POLISH JOURNAL OF FOOD AND NUTRITION SCIENCES

http://journal.pan.olsztyn.pl
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Pol. J. Food Nutr. Sci.
2010, Vol. 60, No. 3, pp. 251-259

EFFECT OF EXTRUSION-COOKING PROCESS ON THE CHEMICAL COMPOSITION OF CORN--WHEAT EXTRUDATES, WITH PARTICULAR EMPHASIS ON DIETARY FIBRE FRACTIONS

Aldona Sobota, Emilia Sykut-Domańska, Zbigniew Rzedzicki

Engineering and Cereals Technology Department, University of Life Sciences in Lublin

Key words: extrusion–cooking, dietary fibre, wheat bran, corn grits, cereals

A study was conducted on the use of wheat bran as a potential source of dietary fibre in the technology of counter-rotation twin-screw extrusion. The determinations included the effect of the composition of mixtures, distribution of barrel temperatures and of corn grits mixture moisture content on the possibility of extrusion conditions stabilisation, dry mass solubility, and chemical composition. The process of extrusion resulted in a decrease in the content of proteins, in the content of crude fibre, and in the content of all fibre fractions determined with the detergent method. Also, significant changes were observed in the fraction composition of dietary fibre determined with the enzymatic method, showing a decrease in the content of total dietary fibre (TDF) and of its insoluble fraction (IDF) in the extrudates. As a result of the process of extrusion, an increased content of the soluble fraction of dietary fibre (SDF) was recorded. Extrusion process caused also a very significant increase of solubility of dry matter (WSI).

ABBREVIATIONS

ADF – acid detergent fibre, ADL – acid detergent lignin, CEL – cellulose, CF – crude fibre; HCEL – hemicelluloses, IDF – insoluble dietary fibre, NDF – neutral detergent fibre, SDF – soluble dietary fibre, TDF – total dietary fibre, WSI – water solubility index.

INTRODUCTION

The second half of the 20th century brought humanity not only immense technological progress, but also an epidemic of civilisation diseases. For many years scientists have searched for effective methods of prophylactics and treatment of cardiovascular system diseases, cancer, type II diabetes, and obesity. Already in the nineteen sixties a series of experiments were begun that indicated a positive effect of dietary fibre on human health [Kritchewsky, 2001]. Commonly known institutions dealing with the evaluation of human diet, including the US FDA, promote increased consumption of whole grain cereal products [Marquardt, 2004]. Numerous studies indicate that insoluble dietary fibre counteracts constipation, increases the mass and volume of faeces, accelerates intestinal peristalsis and has an inhibitory effect on the growth of numerous forms of tumors of the large intestine [Bingham, 2004; Hill, 1998; Kritchevsky, 2001; Srikumar 2000]. It has been shown that consumption of wholemeal bakery products considerably lowers the pH of colonic contents. The soluble fraction of dietary fibre counteracts the development of metabolic diseases, affecting the transformations of sugars and fats in the organism. The prophylaxis and treatment of diabetes and obesity make use of the property of lowering the after-meal glucose concentration in blood, characteristic for soluble dietary fibre; it has been shown that there exists a relation between decrease of the glycaemic index and increase in the content of (1→3, 1→4)-β-D-glucans of barley in the diet of persons examined [Cavallero *et al.,* 2002]. However, attention is drawn to a decrease in the concentration of LDL-cholesterol and a decrease in the relation of LDL-cholesterol to HDL-cholesterol [Maki & Davidson, 2003; Schaarmann & Schneider, 1999]. It has also been shown that increase in the consumption of soluble dietary fibre by 5-10 g per day reduces the level of cholesterol by 5% [Jenkins *et al*., 1998].

In spite of the indisputably proven importance of dietary fibre in the prophylaxis and treatment of civilisation diseases, the level of consumption of that component is still decidedly low [Miller Jones, 2004; 2006]. The actual consumption of dietary fibre may be even lower than the estimated values, as hitherto analytical methods have been incompatible with the physiological definition of dietary fibre. Saura-Calixto *et al*. [2000] claim that the tables of food components do not give credible data on the content of dietary fibre in the foods consumed.

The problems involved in the balancing of dietary fibre and analysing its consumption over longer periods of time are magnified by the divergence of the analytical methods applied. The crude fibre method, developed at the end of the 19th century, based on acid and alkaline hydrolysis, caused excessive losses in the content of the particular components of the fibre. The methods of Van Soest and of Van Soest and Wine made use of detergents in order to dissolve digestible components of the analysed products, which permitted the obtaining of residual fibre with low content of nitrogen [Van

Author's address for correspondence: dr inż. Aldona Sobota, Engineering and Cereals Technology Department, University of Life Science in Lublin, ul. Skromna 8, 20-704 Lublin, Poland; tel.: (48 81) 46 23 316; e-mail: aldona.sobota@up.lublin.pl

Soest, 1963a, 1963b; Van Soest & Wine, 1967]. At present the most popular is the enzymatic-gravimetric method, using the MES-TRIS buffer. The method was recommended as the most accurate method for the determination of the total content of dietary fibre at the latest dietary fibre congresses (2003, 2000). It permits the determination of the total dietary fibre and of the insoluble and soluble fractions of the fibre. Numerous authors put particular emphasis on the fact that the enzymatic-gravimetric method provides the most credible results of determination of dietary fibre content as compared to other methods [Li *et al*., 2002; Marlett & Vollendorf, 1993]. The next fibre congress, "DF 2006" in Helsinki, refined the definition of dietary fibre, while the "Dietary Fibre Workshop" refined the recommended analytical methods.

