Journal of Agricultural Science and Technology A 9 (2019) 351-363
doi: 10.17265/2161-6256/2019.06.004

The Nutritional Value of Yellow Lupine (*Lupinus luteus*) for Growing Pigs

Anita Zaworska-Zakrzewska, Małgorzata Kasprowicz-Potocka, Piotr Nowak, Zuzanna Wiśniewska and Andrzej Rutkowski

Department of Animal Nutrition, Poznan University of Life Sciences, Poznań, Wołyńska 33, 60-637, Poland

Abstract: The aim of the study was a comparison of the composition and apparent total tract digestibility (ATTD) of nutrients in the seeds of two varieties of yellow lupine (YL). Moreover, an examination of the level of soybean meal (SBM) substitution by YL meal and in a combination with rapeseed meal (RSM) on the pigs' performance was performed. In a digestibility trial, 30 male pigs were tested using a marker method. In two growth experiments, 60 pigs (in each) were fed diets where SBM was replaced by YL in 0%, 20%, 40%, 60%, 80% and 100% or by a mixture of RSM and YL or by both these components. The chemical composition of varieties differed among crude protein (CP), fiber, acid detergent fiber (ADF), neutral detergent fiber (NDF) and fat. The digestibility coefficients of protein, fat and gross energy were similar for both varieties. The substitution of SBM with YL did not negatively affect the pigs' performance. A mixture of RSM with YL had no negative effect on growth parameters, except for the starter phase, when a level of above 15% RSM in the diet reduced the pigs' gains. In conclusion, YL alone and with RSM may be a sustainable alternative to SBM in pig nutrition.

Key words: Alternative protein source, chemical composition, digestibility, growth, pig, yellow lupine.

1. Introduction

In recent decades, the usage of soybean meal (SBM) as a main component of feedstuff has become a type of foundation in animal nutrition. As an unmatched source of protein, SBM is difficult to replace. However, under certain circumstances, for instance public pressure regarding the utilization of non-genetically modified organisms (non-GMO) components in animal feedstuff or searching for less expensive, native substitutes of SBM, there is an obligation to use a new vegetable protein.

A promising solution may be the usage of legume seeds—in the past it has almost been excluded from animal nutrition in relation to its high anti-nutritional factors. The progress in plant breeding allowed for a reduction of the alkaloid content in seeds. From cultivated lupine species, yellow lupine (YL) (*Lupinus luteus* L.) stands out from other species with a higher protein content similar to SBM, but despite numerous nutritional benefits it is less often cultivated due to the greater susceptibility to anthracnose [1-3]; In comparison with narrow-leafed lupine, YL also contains lower amounts of crude fiber (CF) but a higher level of oligosaccharides and phytate [3, 4]. Nevertheless, as reported by Martinez-Villaluenga *et al*. [5] and Kasprowicz-Potocka *et al*. [6] nutritional substance content in lupines and plant condition depends on their variety and cultivating conditions. Therefore, the values among varieties may differ significantly. Some researchers have found that Australian YL seeds could be included up to 15% in weaner diets and up to 30% in the diet of Grower and Finisher pigs without compromising pig performance [7]. This is not fully recognized for new lupine varieties in Europe, especially in the context of replacing SBM in pigs' diets. The replacement of up to 100% of SBM in diets with narrow-leafed lupine seeds (var. Sonet) did not have a negative effect on the fattener performance but negatively affected the

Corresponding author: Małgorzata Kasprowicz-Potocka, Ph.D., research fields: animal nutrition and bioprocess engineering.

weaner results [8]. Lupine seeds are a poor source of sulphur amino acids, so it is optimistic to use these seeds in combination with rapeseed meal (RSM), which is the main by-product of the oilseed rape processing and is rich in methionine and cystine. On the other side, rapeseed can contain glucosinolates that could negatively impact the animals' results, but in the Polish species these substances were reduced below 15 μmol/g. Despite this, the substitution of SBM by a combination of narrow-leafed lupine and RSM significantly reduced the performance of growing and finishing pigs [8]. In the study hypothesized that because of the higher protein and energy content and better digestibility of the nutrients, YL seeds and also seeds in combination with RSM can be used as a total replacement of SBM in all pig groups.

The aim of the present investigation was: (1) a comparison of the nutrient composition and apparent total tract digestibility (ATTD) of nutrients in the seeds of two new varieties of YL; (2) an examination of the level of SBM substitution by YL seeds in diets for pigs without compromising growth; (3) replacing SBM in diets of growing and finishing pigs with a combination of YL seeds and RSM.

2. Materials and Methods

2.1 Lupine Seeds

Two cultivars of YL seeds (*L. luteus* L.) were harvested in 2012: Lord and Mister, registered 2006 and 2003, respectively. Seeds were obtained from the plant breeding stations in Przebedowo and Wiatrowo (both Poland).

2.2 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, but there was no necessity to provide ethical approval. Pigs received the necessary veterinary vaccinations and had unlimited access to water and feed.

2.3 Experiment I

The digestibility experiment was conducted on 30 male pigs of about 25 kg body mass (BM) (Naima × (Pietrain × Duroc)). Before starting the experiment, animals were housed on straw, which was withdrawn before starting the experiment. The pigs were randomly assigned to three dietary treatments (10 replications in each) and kept in individual cages.

The crude protein (CP) content in the basal diet was approx. 183 g/kg and calculated metabolisable energy (ME) approx. 12.6 MJ/kg of diet. The control pigs were fed the basal diet (Table 1). For the remaining two treatments, the basal diet was mixed at a ratio of 75:25 (*w*/*w*) with the different ground lupine seeds (var. Lord and Mister, respectively). The chemical composition of all diets was analyzed (Table 2).

Table 1 Basal diet composition.

Components	%
Wheat meal	47.87
Corn meal	26.00
Soybean meal (SBM)	23.00
Monocalcium phosphate	1.0
Limestone	1.5
NaCl	0.3
Mineral premix[a]	0.3
Vitamin premix[b]	0.03
Nutritional value	
Crude protein (CP) (g/kg)	183
Lysine (g/kg)	9.3
Methionine (g/kg)	3.0
Threonine (g/kg)	6.4
Tryptophan (g/kg)	2.1
Ca (g/kg)	8.4
P (g/kg)	6.3
Calculated metabolisable energy (ME) (MJ/kg)	12.6

[a] Provided per kg diet: Ca, 0.705 g; Fe, 180 mg; Cu, 30 mg; Co, 1.2 mg; Mn, 120 mg; Zn, 180 mg; I, 2.4 mg; Se, 0.6 mg.

