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EXPANDER COOKING OF RAPESEED-FABA BEAN MIXTURES

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ABSTRACT

Feed components were produced by expander cooking of a mixture of 50% dehulled faba beans and 50% whole rapeseed, using an expander Contivar AL 150. The maximum barrel temperature was 140°C, and the initial water content 15-25%. Lipids changed only a little during the expansion. Polar lipids were bound more intensively into nonextractable lipids than low polar triacylglycerols. Oxidation of lipids, carotenoids, and the destruction of chlorophylls were only moderate because of short time and relatively low temperature (compared to baking). Volatile lipid oxidation products could not be detected by sensory analysis. Nonenzymic browning reactions were only slight, especially at low initial water content, and the sugar content changed only a little. The destruction of available lysine was negligible. Roasted flavour notes were hardly perceptible, and colour changes were on the limit of detectability. Losses of alfa-galactosides were insignificant, on the contrary, slight, insignificant increase was observed at higher water contents. The concentration of extractable tannins substantially decreased. Ratios of inositol esters remained the same during the expander cooking. Total glucosinolates were reduced in pronounced degree. As the feed quality decreased at the same extent as during our former experiments using broilers, the process may be considered for production of the mixtures of high nutritional quality. The deactivation of undesirable components was found suitable at higher moisture content before the extrusion.

Key words: expander, rapeseed, faba been, chemical composition, process condition, barothermal processing

INTRODUCTION

Extrusion cooking and expander cooking are advantageous useful alternatives to baking for food products, especially because of low energy needs, short time, and relatively of low reaction temperature [16]. The technology is very useful from the standpoint of nutritional value as nutrient losses are only low. Nowadays, expander cooking is widely used in the feed industry because of the positive effect of a soft barothermal treatment (such as moistening of mash, gelatinization of starch, and sanitation of feed components), low investment cost, and cost of exploitation, substantially lower than in the case of extrusion cooking. A combination of extrusion and expander cooking of soybeans yields soya meals of very good feeding quality [48].

Regular compound feed consumption needs high capacity equipment with the minimum operation cost. This type of feed industry process is marginal in profit, and the added value of labour and energy with respect to the raw material cost is extremely low. Therefore, the more expensive conventional techniques cannot be used. The extrusion cooking with much lower energy consumption is more suitable, but still rather expensive. Therefore, the expander cooking was studied as the energy consumption is much lower than that of extrusion cooking, the barothermal processing is not so deep in case of the expander cooking, and the equipment is less complicated, and thus cheaper. The more expensive extrusion cooking is suitable for pet food and aquafeed or for feed components with extraordinary properties, such as full-fat soya beans, which need long instant time treatment, or fully gelaninized starch components. They are too expensive, however, for the production of broiler compound feed mixtures.

Another very important application is the production of feeds [10]. Precooked and pelleted material is processed in expanders, where steam is applied in the feeding area. Starch is only partially gelatinized under these conditions. Because of mild processing conditions, only very small losses of nutrients are observed [9], and the availability of protein is usually improved [7]. Some negative factors, such as trypsin inhibitors or lectins, are destroyed at higher extrusion temperatures [23], the lipoxygenase activity decreases [14], and antigens are partially destroyed [35]. Feeds processed by extrusion or expander cooking are particularly suitable for monogastric animals, including broilers [27]. The inactivation of trypsin inhibitors [47] and soybean antigenicity [35] are important factors.

In our earlier experiments, we studied changes during the extrusion cooking of peas or faba bean-rapeseed mixtures, which were found very suitable as feed for broilers [27, 29, 41, 42]. The ratio of the two main components, namely protein and oil, was optimized. Losses of energy and of nutrients, such as available lysine and other essential amino acids, essential fatty acids and tocopherols, were only low, and the performance in chicken was fully acceptable. The nutritional value of multicomponent extrudates with faba beans or a mixture of faba beans with casein improved the sensory value, nutritional value and increased the feed intake, when fed to broilers.

As we found in our earlier experiments [27, 31, 32] that the extrusion cooking was very useful in improving the feed value, we wanted now to compare them with those occurring during the expander cooking. The aim was to ascertain, whether the effect was the same, or very close, to that obtained during the extrusion cooking.

In this paper, we present results on some chemical, physical, and sensory changes during expander cooking of dehulled faba bean-whole rapeseed mixtures under different moisture contents. The moistening of mash is very important during thermal treatment in the expander cooking procedure, more than in case of extrusion cooking, and more than in case of temperature of expander cooking [29]. The temperature should not exceed 140°C, otherwise, non-enzymic browning reactions would become too fast and would decrease the nutrition value. The intensity of physical and chemical changes occurring during the expander cooking process largely depends on the moisture content. Even for mechanical reasons, the moisture control is critical as the moisture content influences the friction and pressure conditions of expanded material. It is a reason, why water and/or steam additions to expanders and/or to extruders are precisely controlled by special dosing systems, provided with electrovalves and sensors.

MATERIAL AND METHODS

Material

Faba beans (*Faba vulgaris* L., cv. 'Nadwiślański') were grown in central Poland and dehulled in an Ekonos machine, manufactured by F. M. R., Rogozno, Poland). Whole rapeseed (*Brassica napus* L. cv. 'Bolko') was a double-low winter cultivar, grown in central Poland, and harvested at the degree of full ripeness. Rapeseed

contained 42.5% oil (on the dry matter basis), the erucic acid content was 0.84% (based on total acid peak area in the GLC), and the content of total glucosinolates was 24.65g kg^{-1} of dry seeds. Both seeds were stored for 9 months after harvest at ambient temperature in metallic containers.

