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EFFECT OF EXTRUSION ON NUTRIENTS DIGESTIBILITY, METABOLIZABLE ENERGY AND NUTRITIONAL VALUE OF YELLOW LUPINE SEEDS FOR BROILER CHICKENS*

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Abstract

The aim of investigations was the estimation of nutritional value of currently cultivated yellow lupine cultivars in raw and extruded form, and their usefulness for broiler chickens. Two experiments were conducted with male Ross 308 chickens. In a digestibility trial 60 fifteen-day-old birds were randomly assigned to three dietary treatments (20 replications in each). Birds were kept in individual pens. Digestibility was calculated using the difference method. From day 16 to 21, diets contained lupine meal in raw or extruded form and the basal diet in the ratio 20:80. Subsequently, the total digestibility of dry matter and crude fat, also apparent nitrogen retention and AME_N value of lupine seeds were determined on chickens fed different forms of lupine. The ileal digestibility of crude protein and amino acids of lupine seeds was also analyzed. In the second experiment the one-day-old birds were randomly assigned to ten dietary treatments (10 replications in each) and were fed diets with increasing amounts of raw or extruded lupine from 10 to 30%. The chickens in control treatments were fed a diet without lupine. Extruded yellow lupine meal was characterized by lower phytic P content in comparison to raw yellow lupine meal. The content of remaining ingredients and antinutritional substances was similar. Yellow lupine seeds post extrusion were characterized by better total crude fat digestibility, nitrogen retention and AME_N values, compared to raw seeds. Higher ileal digestibility was confirmed in numerous amino acids, except lysine, threonine and valine ($P \leq 0.05$). By feeding the broilers with diets consisting of 10 to 30% of lupine seeds post extrusion (experiment II), improved apparent fat digestibility, apparent nitrogen retention and AME_N values were achieved in young chickens ($P<0.01$). Using 10 and 20% of lupine in the diets showed significant positive effects of extrusion on body weight gains, feed intake and feed conversion rate. The performance indices of chickens were drastically decreased by use of 25% ratio of both raw and extruded yellow lupine in the diet. This effect was heightened by a 30% share in feed mixtures.

Key words: broiler chickens, lupine, extrusion, digestibility

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Legume seeds are an important protein source for humans and animals in many countries. Yellow lupine protein is rich in lysine, but it is deficient in sulfur-containing amino acids and leucine (Sujak et al., 2006). Lupine seeds are rich in crude fat ~5–9%, but also the content of dietary fiber is relatively high (Gdala, 1998; Zalewski et al., 2001; Zduńczyk et al., 2014; Krawczyk et al., 2015; Kaczmarek et al., 2016). Legume seeds, including lupines, are also rich in microelements, e.g., Mn, Zn, Cu (Wasilewko and Buraczewska, 1999) and antioxidants – selenium and tocopherol (Erbaş et al., 2005).

In the past, the use of yellow lupine (*Lupinus luteus*) as a valuable source of protein for poultry was limited due to high alkaloid and non-starch polysaccharide (NSP) contents that negatively affect growth, feed intake and nutrient utilization (Kluge et al., 2002; Olkowski et al., 2005). Current yellow lupine cultivars are characterized by low concentrations of alkaloids, but they still contain other anti-nutritional factors, which can reduce nutrient digestibility. The main lupine anti-nutritional factors are: α-galactosides (Gdala, 1998; Zalewski et al., 2001), proteases and α-amylase inhibitors (Erbaş et al, 2005; Guillamon et al., 2008), saponins, quinolizidine alkaloids (Wasilewko and Buraczewska, 1999; Mańczak et al., 2007), glycosides, phytates (Jul et al., 2003). According to some researchers quinolizidine and indole alkaloids and raffinose content depends on lupine species and variety (Smulikowska et al., 1999; Wasilewko and Buraczewska, 1999; Kaczmarek et al., 2014; Rutkowski et al., 2015). According to available literature data (Orda et al., 2006; Rutkowski et al., 2015), it has been shown that yellow lupine can be a beneficial component of poultry diets.