[b] Provided per kg diet: Ca, 0.017 g; vitamin A, 15,000 IU; vitamin D3, 1,500 IU; vitamin E, 45 mg; vitamin K3, 1.5 mg; vitamin B1, 2.25 mg; vitamin B2, 4.5 mg; nicotinic acid, 22.5 mg; vitamin B6, 3.0 mg; pantothenic acid, 1.08 mg; vitamin B12, 30 μg; biotin, 75 μg; vitamin C, 60 mg; folic acid, 0.45 mg; antioxidant, 1.5 mg.

Table 2 Chemical composition of diets (g/kg)—Experiment I.

Diets	Dry matter (DM)	Crude ash (CA)	CP	Crude fiber (CF)	Ca	P
Basic	888.4	54.60	190.0	26.80	10.6	4.90
75% Basic + 25% seeds var. Lord	888.7	52.80	241.9	57.80	8.10	6.00
75% Basic + 25% seeds var. Mister	886.7	52.20	232.8	57.80	7.50	5.60

To allow the digestibility to be determined, 3 g/kg titanium dioxide was included as a non-absorbable marker. Fresh water and feed were provided *ad libitum* throughout the experiment. The experimental diets were fed for a 4-day adaptation period and 3 d of excreta collection. Excreta was individually collected twice per day and immediately frozen and lyophilized before analysis (n = 10). The digestibility coefficients of the component in the test feedstuffs were calculated according to Adeola [9]. The coefficients of ATTD of the components in the test feedstuffs were calculated:

$$\text{ATTD (\%)} = 100 \times [(T \times Tp) - (B \times Bp)/Ap] \quad (1)$$

where: ATTD is the digestibility coefficient of the component in the test feedstuff, %; T is the digestibility of the component in the total diet (basal diet plus the test feedstuff), %; B is the digestibility of the component in the basal diet, %; Bp is the proportion of the component in the total diet contributed by the basal diet, %; Ap is the proportion of the component in the total diet contributed by the test feedstuff, %; $Tp = Bp + Ap = 100\%$.

2.4 Experiment II

The experiment was conducted on 60 pigs (Naima × (Pi × Du)) of approx. 16.5 kg BM. The pigs were allocated by body weight (BW) and sex (5♀ and 5♂) to six dietary treatments (10 replications each) and kept in individual cages. All of the experimental diets were offered *ad libitum* in mash form. The animals from the control group were offered feed with SBM as the sole protein component in the diet (100%), whereas in the experimental groups, respectively, 20% (L20), 40% (L40), 60% (L60), 80% (L80) and 100% (L100) of SBM was replaced by YL meal (var. Mister). The protein profile was supplemented with crystal amino acids, according to the pigs' requirements [10]. The experiment lasted 105 d and was divided into three periods—Starter for 37 d, Grower for 34 d and Finisher for 34 d (Tables 3-5). At approximately 105 kg, the pigs were transported to a commercial abattoir for slaughter. Body weight gain (BWG) and feed intake (FI) were recorded, and from this, the average feed conversion ratio (FCR) was calculated.

2.5 Experiment III

The experiment was conducted on 60 pigs (Naima × (Pi × Du)) approx. 26 kg BM. The pigs were allocated by BM and sex (5♀ and 5♂) to six dietary treatments (10 replications each) and kept in individual cages. All of the diets were offered in mash form. The animals from the control group were offered feed with SBM as the sole protein component in the diet (100%), whereas in Group I, 100% of SBM was replaced in a proportion of 75:25 (*w*/*w*) with RSM and YL (var. Mister); in Group II, a proportion of 50:50 (*w*/*w*) was replaced with RSM and lupine seeds; in Group III a proportion of 25:75 (*w*/*w*) was replaced with RSM and lupine seed; in Group IV 100% of SBM was replaced by lupine seeds; in Group V 100% of SBM was replaced by RSM. The experiment lasted 83 d and was divided into three periods—Starter for 21 d, Grower for 35 d and Finisher for 29 d (Tables 6-8). The experiment was finished when animals recorded 105 kg of BM. BWG and FI were recorded and FCR was calculated.

2.6 Chemical Analysis

For chemical analysis, representative samples of seeds were ground to pass through a 0.5 mm sieve. Seeds were analyzed (n = 4) for dry matter (DM), crude ash (CA), CP, ether extract (EE), CF, acid

Table 3 The composition and nutritional value of diets Starter—Experiment II.

Components (%)	Control[a]	L20[b]	L40[c]	L60[d]	L80[e]	L100[f]
SBM (46%)	24.00	19.20	14.40	9.60	4.80	-
Yellow lupin (YL) meal	-	6.00	12.00	17.50	23.00	29.00
Triticale	72.5	71.26	69.99	69.27	68.5	67.24
Calcium phosphate	1.20	1.20	1.20	1.20	1.20	1.20
Limestone	1.30	1.30	1.30	1.30	1.30	1.30
NaCl	0.35	0.35	0.35	0.35	0.35	0.35
Premix Starter[g] (0.5%)	0.50	0.50	0.50	0.50	0.50	0.50
L-lysine (98.5%)	0.15	0.16	0.20	0.17	0.20	0.22
DL-methionine (99%)	0.00	0.00	0.02	0.04	0.07	0.08
L-tryptofane (95%)	0.00	0.00	0.01	0.02	0.02	0.04
Threonine	0.00	0.03	0.03	0.05	0.06	0.07
Nutritional value (g/kg)						
ME (MJ/kg)	13.0	12.9	13.0	12.9	12.9	12.9
CP	180.0	180.0	180.0	180.0	180.0	180.0
Ca	9.35	9.13	9.23	9.35	9.23	9.29
P	6.25	6.53	6.53	6.59	6.40	6.77

[a] Control—groups were offered feed with SBM as the sole protein component in the diet; [b] 20% (L20), [c] 40% (L40), [d] 60% (L60), [e] 80% (L80) and [f] 100% (L100) of SBM was replaced by YL meal (var. Mister); [g] Provided per kg diet: Fe, 100 mg; Cu, 160 mg; Co, 0.4 mg; Mn, 40 mg; Zn, 140 mg; I, 0.8 mg; Se, 0.2 mg; vitamin A, 12,000 IU; vitamin D3, 1,500 IU; vitamin E, 70 mg; vitamin K3, 1.5 mg; vitamin B1, 1.5 mg; vitamin B2, 4.0 mg; vitamin B6, 3.0 mg; vitamin B12, 25 µg; choline chloride, 400 mg; pantothenic acid, 10 mg; nicotinic acid, 20 mg; folic acid, 2.0 mg; biotin, 100 µg; Ca, 0.9 g; antioxidants (butylated hydroxyanisole, butylated hydroxytoluene).

Table 4 The composition and nutritional value of diets Grower—Experiment II.