Faba beans were ground in a hammer-type mill, Type MR 7 (Znin, Poland), while rapeseed was used without any previous grinding. The mixtures consisted of 50% dehulled ground faba beans and 50% whole rapeseed (on the weight basis). The above mentioned ratio of faba beans and rapeseed was selected as the best possible and representative combination, recommended by nutritionists [34] and confirmed by our previous experiments [27, 28, 32].

Expander cooking

Before the expander cooking, the mixture was preconditioned in a preconditioner type Contivar, installed on an expander Contivar AL 150 (Almex BV, Zutphen, The Netherlands), which was used for final processing [30]. The scheme of the expander is shown in Figure 1, and the view of the equipment is presented in Figure 2. It is an annular gap expander with a single screw operating in a barrel. Steam was injected into the barrel, heated by a steam jacket. The barrel was provided with shear bolts, aiding a kneading action on the feed mixture. The size of the expansion gap at the end of the barrel was changed by an adjustable cone. Technical data of the machine were as follows: the maximum power input: 25 kW; the maximum screw speed: 143 rpm (2.38 s^{-1}); the maximum barrel temperature: 140°C; the maximum conditioner temperature: 90°C; the maximum capacity: 800 kg h^{-1}; the motor power: 22 kW; the maximum steam pressure: 0.6 MPa; the residence time was adjusted to 10-15 s; the maximum addition of water: 150 l h^{-1}; the compression ratio of the screw: 1.1, and the length: diameter ratio: 16.

Fig. 1. A schematic of the expander used

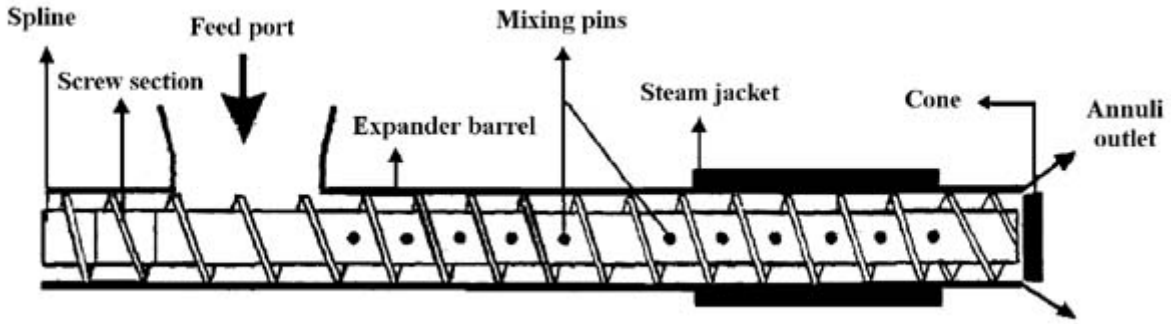
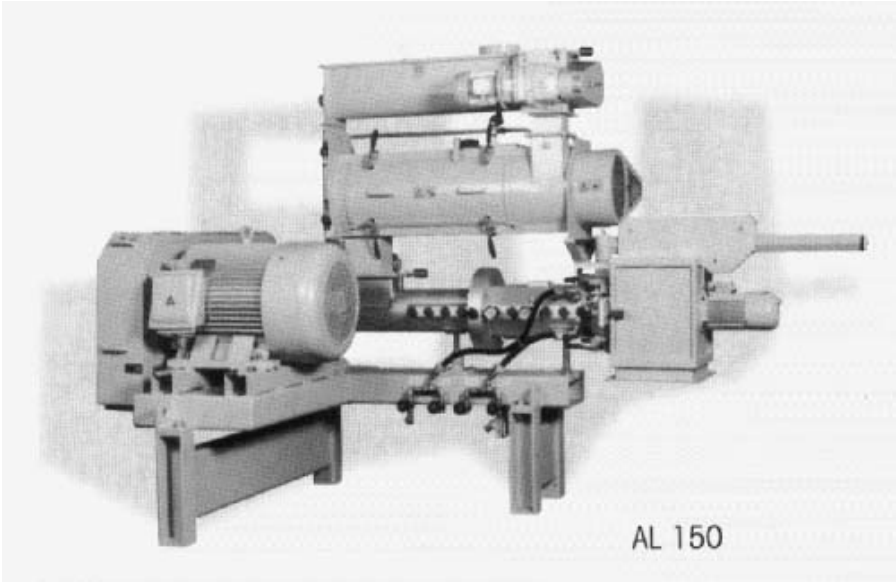


Fig. 2. View of the Almex Contivar Expander-Conditioner



The desired quality and quantity of premixed raw materials were constantly available in the feed zone of the barrel. The feeding line was used to combine the ingredients to form a homogenous mixture prior to its introduction into the expander. Within the feed zone of the expander barrel, raw materials still existed as discrete particles. When they were transported forwards into the feed zone, there was a positive pumping action with some compression of the material. The compression pushed the particles into a more solid homogenous mass. The kneading section continued the compression, and at the same time, provided mixing and mild shear, resulting in heating of the extrudate until the particles were transformed into a dough-like mass. The pumping effect was less positive than in the feeding zone, but void spaces still existed. Just behind the sherlock, the screw flights were, however, completely filled. The expander barrel was not completely full in front of the sherlocks, unless a choke point condition has been reached. Before the extpandate reached the final cooking zone, the expander barrel became completely filled with the product. Leakage flow and pressure flow were greatest within the final cooking zone. As the material became highly viscous, the maximum heat was generated by friction.

The moisture content was adjusted to the desired value by proper regulation of steam and water addition to the conditioner accordingly to calculated ratio (permanent sensors monitoring).

The extruded material was immediately packed in plastic bags, and stored at ambient conditions.

