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The influence of dietary raw and extruded field peas (*Pisum sativum* L.) on nutrients digestibility and performance of weaned and fattening pigs

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ABSTRACT. The affectivity of extrusion process of pea seeds on nutrients digestibility or growth performance of pigs was analysed. The first study was conducted on 30 male pigs allocated to three dietary treatments for 28 days. The control animals were offered a basal diet whereas the experimental groups received basal diets mixed with raw or extruded pea seeds in the proportion of 75:25 (w/w). The apparent ileal and total tract digestibilities were determined using the difference method with titanium dioxide. The second semi-practical experiment was conducted on 60 pigs (29 ± 0.3 kg) and lasted 75 days. The growth performance of the pigs receiving control diet with soyabean meal (SBM) or diets where SBM was replaced with raw or extruded pea seeds mixed with rapeseed meal (RSM) was analysed. The extrusion of pea seeds significantly reduced the content of resistant starch, phytate-P, crude fibre and neutral detergent fibre levels, and trypsin inhibitor activity. Extrusion only enhanced ($P < 0.05$) the apparent total tract digestibility of crude protein, and improved the apparent ileal digestibility of Asp, Glu and Cys ($P < 0.05$). The inclusion of pea seeds with RSM into the diet of growing pigs reduced their daily gain and feed conversion ratio, but not during finishing phase and during the whole time of experiment. The final body weight of pigs receiving pea seeds and RSM was lower in comparison to the control group. In conclusion, extrusion significantly influenced the chemical composition of pea seeds but it did not improve the production results of the animals.

Introduction

The intensification of controversies regarding the use of GMO soya products in animal nutrition caused a rapid increase in the cultivation of leguminous plants, including peas (*Pisum sativum* L.). Pea seeds contain active globulin proteins rich in lysine, but they are deficient in sulphur amino acids, tryptophan and isoleucine (Duranti, 2006; Friesen et al., 2006; Jamroz and Kubizna, 2008). Therefore, in the case of the isonitrogen replacement of soyabean with pea seeds as an alternative protein source, it is necessary to supplement methionine and other amino acids, and to use higher amounts of seeds. Diets containing pea seeds are usually completed with other protein sources, for example, soyabean meal (SBM) or rapeseed meal (RSM). The side effect of this is an increased content of the antinutritive factors (ANF) in the diets: proteases inhibitors, polyphenolic substances, raffinose family oligosaccharides (RFO), phytate, haemagglutinins, glucosinolates, lectins and tannins (Griffiths, 1981;

Alonso et al., 1998; Salgado et al., 2002a,b; Duranti, 2006; Heng et al., 2006; Jamroz and Kubizna, 2008; Jezierny et al., 2010). Recently, considerable progress in plant breeding has been observed, and low ANF legume cultivars have become available (Jezierny et al., 2010). The results of Masoero et al. (2005), Tuśnio et al. (2017) and other authors indicate that using pea in pig nutrition can be beneficial. The restrictions in the amounts of introduced pea seeds into non-ruminant diets may be alleviated by inactivation of antinutritive substances and improvement of the nutritional value of seeds (starch and protein availability) through high temperature short-time processing (Hejdysz et al., 2016). It was hypothesized that the extrusion process can significantly improve the nutritional value of pea seeds so they can be used instead of SBM in diets for growing and fattening pigs without a negative influence on their growth performance.

The aim of the present study was: 1. to determine the effect of extrusion of pea seeds var. Tarchalska on composition, nutritive value and digestibility of seeds and growth performance of pigs; 2. to evaluate the effect of replacing SBM in diets of growing and finishing pigs with a combination of raw or extruded pea seeds with RSM.