Components (%)	Control[a]	L20[b]	L40[c]	L60[d]	L80[e]	L100[f]
SBM (46%)	22.00	17.60	13.20	8.80	4.40	-
YL meal	-	5.50	11.00	16.00	21.50	27.00
Triticale	74.82	73.77	72.46	71.81	70.65	69.50
Calcium phosphate	0.90	0.95	0.95	0.94	0.85	0.85
Limestone	1.30	1.20	1.30	1.30	1.40	1.40
NaCl	0.29	0.29	0.30	0.30	0.30	0.31
Premix Grower[g] (0.5%)	0.50	0.50	0.50	0.50	0.50	0.50
L-lysine (98.5%)	0.13	0.15	0.16	0.18	0.20	0.21
DL-methionine (99%)	0.00	0.02	0.03	0.05	0.08	0.09
L-tryptofane (95%)	0.01	0.01	0.03	0.04	0.04	0.06
Threonine	0.02	0.01	0.07	0.08	0.08	0.08
Nutritional value (g/kg)						
ME (MJ/kg)	13.3	13.3	13.3	13.3	13.3	13.3
CP	181.0	180.0	180.0	181.1	180.0	180.0
Ca	8.76	8.56	8.73	7.72	8.64	8.65
P	6.00	6.29	6.18	6.10	6.14	6.07

[a] Control—groups were offered feed with SBM as the sole protein component in the diet; [b] 20% (L20), [c] 40% (L40), [d] 60% (L60), [e] 80% (L80) and [f] 100% (L100) of SBM was replaced by YL meal (var. Mister); [g] Provided per kg diet: Fe, 75 mg; Cu, 20 mg; Co, 0.3 mg; Mn, 30 mg; Zn, 75 mg; I, 0.6 mg; Se, 0.15 mg; vitamin A, 7,500 IU; vitamin D3, 1,500 IU; vitamin E, 52.5 mg; vitamin K3, 1.1 mg; vitamin B1, 1.1 mg; vitamin B2, 3.0 mg; vitamin B6, 2.25 mg; choline chloride, 200 mg; pantothenic acid, 7.5 mg; nicotinic acid, 15 mg; folic acid, 1.5 mg; vitamin B12, 18.5 µg; biotin, 75 µg; Ca, 1.3 g; antioxidants (butylated hydroxyanisole, butylated hydroxytoluene).

Table 5 The composition and nutritional value of diets Finisher—Experiment II.

Components (%)	Control[a]	L20[b]	L40[c]	L60[d]	L80[e]	L100[f]
SBM (46%)	15.00	12.00	9.00	6.00	3.00	-
YL meal	-	4.00	8.00	11.50	15.00	19.00
Triticale	82.38	81.39	80.37	79.80	79.28	78.25
Calcium phosphate	0.32	0.31	0.30	0.29	0.28	0.27
Limestone	1.40	1.40	1.40	1.40	1.40	1.40
NaCl	0.22	0.24	0.23	0.24	0.23	0.24
Premix Finisher[g] (0.5%)	0.50	0.50	0.50	0.50	0.50	0.50
L-lysine (98.5%)	0.14	0.13	0.17	0.17	0.17	0.18
DL-methionine (99%)	0.00	0.00	0.00	0.03	0.05	0.06
L-tryptofane (95%)	0.02	0.02	0.03	0.03	0.04	0.05
Threonine	0.02	0.02	0.03	0.04	0.05	0.05
Nutritional value (g/kg)						
ME (MJ/kg)	13.4	13.4	13.5	13.5	13.5	13.4
CP	161.0	161.0	160.0	160.0	160.0	160.0
Ca	7.81	7.69	7.78	7.74	7.72	7.75
P	4.32	4.96	4.58	4.48	4.41	5.27

[a] Control—groups were offered feed with SBM as the sole protein component in the diet; [b] 20% (L20), [c] 40% (L40), [d] 60% (L60), [e] 80% (L80) and [f] 100% (L100) of SBM was replaced by YL meal (var. Mister); [g] Provided per kg diet: Fe, 50 mg; Cu, 20 mg; Co, 0.2 mg; Mn, 20 mg; Zn, 40 mg; I, 0.4 mg; Se, 0.1 mg; vitamin A, 5,000 IU; vitamin D3, 1,000 IU; vitamin E, 35 mg; vitamin K3, 0.75 mg; vitamin B1, 1.1 mg; vitamin B2, 2.0 mg; vitamin B6, 1.5 mg; cholinechloride, 100 mg; pantothenic acid, 5.0 mg; nicotinic acid, 10 mg; folic acid, 1.0 mg; vitamin B12, 12.5 µg; biotin, 50 µg; Ca, 1.4 g; antioxidants (butylated hydroxyanisole, butylated hydroxytoluene).

Table 6 Composition and nutrient concentration of the Starter diets in the Experiment III.

Components (%)	Control[a]	I[b]	II[c]	III[d]	IV[e]	V[f]
SBM (46%)	22.00	-	-	-	-	-
YL meal	-	7.5	15	22	28.5	-
Rapeseed meal (RSM)	-	23	15	7.5	-	31.5
Triticale	74.64	64.11	64.39	65.68	67.02	62.73
Soya oil	-	2.5	2.5	1.5	1	3
Calcium phosphate	1	0.5	0.7	0.9	1	0.4
Limestone	1.4	1.4	1.4	1.4	1.4	1.4
NaCl	0.34	0.34	0.35	0.35	0.36	0.34
Premix Starter[g] (0.5%)	0.5	0.5	0.5	0.5	0.5	0.5
L-lysine (98.5%)	0.1	0.15	0.16	0.17	0.2	0.13
DL-methionine (99%)	0.02	-	-	-	-	-
Threonine	-	-	-	-	0.02	-
Nutritional value (g/kg)						
ME (MJ/kg)	13.0	12.9	13.0	12.9	12.9	12.9
CP	180	180	180	180	180	180
Ca	9.35	9.13	9.23	9.35	9.23	9.29
P	6.25	6.53	6.53	6.59	6.4	6.77

[a] Control—groups were offered feed with SBM as the sole protein component in the diet; [b] I-100% of SBM was replaced in a proportion of 75:25 (*w*/*w*) with RSM and YL; [c] II-100% of SBM was replaced in a proportion of 50:50 (*w*/*w*) with RSM and YL; [d] III-100% of SBM was replaced in a proportion of 25:75 (*w*/*w*) with RSM and YL; [e] IV-100% of SBM was replaced by YL; [f] V-100% of SBM was replaced by RSM; [g] Provided per kg diet: Fe, 100 mg; Cu, 160 mg; Co, 0.4 mg; Mn, 40 mg; Zn, 140 mg; I, 0.8 mg; Se, 0.2 mg; vitamin A, 12,000 IU; vitamin D3, 1,500 IU; vitamin E, 70 mg; vitamin K3, 1.5 mg; vitamin B1, 1.5 mg; vitamin B2, 4.0 mg; vitamin B6, 3.0 mg; vitamin B12, 25 µg; choline chloride, 400 mg; pantothenic acid, 10 mg; nicotinic acid, 20 mg; folic acid, 2.0 mg; biotin, 100 µg; Ca, 0.9 g; antioxidants (butylated hydroxyanisole, butylated hydroxytoluene).