Analytical methods

Dry matter was determined by drying at 105°C for 3 h, and the moisture content was calculated from the weight loss. The fat determination using the Polish standard for feeds (use of diethyl ether or petroleum ether as a solvent) is not suitable for extruded or expanded products as lipids are partially converted into complexes unextractable with non-polar solvents. Therefore, a combination of two methods was used. The method for the determination of extractable lipids was the Soxhlet extraction with hexane [21]. Lipids extractable with polar solvents, but not with hexane, were determined by modified chloroform-methanol extraction after Folch.

Polar lipids were determined by HPLC [1] in a Hewlett-Packard apparatus Type HP 1050, provided with an autosampler HP 1050 and an integrator HP 3396 Series II. Column (250×4 mm) was packed with Separon SGX (C 18), grain size 5 μm (Tessek, Prague, Czech Republic), heated to 40°C. The 30 μl volume of the extract was dried with anhydrous sodium sulfate, dissolved in 1.5 ml of the mobile phase (acetone, acetonitrile and methanol in volume ratios of 4:2:1), and 50 μl were injected; the flow rate was 1 ml min^{-1}; differential refractometer HP 1047 A was used as a detector; method of inner calibration was used for calibration. Conjugated dienoic acids were determined spectrophotometrically at 234 nm after IUPAC [21]. Total carotenoids were determined spectrophotometrically at 450 nm, chlorophylls spectrophotometrically both after IUPAC [21] and AOCS [2].

Glucose, fructose and sucrose were analyzed in an extract obtained by extraction with 80% aqueous ethanol, purification using the Carrez reagent [1]; for the separation, HPLC on a HP 1050 instrument (as above) was used, the column 250×4 mm was packed with LiChrospher 100-NH_2, grain size 5 μm (Merck, Darmstadt, Germany); injection: 30 μl; flow rate: 1 ml min^{-1}; mobile phase: 80% aqueous acetonitrile; a differential refractometer HP 1047 A served as a detector. Available lysine was determined by a modified Carpenter method [5]. The browning was evaluated by measuring the colouration using a chromometer Minolta CR-110 (produced by Minolta Camera Co., Tokyo, Japan), the light source C; measuring distance: 5 mm; standard disk: barium sulfate; tristimulus parameters were determined at the luminance level of 65%; the tristimulus colour coordinates X, Y, Z were measured in the duplicate, and the values of L* (luminance in %), a* (red colour coordinate) and b* (yellow colour coordinate) were calculated from the X, Y, Z values [3]. The chroma is defined as: $C^* = (a^{*2} + b^{*2})^{0.5}$; the hue angle is defined as: $h^* = \tan^{=1} b^*/a^*$.

The sensory analysis was carried out under standard conditions (ISO 6658:1985) with a group of trained assessors (ISO 8586-1:1993), and unstructured graphical scales (ISO 4121:1983) were used for rating; the colour was evaluated under the standard light source C; the odour notes were assayed by sniffing from a 250 ml ground glass bottle; the sensory profile (ISO 6564:1985) consisted of the determination of rancid, oily, buttery, grassy, roasted, bread crust and burnt odour notes.

Oligosaccharides were determined by HPLC after extraction with 80% aqueous methanol, essentially after literature [35] under the following conditions: a Shimazu chromatograph, pump No. LC 10 AD, CTO 6 A column oven; a column 250×4 mm, packed with LiChrospher NH_2, grain size 5 µm, manufactured by Merck (Darmstadt, Germany); oven temperature: 35°C; mobile phase: 72% aqueous acetonitrile; flow rate: 1.2 ml min^{-1}. Tannins were determined by spectrophotometry [38] after extraction with 75% aqueous acetone.

Inositol phosphates (phytins) were analyzed by HPLC [43]; the same apparatus as for oligosaccharides; mobile phase: methanol and 0.05 M formic acid (51:49 v/v); flow rate: 0.7 ml min^{-1}; column temperature: 35°C. Glucosinolates were analyzed by HPLC [17] after extraction with 70% methanol. A Shimazu chromatograph as above, a 150×4 mm column packed with LiChrospher RP-18; a UV-detector (229 nm); a gradient solvent system: A = water; B = 20% aqueous acetonitrile; flow rate: 1.3 ml min^{-1}; elution program: 99% A + 1% B for 1 min; 1% A + 99% B for 30 min (a gradient curve: -3); 1% A + 99% B for 6 min; 99% A + 1% B for 5 min (linear gradient), 99% A + 1% B for 8 min (column balance).

All analyses were carried out twice (in the case that the results differed by more than the standard deviation specified in the analytical standard method, the determination was repeated). The sensory analysis was repeated 12 times. The significance of differences between samples was determined using the one-way ANOVA method (STATISTICA 3.1, Microsoft). The probability level was P = 0.95 (5%) in all cases.

Planning of the experiments

The research plan was reduced to 4 experiments, mainly from economical reasons (high costs of trials on an equipmenmt with high capacity). The laboratory equipment was used only for preliminary trials, which are not given here to save space. The experiments on a technical scale were then planned, which would better correspond to industrial processing conditions.

Table 1. Conditions during the expander cooking of faba bean – rapeseed mixtures

Parameter	Sample 1	Sample 2	Sample 3	Sample 4
Maximum processing temperature, °C	90	90	90	90
Maximum barrel temperature, °C	140	140	140	140
Capacity, kg h^{-1}	216	216	216	131.7
Moisture content, %	24.8	20.8	16.6	15.4
Preconditioning, °C	85	80	90	90
ME-input, kWh t^{-1}	92.6	91.2	81.0	58.4
Power input, kW	20.0	19.7	17.5	18.5

From the above reasons, the temperature, which was found less important, was chosen be kept constant (tab. 1), while the moisture content was selected as a more important variable.