The nutritive value of seeds can be efficiently improved by extrusion (Leontowicz et al., 2001; Kiczorowska and Lipiec, 2002 a, b). The extrusion process reduces the activity of thermolabile harmful substances, decreases the negative action of oligosaccharides and protease inhibitors, and can inactivate pathogens (Guillamon et al., 2008; Nalle, 2009). Additionally, according to Alonso et al. (2000) extrusion decreases phytic P content in seeds because some molecules of inositol hexaphosphate are hydrolyzed to penta-, tetra- and triphosphates. However, the effect of extrusion on the nutritive value of yellow lupine is not well understood. Moreover, there is no comparative information on the influence of extrusion on the nutritive value of yellow lupine and broiler chickens performance.

The objective of this study was to determine AME_N and digestibility of selected nutrients of raw and extruded yellow lupine seeds and compare the effects of the use of different amounts of raw or extruded yellow lupine seeds in place of soya bean meal in broiler diets.

Material and methods

All procedures used in the experiment were accepted by the Local Ethics Commission with respect to animal experimentation.

Lupine seed and processing

Raw or extruded yellow lupine (*Lupinus luteus*) cv. Mister seeds harvested in 2014 were used. Seeds were extruded with KNZ 2 extruder (Russia) (500 kg/h), at temperature 135±10°C, pressure 30 kg/m^2, cylinder speed 1000 rotations per minute. Seeds were analyzed for basal nutrients, amino acids and anti-nutritive substances (Table 1).

Table 1. Chemical composition of raw and extruded yellow lupine seeds var. Mister

Item	Lupine seeds	
	raw	extruded
Dry matter (%)	89.01	89.35
Crude ash (% DM)	4.15	4.14
Crude protein (% DM)	38.98	39.12
Crude fiber (% DM)	19.23	19.18
ADF (% DM)	24.24	23.96
NDF (% DM)	28.24	28.41
Crude fat (% DM)	5.26	5.42
Gross Energy (MJ/kg DM)	20.49	20.55
WEV (cP)	1.09	1.17
Amino acid (g/16 g N)		
Asp	8.81	8.64
Thr	3.17	3.21
Ser	4.24	4.34
Glu	24.46	24.05
Pro	6.08	6.16
Gly	3.47	3.52
Ala	2.83	2.85
Val	3.17	3.26
Ile	3.20	3.28
Leu	6.50	6.52
Tyr	3.24	3.18
Phe	4.24	4.17
His	3.32	3.22
Lys	4.76	4.81
Arg	10.12	10.30
Anti-nutrients in DM		
Total alkaloids (mg/kg)	27.0	28.0
Lupinine, in total alkaloids (%)	63.29	64.58
Sparteine, in total alkaloids (%)	33.6	34.1
Ammodendrine, in total alkaloids (%)	3.12	3.18
Oligosaccharides (%)	8.57	8.61
Raffinose (%)	1.10	1.14
Stachyose (%)	4.94	4.97
Verbascose (%)	2.53	2.50
P phyt. (%)	0.70	0.59
P phyt./P total	75	63

WEV – water extract viscosity.

Bird management and sample collection

Experiment 1

The experiment was conducted on sixty 16-day-old Ross 308 male chickens, reared in the first days of life in pens and fed basal diets (BD) (Table 2). At day 16 of age the birds were randomly allocated to individual pens and assigned to three dietary treatments, each with 20 replications. Chickens in control treatment were fed BD, in treatment 2 with 80% BD + 20% raw lupine, and in treatment 3 with 80% BD + 20% of extruded lupine. For the determination of total or ileal digestibility as well as AME_N, 3 g/kg of titanium dioxide was included into diets as a non-absorbable marker. The difference method for the digestibility calculation was used (Hejdysz et al., 2015). All diets were offered *ad libitum* in mash form.

