10 mg kg^{-1} d.m. (Fig. 2b).

Also tested was the effect of cylinder temperature on the level of metallic contamination. Increase in the process temperature caused a slight increase in the level of the contamination. The highest increase of iron content, 9.21 mg kg^{-1} d.m., was recorded in the case of samples obtained at the temperature of 175ºC (Fig. 2c). The observed orientation of changes shows that the dominant factor determining the level of metallic contamination is not the physical wear of the working elements. Increase in the process temperature results in a decrease in viscosity, so a reduction of such contamination should be observed. The direction of changes, however, is reverse, which demonstrates that the dominant cause of the contamination is the transition of metals to the product as a result of chemical reactions.

The levels of metallic contamination recorded in this study were low compared to literature data (Artz *et al*., 1992), where even 5-6-fold increase in the content of metals in the extrudate was noted compared to the raw material. Our study does not support such results; on the contrary – we believe them to be technically impossible.

CONCLUSIONS

1. The process of extrusion causes multi-directional chemical transformations in the extrudates, the intensity of which is determined by the raw material composition of mixtures subjected to processing, and by the applied range of process parameters.

2. As a result of extrusion, only a slight decrease was observed in the content of proteins.

3. In the extrudates studied very intensive binding of fat was observed.

4. As a result of extrusion, a decrease was observed in the content of crude fibre, NDF, ADF, HCEL, CEL, TDF and IDF; at the same time an increase was noted in the content of acid-detergent lignin (ADL) and of soluble dietary fibre (SDF).

5. The process of extrusion leads to a slight increase in the content of iron in the extrudates compared to the raw material composition.

6. Suitable selection of the raw material mixture composition and of the process parameters permits extensive modelling of the physical properties and the chemical composition of extrudates.

REFERENCES

AACC- Approved Methods of the American Association of Cereal Chemists, **2000.** AACC Press, St. Paul, MN, USA.

Alonso R., Rubio L.A., Muzquiz M., and Marzo F., 2001. The effect of extrusion cooking on mineral bioavailability in pea and kidney bean seed melas. Animal Feed Sci. Technol., 94, 1-13.

Artz W.E., Rao S.K., and Sauer R.M., 1992. Lipid oxidation in extruded products during storage as affected by extrusion temperature and selected antioxidants. In: Food Extrusion Science Technology. Dekker Press, New York, USA.

Bhatnagar S. and Hanna M.A., 1994a. Amylose-lipid complex formation during single-screw extrusion of various corn starches. Cereal Chem., 71, 6, 582-587.

Bhatnagar S. and Hanna M.A., 1994b. Extrusion processing conditions for amylase-lipid complexing. Cereal Chem., 71, 6, 587-593.

Bhatnagar S. and Hanna M.A., 1996. Starch-stearic acid complex development within single and twin screw extruders. J. Food Sci., 61, 4, 778-782.

Camire M.E., 2001. Extrusion and nutritional quality. In: Extrusion Cooking Technologies and Applications. Woodhead Press, London, UK.

Fornal Ł., Majewska K., Kondrusik R., and Wójcik E., 1995. Application of oat grain in extrusion-cooking. Technol. Alim., 28, 109-117.

Fornal Ł., Majewska K., and Wicklund T., 1998. The quality of oat extrudates. Technol. Alim., 30, 119-126.

Fornal Ł., Wlaź B., and Bąkowska B., 1993. Conversion of polymer carbohydrates during extrusion. Technol. Alim., 25, 125-135.

González Z. and Pérez E., 2002. Evaluation of lentil starches modified by microwave irradiation and extrusion cooking. Food Res. Int., 35, 415-420.

Guzman L.B., Lee T.C., and Chichester C.O., 1992. Lipid binding during extrusion cooking. In: Food Extrusion Science Technology. Dekker Press, New York, USA.

Harper J.M., 1989. Food extruders and their applications. In: Extrusion Cooking. AACC Press, St. Paul, MN, USA.

Ho C.T. and Izzo M.T., 1992. Lipid-protein and lipid-carbohydrate interactions during extrusion. In: Food Extrusion Science Technology. Dekker Press, New York, USA.

Huber G., 2001. Snack foods from cooking extruders. In: Snack Foods Processing. CRC Press, Boca Raton, FL, USA.

Kasprzak M. and Rzedzicki Z., 2007. Effect of bath temperature and soaking time on the dynamics of water holding capacity of everlasting pea-wheat extrudates. Int. Agrophysics, 21, 241-248.

Kozłowska H. and Troszyńska A., 1995. Storage substances of legumes (in Polish). Post. Nauk Roln., 6, 75-82.

Lambein F. and Kuo Y.H., 1997. *Lathyrus sativus*, a neolithic crop with a modern future? An overview of the present situation. Proc. Int. Symp. '*Lathyrus sativus* – cultivation and nutritive value in animals and humid`, June 9-10, Lublin-Radom, Poland.

Leontowicz H., Leontowicz M., Kostyra H., Gralak M.A., and Kulasek G.W., 1999. The influence of extrusion or boiling on trypsin inhibitor and lectin activity in leguminous seeds and protein digestibility in rats. Polish J. Food Nutr. Sci., 49, 77-87.

Lipiec A., Grela E.R., and Zdunek B., 1997. Quantitative and qualitative changes in dietary fibre of flat pea (*Lathyrus sativus*) seeds subjected to various extrusion-cooking conditions (in Polish). Biul. Nauk. Przem. Pasz., XXXVI, 1, 13-19.

Pansawat N., Jangchud K., Jangchud A., Wuttijumnong P., Saalia F.K., Eitenmiller R.R., and Philips R.D., 2008. Effects of extrusion conditions on secondary extrusion variables and physical properties of fish, rice-based snacks. LWT, 41, 632-641.

Rzedzicki Z., 1997. Extrusion cooking technology of everalsting pea (*Lathyrus sativus*) (in Polish). Proc. Int. Symp. '*Lathyrus sativus* – cultivation and nutritive value in animals and humid`, June 9-10, Lublin-Radom, Poland.

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

Rzedzicki Z. and Wirkijowska A., 2006. Analysis of chemical composition of selected corn breakfast cereals particulary fractional composition of dietary fiber (in Polish). Bromat. Chem. Toksykol., 39, 97-102.

Singh S., Gamlath S., and Wakeling L., 2007. Nutrition aspects of food extrusion. Int. J. Food Sci. Technol., 42, 916-929.

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

Troszyńska A., Bednarska A., Łatosz A., and Kozłowska H., 1997a. Polyphenolic compounds in the seed of legume seeds. Pol. J. Food Nutr. Sci., 47, 37-45.

Troszyńska A., Honke J., Milczak M., and Kozłowska H., 1997b. Bioactive compounds in lathyrus sativus seeds (*Lathyrus sativus*) and lentil (*Lens culinaris Medik*) (in Polish). Proc. Int. Symp. '*Lathyrus sativus* – cultivation and nutritive value in animals and humid`, June 9-10, Lublin-Radom, Poland.

Van Soest P., 1963a. Use of detergents in the analysis of fibrous feeds. I: Preparation of fiber residues of low nitrogen content. J. Offic. Agric. Chem., 46, 5, 825-829.

Van Soest P., 1963b. Use of detergents in the analysis of fibrous feeds. II: A rapid method for the determination of fiber and lignin. J. Offic. Agric. Chem., 46, 5, 829-835.

Wang W.M., Klopfenstein C.F., and Ponte J.G., 1993. Effects of twin-screw extrusion on the physical properties of dietary fiber and other components of whole wheat and wheat bran and of the baking quality of the wheat bran. Cereal Chem., 70, 712-717.