RESULTS AND DISCUSSION

Changes of lipids and their degradation

Samples of the expanded material were dried after the expander cooking, before packaging in plastic bags. Low water content in all samples (tab. 2) proves that samples did not reabsorb moisture from air during transportation and storage.

Table 2. Contents of moisture and of the lipidic fraction in original and treated samples

Component	Original mixture	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Dry matter (DM), %	92.01 (0.12	93.18 (0.13)	93.29 (0.10)	94.79 (0.11)	95.03 (0.10)
Moisture, %	7.99 (0.12)	6.82 (0.13)	6.71 (0.11)	5.21 (0.12)	4.97 (0.10)
Fat-free dry matter (FFDM), %	69.9 (0.14)	74.4 (0.18)	76.7 (0.18)	73.1 (0.19)	73.9 (0.17)
Fat, absolute, %	22.1 (0.15)	18.8 (0.18)	16.6 (0.17)	21.7 (0.20)	21.1 (0.18)
Fat, relative, %	100 (0.8)	81.0 (0.9)	74.7 (0.8)	98.2 (1.0)	97.0 (0.9)
Fat after Folch, absolute, %	24.0 (0.34)	23.1 (0.37)	23.9 (0.50)	23.7 (0.33)	23.8 (0.46)
Fat after Folch, relative, %	100 (1.4)	96.4 (1.5)	97.8 (2.0)	98.8 (1.4)	99.0 (1.7)
Polar fraction, % fat	5.50 (0.85)	2.15 (0.72)	2.98 (0.71)	3.40 (0.65)	4.16 (0.94)
Conjugated dienes, mg kg^{-1} DM	43 (2.5)	107 (3.9)	79 (1.9)	174 (3.2)	156 (3.6)
Carotenoids, mg kg^{-1} DM	13.1 (1.2)	13.1 (1.0)	8.7 (1.3)	8.9 (1.2)	11.0 (1.0)
Chlorophylls IUPAC, mg kg^{-1}	5.0 (0.8)	4.8 (0.3)	3.7 (0.4)	4.0 (0.5)	4.3 (0.5)
Chlorophylls AOCS, mg kg^{-1}	2.2 (0.3)	2.1 (0.2)	1.6 (0.1)	1.7 (0.2)	1.8 (0.2)
Chlorophylls, relative, %	100 (11)	95.8 (10)	73.4 (6)	78.6 (13)	81.0 (12)

Note: Standard deviations are given in parantheses under the respective mean values

The original mixture of faba beans with fullfat rapeseed was relatively rich in fat because of its high content (more than 40%) in whole rapeseed. Changes of lipids, extractable with hexane as a typical non-polar solvent, during expansion were only moderate (tab. 2). The main reason for the relatively low formation of nonextractable lipids during the processing is low starch content in faba bean-rapeseed mixtures, only 25% in the mixture. On the contrary, in such high-starch mixtures as in corn-soy blends, where the starch content was higher (about 32%) only 6.95% lipids could be extracted after extrusion [44] as the rest remained bound to starch. After hydrolysis of starch in those extruded products, catalyzed by α-amylase, the amount of lipids extractable with hexane rose to 11.63%.

The values obtained using the procedure after Folch with a more polar solvent (methanol-chloroform as solvents) did not show any significant differences resulting from expander cooking. The reason was that lipids bound to starch and thus unextractable with hexane, could be extracted with a solvent mixture containing methanol, which disturbs the hydrogen bonds between lipids and starch.

Moderate decrease of lipid content was observed even in protein-rich material, e.g. in mixtures of corn gluten with defatted soy protein concentrate. However, the loss was smaller as the lipid content decreased only by 2% [4]. In protein-lipid mixtrures, lipids are bound to proteins probably by non-covalent hydrophobic interactions [22].

The amount of lipids bound into hexane-unextractable forms depends on the water content in the original expanded mixture. Therefore, the contents of hexane-unextractable lipids were significantly lower in experiments Nos. 1 and 2 than in Nos. 3 and 4 or the original mixture. No such difference was observed in case of the extraction after Folch.

Polar lipids, such as monoacylglycerols, diacylglycerols, free fatty acids and lipid oxidation products, form interaction products with proteins more easily than non-polar triacylglycerols [37], therefore, their decrease during extrusion was very pronounced, especially in less moist samples (tab. 2). The decrease was stistically significant in case of samples Nos. 1 and 2, higher in the original moisture contents, than in samples Nos. 3 and 4.

In spite of short cooking time and restricted access of air, lipids are oxidized during the process [39]. Peroxides are usually mostly destroyed at the extrusion temperature, but decomposition products with intact conjugated dienoic system remain there, and can be detected. Therefore, we have determined the content of conjugated dienes in the extract (tab. 2). Their content substantially increased (the increase was statistically significant in all treated samples), especially in extruded mixtures with low moisture content. Thin water layer protects lipid dispersion against access of oxygen [37], therefore, the content of oxidation products was lower at high original water content. The differences between the samples Nos. 1 and 2 on one hand and the samples Nos. 3 and 4 on the other hand were statistically significant.

Carotenoids were decomposed at some, statistically insignificant extent (tab. 2), but their losses had no significant effect on the nutrition value because of low level already in the raw material. According to the literature [26], the mechanism of carotene destruction during extrusion cooking is very complicated, with formation of many decomposition products. Other, structurally related natural colourants are decomposed, too [24]. The decomposition of chlorophylls during the process was similarly intensive as that of carotenoids (tab. 2), but chlorophylls have no importance for animal nutrition. On contrary, their effect is rather negative as they act as photosensibilizers in lipid oxidation.