It is commonly believed that cereals, an important element of the daily diet, are an excellent source of natural dietary fibre, favourably affecting human organism. However, particular cereal species differ in their chemical composition, including the content and fraction composition of dietary fibre. Also, not all cereal products meet the criteria; *e.g.* corn grits, a material commonly used in the technology of breakfast cereals, is characterised by very low content of proteins and very low content of dietary fibre. Every admixture of high-fibre components to corn breakfast cereals can decidedly improve the nutritional quality of such products [Rzedzicki, 2005]. Keeping in mind that cereal No. 1 in the world is wheat, the objective of this study was to examine the possibility of using wheat bran and meal as sources of dietary fibre in the production of extrudates, and to determine the effect of the process parameters and of the features of the raw material mixture on the intensity of changes in the chemical composition of extrudates, and in particular on changes in the fractional composition of dietary fibre.

MATERIAL AND METHODS

Raw materials

In the tests, commercially available corn grits obtained through grinding of grain of vitreous corn with the hulls and germs removed, was used as a structure-forming material. The source of dietary fibre was bran of the high-gluten cultivar Henika. The chemical composition of the raw materials is given in Tables 1 and 2.

TABLE 1. Chemical composition of the raw materials (% d.b.).

Raw material	Crude protein	Crude fat	Crude ash	Crude fiber
	(% d.b)			
Corn grits	11.11±0.28	1.01±0.05	1.32±0.03	0.45±0.11
Wheat bran	17.46±0.32	2.45±0.08	3.92±0.09	5.34±0.16

The results were calculated as mean values of three replications ± SD.

Extrusion process

The process of extrusion was effected using a twin-screw counter-rotating extruder- Metalchem 2S-9/5: screw speed 72 rpm, die diameter 4.2 mm and 3.2 mm, L/D 12:1, applying process parameters such as: profiles of barrel temperature distribution and moisture content of raw material in accordance with the adopted model of the experiment (Table 3).

TABLE 3. Model of experiments.

Sample no.	Corn grits	Wheat bran	Moisture	Temperature (°C)	Extruder die (mm)
	(%)				
1	80	20	14	120/150/170/160/130	4.2
2	70	30	14	120/150/170/160/130	4.2
3	60	40	14	120/150/170/160/130	4.2
4	50	50	14	120/150/170/160/130	4.2
5	40	60	14	120/150/170/160/130	4.2
6	30	70	14	120/150/170/160/130	4.2
7	20	80	14	120/150/170/160/130	4.2
8	60	40	14	120/150/170/160/130	4.2
9	60	40	17	120/150/170/160/130	4.2
10	60	40	20	120/150/170/160/130	4.2
11	60	40	23	120/150/170/160/130	4.2
12	60	40	26	120/150/170/160/130	4.2
13	60	40	29	120/150/170/160/130	4.2
14	60	40	14	80/100/120/110/130	4.2
15	60	40	14	100/120/140/130/130	4.2
16	60	40	14	115/130/160/140/130	4.2
17	60	40	14	120/140/180/160/130	4.2
18	60	40	14	130/160/200/180/130	4.2
19	60	40	14	135/180/220/200/130	4.2
20	80	20	14	120/150/170/160/130	3.2
21	70	30	14	120/150/170/160/130	3.2
22	60	40	14	120/150/170/160/130	3.2
23	50	50	14	120/150/170/160/130	3.2
24	40	60	14	120/150/170/160/130	3.2
25	30	70	14	120/150/170/160/130	3.2
26	20	80	14	120/150/170/160/130	3.2

TABLE 2. Detergent and enzymatic fiber of the raw material (% d.b.).

Raw material	NDF	ADF	HCEL	CEL	ADL	TDF	IDF	SDF
	(% d.b.)							
Corn grits	3.62±0.08	0.83±0.05	2.79	0.66	0.17±0.04	6.5	5.4±0.08	1.1±0.06
Wheat bran	24.8±0.54	6.82±0.12	17.98	5.12	1.7±0.06	29.3	25.4±0.15	3.9±0.09

The results were calculated as mean values of three replications ± SD.

Physical property of extrudates

Dry matter water solubility index (WSI) was determined for extrudates according to the standard method [AACC, Method 56-20] as modified by Rzedzicki *et al.* [2004b].