Table 1. Chemical composition of raw and extruded pea seeds var. Tarchalska

Indices	Pea seeds raw (n = 4)	Pea seeds extruded (n = 4)	SEM	*P*-value
Content, g · kg^{-1} DM				
crude protein	231.4	234.2	23.5	0.807
ether extract	12.8	12.6	2.0	0.879
crude fibre	68.4^a	61.0^b	7.4	0.038
ADF	94.6	85.5	10.2	0.062
NDF	158.4^a	113.8^b	27.3	0.002
crude ash	28.8	28.8	1.3	0.974
starch	415.8	414.7	8.9	0.865
resistant starch	164.2^a	17.9^b	23.1	0.001
nitrogen-free extractives	658.6	663.3	6.0	0.440
P	4.52	4.50	0.09	0.955
Ca	1.20	1.20	0.01	0.980
total oligosaccharides	80.62	78.98	2.58	0.533
raffinose	8.78	8.56	0.44	0.622
stachyose	33.70	33.00	2.12	0.746
verbascose	38.14	37.42	1.87	0.844
phytate-P	3.30^a	2.36^b	0.33	0.011
tannins	0.24	0.23	0.07	0.956
TIA, mg · g^{-1}	0.42^a	0.36^b	0.02	0.010
Essential amino acids content, g · 16 g^{-1} N				
Lys	6.81	6.93	0.20	0.756
Thr	3.92	3.77	0.11	0.495
Met	0.67	0.65	0.04	0.576
Cys	1.51	1.69	0.05	0.060
Ile	3.85	3.74	0.08	0.399
Val	4.51	4.35	0.09	0.171
Leu	6.82	6.82	0.08	0.491
Phe	4.56	4.44	0.12	0.308
His	2.95	2.83	0.10	0.141
Arg	7.37	7.30	0.36	0.348
Gly	4.34	4.18	0.16	0.585
Non-essential amino acids content, g · 16 g^{-1} N				
Tyr	2.97	2.85	0.07	0.090
Ala	4.08	3.92	0.28	0.455
Asp	10.97	10.72	0.20	0.493
Glu	19.28	19.33	0.13	0.909
Ser	4.58	4.49	0.08	0.250
Pro	5.84	5.60	0.16	0.255

DM – dry matter; SEM – standard error of the mean; ADF – acid detergent fibre; NDF – neutral detergent fibre; TIA – trypsin inhibitor activity; [ab] – values within a row with different superscripts are significantly different at $P < 0.05$

Material and methods

Pea seeds (*Pisum sativum* L.) of white flowered narrow-leaved var. Tarchalska obtained from Danko (Poland) were used. The samples were harvested from four different experimental fields in 2014. The environmental conditions of the different experimental fields (fertilisation, time of growing season and water amount in critical periods) were similar. The grounded pea seeds (Bąk, Poland) were extruded using a KMZ 2 extruder (Sharkan, Russia) (500 kg · h^{-1}) at moisture approx. 22%, exposition time 10 s, temperature 135 ± 10 °C and pressure 30 kg · cm^{-2}. The extruded seeds were allowed to cool down to room temperature and ground in a laboratory grinder with 3.18 mm sieve (Retsch, Haan, Germany), and stored at 4 °C. The chemical composition of raw and extruded seeds is presented in Table 1.

Animals and diets

All experimental procedures used in this study were in accordance with the guidelines of Directive 2010/63/EU of the European Parliament and of the Council on the protection of animals used for scientific purposes.

Pigs were housed under standard conditions (temperature 20–22 °C, air humidity 60–70%). The animals received all necessary vaccinations and had *ad libitum* access to water and feed.

Both experiments were conducted in two stages. In the first experiment the apparent total tract digestibility coefficients (ATTD) and apparent ileal digestibility coefficients (AID) of nutrients were determined, whereas in the second experiment semi-practical research was provided.

Digestibility-growth experiment (Experiment 1)

In this experiment 30 castrated male piglets (Naïma × (Pietrain × Duroc)) with initial body weight (BW) of 10 ± 0.3 kg, weaned at 35 day of age, were used. Before the experiment, the animals were housed on straw, which had been withdrawn before the experiment started. The young pigs were randomly allocated to three dietary treatments and kept in the individual cages for 28 days. The cages met the welfare requirements for pigs in accordance with the Polish legal guidelines applicable during the time of performing the experiments (Regulation of the Minister of Agriculture and Rural Development, Journal of Laws 2006, No 50, item 368). The pigs in the first (control) treatment were fed basal maize-soyabean diet without pea seeds (Table 2). The other two treatments consisted of the basal diet mixed in a ratio of 75:25 (w/w) with raw or extruded pea seeds var. Tarchalska. A titanium dioxide (3 g · kg^{-1}) as a non-digestible and non-absorbable marker was also added in order to determine the digestibility. The complete diets for each experiment were formulated according to GfE (2006) recommendations. The animals had *ad libitum* access to feed and fresh water. All diets were offered in a mash form. During the last three days of the experiment, twice a day excreta were individually collected (n = 10) to plastic bags and frozen. After the experiment, the animals were stunned by electric shock, exsanguinated and their small intestines were dissected. The pigs were offered their meal on the day of sampling in a staggered fashion. The period between feeding and euthanasia lasted 3 h ± 15 min. Samples from ileum (approx. 50 cm length before the ileal-caecal valve) were collected individually. The coefficients of ATTD and AID of the pea seeds were calculated as:

$$\text{ATTD (\%); AID (\%)} = 100 * [((T * Tp) - (B * Bp)) / Ap]$$

where: ATTD and AID – digestibility coefficients of pea seeds, %; T – digestibility of the component in the total diet (basal diet plus tested feedstuff), %; B – digestibility of the component in the basal diet, %; Bp – proportion of the component in the total diet contributed by the basal diet, %; Ap – proportion of the component in the total diet contributed by the tested feedstuff, %; Tp = Bp + Ap = 100 (%).

Table 2. Composition of diets used in digestibility-growth experiment

Indices	Diets		
	control without pea	with raw pea seeds	with extruded pea seeds
Components, g · kg^{-1}			
raw pea seeds	-	250.0	-
extruded pea seeds	-	-	250.0
wheat meal	478.7	359.0	359.0
maize meal	260.0	195.0	195.0
soyabean meal	230.0	172.5	172.5
phosphate 1-Ca	10.0	7.50	7.50
limestone	15.0	11.25	11.25
NaCl	3.0	2.25	2.25
mineral premix[1]	3.0	2.25	2.25
vitamin premix[2]	0.3	0.25	0.25
Calculated nutrient content, g · kg^{-1}			
ME[3], MJ · kg^{-1}	12.6	12.5	12.5
crude protein	183.0	195.7	200.1
Lys	9.3	10.3	10.5
Met	3.0	2.8	2.9
Thr	6.4	6.7	6.7
Trp	2.1	2.2	2.2
Ca	8.4	8.3	8.3
P	6.3	5.0	5.0
Calculated standardized ileal digestible amino acid, g · kg^{-1}			
Lys	8.60	8.78	8.78
Met	2.59	2.40	2.40
Thr	5.55	5.74	5.74
Trp	1.90	1.80	1.80

[1] mineral premix content per kg: g: Ca 235; mg: Fe 60 000, Cu 10 000, Co 400, Mn 40 000, Zn 30 000, I 800, Se 200; [2] vitamin premix content per kg: IU: vit. A 50 000 000, vit. D_3 5 000 000; mg: vit. E 150 000, vit K_3 5 000, vit. B_1 7 500, vit B_2 15 000, vit B_3 75 000, vit. B_6 10 000, pantothenic acid 3 600, folic acid 1 500, vit. C 200 000, antioxidant (butylated hydroxyanisole, butylated hydroxytoluene) 5 000; µg: vit. B_{12} 100 000, biotin 250 000; [3] ME – metabolizable energy (GfE, 2006)

Semi-practical experiment (Experiment 2)

The semi-practical experiment was conducted on 60 male castrated pigs (Naïma × (Pietrain × Duroc)) of about 28 ± 0.9 kg BW. The pigs were allocated according to BW and sex (50% ♀ and 50% ♂) to three dietary treatments and housed in the individual pens. All diets were offered in a mash form (Table 3). The control animals were fed diet with SBM as the main protein component, whereas experimental animals were fed raw or extruded pea seed meal var. Tarchalska and RSM that replaced SBM. In the preparation of diets the nutritional values and digestibility coefficients from the Experiment 1 were used. The experiment lasted 75 days and was divided into grower and finisher periods. The daily feed intake (dFI) and body weight gain (BWG) were recorded and the feed conversion ratio (FCR) was calculated.