Volatile products may be formed from lipid hydroperoxides during the extrusion, but we could not detect any rancid off-flavour by sniffing the samples. Several aldehydes were identified in extruded zein-corn oil mixtures, such as hexanal or 2,4-decadienals [6], but their amount was too low in our case to be detected either by human senses or by other instrumental methods. They could be also bound in thermostable complexes to protein or starch as was shown on the example of menthol [25].

Non-enzymic browning reactions during expander cooking

Reducing sugars, mainly glucose and fructose are mainly responsible for the nonenzymic browning of extruded material. Only very small amounts of the two sugars were present in the original mixture before the extrusion, but additional glucose and fructose could be formed by hydrolysis of sucrose, the concentration of which was more than ten times higher than that of reducing monosaccharides. Changes of sugars are shown in table 3. Losses of sucrose were small in mixtures with higher water content in the beginning of expander cooking process. In the samples, where the original water content was lower, the amounts of both reducing sugars and of sucrose increased, but the differences were statistically insignificant. They could be probably released from some bound forms. In our previous experiments [11, 40], more intensive degradation of reducing sugars and sucrose was observed, but the extrusion temperature at these former experiments was much higher (180 and 200°C), while in the present experiments, the maximum temperature in the barrel was only 140°C. This temperature was used in order to minimize browning reactions as they would result in losses of the content of available lysine.

Another class of compounds participating in non-enzymic browning (Maillard) reactions are free amino acids. Only very small amounts of free amino acids were present in the extruded material (less than 0.1%). Therefore, reducing sugars or carbonylic sugar degradation products reacted at least with other amine groups available, especially with the 6-amine group of lysine bound in protein. Primary condensation products are hydrolyzable back to lysine, but secondary products are not cleaved and reduce thus the bioavailability of lysine. Under mild processing conditions in our experiments, the reaction did not obviously proceed to the second, irreversible stage so that losses of available lysine were only low, up to 5% of the original amount, but still statistically significant. Such minute losses are negligible from the standpoint of nutrition value.

Table 3. Contents of nonenzymic browning precursors and browning parameters in original and treated samples

Characteristic	Original mixture	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Fructose, % NFDM	0.22 (0.04)	0.19 (0.03)	0.24 (0.03)	0.48 (0.04)	0.16 (0.02)
Glucose, % NFDM	0.28 (0.04)	0.30 (0.05)	0.36 (0.04)	0.48 (0.03)	0.33 (0.03)
Sucrose, % NFDM	2.75 (0.08)	2.58 (0.06)	2.56 (0.07)	2.93 (0.08)	2.79 (0.06)
Total sugars, % NFDM	3.25 (0.07)	3.07 (0.06)	3.16 (0.06)	3.89 (0.06)	3.28 (0.06)
Available lysine, % NFDM	1.62 (0.04)	1.53 (0.05)	1.55 (0.04)	1.58 (0.06)	1.59 (0.06)
Trichromatic values					
coordinate value *x*	0.368 (0.02)	0.373 (0.01)	0.368 (0.01)	0.366 (0.03)	0.365 (0.03)
coordinate value *y*	0.375 (0.01)	0.375 (0.01)	0.375 (0.02)	0.375 (0.01)	0.374 (0.01)
trichromatic value *a**	-0.05 (0.01)	-0.05 (0.01)	-0.24 (0.02)	-0.41 (0.02)	-0.69 (0.01)
trichromatic value *b**	+22.93 (0.05)	+22.72 (0.03)	+22.94 (0.02)	+23.08 (0.03)	+22.90 (0.02)
Chroma *C*	22.91 (0.06)	22.71 (0.05)	22.94 (0.07)	23.08 (0.07)	22.90 (0.08)
Hue angle *h*	90.1 (0.1)	90.1 (0.4)	89.5 (0.2)	91.0 (0.3)	91.7 (0.3)
Sensory darkness, % of the scale	38 (4)	39 (3)	43 (4)	48 (3)	50 (5)

Notes: Standard deviations are given in parantheses under the respective mean values; NFDM = non-fat dry matter; the significances of browning parameters are explained in the text

Sugars are precursors of flavour compounds during the extrusion [19]. In our earlier experiments [13], an addition of glucose, fructose, and in lesser degree sucrose, considerably increased the formation of substituted pyrazines, pyrroles, furans and pyrones, which are key substances of roasted flavour. The intensity of formation of these flavour-active heterocycles was still more increased by addition of free amino acids [12]. In the expanded products prepared in the present experiments, the formation of roasted flavour compounds was negligible because of low processing temperature. Intensities of roasted flavour between 5-12% of the graphical scale were determined by sensory profiling, i. e. values at the detection limit. Of course, roasted flavour notes are less important in feed mixtures than in human foods.

The course of browning was also evaluated using trichromatic methods (tab. 3). The only difference observed were small changes in the a* value (degree of redness), corresponding to a very small change from brown to reddish brown hue, due probably to the destruction of chlorophyll pigments. Such small changes of hue would not be detectable by human senses. The absolute browning (darkness due to decreases in luminancy) was assayed by sensory analysis, and was also on the border of perception, but differences from the original mixture were still statistically significant. Colour changes are correlated with texture of expanded feed pellets [15], however, in spite of negligible darkening, the product was completely crunchy and crispy.

Changes of nutritionally negative factors during the expander cooking

Several nutritionally negative groups of compounds are present both in faba beans and in rapeseed. The following classes of compounds were chosen for more detailed study because of their importance for the nutrition value: alfa-galactosides, inositol phosphates (phytins), tannins and glucosinolates. Changes of their concentrations during the processing are summarized in table 4.