Table 2. Composition of basal diet, % (Experiment 1)

Components	g/kg^{-1}
Maize	600.0
Soya bean meal	293.5
Soya oil	41.6
Fish meal	29.4
Monocalcium phosphate	10.3
Limestone	5.1
Premix[1]	10.0
NaCl	2.0
$NaHCO_3$	0.1
DL-methionine	2.7
L-lysine	1.7
L-threonine	0.6
TiO_2	3.0
Calculated	
Metabolizable energy (MJ/kg)	12.5
Analyzed	
Crude protein (g/kg^{-1})	212

[1]provides per kg diet: IU: vit. A – 11250, cholecalciferol – 2500; mg: vit. E – 80, menadione – 2.50, vit. B_{12} – 0.02, folic acid – 1.17, choline – 379, D-pantothenic acid – 12.5, riboflavin – 7.0, niacin – 41.67, thiamin – 2.17, D-biotin – 0.18, pyridoxine – 4.0, ethoxyquin – 0.09, Mn – 73, Zn – 55, Fe – 45, Cu – 20, I – 0.62, Se – 0.3, salinomycin – 60; g: Ca – 3.8.

For purposes of acclimatization, during five days, birds were fed experimental diets. On days 19 and 20 of age, excreta were individually collected, daily, and immediately frozen for analyses (n=20/treatment). On day 21 of age, all chickens from each group were sacrificed by cervical dislocation and their ileum removed. Digesta were flushed from the terminal ileum (15 cm, adjacent to the ileocecal junction) and pooled (4 birds/sample) to provide sufficient material for chemical analyses (n=5).

Table 3. Composition of starter and grower diets, g/kg^{-1} (Experiment 2)

Component	Starter					Grower				
	L30	L25	L20	L10	C	L30	L25	L20	L10	C
Maize (9.4)[1]	333.6	372.7	380.1	389.5	395.0	305.4	343.3	356.6	361.5	367.2
Yellow lupine (37.8)[1]	300.0	250.0	200.0	100.0	-	300.0	250.0	200.0	100.0	-
Wheat (11.8)[1]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Soya oil	75.0	66.0	66.0	60.0	56.0	100.0	92.0	87.0	85.0	81.0
Soya bean meal (41.7)[1]	-	50.0	100.0	200.0	300.0	-	50.0	100.0	200.0	300.0
Rapeseed meal (34.9)[1]	50.0	40.0	40.0	40.0	40.0	50.0	40.0	40.0	40.0	40.0
DDGS (36)[1]	50.0	40.0	40.0	40.0	40.0	50.0	40.0	40.0	40.0	40.0
Pea (22.6)[1]	50.0	40.0	40.0	40.0	40.0	50.0	40.0	40.0	40.0	40.0
Limestone (<2mm)	6.2	6.2	-	-	-	6.2	6.2	-	-	-
Monocalcium phosphate	13.1	13.2	13.2	12.5	12.5	13.2	13.3	13.2	12.5	12.5
Premix[2]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
$NaHCO_3$	3.1	3.2	3.2	2.5	2.2	3.6	3.7	3.7	3.2	2.5
NaCl	0.5	0.6	0.7	1.2	1.5	0.4	0.6	0.6	1.0	1.5
L-lysine HCL	4.1	3.8	3.4	2.3	1.2	3.5	3.3	2.8	1.7	0.6
DL-methionine	1.9	1.9	1.9	1.7	1.6	2.0	2.0	2.0	1.8	1.7
L-threonine	1.2	1.1	0.9	0.3	-	1.3	1.2	1.0	0.3	-
L-valine	1.3	1.3	0.6	-	-	1.4	1.4	0.9	-	-
TiO_2	-					3.0	3.0	3.0	3.0	3.0
Calculated										
Metabolizable energy (MJ/kg)	12.2	12.2	12.3	12.1	12.1	12.9	12.9	13.0	12.9	12.9
Analyzed										
Crude protein (g/kg)	220	221	220	223	220	210	211	209	211	210