Chemical compounds of extrudates

The following parameters were determined for the raw materials and the extrudates – content of dry matter [AACC, Method 44-15A], content of crude proteins [AACC, Method 46-08, N x 6.25], content of crude fat [AOAC, Method-963.15, using non-polar solvent – hexane], ash [AACC, Method 08-01], crude fibre [AACC, Method 32-10]. Also, comparative tests were made for the content of dietary fibre, using the detergent method [Van Soest, 1963a, 1963b], and for the dietary fibre with the enzymatic method [AOAC, 991.43; AACC, 32-07; AACC, 32-21; AOAC, 985.29; AACC, 32-05]. Total dietary fibre and its soluble and insoluble fractions were determined with the use of enzymes and methodological procedures of the Megazyme company. All the AACC and AOAC methods were sources from the Approved Methods of AACC. The correctness of dietary fibre determinations was verified using the "TDF Controls" from Megazyme. In addition, for every series of determinations control samples were added, prepared from a mixture of pure casein and starch. Chemical analyses were made in three replications, and the WSI determinations in six replications.

Statistical analysis

The mean values, standard deviations and coefficients of variations were calculated. If the values of the coefficient of variation exceeded the experimentally-determined error limits for a given method, analyses were repeated until the correct scatter of results was obtained. For continuous variables, the analysis of regression was made and coefficients of determination R^2 were calculated. The results were statistically analysed using SAS ver. 9.1 software.

RESULTS

Influence of process parameters on WSI of extrudates

Intensive thermoplastic treatment of the raw materials caused, in the first place, changes in the solubility of the dry

TABLE 4. WSI and chemical composition of extrudates (% d.b.).

Sample no.	WSI (%)	Crude protein	Crude fat*	Free fat	Crude ash	Crude fiber
		(% d.b.)				
1	16.02±0.06	11.46±0.10	1.3	0.38±0.04	2.24	1.5
2	7.86±0.03	12.36±0.18	1.44	0.61±0.04	2.51	1.57
3	6.56±0.10	13.18±0.33	1.59	0.62±0.01	2.76	1.92
4	5.41±0.10	13.48±0.12	1.73	0.79±0.14	3.08	2.12
5	5.22±0.04	14.51±0.07	1.87	1.15±0.11	3.14	2.4
6	5.16±0.08	15.53±0.25	2.02	1.3±0.08	3.49	2.69
7	4.71±0.10	15.71±0.45	2.16	1.52±0.01	3.62	2.89
8	6.56±0.07	13.18±0.33	1.59	0.62±0.01	2.76	1.92
9	6.08±0.06	12.75±0.11	1.59	0.4±0.06	2.48	1.46
10	5.37±0.06	13.25±0.07	1.59	0.49±0.02	2.46	1.43
11	5.21±0.07	13.21±0.51	1.59	0.63±0.02	2.54	1.63
12	4.89±0.06	13.3±0.41	1.59	0.65±0.01	2.53	1.89
13	2.96±0.06	13.04±0.23	1.59	0.82±0.02	2.57	2.08
14	3.77±0.16	13.15±0.66	1.59	0.92±0.01	2.64	1.78
15	4.05±0.06	13.32±0.39	1.59	0.98±0.01	2.69	1.49
16	4.12±0.04	13.23±0.21	1.59	0.99±0.04	2.62	1.4
17	4.69±0.04	12.65±0.05	1.59	0.95±0.01	2.71	1.38
18	4.72±0.08	12.82±0.23	1.59	0.98±0.01	2.59	1.5
19	4.92±0.07	13.15±0.13	1.59	1.1±0.01	2.69	1.66
20	14.13±0.04	12±0.28	1.3	0.72±0.01	2.08	1.09
21	7.08±0.06	12.06±0.07	1.44	0.47±0.03	2.22	1.15
22	4.91±0.01	13.07±0.30	1.59	0.86±0.01	2.56	1.43
23	3.2±0.03	13.31±0.49	1.73	0.95±0.01	2.82	1.5
24	2.86±0.04	14.79±0.26	1.87	1.01±0.01	3.05	1.62
25	2.84±0.08	15.51±1.22	2.02	1.04±0.01	3.33	2.21
26	2.67±0.03	16.02±0.08	2.16	1.29±0.01	3.51	2.62

The results were calculated as mean values of six (WSI) or three replications ± SD. *- calculated value of component, based on the composition of the raw material.

matter of the products. Both the raw material composition and the material moisture had a significant effect on the solubility of dry matter (p=0.05), while barrel temperature had a moderate, but statistically significant effect. With increasing content of the high-fibre component, a notable decrease was observed in the value of WSI (Table 4). The value of WSI for products containing 20% of wheat bran was 16.02%, while for a bran content of 80% the recorded value of WSI was only 4.71% (extruder die diameter – 4.2 mm). The increase in raw material moisture caused a drop in WSI value from 6.56% to 2.96%. Process temperature did not have such a large effect on the values of WSI: with temperature increase from 120°C to 220°C the recorded increase in the value of WSI was only 0.4%. High solubility of dry matter characteristic of highly processed products, that resulted in decomposition of polymers present in the raw material (mainly starch and dietary fibre) to water–soluble forms, is not advantageous. Strongly degraded products are rapidly digested and absorbed, dangerously modifying the post-meal glycaemia [Guillon & Champ, 2000]. Therefore, skilful control of the process parameters permits extensive modification of that highly important feature of the food product. In some breakfast cereals dry matter solubility levels reaching even 50% have been recorded [Rzedzicki, 2005; Rzedzicki & Wirkijowska, 2006]. Also, the die diameter was found to affect the water solubility index of the dry matter. When extruding raw materials and using a higher die diameter (4.2 mm), we obtain a product characterised by considerably higher WSI values.