Table 7 Composition and nutrient concentration of the Grower diets in the Experiment III.

Components (%)	Control[a]	I[b]	II[c]	III[d]	IV[e]	V[f]
SBM (46%)	22.50	-	-	-	-	-
YL meal	-	7.5	15.3	22.5	29	-
RSM	-	23.5	15.3	7.5	-	32
Triticale	73.35	61.84	63.01	63.91	65.2	61.07
Soya oil	1	4	3.5	3	2.5	4.5
Calcium phosphate	0.9	0.4	0.55	0.7	0.9	0.1
Limestone	1.3	1.3	1.35	1.35	1.3	1.4
NaCl	0.29	0.29	0.3	0.3	0.31	0.29
Premix Grower[g] (0.5%)	0.5	0.5	0.5	0.5	0.5	0.5
L-lysine (98.5%)	0.12	0.17	0.19	0.21	0.22	0.14
DL-methionine (99%)	0.04	-	-	-	0.02	-
Threonine	-	-	-	0.03	0.05	-
Nutritional value (g/kg)						
ME (MJ/kg)	13.3	13.3	13.3	13.3	13.3	13.3
CP	181	180	180	181	180	180
Ca	8.76	8.56	8.73	8.72	8.64	8.65
P	6.00	6.29	6.18	6.10	6.14	6.07

[a] Control—groups were offered feed with SBM as the sole protein component in the diet; [b] I-100% of SBM was replaced in a proportion of 75:25 (*w/w*) with RSM and YL; [c] II-100% of SBM was replaced in a proportion of 50:50 (*w/w*) with RSM and YL; [d] III-100% of SBM was replaced in a proportion of 25:75 (*w/w*) with RSM and YL; [e] IV-100% of SBM was replaced by YL; [f] V-100% of SBM was replaced by RSM; [g] Provided per kg diet: Fe, 75 mg; Cu, 20 mg; Co, 0.3 mg; Mn, 30 mg; Zn, 75 mg; I, 0.6 mg; Se, 0.15 mg; vitamin A, 7,500 IU; vitamin D3, 1,500 IU; vitamin E, 52.5 mg; vitamin K3, 1.1 mg; vitamin B1, 1.1 mg; vitamin B2, 3.0 mg; vitamin B6, 2.25 mg; choline chloride, 200 mg; pantothenic acid, 7.5 mg; nicotinic acid, 15 mg; folic acid, 1.5 mg; vitamin B12, 18.5 µg; biotin, 75 µg; Ca, 1.3 g; antioxidants (butylated hydroxyanisole, butylated hydroxytoluene).

Table 8 Composition and nutrient concentration of the Finisher diets in the semi-practical experiment.

Components (%)	Control[a]	I[b]	II[c]	III[d]	IV[e]	V[f]
SBM (46%)	17.00	-	-	-	-	-
YL meal	-	6	11.5	17	22	-
RSM	-	18	11.5	5.5	-	24
Triticale	79.49	70.26	71.13	72.01	72.89	69.81
Soya oil	1	3.5	3.5	3	2.5	4
Calcium phosphate	0.2	-	-	0.1	0.2	-
Limestone	1.5	1.4	1.5	1.5	1.5	1.35
NaCl	0.25	0.24	0.25	0.25	0.26	0.24
Premix Finisher[g] (0.5%)	0.5	0.5	0.5	0.5	0.5	0.5
L-lysine (98.5%)	0.06	0.1	0.12	0.14	0.15	0.1
Nutritional value (g/kg)						
ME (MJ/kg)	13.4	13.4	13.5	13.5	13.5	13.4
CP	161	161	160	160	160	160
Ca	7.81	7.69	7.78	7.74	7.72	7.75
P	4.32	4.96	4.58	4.48	4.41	5.27

[a] Control—groups were offered feed with SBM as the sole protein component in the diet; [b] I-100% of SBM was replaced in a proportion of 75:25 (*w/w*) with RSM and YL; [c] II-100% of SBM was replaced in a proportion of 50:50 (*w/w*) with RSM and YL; [d] III-100% of SBM was replaced in a proportion of 25:75 (*w/w*) with RSM and YL; [e] IV-100% of SBM was replaced by YL; [f] V-100% of SBM was replaced by RSM; [g] Provided per kg diet: Fe, 50 mg; Cu, 20 mg; Co, 0.2 mg; Mn, 20 mg; Zn, 40 mg; I, 0.4 mg; Se, 0.1 mg; vitamin A, 5,000 IU; vitamin D3, 1,000 IU; vitamin E, 35 mg; vitamin K3, 0.75 mg; vitamin B1, 1.1 mg; vitamin B2, 2.0 mg; vitamin B6, 1.5 mg; choline chloride, 100 mg; pantothenic acid, 5.0 mg; nicotinic acid, 10 mg; folic acid, 1.0 mg; vitamin B12, 12.5 µg; biotin, 50 µg; Ca, 1.4 g; antioxidants (butylated hydroxyanisole, butylated hydroxytoluene).

detergent fiber (ADF), neutral detergent fiber (NDF), amino acids, calcium and phosphorus, according to AOAC [11].

Nitrogen-free extractives (NFE) were calculated:

$$NFE = DM - (CP + CA + CF + EE) \quad (2)$$

Metabolic energy was calculated according to recommendations for energy—Empfehlungen zur Energie (GfE) [10]. Titanium dioxide was determined according to Short *et al*. [12]. The samples were prepared in accordance with the procedure proposed by Myers *et al*. [13]. Lupine alkaloids were extracted from the meal with trichloroacetic acid and methylene chloride as well as determined by gas chromatography (Shimadzu GC17A) using a capillary column (Phenomenex). Raffinose family oligosaccharides (RFO) were extracted and analyzed by high-resolution gas chromatography as described previously by Zalewski *et al*. [14]. Phytate-P was determined using the method described by Haug and Lantzsch [15]. For viscosity determination, 1 g samples of lupine meal were incubated with 5 mL of water by 30 min at 30 °C and centrifuged at 10,000 *g* for 10 min at 4 °C. The supernatant was withdrawn, and the viscosity was determined in a Brookfield Digital DV-II + cone/plate viscometer (Brookfield Engineering Laboratories, Stoughton, MA, USA) maintained at 30 °C at a shear rate of 60/s. Viscosity units are mPas × s = cP.