Table 3. Composition of diets used in semi-practical experiment

Indices	Grower diets			Finisher diets		
	control without pea	with raw pea	with extruded pea	control without pea	with raw pea	with extruded pea
Components, g · kg^{-1}						
soyabean meal (46% CP[1])	190.0	–	–	125.0	–	–
raw peaseeds	–	240.0	–	–	140.0	–
extruded pea seeds	–	–	240.0	–	–	140.0
rapeseed meal	–	150.0	150.0	–	100.0	100.0
triticale	774.4	570.0	570.0	848.0	731.4	731.4
soyaoil	5.0	13.0	13.0	2.0	5.0	5.0
limestone	13.0	14.0	14.0	13.0	12.9	12.9
phosphate 1-Ca	7.2	4.0	4.0	2.8	2.0	2.0
NaCl	2.9	2.9	2.9	2.2	2.3	2.3
premix grower[2]/finisher[3]	5.0	5.0	5.0	5.0	5.0	5.0
L-lysine 98.5%	1.6	0.7	0.7	1.8	1.3	1.3
DL-methionine 99%	0.2	0.4	0.4	–	–	–
L-threonine 99%	0.7	–	–	0.1	–	–
L-tryptophan 95%	–	0.1	0.1	–	0.1	0.1
Calculated nutrient content, g · kg^{-1}						
ME[4], MJ · kg^{-1}	13.1	13.1		13.1	13.1	
crude protein	174.0	175.0		155.0	155.0	
Lys	9.8	9.7		8.5	8.4	
Met	3.2	3.2		2.7	2.6	
Trp	1.9	2.0		1.7	1.7	
Thr	6.6	6.6		5.4	5.6	
Ca	8.2	8.4		7.0	7.2	
P	5.5	5.6		4.5	4.8	
Na	1.3	1.3		1.0	1.0	
Calculated standardized ileal digestible amino acid, g · kg^{-1}						
Lys	8.28	8.15		7.00	7.01	
Met	2.64	2.67		2.16	2.18	
Thr	5.44	5.38		4.40	4.38	
Trp	1.50	1.52		1.32	1.34	

[1] CP – crude protein; [2] grower premix content, per kg: IU: vit. A 1 500 000, vit. D_3 300 000; mg: choline chloride 40 000, Fe 15 000, Cu 4 000, Co 60, Mn 6 000, Zn 15 000, J 120, Se 30, vit. E 10 500, vit. K_3 220, vit. B_1 220, vit. B_2 600, vit. B_6 450, pantothenic acid 1 500, nicotinic acid 3 000, folic acid 300; µg: vit. B_{12} 3 700, biotin 15 000; g: Ca 260; and antioxidants (butylated hydroxyanisole, butylated hydroxytoluene); [3] finisher premix content per kg: IU: vit. A 1 000 000, vit. D_3 200 000; mg: choline chloride 20 000, Fe 10 000, Cu 4 000; [4] ME – metabolizable energy

Chemical analysis

The chemical composition of raw and extruded pea seeds, diets and excreta were analysed using standard methods of AOAC International (2007). For chemical analysis representative samples of seeds and feed were ground to pass through a 0.5-mm sieve. The excreta and digesta samples were immediately frozen after sampling and lyophilised before analysis. Seeds were analysed (n = 4) for dry matter (DM), crude ash, crude protein (CP), ether extract (EE), crude fibre (CF), acid detergent fibre, neutral detergent fibre, calcium and phosphorus. Gross energy was determined using an adiabatic bomb calorimeter (KL 12Mn, Precyzja-Bit PPHU, Bydgoszcz, Poland) standardised with benzoic acid (Sigma-Aldrich, St. Louis, MO, USA). The amino acid (AA) content was determined with an AAA-400 Automatic Amino Acid Analyser (INGOS, Praha, Czech Republic) using ninhydrin (Sigma-Aldrich, St. Louis, MO, USA) for post-column derivatisation. Before the analysis, the samples were hydrolysed with 6 N HCl (POCH, Gliwice, Poland) for 24 h at 110 °C (AOAC International, 2007). The starch content in pea seeds was determined using a diagnostic assay kit for agricultural industries (Megazyme International, Wicklow, Ireland) based on the use of thermostable α-amylase and amyloglucosidase (AOAC International (2005): method 996.11). Nitrogen-free extract was calculated on the basis of chemical composition. Titanium dioxide (POCH, Gliwice, Poland) was determined according to Short et al. (1996) and the samples were prepared in accordance with the procedure proposed by Myers et al. (2004). RFO were extracted and analysed by high-resolution gas chromatography as described previously by Zalewski et al. (2001). Phytate bound phosphorus was determined according to the method of Haug and Lantzsch (1983). The tannin content of pea seeds samples was examined according to the method of Kuhla and Ebmeier (1981), while the trypsin inhibitor activity (TIA) was evaluated according to PN-EN ISO 14902:2005. The resistant starch (RS) contents were analysed using an assay kit (Megazyme International, Wicklow, Ireland; AOAC International (2005): method 2002.02). Samples were incubated in a shaking water bath with pancreatic α-amylase and amyloglucosidase for 150 min, where non-resistant starch was solubilised and hydrolysed to D-glucose by the combined action of the two enzymes.