Influence of process parameters on chemical composition of extrudates

Changes in proteins content

The twin-screw counter-rotating extrusion applied in the experiment, caused significant changes in the chemical composition of corn-wheat extrudates (Table 4). Comparing the chemical composition of the raw materials with that of the extrudates, a significant decrease was recorded in the content of proteins, which was characteristic for extrudates obtained at die with a diameter of 4.2 mm and 3.2 mm. Similar changes were also noted by Rzedzicki *et al.* [2004a], and by Zieliński *et al.* [2001]. In turn, Stanley [1989] attributes reductions in nitrogen content due to extrusion as an effect of the formation of isopeptide bonds between ε-amine groups of lysine and amide groups of asparagines or glutamine, accompanied by the release of ammonia.

Changes in crude fat content

For all the extruded samples, notable complexing of fats was recorded, as well as a distinct reduction in the content of free fats, extracted by hexane (Table 4). There was a clear effect of the mixture composition and chemical composition of the extruded mass on the intensity of fat complexing, thus supporting the theses by Wang *et al*. [1993] on the effect of the content of starch in the extruded material on the level of lipid complexing. The presence of starch and proteins in the raw material is conducive to the formation of starch-lipid and lipid-protein complexes [Guzman *et al*., 1992]. In the tested samples with 20% content of wheat bran (extruder die diameter – 4.2 mm) the degree of fats complexing was 70.77%. As the content of bran increased, reduced complexing of fat was observed; whilst at bran content of 80% the degree of fat complexing was only 29.63%.

No distinct effect of the die diameter on lipid bonding was observed, while such an effect on lipid bonding was exerted by the moisture content of the extruded mass. The content of free fats in the extrudates increased inconsiderably with increasing moisture of the extruded cereal mixture: from 0.62% d.m. at the moisture content of 14% to 0.92% d.m. at the moisture of 29%.

The effect of barrel temperature on lipid binding was not significant.

Changes in dietary fibre content, determined with three different analytical methods

In all of the extruded samples a decrease was recorded in the content of crude fibre and of dietary fibre fractions determined by the detergent method (Table 5), as compared to the expected values resulting from the raw material composition. Typical characteristic examples of changes in fibre content determined with the detergent method and in fibre determined with the enzymatic method are shown in Figure 1. The extent of the changes was related to the process param-

TABLE 5. Detergent fiber of extrudates (% d.b.).

Sample no.	NDF (% d.b.) $\bar{x}$ ±SD	ADF (% d.b.) $\bar{x}$ ±SD	HCEL (% d.b.)	CEL (% d.b.)	ADL (% d.b.) $\bar{x}$ ±SD
1	6.25±0.28	1.96±0.01	4.29	1.53	0.43±0.03
2	8.26±0.07	2.38±0.07	5.88	1.79	0.59±0.01
3	9.93±0.07	2.83±0.04	7.09	2.2	0.63±0.04
4	11.75±0.08	3.46±0.07	8.3	2.52	0.94±0.03
5	14.19±0.11	3.73±0.07	10.46	2.75	0.98±0.03
6	15.47±0.08	4.39±0.03	11.08	3.27	1.11±0.03
7	15.45±0.07	4.53±0.04	10.91	3.26	1.27±0.03
8	9.93±0.07	2.83±0.03	7.09	2.2	0.63±0.04
9	8.56±0.07	2.44±0.01	6.12	1.85	0.59±0.01
10	8.54±0.08	2.35±0.04	6.19	1.7	0.65±0.01
11	9.18±0.25	2.47±0.04	6.72	1.87	0.59±0.03
12	10.34±0.13	2.66±0.06	7.68	2.03	0.63±0.03
13	10.86±0.16	2.71±0.04	8.14	1.95	0.76±0.04
14	9.39±0.08	2.51±0.06	6.88	1.91	0.6±0.04
15	9.62±0.13	2.53±0.04	7.1	1.85	0.67±0.04
16	9.54±0.06	2.74±0.03	6.8	2.06	0.68±0.04
17	9.2±0.03	2.78±0.03	6.42	2.16	0.62±0.03
18	9.09±0.07	2.45±0.06	6.64	1.8	0.65±0.01
19	9.76±0.06	2.8±0.06	6.96	2.11	0.69±0.04
20	5.65±0.10	1.82±0.04	3.82	1.61	0.21±0.04
21	7.14±0.06	2.32±0.01	4.82	1.79	0.53±0.04
22	9.14±0.07	2.61±0.06	6.54	2.02	0.58±0.03
23	9.99±0.24	3.12±0.04	6.87	2.35	0.77±0.06
24	10.96±0.11	3.26±0.04	7.7	2.44	0.82±0.01
25	13.69±0.06	3.93±0.06	9.76	2.87	1.05±0.03
26	15.64±0.04	4.33±0.06	11.31	3.2	1.13±0.01