2.7 Statistical Analysis

Statistical analysis was conducted using the SAS Enterprise Guide 9.1 (USA) computer program. The data were analyzed employing one-way analysis of variance, and the differences among the means were compared by high-range statistical domain at $p < 0.05$ using Duncan's test. The significance of the differences between the two groups was calculated using the Student's *t*-test at $p < 0.05$.

3. Results

The chemical composition of YL seeds varied within broad limits (Table 9). The protein content was higher and fat content lower in seeds var. Lord than Mister. The content of ash, phytate and level of viscosity and calculated metabolic energy were similar. Fiber participation in DM reached 192.3 g/kg in seeds var. Mister and 209.1 g/kg in seeds var. Lord. Seeds of var. Mister were characterized by higher ADF, NDF and NFE content in comparison with Lord. The amino acid content was slightly higher in seeds var. Mister than Lord. The level of total alkaloids (TA) in the seeds of var. Lord was twice higher than in Mister but it did not exceed 0.5 g/kg (sweet lupine) in both varieties. The alkaloid profile was different. In the seeds of var. Lord, gramine and epilupanine but no ammodendrine were found in comparison with Mister. The total oligosaccharides (TO) level reached 85.6 g and 103.4 g in 1 kg of DM for var. Mister and Lord, respectively, with stachyose as a dominated sugar.

There were no significant differences in ATTD coefficients of protein, EE and gross energy (Table 10). ATTD of CP was approx. 77%, gross energy 80%. The coefficient of apparent digestibility of fat ranged from 66.8% in var. Lord to 70.5% in var. Mister.

The substitution of SBM in the diet by 20% to 100% with lupine seeds did not significantly affect ($p > 0.05$) performances of pigs (Table 11). During the Starter, Grower and Finisher phase, no differences in term of gains, FI, or feed utilization were found, except the Starter time when pigs from all of the experimental groups consumed more feed than in the control ($p < 0.05$).

In general, the total replacement of SBM in Starter, Grower and Finisher diets by a combination of YL seeds and RSM did not reduce the pigs' performance (Table 12). In the Starter period only, in Groups I and V with the highest RSM content, a negative effect of the diets on the BWG of pigs was observed ($p < 0.05$).

4. Discussion

The chemical composition of legume seeds could vary significantly because of the variety and environmental conditions. The seeds of *L. luteus* var.

Table 9 Chemical composition of YL seeds in DM.

Composition	Lord	Mister	Mean	SD
CA (g/kg)	42.73	41.53	42.13	0.41
CP (g/kg)	443.75	389.84	416.85	30.21
CF (g/kg)	209.12	192.34	200.73	0.51
Acid detergent fiber (ADF) (g/kg)	201.14	242.42	221.83	10.82
Neutral detergent fiber (NDF) (g/kg)	238.22	282.42	260.32	14.65
Ether extract (EE) (g/kg)	44.72	52.61	48.71	2.11
N-free extractives (NFE) (g/kg)	259.96	323.82	291.94	7.64
Lysine (g/100 g of protein)	4.55	4.76	4.66	0.11
Methionine + cystine (g/100 g of protein)	2.89	3.37	3.13	0.09
Threonine (g/100 g of protein)	3.29	3.17	3.23	0.09
P-phytate (g/100 g)	7.33	7.03	7.23	1.21
P phytate/P total (%)	81.00	75.00	78	2.00
Total alkaloids (TA) (g/kg)	0.42	0.27	0.30	0.07
Gramine + gramineisomer (% TA)	8.00	0.00	4.00	0.42
Epilupinine (% TA)	2.67	0.00	1.34	0.07
Lupinine (% TA)	70.24	63.29	66.77	4.45
Sparteine (% TA)	19.11	33.6	26.36	2.65
Ammodendrine (% TA)	0.00	3.12	1.56	0.11
Total oligosaccharides (TO) (g/kg)	103.45	85.61	94.53	13.15
Raffinose (% TO)	8.41	12.84	10.62	0.98
Stachyose (% TO)	59.86	57.64	58.75	2.40
Verbascose (% TO)	31.72	29.52	30.62	1.36
Viscosity (cP)	1.19	1.09	1.14	0.03
ME for pigs (MJ/kg DM)	12.66	12.90	12.78	1.65

SD: standard deviation.

Table 10 Apparent total digestibility coefficients of CP, EE and gross energy—Experiment I.

Digestibility coefficients (%)	Lord	Mister	SEM	*p*
CP	77.857	77.052	1.859	0.667
EE	66.804	70.549	4.230	0.391
Gross energy	80.636	79.769	1.314	0.526

SEM: standard error of mean.

Table 11 Performance results—Experiment II.

Item		Control[c]	L20[d]	L40[e]	L60[f]	L80[g]	L100[h]	SEM	*p*
Starter	Initial BW (kg)	16.2	16.5	16.1	16.8	16.7	17.1	2.20	0.501
	Final BW (kg)	40.2	41.9	40.1	40.9	39.7	40.1	0.30	0.334
	BWG (kg)	24.0	25.4	24.0	24.1	23.0	22.9	0.30	0.139
	DBWG (g/d)	649	686	649	652	622	620	7.50	0.139
	FI (kg)	56.6[b]	57.9[a]	57.6[a]	57.6[a]	57.7[a]	57.4[a]	3.10	0.024
	FCR (kg/kg)	2.38	2.28	2.41	2.39	2.54	2.54	0.03	0.151
Grower	Final BW (kg)	76.1	77.6	74.2	75.1	74.0	74.0	3.63	0.394
	BWG (kg)	35.9	35.7	34.1	34.3	34.3	33.9	0.40	0.538
	DBWG (g/d)	1,024	1,020	974	979	980	969	11.0	0.538
	FI (kg)	97	99.4	98.9	100	100	99.2	7.50	0.161
	FCR (kg/kg)	2.72	2.80	2.92	2.94	2.94	2.94	0.03	0.144

(Table 11 to be continued)

Item		Control[c]	L20[d]	L40[e]	L60[f]	L80[g]	L100[h]	SEM	*p*
Finisher	Final BW (kg)	104.6	106.9	103.0	104.8	104.0	103.7	5.71	0.701
	BWG (kg)	28.5	29.3	28.8	29.7	29.9	29.7	0.40	0.873
	DBWG (g/d)	837	860	847	872	881	872	12.6	0.873
	FI (kg)	99.98	99.97	100	100.1	99.88	99.97	3.97	0.999
	FCR (kg/kg)	3.53	3.44	3.53	3.40	3.40	3.41	0.05	0.923
Total	BWG (kg)	88.3	90.4	86.9	88.1	87.3	86.5	0.73	0.801
	DBWG (g/d)	833	852	820	831	823	816	7.76	0.671
	FI (kg)	253.6	257.3	256.5	257.6	257.7	256.7	8.94	0.076
	FCR (kg/kg)	2.89	2.85	2.96	2.93	2.97	2.98	0.02	0.583

[a, b] Values in the same rows with different letters differ significantly at $p < 0.05$; [c] Control—group were offered feed with SBM as the sole protein component in the diet; [d] 20% (L20), [e] 40% (L40), [f] 60% (L60), [g] 80% (L80) and [h] 100% (L100) of SBM was replaced by YL meal (var. Mister).
BW: body weight; BWG: body weight gain; DBWG: daily body weight gain; FI: feed intake; FCR: feed conversion ratio; SEM: standard error of mean.