[1] % crude protein; [2] provides per kg diet: IU: vit. A – 11250, cholecalciferol – 2500; mg: vit. E – 80, menadione – 2.50, vit. B_{12} – 0.02, folic acid – 1.17, choline – 379, D-pantothenic acid – 12.5, riboflavin – 7.0, niacin – 41.67, thiamin – 2.17, D-biotin – 0.18, pyridoxine – 4.0, ethoxyquin – 0.09, Mn – 73, Zn – 55, Fe – 45, Cu – 20, I – 0.62, Se – 0.3, salinomycin – 60; g: C – 3.8.

Experiment 2

Eight hundred one-day-old male Ross 308 chickens of average initial weight 44.3 g were randomly assigned to ten treatments. Each treatment comprised ten replications of 8 birds each. Chickens were kept in pens (0.5 m^2, each with 8 birds) on straw litter. The environmental conditions were typical for broiler rearing; the lighting program in the first 7 days was 24 h/day, and after that 18h light: 6h darkness. Birds were reared in two identical rooms with controlled environmental conditions.

Composition of diets was shown in Table 3. Control diet was based on maize and wheat, and contained soybean meal (SBM), rapeseed meal, distilled dried grain with solubles (DDGS) and pea as protein sources. In experimental diets SBM was replaced (w/w) by growing amounts of ground yellow lupine seeds, raw or extruded (Table 3). Control diets (5 and 10) did not contain lupine seeds. Diets were isoenergetic and isonitrogenous. The chickens were fed starter (1–14 days) and grower diets (15–35 days) in mash form. Diets and water were accessible *ad libitum*. The composition of diets was calculated based on chemical analyses of feed compounds applied using simple linear optimization.

The body weight gains (BWG) of chickens and feed intake (FI) were measured for each cage after day 14 and day 35 of experiment and mortality was registered as it occurred.

In Experiment 2, to allow the digestibility to be determined, 3 g/kg titanium dioxide was included as a non-absorbable marker in diets fed during days 33 and 34 of growth experiment. The floor of each cage was covered with thick plastic foil and excreta were collected twice a day. The samples were immediately homogenized and frozen for chemical analyses (n=10) similar as in Experiment 1.

Chemical analyses

For chemical analyses, representative samples of seeds and diets were ground to pass through a 0.5 mm sieve. Raw and extruded seeds, diets, ileum digesta and excreta were analyzed in duplicate for dry matter (DM), nitrogen retention, ether extract (EE), using methods AOAC (2007) no: 934.01, 976.05, 920.39, respectively. Acid detergent fiber (ADF), and neutral detergent fiber (NDF) were analyzed only in seeds by methods 942.05, 973.18 (AOAC, 2007), respectively.

The amino acid (AA) content was determined in raw and extruded seeds, diets and ileal digesta with the assistance of an AAA-400 Automatic Amino Acid Analyzer (INGOS s.r.o., Praha, Czech Republic) using ninhydrin for post-column derivatization. Before analyses, the samples were hydrolyzed with 6NHCl for 24 h at 110°C (procedure 994.12; AOAC, 2007). Gross energy (GE) was determined in raw and extruded seeds, diets and excreta using an adiabatic bomb calorimeter (KL 12Mn, Precyzja-Bit PPHU, Poland) standardized with benzoic acid. Titanium dioxide was estimated according to Short et al. (1996) and samples were prepared in accordance with the procedure proposed by Myers et al. (2004).