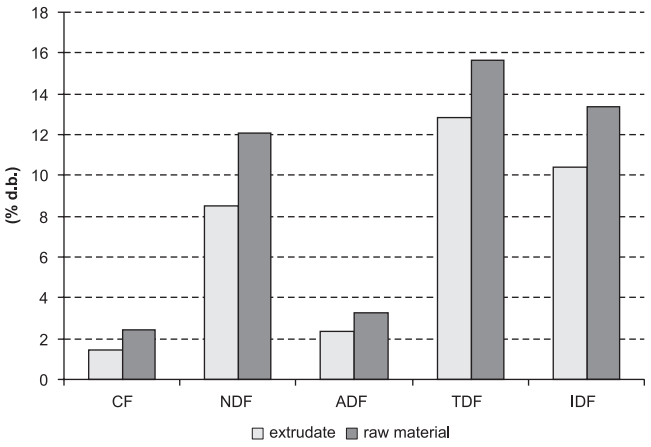

FIGURE 1. Content of CF, NDF, ADF, TDF and IDF in corn-wheat extrudates (wheat bran 40%, corn semolina 60%, moisture 20%, temp. 170°C, die 4.2 mm).

eters. Using constant mixture composition (40% of wheat bran and 60% of corn grits) a study was made on the effect of variable parameters of the process of extrusion (moisture, barrel temperature and die diameter) on the content of dietary fibre in the extrudates. In each of the tested samples lower contents of TDF and IDF were recorded as compared to the raw materials mixture, and an increased content of SDF. As the moisture content of the raw material increased from 14% to 20%, a decrease was observed in the content of total dietary fibre – TDF, and of the insoluble dietary fibre – IDF. Therefore, moisture content increase within that range meant increased degradation of fibre (Figure 2). Such a result is difficult to explain, thus it needs further investigation. Likewise, there was a decrease in the content of crude fibre (from 1.92% to 1.43%) (Table 4) and in the content of NDF (from 9.93% to 8.54%) (Table 5), which undoubtedly was due to a decrease in the content of hemicelluloses and of ADF fibre (Figure 3). Further increase in the moisture of the raw material above the level of 20% caused a reversal of the decreasing trend a directional change in the orientation of the curves. The content of total dietary fibre and its insoluble fraction in the extrudates increased from 12.08% to 14.5% and from 9.38% to 11.4%,

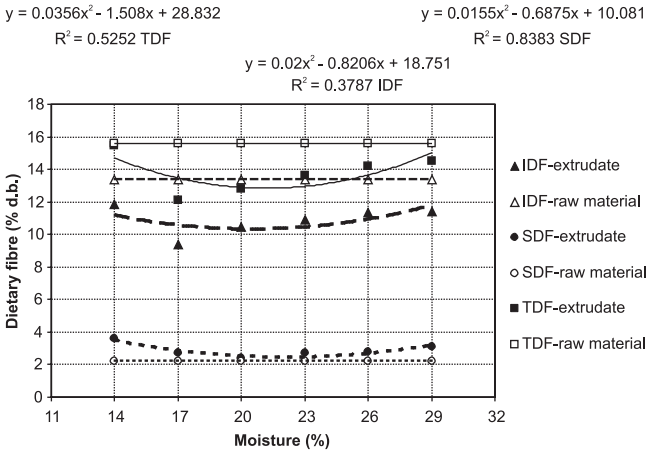

FIGURE 2. Moisture influence on TDF, IDF and SDF content (wheat bran 40%, corn semolina 60%, temp. 170°C, die 4.2mm).

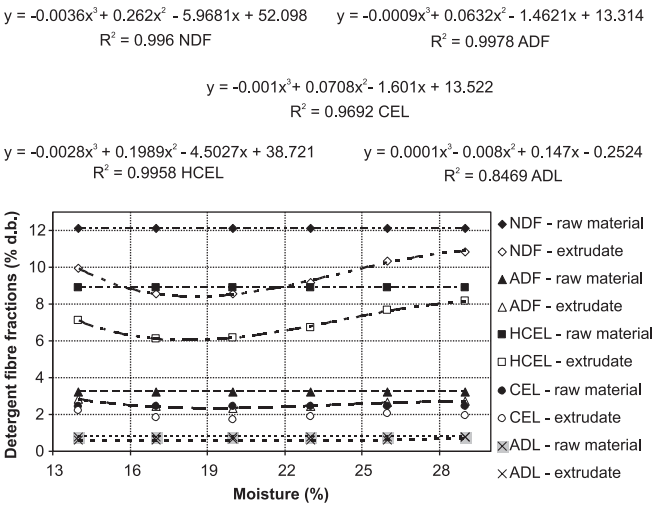

FIGURE 3. Moisture influence on detergent fibre fractions content (wheat bran 40%, corn semolina 60%, temp. 170°C, die 4.2 mm).