Table 4. Contents of negative factors in original and treated samples

Analytical characteristic	Original mixture	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Total oligosaccharides, mg g^{-1} NFDM	53.27 (0.42)	54.40 (0.36)	53.41 (0.33)	58.06 (0.42)	58.06 (0.44)
Sucrose, mg g^{-1} NFDM	36.30 (3.4)	34.20 (3.3)	32.71 (3.0)	37.51 (3.7)	37.51 (3.7)
Raffinose, mg g^{-1} NFDM	2.21 (0.06)	2.32 (0.08)	2.12 (0.05)	2.35 (0.11)	1.99 (0.07)
Stachyose, mg g^{-1} NFDM	10.28 (0.21)	9.64 (0.18)	9.66 (0.20)	10.74 (0.22)	10.42 (0.24)
Verbascose, mg g^{-1} NFDM	7.66 (0.18)	8.14 (0.22)	8.92 (0.24)	8.52 (0.20)	8.14 (0.21)
Total alfa-Galactosides, mg g^{-1} NFDM	20.15 (0.33)	20.10 (0.30)	20.60 (0.35)	20.61 (0.42)	20.55 (0.48)
Tannins, % NFDM	0.68 (0.08)	0.31 (0.03)	0.41 (0.03)	0.44 (0.04)	0.45 (0.04)
Inositolphosphates, mmol kg^{-1} NFDM					
Inositoltetraphosphate	0.10 (0.02)	0.18 (0.04)	0.20 (0.04)	0.40 (0.11)	0.21 (0.08)
Inositolpentaphosphate	1.02 (0.03)	2.16 (0.05)	2.10 (0.07)	1.52 (0.09)	2.03 (0.10)
Inositolhexaphosphate	30.50 (1.24)	38.58 (1.58)	38.56 (1.90)	27.14 (1.11)	34.28 (1.30)
Total inositolphosphates	31.62 (1.84)	40.92 (1.65)	40.86 (2.05)	29.03 (1.78)	36.52 (1.85)
Total inositolphosphates, mg g^{-1} NFDM	20.86 (1.67)	27.01 (1.34)	26.96 (1.03)	19.15 (1.50)	24.10 (1.12)
Progoitrin, mg g^{-1} NFDM	1.27 0.19)	0.61 (0.20)	0.50 (0.18)	0.68 (0.22)	0.64 (0.20)
Glucoraphanin	0.03 (0.01)	trace	trace	trace	trace
Napoleiferin	0.41 (0.07)	0.20 (0.04)	0.17 (0.04)	0.24 (0.06)	0.23 (0.03)
Glucoalyssin	0.71 (0.03)	0.34 (0.05)	0.28 (0.05)	0.38 (0.04)	0.37 (0.06)
Gluconapin	6.36 (1.11)	3.08 (0.78)	2.48 (0.80)	3.45 (0.69)	3.27 (0.64)
Glucobrassicanapin	4.83 (0.85)	2.33 (0.62)	1.92 (0.40)	2.57 (0.68)	2.53 (0.72)
Glucoerucin	0.29 (0.14)	trace	trace	trace	trace
4-Hydroxyglucobrassicin	1.50 (0.11)	0.55 (0.24)	0.44 (0.18)	0.62 (0.21)	0.60 (0.12)
Glucobrassicin	0.02 (0.00)	0.02 (0.01)	0.02 (0.01)	0.02 (0.00)	0.02 (0.00)
Total glucosinolates	15.42 (0.75)	7.13 (0.86)	5.81 (0.64)	7.96 (0.75)	7.76 (0.85)

Notes: Standard deviations are given in paratheses under the respective mean values; NFDM = non-fat dry matter

The sucrose content was determined using the method for the determination of alfa-galactosides (tab. 4), but the results did not significantly differ from the respective sucrose contents obtained by another method (tab. 3).

Alfa-galactosides are less digestible than other oligosaccharides in human nutrition and also for non-ruminant farm animals because suitable respective alfa-galactosidases are lacking, which are necessary for the digestion. Galactosides are present both in rapeseed and in faba beans, but in lower amounts than in peas [10, 18]. Changes of alfa-galactosides were of the same order of magnituition as changes of reducing sugars discussed above. Their

losses due to processing were insignificant. They were probably decomposed on one hand, and liberated from their bound forms, most probably of oligosaccharides or polysaccharides, on the other hand during the expansion cooking. Relative losses of stachyose in water-richer samples were slightly higher than those of other alfa-galactosides, but the differences were insignificant.

Another group of antinutritional substances are tannins. The content of tannins is relatively low both in rapeseed [20] and in legumes [18], but still they have moderate negative effect on feed quality. Their decrease during the extrusion (tab. 4) was very high, statistically significant in all samples, especially in the sample No. 1, where the initial water content was higher than in other samples, but they were most probably not destroyed, but simply bound to proteins, forming insoluble complexes [45].

The group of phytic acids includes mainly inositolhexaphosphate, but also penta and tetraphosphates were present even in raw material. They bind calcium, magnesium, iron and other metals into unavailable complex salts, therefore, they are considered as negative factors in nutrition. Hexaphosphates prevailed in both raw mixtures and in expanded materials (tab. 4). Their proportions were about the same, irrespective of the expansion processing. It is interesting that the expansion cooking caused increase in all inositol esters, especially in mixtures with higher initial water content, but the increase was statistically insignificant. They were set free from their bonds with proteins and phospholipids under processing conditions.

Glucosinolates are important antinutritional factors for monogastric animals in rapeseed, but they are not present in legumes. The original content in rapeseed is thus diluted by a half with faba beans, but still, they have negative effect in feeding broilers. In our samples, low-glucosinolate rapeseed was used, which is more suitable as broiler feed than the traditional high-glucosinolate cultivars. Pronounced decrease (to 47%) was observed (tab. 4) during expander cooking, especially at higher moisture levels (decrease to 41.4%) than in samples with lower original moisture (decrease only to 50.9%). The decomposition degree was almost the same in different glucosinolates, but residual amounts were substantially higher in case of 4-hydroxyglucobrassicin (to 29.3-41.3% of the original value).