In the yellow lupine samples, the raffinose family oligosaccharides (RFO) were extracted and analyzed using high-resolution gas chromatography as described previously by Zalewski et al. (2001). Phytic phosphorus was determined by extracting the sample in hydrochloric acid (0.2 M). Next, iron-ammonium sulfate was added to the centrifuged extract which was heated and then centrifuged. Bipyridine solution was added to the supernatant and absorbance was determined using spectrophotometer Media (Marcel Lamidey S.A., Châtillon, France) at 519 nm wavelength (Haug and Lantzsch, 1983). The water extract viscosity (WEV) of lupin seeds was measured *in vitro*. Prior to the determination of WEV, lupin samples were ground in a mill using a sieve with 0.5 mm mesh and then 1 g of each of the examined cultivars was mixed with 5 ml distilled water for 1 h at 40°C. The samples were centrifuged at 10 000 g for 10 min at 4°C, the supernatant was withdrawn and viscosity was determined in a Brookfield Digital DV-II+ cone/plate viscometer (Brookfield Engineering Laboratories Inc., Stoughton, MA, USA) maintained at 40°C at a shear rate of 12 · s–1. WEV units are mPas·s = cP = 1 × 100 dyne s cm^{-2}

The metabolizable energy of diets used in growth experiment was calculated on the basis of the European Tables of Energy Values of Feeds for Poultry (1989) and Smulikowska and Rutkowski (2005).

Calculations of results and statistical analysis

Experiment 1

Using crude fat (CF) calculation as an example, the following equation was used to calculate the digestibility (AID – apparent ileal digestibility and ATTD – apparent total tract digestibility) of various dietary components of the basal and experimental diets:

$$DC\ (\%) = \{1 - [(TiO_{2\%\ diet} / TiO_{2\%\ digesta/excreta}) \times (CF_{\%digesta/excreta} / CF_{\%\ diet})]\}$$

The following equation was used to calculate the digestibility coefficients of various dietary components and the AME_N level of lupine seeds:

$$DC_{CF} = (DC_{CFdiet} \times C_{CFdiet} – DC_{CFbasal} \times C_{CF\ basal} \times 0.20) / (C_{CFdiet} – C_{CFbasal} \times 0.20)$$

where:

DC_{CF} = digestibility coefficient of CF,
DC_{diet} = digestibility coefficient CF in diet,
C_{diet}= concentration of CF in diet,
DC_{basal} = digestibility coefficient CF in basal diet,
C_{basal} = concentration of CF in diet.

AME_N of all basal and experimental diets was calculated using the above equations and was corrected to zero nitrogen balance using 34.4 kJ/g N retained (Hill and Anderson, 1958).

All data had been previously explored to discard any possible outliers. Analyses were performed using the appropriate procedures of SAS Software (2009) (distribution analyses; outliers were defined as observations whose distance to the location estimate exceeded 3 times the standard deviation). The obtained results were subjected to the T test, at the level of P<0.05.

Experiment 2

The apparent digestibility of nutrients and apparent metabolizable energy value of diets were determined by the classical method. AME_N was corrected to zero nitrogen balance using 34.4 kJ/g N retained (Hill and Anderson, 1958)

Statistical calculations were conducted with the assistance of the SAS® v.9.1 package (2009). Differences between treatments and experimental factors were determined by employing the two-way linear model of ANOVA:

$$Y_{ijk} = \alpha_j + \beta_k + (\alpha\beta)_{jk} + e_{ijk}$$

where:

Y_{ijk} is the value of the analyzed trait,
α_j is the constant effect of the ith lupine seed,
β_k is the constant effect of the extrusion,
$(\alpha\beta)_{jk}$ is the interaction between α and β,
e_{ijk} is the effect of experimental error.

Means from experiments were compared using the Duncan's test and the significance of differences was assumed to be at the level of $P \leq 0.05$.

Results

Experiment 1

The chemical composition of raw or extruded seeds of yellow lupine (Mister cv.) was shown in Table 1. Raw seeds have 39% protein and 0.027 g/kg of alkaloids. Extrusion slightly changed the content of basic nutrients, amino acids and anti-nutritive substances (not confirmed statistically) and reduced the content of phytic phosphorus in seeds from 0.7 to 0.59 % (Table 1). It should be stressed that measurements were performed in two replications per sample and were not elaborated statistically.