respectively (Figure 2). A reversal of decreasing trends was also observed for the detergent fibre fraction (Figure 3), although in this case the changes form a third degree equation. Increasing moisture of the extruded mixture certainly caused a decrease in the viscosity of the extruded mass, and thus a reduction in the flow resistance during its passage along the barrel, accelerating the flow of the mixture through the extruder. This caused a shortening of the time of the process factors action on the components of the extruded mass fibres and at the same an increase in the determinability of the examined components due to their lower degradation. Such a system of curves may also be the result of intensifying processes of starch degradation and of the formation of resistant starch. In such a case, however, there should be observable increase in the content of ADL lignin, which was not the case in the reported study.

The study showed also that the intensity of depolymerization of non-starch polysaccharides depended also on the process temperature. In each of the tested samples a lower content of TDF and IDF was recorded, as compared to the raw material mixture, and an increased content of SDF (Figure 4). With a constant percentage of corn semolina (60%) and wheat bran (40%) the curves of the content of total dietary fibre TDF and its insoluble fraction IDF reached their minima at the temperature of 200oC and their maxima at 140°C. The content of insoluble components of fibre dropped slightly with an increase in temperature. Further increase in temperature, above 200°C, caused a non significant increase in the content of total dietary fibre TDF and its insoluble fraction, which may be related with intensifying formation of resistant components of starch. A similar orientation of changes in the effect of temperature was observed for the detergent fibre fraction (Figure 5).

The study included also investigation of the possibility of modifying the fractional composition of dietary fibre through a change in the raw material composition of the mixture. The tests were made for two die diameters – 3.2 mm and 4.2 mm. Increase in the share of wheat bran from 20 to 80%, with constant parameters of extrusion temperature of 170°C and raw material moisture of 14%, permitted considerable

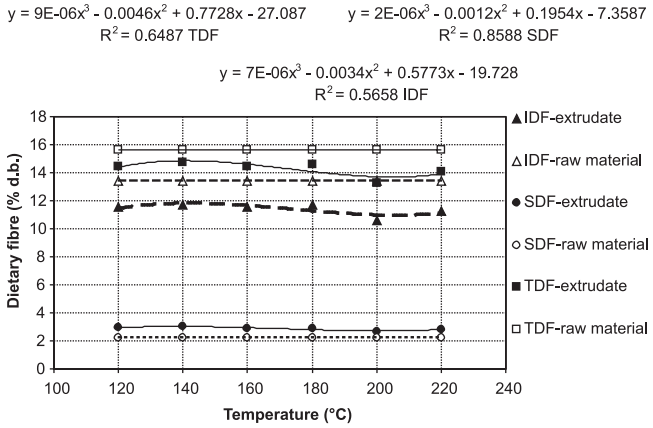

FIGURE 4. Temperature influence on TDF, IDF and SDF content (wheat bran 40%, corn semolina 60%, temp. 170°C, die 4.2 mm).

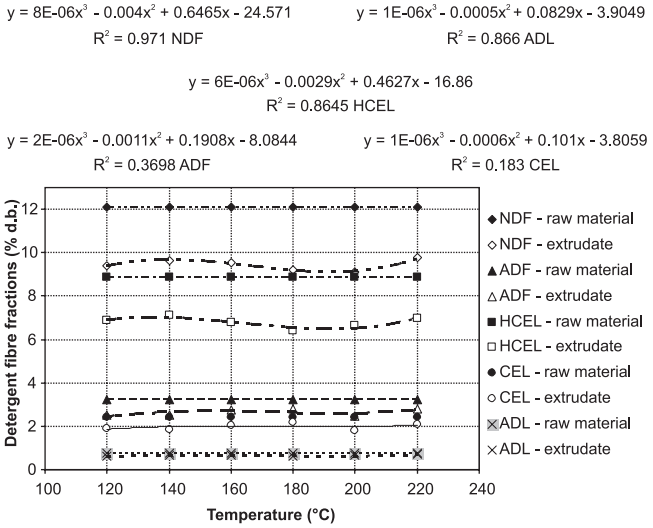

FIGURE 5. Temperature influence on detergent fibre fractions content (wheat bran 40%, corn semolina 60%, temp. 170°C, die 4.2 mm).