The decreases during processing were not statistically significant in case of individual glucosinolates, but the destruction during expander cooking was statistically significant in case of total glucosinolates. Differences between individual treated samples were, however, insignificant. This decomposition is approximately of the same order as that occurring during toasting of rapeseed extraction meal in oilseed processing plants [46]. Nearly 50% decrease of total glucosinolates in expanded mixtures (irrespectively of the moisture content) favourably affect the nutritional value.

CONCLUSIONS

1. Expander cooking of mixtures having different moisture content and containing dehulled faba beans and whole rapeseed in the 1:1 ratio caused only negligible effect of the process and addition of water (from 15% to 25%) on changes of the analyzed components (lipids, carotenoids, chlorophylls, sugars, available lysine, and total phytates);
2. Polar lipids, such as monoacylglycerols, diacylglycerols, free fatty acids and lipid oxidation products, form interaction products with proteins more easily than non-polar triacylglycerols, therefore, their decrease during extrusion was very pronounced, especially in less moist samples (tab. 2).
3. Thin water layer protects lipid dispersion against access of oxygen, therefore, the content of oxidation products was lower at high original water content.
4. Carotenoids were decomposed at some, statistically insignificant extent (tab. 2), but their losses had no significant effect on the nutrition value because of low level already in the raw material.
5. Losses of sucrose were small in mixtures with higher water content in the beginning of expander cooking process. In the samples, where the original water content was lower, the amounts of both reducing sugars and of sucrose increased, but the differences were statistically insignificant. In our experiments, the maximum temperature in the barrel was only 140°C. This temperature was used in order to minimize browning reactions as they would result in losses of the content of available lysine.
6. Deactivation of some undesirable components (glucosinolates and tannins) shows that the expander cooking as an additional thermal treatment allows production of high-quality feed components for broilers feeding.

REFERENCES

1. AOAC, 1990, Asscoiation of Official Analytical Chemists, Official Methods of Analysis, 15th ed. 1990. AOCS, Washinton, DC.
2. AOCS Official Methods and Recommended Practices, 5th ed. 1998. AOCS, Campaign, IL.
3. ASTM Standards on Color and Appearance Measurement, 5th ed. 1996. ASTM, Washington, DC.
4. Bhattacharya M., Hann M. A., 1988. Effect of lipids on the properties of extruded products. J. Food Sci. 53, 1230-1231.
5. Booth V. H., Carpenter K. J., 1973. Damage to lysine in food processing: its measurement and its signification. Nutr. Abs. Rev., Ser. B, 42, 36-38.
6. Bruechert L. J., Zhang Y., Huang T. -C., Hartman T. G., Rosen R. T., Ho C.-T., 1988. Contribution of lipids to volatiles generation in extruded corn-based model systems. J. Food Sci. 53, 1444-1447.
7. Camire M. E., 1991. Protein functionality modification by extrusion cooking. J. Amer. Oil Chem. Soc. 68, 200-205.
8. Chang, Y. K., Wang, S., 1996. Advances in Extrusion Technology. Technomic, Lancaster.
9. Cheftel J. C., 1986. Nutritional effects of extrusion cooking. Food Chem. 20, 263-283.
10. Dostálová J., Krejčová A., Réblová Z., Pokorný J., 1999. Changes of α-galactosides during soaking and cooking of peas. Bull. Potrav. Výsk. 38, 133-140.
11. Farníková L., Réblová Z., Pudil F., Pokorný J., Mościcki L., van Zuilichem D. J., 1996. Browning reactions during the extrusion-cooking of peas, faba beans and rapeseed. Biul. nauk Przem. Pasz. 35, 15-28.
12. Farouk A., Pudil F., Janda V., Pokorný J., 2000. Effect of amino acids on the composition and properties of extruded mixtures of wheat flour and glucose. Nahrung 44, 188-192.
13. Farouk A., Pudil F., Janda V., Pokorný J., 2001. Changes during the extrusion of semolina in mixture with sugars. Czech J. Food Sci. 19, 24-30.
14. Fretzdorff B., Seiler K., 1987. The effects of twin-screw extrusion cooking on cereal enzymes. J. Cereal Sci. 5, 73-82.
15. Gao X., Tan J., Shatadal P., Heymann H., 1999. Evaluating expanded-food sensory properties by image analysis. J. Texture Stud. 30, 291-304.
16. Guy R. C. E., 2001. Extrusion Cooking, Principles and Technologies. Woodhead Publishing, Cambridge.
17. Heaney R. K., Spinks E. A., Hanley A. B., Fenwick G. R., 1986. Analysis of glucosinolates in rapeseed. Techn. Bull. AFRC. Food Research Institute, Norwich (UK).
18. Hedley C. L., Cunningham J., Jones A., 2001. Carbohydrates in Grain Legume Seeds. Wallington, New York, CABI Publishing, 63.
19. Huber G. R., 1991. Carbohydrates in extrusion processing. Food Technol. 3, 160-161, 168.
20. Iqbal R., Siddiqui I., Wood P., 1977. Carbohydrates of rapeseed. J. Sci. Food Agr. 28, 530-538.
21. IUPAC Standard Methods for the Analysis of Oils, Fats and Derivatives, 1st Suppl. to the 7th ed. 1992. A. Dieffenbacher and W. D. Pocklington, eds. Blackwell, Oxford.
22. Izzo M., Ho C.-T., 1989. Protein-lipid interaction during single-screw extrusion of zein and corn oil. Cereal Chem. 66, 47-51.
23. Leontowicz H., Leontowicz M., Kostyra H., Gralak M. A., 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. 8, 77-87.
24. Maga J. A., Kim C. H., 1990. Stability of natural colourants (annato, beet, paprika, turmeric) during extrusion cooking. Lebensm. Wiss. Technol. 23, 427-432.
25. Maier H. G., Moritz K., Schmidt E., 1987. Thermostabile Bindungen von Aromastoffen an Stärke durch Extrudieren. Lebensmittelchem. Gerichtl. Chem. 41, 56-59.
26. Marty C., Berset C., 1988. Degradation products of *trans*-β -carotene produced during extrusion cooking. J. Food Sci. 53, 1880-1886.
27. Matyka S., Mościcki L., Jaskiewicz J., Pokorný J., 1996. Extrusion cooked faba bean-rapeseed concentrate in broiler chicks diets. Sci. Agr. Bohem. 27, 211-220.
28. Mościcki L., Pisarski L., Wójcik S., 1988. Użyteczność mieszanek paszowych o różnym udziale extrudowanych nasion lupinu i bobiku w żywieniu kurcząt broilerów (Feeding value of broiler feed mixtures containing different ratios of extrusion cooked lupine or broad beans). Biul. Inform. Przem. Paszowego 4, 22-30 [in Polish].
29. Mościcki L., Pokorný J., Kozłowska H., van Zuilichem D. J., 1997. Influence of extrusion and expander-cooking on physicochemical properties of rapeseed-faba bean mixtures. In: Jorwitt R., Editor, Engineering and Food at ICEF, 7, Pt. 2, Sheffield Academic Press, Sheffield, pp. H25-H28.
30. Mościcki, L., Stawarz W., 1996. Ekspandery – budowa i zastosowanie (Expanders – construction and application). Zesz. Probl. Post. Nauk Roln. 430, 157-162 [in Polish].
31. Mościcki L., Wideński K., Rzedzicki Z., 1990. The research of white lupine extrudate introduction to piglets´ feed, World Review of Animal Production, FAO, Roma, 25, 4.
32. Mościcki L., Wójcik S., Plaur K., van Zuilichem D. J., 1984. Extrusion cooking to improve the animal feed quality of broad beans. J. Food Eng. 3, 307-316.
33. Muzquiz M., Rey C., Cuadrado C., 1992. Effect of germination on oligosaccharides content of lupin species. J. Chromatogr. 607, 349-352.
34. Normy żywienia Drobiu (Polish feeding standards for poultry). 1996, Instytut żywienia Zwierząt PAN, Jablonna k. Warszawy [in Polish].