Table 4. Coefficients of apparent total tract digestibility (ATTD) of dry matter, crude fat, nitrogen retention and, AME_N value and AME_N/GE of raw and extruded yellow lupine seeds (Experiment 1)

Item	Lupine seeds		SEM	P-value
	raw	extruded		
Dry matter ATTD	0.632	0.649	0.011	0.071
Crude fat ATTD	0.767 B	0.910 A	0.013	<0.001
Nitrogen retention ATTD	0.481 b	0.565 a	0.036	0.021
AME_N (MJ/kg)	9.53 B	10.64 A	0.14	<0.001
AME_N/GE (%)	53 B	57 A	0.080	<0.001

a, b, A, B – within main effects means in columns with different superscripts differ significantly at: a, b – P<0.05, A, B – P<0.01.

Extrusion improved total tract and ileal fat digestibility (P<0.001) and the apparent metabolizable energy value of lupine seeds (Table 4). Also, apparent nitrogen retention in birds fed diets with extruded lupine was higher (P<0.05), compared to diets containing raw seeds. Birds fed yellow lupine seeds in extruded form had better ileal digestibility of crude protein and all analyzed AAs, except Lys, Thr and Val and also crude fat (Table 5).

Table 5. Coefficients of apparent ileal digestibility of crude protein, crude fat and amino acids from yellow lupine seeds (Experiment 1)

Coefficients	Lupine seeds		SEM	P-value
	raw	extruded		
Crude protein	0.701 B	0.819 A	0.027	0.004
Crude fat	0.712 B	0.843 A	0.027	0.001
Asp	0.838	0.812	0.016	0.087
Thr	0.719	0.758	0.028	0.283
Ser	0.722 b	0.804 a	0.026	0.015
Glu	0.703 B	0.892 A	0.024	<0.001
Pro	0.761	0.789	0.024	0.333
Gly	0.876 A	0.778 B	0.017	0.001
Ala	0.758 B	0.813 A	0.024	0.047
Val	0.802	0.794	0.022	0.704
Iso	0.782 b	0.832 a	0.022	0.047
Leu	0.603 A	0.796 B	0.026	<0.001
Tyr	0.622 a	0.798 b	0.023	<0.001
Phe	0.858 a	0.821 b	0.016	0.045
His	0.822 A	0.602 B	0.020	<0.001
Lys	0.661	0.649	0.014	0.988

a, b, A, B – within main effects means in columns with different superscripts differ significantly at: a, b – P<0.05, A, B – P<0.01.

Experiment 2

Extrusion of yellow lupine seeds showed a positive effect on apparent nitrogen retention. Moreover, there was clear negative effect of dietary level of yellow lupine seeds on value of this parameter (Table 6). Applying 20, 25 and 30% of seeds in diets decreased the apparent nitrogen retention (P<0.01) (Table 6). The highest crude fat digestibility was noted for treatments fed diet with 10% of yellow lupine seeds inclusion (P<0.05). In general, the extrusion significantly (P<0.01) improved the total fat digestibility. The AME_N value of the diets was significantly affected by lupine level. A high ratio of raw lupine (20–30%) clearly decreased the AME_N value of the diets used, the extrusion of lupine seed improved AME_N by 0.28 MJ/kg (P≤0.0001).

The health status of chickens was very good, culls and mortality were very low (2%). Significant (P<0.01) differences in performance indices among treatments and also for experimental factors were noted (Table 7). The highest level of yellow lupine affected negatively (P<0.01) the BWG. Inclusion of 30% of raw or extruded lupine caused a depression in feed consumption and also, in growth which was especially pronounced in chickens fed diets with raw lupine seeds. The feed conversion ratio in chickens was relatively similar (1.67–1.70 kg/kg) at all dietary lupine levels. An exception was noted for chickens fed diets with 25% of raw seeds (1.76–1.86) and when 30% of extruded lupine was incorporated into the diet (2.01 kg/kg BWG). Baro-thermal processing of lupine seed significantly decreased the feed intake and in consequence – also influenced the FCR for day 15–35 and 0–35 periods. Interactions between lupine levels and extrusion effects were significant for feed intake and FCR.