Statistical analysis

One-way analysis of variance was performed. The significance of the differences between control and experimental groups was calculated using Duncan post-hoc test and an alpha level of $P < 0.05$ was used to assess the significance among means. The statistical analysis was performed using SAS ver. 5.0. (SAS Institute Inc., Cary, NC, USA).

Results

Pea seeds and processing

The extrusion of pea seeds did not influence CP and EE contents; however, it led to a significant ($P < 0.01$) decrease in the amount of CF and NDF. Furthermore, the RS level was radically reduced ($P < 0.01$) from 164 g · kg^{-1} DM to approx. 18 g · kg^{-1} DM (Table 1). No changes were observed in AA, RFO and tannins contents in comparison to raw seeds. The content of phytate-P and trypsin inhibitor activity were significantly reduced ($P < 0.05$) due to pea thermal processing.

Experiment 1

The animals were in good health during the experiment. Extrusion exerted no significant impact ($P > 0.05$) on the ATTD of DM and gross energy, but it increased ($P < 0.05$) the apparent total tract digestibility of CP in young pigs, by about 5 percentage points (Table 4). In general, when the extruded pea seeds were used, coefficients of the ileal digestibility of nutrients were similar to raw pea seeds, and only for Asp, Glu and Cys differences were significant ($P < 0.05$). The performance indices of weaners were similar ($P > 0.05$) in the control as well as in both pea treatments (Table 5). The average daily weight gain was 538 g, whereas FCR equalled 1.96 ($P > 0.05$).

Table 4. Coefficients of apparent total tract digestibility (ATTD) and apparent ileal digestibility (AID) of raw and extruded pea seeds in weaned piglets

Indices	Pea seeds		SEM	*P*-value
	raw	extruded		
ATTD, %				
dry matter	77.6	77.5	0.33	0.816
crude protein	75.2[a]	80.2[b]	1.22	0.043
gross energy	74.9	75.6	0.56	0.492
AID, %				
dry matter	51.5	52.8	0.53	0.120
crude protein	63.7	64.6	0.54	0.261
Asp	52.9[a]	55.6[b]	0.46	0.002
Thr	41.6	42.9	0.67	0.185
Ser	60.9	60.3	0.56	0.563
Glu	69.1[a]	72.1[b]	0.32	0.004
Pro	56.9	57.9	0.54	0.191
Cys	61.4[a]	64.9[b]	1.00	0.031
Ala	46.9	47.1	0.59	0.811
Val	57.8	58.5	0.52	0.370
Met	75.3	84.5	3.90	0.212
Ile	65.3	65.2	0.37	0.988
Leu	58.4	59.5	0.46	0.686
Tyr	59.1	58.6	0.72	0.623
Phe	68.1	68.7	0.41	0.249
His	54.0	54.9	0.49	0.204
Lys	63.1	62.2	0.41	0.157
Arg	73.8	73.5	0.36	0.193

SEM – standard error of the mean; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

Table 5. Initial body weight (BW), body weight gain (BWG), daily feed intake (dFI) and feed conversion ratio (FCR) of weaned pigs (10–26 kg BW) in the growth experiment (n = 10)

Indices	Diets			SEM	*P*-value
	control without pea	with raw pea seeds	with extruded pea seeds		
Initial BW, kg	10.8	10.6	10.9	0.1	0.889
BWG, g · d^{-1}	546	535	533	11.0	0.764
dFI, kg	1.06	1.07	1.00	0.06	0.221
FCR	1.95	2.02	1.90	0.1	0.430