Table 12 Performance results—Experiment III.

Item		Control[c]	I[d]	II[e]	III[f]	IV[g]	V[h]	SEM	*p*
Starter	Initial BW (kg)	26.30	26.05	25.90	25.85	26.15	26.78	0.30	0.981
	Final BW (kg)	40.60	38.60	38.75	39.50	40.35	39.11	0.40	0.595
	BWG (kg)	14.30[a]	12.55[b]	12.85[ab]	13.65[ab]	14.20[a]	12.33[b]	0.20	0.017
	DBWG (g/d)	0.681[a]	0.598[b]	0.612[ab]	0.650[ab]	0.676[a]	0.587[b]	0.01	0.017
	FI (kg)	32.00	32.00	32.00	32.00	32.00	31.77	2.03	0.360
	FCR (kg/kg)	2.26	2.56	2.52	2.36	2.27	2.72	0.35	0.095
Grower	Final BM (kg)	76.65	71.10	71.65	72.05	73.55	72.44	0.60	0.050
	BWG (kg)	36.05	32.50	32.90	32.55	33.20	33.33	0.40	0.062
	DBWG (g/d)	1.092	0.985	0.997	0.986	1.006	1.010	0.01	0.062
	FI (kg)	90.06	89.86	89.79	90.03	90.00	99.94	3.21	0.999
	FCR (kg/kg)	2.50	2.80	2.76	2.79	2.74	2.71	0.24	0.127
Finisher	Final BM (kg)	107.15	100.9	101.1	102.4	105.2	104.67	0.80	0.092
	BWG (kg)	30.5	29.8	29.45	30.35	31.65	32.22	0.40	0.197
	DBWG (g/d)	1.049	1.030	1.018	1.050	1.092	1.111	0.010	0.197
	FI (kg)	93.26	91.98	93.33	93.32	87.59	93.23	5.42	0.492
	FCR (kg/kg)	3.06	3.13	3.2	3.09	2.79	2.92	0.14	0.151
Total	BWG (kg)	80.85	74.85	75.20	76.55	79.05	77.89	0.70	0.098
	DBWG (g/d)	0.974	0.902	0.906	0.922	0.952	0.938	0.01	0.098
	FI (kg)	215.26	213.98	215.33	215.32	209.59	215.01	6.87	0.503
	FCR (kg/kg)	2.67	2.88	2.88	2.82	2.66	2.80	0.08	0.093

[a, b] Values in the same rows with different letters differ significantly at $p < 0.05$; [c] Control—groups were offered feed with SBM as the sole protein component in the diet; [d] I-100% of SBM was replaced in a proportion of 75:25 (*w/w*) with RSM and YL; [e] II-100% of SBM was replaced in a proportion of 50:50 (*w/w*) with RSM and YL; [f] III-100% of SBM was replaced in a proportion of 25:75 (*w/w*) with RSM and YL; [g] IV-100% of SBM was replaced by YL; [h] V-100% of SBM was replaced by RSM.
BW: body weight; BWG: body weight gain; DBWG: daily body weight gain; FI: feed intake; FCR: feed conversion ratio; SEM: standard error of mean.

Mister analyzed in this study differed in chemical composition from what was reported by Hanczakowska and Swiatkiewicz [16]. In the current research, a higher level of CF, ADF, NDF, EE and CA was found. The TA content was similar. The seeds of var. Lord possessed a slightly higher amount of CP and CF than found by Chilomer *et al*. [17] and Kasprowicz-Potocka *et al*. [18]. The seeds of var. Lord analyzed by Kasprowicz-Potocka *et al*. [18] were characterized by a favorable amount of P-phytate (5.9 g/kg vs. 7.3 g/kg

DM) and TA (0.16 g/kg vs. 0.42 g/kg DM) than in the current studies. A lower amount of P-phytate is desirable in relation to its limited bioavailability [19]. Sobotka *et al*. [4] observed comparable values of CP but lower CF, ADF, NDF and EE content. In comparison with the current study, higher values of alkaloids and oligosaccharides were found. Lupine species contain many anti-nutritional factors. Most of them reached a similarly low level as in SBM, for example, trypsin and chymotrypsin inhibitors, tannins, or saponins [20]. However, in the case of lupine alkaloids and oligosaccharides, they can reduce the nutritional value of seeds. Similar to the current results, lupinine was the main alkaloid present in *L. luteus* var. Lord and Mister analyzed by Kaczmarek *et al*. [21]. In contrast, Musco *et al*. [22] confirmed sparteine as the dominant alkaloid present in three varieties of *L. luteus*: Dukat, Mister and Taper. In addition, Musco *et al*. [22] found a higher TA content than in the current study. Differences in alkaloid content may be explained by several factors: harvesting time, environment and geographical location [23]. The second important group of compounds is the oligosaccharides of the raffinose family. The lack of α-galactosidases in pigs' digestive tracts limits their digestion in the small intestine and provides fermentation in the large intestine, which is the consequence of lower feed utilization and flatulence. The TO contents in DM in both varieties are in agreement with the results obtained by Kaczmarek *et al*. [21]. Oligosaccharides quantity depends on the external factors of the environment. Lahuta *et al*. [24] found increasing amounts of oligosaccharides within the lupine seeds raised in dry conditions.

The seeds of both varieties were used in the digestibility study because they are different in anti-nutrient content. The Lord variety contains about twice more alkaloids (with gramine), more oligosaccharides and CF than the Mister. Moreover, the viscosity of seeds var. Lord (in a water solution) was approx. 10% higher, thereby affecting the digestibility of the nutrients. The determined ATTD of protein was approx. 77%, crude fat was approx. 66%-70% and gross energy was approx. 80%. There was no significant difference between the varieties. ATTD of CP in the var. Mister was lower than reported by Hanczakowska and Swiatkiewicz [16]. However, the EE digestibility coefficient was higher. The digestibility coefficient of CP and EE in var. Lord was lower than obtained by Chilomer *et al*. [17]. Froidmont *et al*. [25] proposed that α-galactosides can bind nutrients in indigestible complexes. Protein particles could also bound with NDF and phytate, thereby reducing protein digestibility. Moreover, although the overall digestibility of the DM and energy in lupine seeds is relatively high, a considerable proportion of energy is digested in the hind gut due to the high amounts of the non-starch polysaccharides and galactosides present in seeds. Therefore, the energy from lupines that is available to the pig is likely to be lower than what is anticipated from its digestible energy and ME contents [26].