Table 6. Coefficients of total tract apparent nitrogen retention, fat digestibility and apparent metabolizable energy value of diets (MJ/kg) (Experiment 2)

Treatment	Yellow lupine %	Extrusion	Nitrogen retention	Crude fat digestibility	AME_N
1	30	-	0.565	0.893 D	13.64 B
2	25	-	0.586	0.887 D	13.62 B
3	20	-	0.608	0.896 D	13.76 B
4	10	-	0.643	0.914 BC	14.47 A
5,10	0	-	0.634	0.920 AB	14.45 A
6	30	+	0.630	0.933 A	14.44 A
7	25	+	0.652	0.916 ABC	14.45 A
8	20	+	0.634	0.921 AB	14.19 A
9	10	+	0.662	0.929 AB	14.44 A
SEM			0.004	0.001	0.13
P-value			<0.001	<0.001	<0.001
Lupine level (L)	30		0.598 C	0.911 B	14.04 B
	25		0.619 BC	0.902 C	14.04 B
	20		0.621 BC	0.908 BC	13.98 B
	10		0.652 A	0.920 A	14.46 A
	0		0.634 AB	0.914 AB	14.45 A
Extrusion effect (E)		-	0.612 B	0.903 B	13.98 B
		+	0.645 A	0.923 A	14.26 A
P – level for					
L			<0.001	<0.001	<0.001
E			<0.001	<0.001	<0.001
Interaction L × E			0.147	0.029	<0.001

a, b, A, B – within main effects means in columns with different superscripts differ significantly at: a, b – P<0.05, A, B – P<0.01.

Table 7. Performance of broiler chickens (Experiment 2)

Treatments	Content of yellow lupine	Extrusion	BWG (g)			FI (g)			FCR		
			0–14d	15–35	0–35	0–14d	15–35	0–35	0–14d	15–35	0–35
1	30	-	185 F	1272	1459	381	2061 C	2442 C	2.07 A	1.62 D	1.67 D
2	25	-	291 E	1511	1802	465	2879 A	3344 A	1.61 B	1.90 B	1.86 B
3	20	-	336 D	1650	1985	478	2864 A	3342 A	1.43 CD	1.74 BC	1.68 CD
4	10	-	348 CD	1626	1973	470	2880 A	3350 A	1.36 DE	1.77 BC	1.70 CD
5,10	0	-	347 CD	1626	1973	480	2857 A	3336 A	1.39 CDE	1.76 BC	1.69 CD
6	30	+	281 E	1313	1596	435	2767 B	3202 B	1.54 BC	2.10 A	2.01 A
7	25	+	371 BC	1531	1902	507	2836 AB	3342 A	1.37 DE	1.85 B	1.76 BC
8	20	+	389 AB	1617	2005	509	2830 AB	3339 A	1.31 DE	1.75 BC	1.67 CD
9	10	+	410 A	1613	2022	520	2884 A	3405 A	1.27 E	1.79 BC	1.68 CD
SEM			6.85	16.01	21.29	5.76	27.52	30.78	0.02	0.02	0.01
P-value			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lupine level											
	30		233 D	1292 C	1527 C	408 B	2414 B	2822 B	1.80 A	1.87 A	1.85 A
	25		331 C	1521 B	1852 B	486 A	2858 A	3343 A	1.49 B	1.88 A	1.81 A
	20		362 AB	1633 A	1995 A	493 A	2847 A	3340 A	1.36 C	1.74 B	1.67 B
	10		379 A	1619 A	1998 A	495 A	2883 A	3377 A	1.32 C	1.78 B	1.69 B
	0		349 BC	1604 A	1952 A	480 A	2857 A	3337 A	1.39 C	1.78 B	1.71 B
Extrusion effect		-	301 B	1537	1838	455 B	2708 B	3162 B	1.57 A	1.76 B	1.72 B
		+	363 A	1518	1881	493 A	2829 A	3246 A	1.37 B	1.87 A	1.78 A
P-values											
Lupine level			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.039	<0.001
Extrusion effect			<0.001	0.879	0.057	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Interaction			0.130	0.689	0.439	0.842	<0.001	<0.001	<0.001	<0.001	<0.001