35. Ohishi A., Watanabe K., Urushibata M., Utsuno K., Ikuta K., Sugimoto K., Harada H., 1994. Detection of soybean antigenicity and reduction by twin-screw extrusion. J. Amer. Oil Chem. Soc. 71, 1391-1396.
36. Pokorný J., 1999. Antioxidants in food preservation. In: Editor Rahman M. S., Handbook of Food Preservation. M. Decker, New York, Basel, pp. 309-337.
37. Pokorný J., Réblová Z., Kouřimská L., Pudil F., Kwiatkowska A., 1993. Effect of interactions with oxidized lipids on structure changes and properties of food proteins. In: Schwenke K. D. & Mothes R. (Editors), Food Proteins: Structure and Functionality. VCH, Weiheim, pp. 232-235.
38. Price M. L. Von Scoyos S., Butler C. G., 1975. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. J. Sci. Food Agr. 22, 658-660.
39. Rao S. K., Artz W. E., 1989. Effect of extrusion on lipid oxidation. J. Food Sci. 54, 1580-1583.
40. Réblová Z., Nguyen H. T. T., Pudil F., Dostálová J., Pokorný J., Mościcki L., van Zuilichem D. J., 1996. Nonenzymic browning reactions during the extrusion and expansion cooking process. In: Chemical Reactions in Foods, III, Budapest, Proceedings, pp. 163-166.
41. Réblová Z., Piskačová J., Farníková L., Pokorný J., Mościcki L., Matyka S., 1995a. Influence of extrusion cooking on antinutritive substances in rapeseed-legume concentrates. Biul. Nauk. Przem. Pasz. 34, 5-19.
42. Réblová Z., Piskačová J., Farníková L., Pokorný J., Mościcki L., Matyka S., 1995b. Changes in glucosinolates and phenolics during extrusion cooking of rapeseed-legume mixtures. Sci. Agr. Bohem. 26, 93-104.
43. Sandberg A. S., Ahderinne R., 1986. HPLC method for determination of inositol tri-, tetra-, penta-, and hexaphosphates in food and intestinal contents. J. Food Sci. 51, 547-550
44. Strange E. D., Schaich K. M., 2000. Extraction of lipids from extruded corn-soy blends. J. Food Lipids 7, 217-224.
45. Velíšek J., 1999. Chemie Potravin, Vol. 1. OSSIS, Tábor (Czech Republic), p. 70-71.
46. Velíšek J., Pokorný J., Davídek J., Michová J., Čmolík J., 1991. Degradation of glucosinolates and their decomposition products during the processing of Czechoslovak double-low and high-glucosinolate rapeseed. Sb. Vys. Školy Chem.-Technol. Praze, E 62, 55-85.
47. Wang T., Johnson L. A., 2001. Survey of soybean oil and meal qualities produced by different processes. J. Am. Oil Chem. Soc., 78, 311-318.
48. Wang T., Myers D. J., Heywood A. A., 2002. Characterization and utilization of soy flour produced from extrusion-expelling processing. Inform, 13, 708-710, 712-713.

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