The substitution of SBM by YL did not reduce the performance of the animals. Similar results were obtained by Sońta *et al*. [27] during fattening periods where the animals were fed diets containing 7.5% and 15% of YL (var. Mister). It is noteworthy that in the Starter phase, the pigs from all of the experimental groups consumed more feed ($p < 0.05$). This shows that the presence of alkaloids in the diet did not negatively affect feed palatability, even when 29% of sweet YL was present in the diet (group L100). Pigs are quite sensitive to dietary alkaloids, but it may depend not only on the total amount of alkaloids but also individual alkaloids [20]. Buraczewska *et al*. [28] found that pigs do not tolerate more than 0.12 g of alkaloids of *L. albus* in kg of the diet. The content of alkaloids more than 0.2 g/kg in case of *L. angustifolius* and alkaloids up to 0.45 g/kg of *L. luteus* decrease FI in pigs [20]. Lupine seeds var. Mister used in the experiments were low in alkaloid content. The actual results were in agreement with Experiment III. In all of the fattening phases, pigs offered diets with YL, as a total replacement of SBM (Group IV), had similar results as the control. Gdala *et al*. [29] reported that the substitution of SBM by YL in 30% did not influence the FI compared with the control group. However, in the study by Bugnacka and Falkowski [30], the substitution of 75% and 100% SBM by YL reduced the FI of pigs.

In Experiment III, there was also no difference among the other groups and the control in the Grower and Finisher phases and in total fattening time. Although, in the Starter phase, the pigs from Groups I and V that were offered diets with the highest amount of RSM (23% and 31.5%, respectively) presented reduced gains (total and daily) compared with the control diet and with L100 diet. It is possible that, for young animals, a higher level of RSM is not convenient, which was also found in a previous study [8]. Kasprowicz-Potocka *et al*. [8], and Hanczakowska and Swiatkiewicz [16] did not report a negative effect on the replacement SBM by 30% (Grower period) and 100% (Finisher period) RSM and lupine seeds on the production results in pigs during the whole fattening period. However, animals fed with a mixture containing rapeseed cake and blue lupine seeds reached a significantly lower average daily gain during the Grower period compared to YL. This negative effect may be a response to the usage of a higher amount of RSM than that is recommended. Landero *et al*. [31], in experimental diets containing 5%, 10%, 15% and 20% of expeller-pressed canola, did not notice any negative effects on pigs' performance (total glucosinolates content was 0.01 mmol/kg of feed). On the other hand, Schöne *et al*. [32] found a negative effect when 15% of rapeseed cake was present in the diet (gluosinolates 3.2 mmol/kg of feed).

5. Conclusions

In conclusion, sweet YL (var. Mister and Lord) is characterized by a high digestibility of protein and gross energy. YL and their mixture with RSM can be used as a partial or total substitution of SBM in pigs' diet, but if the inclusion rate of rapeseed meal in a diet is higher, the growth intensity in pigs may decrease. In the Starter phase, more than 15% RSM in the diet can reduce pigs' growth. When formulating a diet containing lupine seeds and rapeseeds meal, it is necessary to optimize the contents of individual nutrients, particularly energy and amino acids.

Acknowledgments

This study was supported by the programme "Improvement of Native Plant Protein Feeds, Their Production, Trade Turnover and Utilization in Animal Feed" of the Ministry of Agriculture and Rural Development of Poland 2016-2020.

References

[1] Wasilewko, J., and Buraczewska, L. 1999. "Chemical Composition Including Content of Amino Acids, Minerals and Alkaloids in Seeds of Three Lupin Species Cultivated in Poland." *J. Anim. Feed Sci.* 8: 1-12.

[2] Grela, E. R., Kiczorowska, B., Samolińska, W., Matras, J., Kiczorowski, P., Rybiński, W., and Hanczakowska, E. 2017. "Chemical Composition of Leguminous Seeds: Part I—Content of Basic Nutrients, Amino Acids, Phytochemical Compounds, and Antioxidant Activity." *Europ. Food Res. Technol.* 243: 1385-95.

[3] Kasprowicz-Potocka, M., Zaworska, A., Wisniewska, Z., and Rutkowski, A. 2017. "The Current State of Research on the Effectiveness of the Use of Domestic Protein Sources in Pig Nutrition." In *Nutritional Recommendations for the Use of Domestic High Protein Feed for Pigs and Poultry*, 1st ed., edited by Rutkowski, A. Bydgoszcz, Poland: APRA, 199. (in Polish)

[4] Sobotka, W., Stanek, M., and Bogusz, J. 2016. "Evaluation of the Nutritional Value of Yellow (*Lupinus luteus*) and Blue Lupine (*Lupinus angustifolius*) Cultivars as Protein Sources in Rats." *Ann. Anim. Sci.* 16: 197-207.

[5] Martinez-Villaluenga, C., Frias, J., and Vidal-Valverde, C. 2006. "Functional Lupin Seeds (*Lupinus albus* L. and *Lupinus luteus* L.) after Extraction of α-Galactosides." *Food Chem.* 98: 291-9.

[6] Kasprowicz-Potocka, M., Chilomer, K., Zaworska, A., Nowak, W., and Frankiewicz, A. 2013. "The Effect of Feeding Raw and Germinated *Lupinus luteus* and *Lupinus angustifolius* Seeds on the Growth Performance of Young

Pigs." *J. Anim. Feed Sci*. 22: 116-21.

[7] Kim, J. C., Pluske, J. R., and Mullan, B. P. 2008. "Nutritive Value of Yellow Lupins (*Lupinus luteus* L.) for Weaner Pigs." *Austral. J. Exp. Agric.* 48*:* 1225-31.

[8] Kasprowicz-Potocka, M., Zaworska, A., Kaczmarek, S., and Rutkowski, A. 2016. "The Nutritional Value of Narrow-Leafed Lupine (*Lupinus angustifolius*) for Fattening Pigs." *Arch. Anim. Nutr*. 70: 209-23.

[9] Adeola, O. 2001. "Digestion and Balance Techniques in Pigs." In *Swine Nutrition*, edited by Lewis, A. J., and Southern, L. L. Boca Raton, Washington: CRC Press, 903-16.