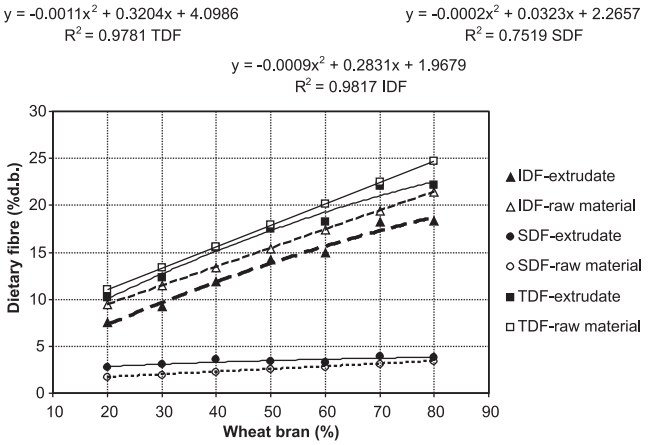

FIGURE 6. Influence of wheat bran share rate on TDF, IDF and SDF content (moisture 14%, temp. 170°C, die 4.2 mm).

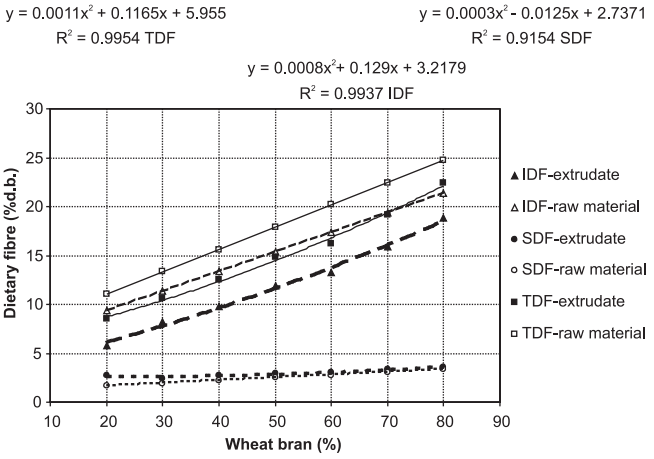

FIGURE 7. Influence of wheat bran share rate on TDF, IDF and SDF content (moisture 14%, temp. 170°C, die 3.2 mm).

DISCUSSION

modification of the chemical composition, including that of dietary fibre; for the die diameter of 4.2 mm an increase was recorded in the content of total dietary fibre TDF from 10.2% to 22.17%, in the content of IDF fraction from 7.51% to 18.33%, and of SDF fraction – from 2.76% to 3.84% (Figure 6).

In that series of tests a notable effect of the die size on the fractional composition of dietary fibre was recorded. Decrease of the die diameter from 4.2 mm to 3.2 mm notably intensified the processes of destruction of dietary fibre. Distinctly lower values of TDF and IDF were recorded for extrudates obtained with die diameter of 3.2 mm (Figure 7). The recorded values of soluble fibre determinations came as a certain surprise – they were substantially lower in the extrudates produced with die diameter of 3.2 mm than in these obtained at die diameter of 4.2 mm. The reduced content of the SDF fraction with a simultaneous decrease in the TDF fraction clearly indicates increased degradation of the soluble fibre fraction SDF which could not be precipitated and determined as SDF fraction.

The study showed that wheat bran used in mixtures with corn grits, can be good, high fibre raw material for use in the extrusion technology. The process of extrusion was correct within the full range of parameters defined in the model of the experiment (Table 3). Neither material slippage nor extruder bake were observed. The applied technology of twin-screw counter-rotating extrusion guarantees stable mass flow and rigid characteristics of the time the material remained in the extruder cylinder, thus ensuring stable flow and product homogeneity. The range of process parameter and mixture composition values applied in the model of the experiment enabled designing products with highly varied structures, such as expanded snacks, hard and compact granules, or gritty breakfast cereals.

Water solubility index is a very good indicator of starch transformation. Our study show that high moisture content of raw material influenced a decrease of starch degradation, so lower WSI is noted. This tendency was also observed by Anguita *et al*. [2006], Rzedzicki & Zarzycki [2006], Ding *et al.* [2005] and Gujral *et al.* [2001]. Water solubility index de-

creased with an increase in feed moisture and increased with the increase in extrusion temperature. Gujral *et al.* [2001] wrote that an increase in WSI with a decrease in feed moisture may be attributed to higher specific mechanical energy (SME) consumption of extruder. Smith [1992] claimed that WSI of extrudates depended mainly on amylopectin content. The high mechanical shear stress degraded macromolecules, the molecular weight of starch granules decreased and consequently, the WSI increased because degraded starch granules are more soluble in water. The influence of critical extrusion conditions on high saccharides content were also observed by Lampart-Szczapa *et al.* [2006]. They suggest that saccharides are released from cellular structures under critical conditions. Addition of wheat bran caused a decrease of WSI and the changes observed turned out similar to those noted by Rzedzicki & Zarzycki [2006]. WSI is also an indicator of the intensity of extrusion process.