SEM – standard error of the mean

Experiment 2

In comparison to diets without pea seeds, grower diets containing 24% of raw or extruded pea seeds and 15% of RSM significantly reduced daily body weight gain of swine from 1050 ± 55 g to 950 ± 32 g and increased FCR from 2.52 to 2.80 ($P < 0.05$), respec-

Table 6. Body weight (BW), body weight gain (BWG), daily feed intake (dFI) and feed conversion ratio (FCR) of weaned pigs (28–95 kg BW) in the semi-practical experiment (n = 20)

Indices	Diets			SEM	*P*-value
	control without pea	with raw pea seeds	with extruded pea seeds		
Grower – diets feeding period (30 days)					
initial BW, kg	28.39	28.09	29.13	0.440	0.638
BWG, $g \cdot d^{-1}$	1050[a]	955[b]	942[b]	0.020	0.002
dFI, kg	2.64	2.67	2.71	0.033	0.401
FCR	2.52[b]	2.80[a]	2.84[a]	0.040	0.001
Finisher – diets feeding period (45 days)					
BWG, $g \cdot d^{-1}$	824	813	840	0.010	0.781
dFI, kg	2.73	2.70	2.72	0.022	0.658
FCR	3.39	3.38	3.27	0.070	0.743
Total – whole experiment (75 days)					
final BW, kg	97.10[a]	93.35[b]	95.17[b]	0.730	0.010
BWG, $g \cdot d^{-1}$	937	884	891	0.010	0.179
dFI, kg	2.69	2.69	2.71	0.210	0.341
FCR	2.96	3.10	3.08	0.040	0.226

SEM – standard error of the mean; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

tively (Table 6). No differences in dFI were noted. During the finisher period, the amount of pea seeds in diets was reduced to 14% and RSM to 10%, which was the result of lower protein demand in that period. No significant differences in the performance indices of pigs were observed between treatments. During the whole experiment significant differences ($P < 0.05$) were only observed in the final BW (higher in the control group).

Discussion

The chemical composition of raw pea seeds. The nutritional composition of pea seeds shows a great variability depending on the cultivar conditions and plant breeds. In the present study the CP content of pea seeds var. Tarchalska was 231 $g \cdot kg^{-1}$ DM. This value is in line with values reported by Stein et al. (2006, 2010), and somewhat higher than that reported by Alonso et al. (1998), but lower than that presented by Jezierny et al. (2010). The NDF and ADF levels were 158 $g \cdot kg^{-1}$ DM and 95 $g \cdot kg^{-1}$ DM, while Stein et al. (2010) presented values 230.1 $g \cdot kg^{-1}$ and 75.7 $g \cdot kg^{-1}$ DM, respectively. The starch content in var. Tarchalska was 415.8 $g \cdot kg^{-1}$ DM, but according to Stein et al. (2010) it was 381.4 $g \cdot kg^{-1}$. The content RS was very high (approx. 16.9% in dry matter, which was approx. 40% of total starch) as compared to de Almeida Costa et al. (2006) – 2.4% of RS, and Dostálová et al. (2009) – up to 6% of RS in the seeds of different pea varieties. The higher RS content in our study can be probably connected with the method used for RS determination, and especially with different incubation time with enzymes. In our studies, the RFO content in var. Tarchalska was 80.6 $g \cdot kg^{-1}$ DM and in studies of Stein et al. (2010) it was 61.2 $g \cdot kg^{-1}$. Seeds of var. Tarchalska were characterised by low TIA activity (0.42 $mg \cdot g^{-1}$) as compared to data published by Tuśnio et al. (2017), where the TIA activity amounted up to 2.35 $mg \cdot g^{-1}$ in pea seeds var. Milwa. Great variability of other chemical compounds in pea seeds was demonstrated in studies of Alonso et al. (1998), Urbano et al. (2005) and Jezierny et al. (2010).