[10] GfE. 2006. *Recommendations for the Energy and Nutrient for Pigs.* Vol. 10, DLG-Verlag: Frankfurt am Main. (in German)

[11] AOAC. 2007. *Association of Official Methods of Analysis*, 18th ed. Gaithersburg, MD: Association of Official Analytical Chemists.

[12] Short, F. J., Gorton, P., Wiseman, J., and Boorman, K. N. 1996. "Determination of Titanium Dioxide Added as an Inert Marker in Chicken Digestibility Studies." *Anim. Feed Sci. Technol.* 59: 215-21.

[13] Myers, W. D., Ludden, P. A., Nayigihugu, V., and Hess, B. W. 2004. "Technical Note: A Procedure for the Preparation and Quantitative Analysis of Samples for Titanium Dioxide." *J. Anim. Sci.* 82: 179-83.

[14] Zalewski, K., Lahuta, L. B., and Horbowicz, M. 2001. "The Effect of Soil Drought on the Composition of Carbohydrates in Yellow Lupin Seeds and Triticale Kernels." *Acta Physiol. Plant* 23: 73-8.

[15] Haug, W., and Lantzsch, H. J. 1983. "Sensitive Method for the Rapid Determination of Phytate in Cereals and Cereal Products." *J. Sci. Food Agric.* 34: 1423-6.

[16] Hanczakowska, E., and Swiatkiewicz, M. 2014. "Legume Seeds and Rapeseed Press Cake as Replacers of Soybean Meal in Feed for Fattening Pigs." *Ann. Anim. Sci*. 14: 921-34.

[17] Chilomer, K., Kasprowicz-Potocka, M., Gulewicz, P., and Frankiewicz, A. 2013. "The Influence of Lupin Seed Germination on the Chemical Composition and Standardized Ileal Digestibility of Protein and Amino Acids in Pigs." *J. Anim. Physiol. Anim. Nutr.* 97: 639-46.

[18] Kasprowicz-Potocka, M., Zaworska, A., Frankiewicz, A., Nowak, W., Gulewicz, P., Zdunczyk, Z., and Juskiewicz, K. 2015. "The Nutritional Value and Physiological Properties of Diets with Raw and *Candida utilis*-Fermented Lupin Seeds in Rats." *Food Technol. Biotechnol*. 53: 286-97.

[19] Kasprowicz-Potocka, M., Zaworska, A., Kaczmarek, S., Hejdysz, M., Mikuła, R., and Rutkowski, A. 2016. "The Effect of *Lupinus albus* Seeds on Digestibility, Performance and Gastrointestinal Tract Indices in Pigs." *J. Anim. Physiol. Anim. Nutr.* 101: 216-24.

[20] Kim, J. C., Pluske, J. R., and Mullan, B. P. 2007. "Lupins as a Protein Source in Pig Diets." *CAB Reviews: Perspectives in Agriculture Veterinary Science, Nutrition and Natural Resources* 2: 12.

[21] Kaczmarek, S. A., Hejdysz, M., Kubis, M., Kasprowicz-Potocka, M., and Rutkowski, A. 2016. "The Nutritional Value of Yellow Lupin (*Lupinus luteus* L.) for Broilers." *Anim. Feed Sci. Technol*. 222: 43-53.

[22] Musco, N., Cutrignelli, M. I., Calabro, S., Tudisco, R., Infascelli, F., and Grazioli, R., Lo Presti, V., Gresta, F., and Chiofalo, B. 2017. "Comparison of Nutritional and Antinutritional Traits among Different Species (*Lupinus albus* L., *Lupinus luteus* L., *Lupinus angustifolius* L.) and Varieties of Lupin Seeds." *J. Anim. Physiol. Anim. Nutr.* 101: 1227-41.

[23] Maknickiene, Z., Asakaviciute, R., Baksiene, E., and Razukaś, A. 2013. "Alkaloid Content Variations in *Lupinus luteus* and *Lupinus angustifolius*." *Archives of Biological Sciences* 65: 107-12.

[24] Lahuta, L. G. R. 2011. "Raffinose in Seedlings of Winter Vetch (*Vicia villosa* Roth.) under Osmotic Stress and Followed by Recovery." *Acta Physiol. Plant* 33: 725-33.

[25] Froidmont, E., Wathelet, B., Beckers, Y., Romnee, J. M., Dehareng, F., Wavreille, J., Schoeling, O., Decauwert, V., and Bartiaux-Thill, N. 2005. "Improvement of Lupin Seed Valorisation by the Pig with the Addition of α-Galactosidase in the Feed and the Choice of a Suited Variety." *Biotechnology, Agronomy, Society and Environment* 9: 225-35.

[26] Van Barneveld, R. J., Baker, J., Szarvas, S. R., and Choct, M. 1995. "Effect of Lupin Kernels on the Ileal and Faecal Digestibility of Energy by Pigs." In *Manipulating Pig Production Hennessy*, edited by Hennessy, D. P., and Cranwell, D. P. Werribee, Victoria: Aust. Pig Sci. Assoc.

[27] Sońta, M., Rekiel, A., and Więcek, J. 2016. "The Efficiency of Fattening Pigs with Mixture Containing Yellow Lupine (*Lupinus luteus*)." *Scient. Ann. Pol. Soc. Anim. Prod.* 12: 9-18.

[28] Buraczewska, L., Pastuszewska, B., Smulikowska, S., and Wasilewko, J. 1993. "Response of Pigs, Rats and Chickens to Dietary Level of Alkaloids of Different Lupin Species." *Recent Advances in Antinutritional Factors in Legumes* 70: 371.

[29] Gdala, J., Jansman, A. J. M., Van Leeuwen, P., Huisman, J., and Verstegen, M. W. A. 1996. "Lupines (*L. luteus*, *L. albus*, *L. angustifolius*) as a Protein Source for Young Pigs." *Anim. Feed Sci. Technol*. 66: 239-49.

[30] Bugnacka, D., and Falkowski, J. 2001. "The Effect of Dietary Levels of Yellow Lupin Seeds (*Lupinus luteus* L.) on Feed Preferences and Growth Performance of Young Pigs." *J. Anim. Feed Sci*. 10: 133-42.

[31] Landero, J. L., Beltranena, E., Cervantes, M., Araiza, A. B., and Zijlstra, R. T. 2012. "The Effect of Feeding Expeller-Pressed Canola Meal on Growth Performance and Diet Nutrient Digestibility in Weaned Pigs." *Anim. Feed Sci. Technol.* 171: 240-5.

[32] Schöne, F., Tischendorf, F., Leiterer, M., Hartung, H., and Bargholz, J. 2001. "Effects of Rapeseed-Press Cake Glucosinolates and Iodine on Performance, the Thyroid Gland and the Liver Vitamin a Status of Pigs." *Arch. Tierernähr.* 5: 333-50.