Changes in protein content observed in this study are correlated with observations made by Rzedzicki *et al*. [2004a] and Zieliński *et al*. [2001]. Stanley [1989] explains the lack of nitrogen during extrusion process as the effect of isopeptides bonds between ε-amine group of lysine and amide groups of asparagine or glutamine, which is connected with ammonia release. Fischer [2004] wrote about intermolecular cross-linking by disulfide bonds as an effect of extrusion cooking. He also observed that moisture content of the investigated wheat flour affected the mode and the nature of the protein polymerization. At the higher moisture content specific mechanical energy is lower, because water acts as a lubricant, the material in the extruder becomes more flexible, and the friction during extrusion is reduced.

The mixture composition and chemical composition of extruded mass were observed to influence lipid binding. Our results confirm the suggestion of Wang *et al.* [1993], that the degree of fat complexing during extrusion depends on starch content in processed material – it facilities the formation of starch-lipid complexes. The presence of starch and protein in raw material favours the formation of starch-lipid and lipid-protein complexes [Guzman *et al*., 1992]. In our study, with an increasing high dietary fiber component concentration (wheat bran), the starch content and degree of lipid complexing decreased, which is consistent with results reported by Rzedzicki *et al.* [2004a].

Wheat bran may be a high-fibre component of high value and may substantially improve the chemical composition of products acquired on the basis of corn grits. However, keeping in mind the comprehensive effect capacity of dietary fibre, one should conclude that wheat bran certainly is a valuable source of dietary fibre, but only in relation to the IDF fraction. Mixtures and compositions of that type should be additionally enriched with raw materials containing high levels of prebiotic fractions of SDF fibre, *e.g.* oat components.

There is also a methodological aspect to the study carried out. Determinations of the content of structural components with the use of three different methods showed total inapplicability of the crude fibre method for fibre content determination in highly-processed extruded food products. The determined crude fibre content values in all the samples were several times lower than the values of detergent fibre content and the total fibre and insoluble fibre content values determined with the enzymatic method (Figure 1). Garcia *et al*. [1997] state that the detergent method is useful for the determination of IDF. One should be aware, however, of the involved losses to the soluble fibre. There may also occur incomplete removal of starch from samples with high starch content. In the experimental results presented herein, changes in the content of total dietary fibre TDF were related, among other things, to the decomposition of insoluble fractions into smaller ones, that were designated as the SDF fraction. In the detergent method such fractions cannot be determined at all. This fact is reflected in the relevant literature of the subject [Camire *et al.,* 1993, 1997; Martin-Cabrejas & Jamie, 1999; Rzedzicki *et al.,* 2004a; Vasanthan *et al*., 2002]. It is necessary, therefore, to pose the question how to make calculations and how to perform comparisons of the levels of dietary fibre consumptions over longer periods of time, which is an absolute necessity when analysing the epidemiology of civilisation diseases.

The small fractions formed as a result of decomposition of the IDF fraction are determined as the soluble fraction, which in the study under presentation caused an increased content of the soluble fraction in the extrudates as compared to the raw materials. However, one should keep in mind, that the artificially formed SDF fraction of dietary fibre has the chemical composition of the insoluble fractions, and that it has also lost its sorptive properties and has no capacity for binding bile acids [Camire *et al.,* 1993]. Vasanthan *et al*. [2002] attribute the changes in the fractional composition of dietary fibre in barley flour in the process of extrusion mainly to the transformation of IDF into SDF and to the formation of resistant starch. Anguita *et al.* [2006] cited Björck *et al.* [1984] who claimed that increased solublity of non-starch polysaccharides during extrusion could be due to the intense mechanical treatment in the extruder, which takes place at high temperature and pressure and low water content, resulting in a uniform and disorganized structure. Camire *et al.* [1993, 1997] and Martin-Cabrejas *et al.* [1999] attribute the changes in the content of soluble and insoluble fibre to the process of decomposition of insoluble fractions to soluble fractions, the process being temperature- and moisture-related.

Considering the fact that the enzymatic method takes into account the physiological character of the definition of dietary fibre and is at present a commonly accepted analytical method, it is necessary to verify anew the available tables of chemical composition of food products. Unequivocal determination of the content of dietary fibre and its fractions must be supported by univocal nature of the applied analytical methods. Scientific information addressed to the consumer must be based on the latest research methodologies and only analytical data acquired in that way may be used as a basis for the formulation of dietary component balance.

CONCLUSIONS

In final conclusion we confirm that the process of extrusion causes significant changes in the chemical composition of corn-wheat extrudates. As a result of extrusion, a slight decrease was observed in the content of proteins and an intensive complexing of fats. The level of complexing was significantly

affected by the process temperature and by the moisture content of the extruded mixture. In all the extrudates – compared to the raw materials – a decrease was observed in the content of total dietary fibre TDF and its insoluble fraction IDF and an increase in the content of the soluble fraction SDF. At the same time a decrease was recorded in the content of crude fibre and in the detergent fibre fractions. Wheat bran may, thus, be a source of dietary fibre, but only of the insoluble fraction, hence it should be applied together with other sources of soluble fibre with probiotic action.

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Received May 2009. Revision received February and accepted March 2010.