The extrusion effects on seeds composition. The changes in the chemical composition indicate that the extrusion improved the nutritional quality of pea seeds especially through the decrease in the level of anti-nutritional components. It significantly reduced CF, NDF, RS and phytate-P contents as well as the activity of trypsin inhibitors. Lower concentrations of these ingredients in extruded seeds were also confirmed by Masoero et al. (2005) and Hejdysz et al. (2016). The temperature used in the process influenced the activity of trypsin inhibitors and content of phytate-P as was reported by Alonso et al. (1998). These authors stated that during extrusion some molecules of inositol hexaphosphate were hydrolysed to penta-, tetra- and triphosphates. In the present research the extrusion reduced RS by 89% in comparison to raw seeds. As previously stated by Hejdysz et al. (2016) the main objective of extrusion is to achieve a high level of starch gelatinisation and disruption of the grain structure. After this process, starch crystallinity is lost and the substrate accessibility to enzymes is greater.

The total tract and ileal digestibility of nutrients. The apparent ileal and total tract digestibility was in a small degree modified by the extrusion. Some AA (Asp, Glu and Cys) were better digested in the ileum, but CP digestibility was slightly affected (1 percentage point, $P > 0.05$). Only CP total tract digestibility enhanced from 75% for raw pea to 80% for extruded var. Tarchalska pea seeds, which can be a result of decreased RS influx in the hind gut. Probably, the low TIA value is also related to the lack of in difference in ileal digestibility of protein, however it is difficult to confirm it clearly. The negative relationships between TIA and ileal digestibility of protein or AA in pea seeds samples were observed by Gdala et al. (1992), but Fan et al. (1994) did not find this kind of relationship, probably due to the small range of TIA in examined pea samples. On the other hand, Stein and Bohlke (2007) observed that the ileal digestibility of starch, CP, AA and energy increased after extrusion. The differences may resulted from process conditions (temperature, time) and also chemical composition of peas and diets.

Performance indices of pigs. In the Experiment 1, the introduction of raw or extruded pea seeds var. Tarchalska into diets for weaners in the proportion of the 25% of pea seeds and 75% of basal diet, had no significant influence on BWG and FCR in comparison to the control group. These growth performance results are only partially useful since diets were different in nutritional values (digestibility experiment). It was shown that pea extrusion did not improve pigs performance, but even the amount of 25% of pea in the diet did not reduce pig performance in comparison to that of the reference diet.

In the Experiment 2, where SBM was replaced by combination of pea seeds and RSM, the effect of both extrusion and diet on pig performance was analysed. The tested diets (with raw or extruded seeds) in the grower period (24% of pea seeds and 15% of RSM) negatively affected FCR and BWG. The probable reason for this negative effect in production results could be the unbalanced standardized ileal digestibility AA pattern in the grower diets. In the finisher period the diet containing pea seeds and RSM (14 and 10%, respectively) did not affect pig performance. Furthermore, no significant influence of diets used on the pig performance was recorded during the entire experiment, except final body weight, which was higher in the group receiving SBM. In addition, in other studies it was demonstrated that the inclusion of pea seeds into piglet diets (up to 18%) and into growing or finishing pigs diets (up to 36%) had no negative influence on their performance and carcass composition (Stein et al., 2006, 2010). On the other hand, Stein et al. (2006) found that the increase of raw pea seeds content in diets for young pigs (from 10 to 60%) contributed to linear reduction of body weight gains. In older animals the amount of pea in the diet did not have any impact on FCR. The reaction of the pigs fed raw or extruded peas was similar. Prandini et al. (2005) and Stein et al. (2010) did not observe any differences in the growth rate in pigs fed diets containing raw or extruded leguminous seeds. In contrast, Tuśnio et al. (2017) found that diets with extruded pea seeds can improve the growth performance of pigs, but this research was conducted on piglets more sensitive to antinutritional substances present in pea seeds. It is also possible that the presence of RSM in the diet (15 and 10% in the grower and finisher diets, respectively) limited the positive impact of extrusion.

Conclusions

Extrusion significantly influenced chemical composition of pea seeds by decreasing the contents of phytate-P and resistant starch, and activity of trypsin inhibitor in seeds, and thus positively influenced apparent ileal digestibility of some amino acids and apparent total tract digestibility of crude protein. However, it did not positively affect pig growth performance. So, it can be stated that the field peas with rapeseed meal may replace soyabean meal in the diets of growing and finishing pigs without any negative effect on pig performance.

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