a, b, A, B – within main effects means in columns with different superscripts differ significantly at: a, b – $P<0.05$, A, B – $P<0.01$.

Discussion

Some harmful factors of legume seeds such as the proteases – trypsin and chymotrypsin inhibitors, lectins, oligosaccharides – are sensitive to thermal or baro-thermal processing such as toasting, granulation, extrusion, boiling and also micronization. Through such preparation a decrease in their activity or anti-nutritive properties may be obtained (Leontowicz et al., 2001; Kiczorowska and Lipiec, 2002 a; Kiczorowska et al., 2002 b). In the present investigations, extrusion of yellow lupine seeds to a limited degree changed the chemical composition of seeds. Very small differences in amino acid content between extruded and raw lupine seed were found. A decrease in phytic phosphorus levels was obtained. It confirms the finding by Alonso et al. (2000), who explained that during extrusion some molecules of inositol hexaphosphate were hydrolyzed to penta-, tetra- and triphosphates; therefore, the level of phytic P in seeds after extrusion was lower. A similar result was confirmed in our earlier study for faba bean and pea (Hejdysz et al., 2016 a, b).

Nevertheless, the apparent nitrogen retention, total digestibility of fat and the AME_N value of lupine seeds determined in young chicken show a significant beneficial effect of extrusion of yellow lupine. Also significantly better ileal digestibility of protein and some amino acids from extruded seeds was found in comparison to raw lupine seeds. A similar beneficial effect of extrusion in terms of protein digestibility in rats was reported by Leontowicz et al. (2001).

Increased levels of lupine seeds in broiler diets, both raw or extruded seeds, led to numerous significant differences among treatments. Using 10 to 30% of lupine, the apparent nitrogen retention, fat digestibility and AME_N value of diets was significantly better in birds fed diets with extruded lupine, while apparent nitrogen retention (63–66% of N intake), fat digestibility (about 92%) and AME_N value (14.19–14.44 MJ/kg) were relatively similar in these treatments.

By the addition of 10 and 20% of lupine in diets, positive effects of extrusion were noted for BWG, FI and feed conversion ratio. Use of 25%, especially 30% of lupine, decreased the performance indices. Extrusion to a limited degree decreased the negative action of large amounts of lupine seeds on broiler growth.

The obtained performance results are in agreement with the experiments of other authors (Leontowicz et al., 2001; Orda et al., 2006). The use of raw as well as extruded yellow lupine seeds at 10 to 20% of the diet, can be expected to lead to a beneficial effect. However, with higher levels (25%) of these seeds in broiler diets the baro-thermal processing of lupine may be beneficial.

The poorer performance results registered for feeding 30% and also 25% of raw as well as extruded yellow lupine seeds indicate that such levels of these legume seeds are too high for young broiler chickens. However, the introduction of 25% of extruded yellow lupine made it possible to obtain better results than with raw seeds. The use of 10 or 20% of raw or extruded lupine in the broiler diets resulted in similar effects in terms of growth and feed conversion, compared to the diet that included soybean meal as a main protein source.

Conclusions

The extrusion process increased the price of lupine seeds, as a result of the energy costs involved in baro-thermal processing, but it could be beneficial when high yellow lupine meal inclusion is applied. The diet containing 10 or 20% of raw and extruded yellow lupine allows obtaining similar results as in control.

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