The effect of white lupine on the performance, health, carcass characteristics and meat quality of market pigs

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ABSTRACT: The purpose of the present study was to assess the effect of diets for market pigs with 20% inclusion of lupine seeds, cv. Amiga, on the performance, health status, carcass characteristics, fatty acids (FA) profile of meat lipids and nutritional and sensory parameters of meat. Another purpose was to increase the nutritional value of a cereal-lupine diet (E1) by supplementation with lysine, methionine, threonine (E2) or fat (E3) and to perform a comparison with control diets containing animal protein (C1) or soy (C2). The experiments were performed on 50 pigs (50% males, 50% females) with initial body weights of 35.6 ± 2.2 kg, fed isonitrogenic and isoenergetic diets partly *ad libitum* for 90 days. Feed intake was not adversely affected by lupine inclusion. The daily body weight gain (BWG) was significantly higher ($P < 0.05$) in group E3 in comparison with the cereal-lupine diet group (E1) and the other groups by 12.6 to 15.9% during the initial 30 days of experiment. The highest BWG (0.88 ± 0.07 kg/kg) during the entire experimental period was obtained with the fat containing diet (E3); that was non-significantly higher by 2.3 to 10.0% in comparison with the other diets. The feed conversion rate was reduced in groups E3 and E2 (2.55 and 2.58 kg/kg BWG) by 3.1 to 7.6% in comparison with groups C1, C2 and E1. No adverse effect of the lupine containing diet was observed on the carcass characteristics or the nutritional quality of the meat. Optimum content of linolenic acid in lupine seeds had a favourable effect on n-6/n-3 polyunsaturated FA ratio in meat lipids of group E3 in comparison with groups C1 and E1 ($P < 0.05$). By sensory meat analysis, significantly better characteristics were found for texture, juiciness ($P < 0.01$, $P < 0.05$) and taste in E3 in comparison with groups C1, C2 and E1. The obtained results indicate that animal and soy protein may be replaced with lupine, tested in the present study, in case a diet is supplemented with amino acids and fat.

Keywords: *L. albus* cv. Amiga; pig growth; feed conversion; pork; fatty acids profile; sensory properties

Due to the fact that the use of feed of animal origin in the nutrition of monogastric animals has been limited, an essential problem arose as how to replace a high quality animal protein without adverse effect on animal health and performance. Most European countries are dependent on imported soy, which is a source of protein for poultry and pig diets. The heat treatment of soy is necessary for inactivation of anti-nutritional substances. Moreover, some soy cultivars contain estrogen-like agents (Sommer, 2003). The use of alternative home prepared diets with a high nutritional value and of reasonable price is attractive. Lupine seeds meet these requirements among leguminous plants cultivated in our country.

According to a prospective study (Dijkstra et al., 2003) lupine has been included among eight potential vegetable sources of protein for the use in feed and food production. The seeds of sweet lupine cultivars (*Lupinus albus, L. angustifolius, L. luteus*) contain 28 to 48% crude protein (CP) in dry matter (DM), which depends on the lupine cultivar and

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climatic conditions (Hove, 1974; Green and Oram, 1983; Sousa et al., 1996; Linnemann and Dijkstra, 2002). The profile of amino acids is characterised by a lower level of sulphur containing amino acids and threonine in comparison with soy (Simon and Jeroch, 1999); in contrast, arginine content is markedly higher (Suchy et al., 2005). The lipid content is 5 to 13%, high percentages (up to 80%) of unsaturated fatty acids (FA) are represented by linoleic and linolenic acids (Yanez et al., 1983) and average levels of metabolised energy for pigs are slightly lower in comparison with soy. In contrast to other leguminous plants, the lupine seed contains more crude fibre; a proportion of that is viewed as dietetically beneficial (Johnson and Gray, 1993). The seed contains minute amounts of starch (5 to 12%), higher levels of soluble non-starch polysaccharides (NSP) and α-galactosides that cannot be digested by endogenous enzymes (Taverner et al., 1983); under such conditions, decreased utilisation of nutrients and energy, disturbed health status and low performance of pigs have been recorded (Batterham, 1992; Veldman et al., 1993; Gdala et al., 1997). The content of anti-nutrient substances, particularly quinolizidine alkaloids, markedly decreased in new sweet lupine cultivars in comparison with bitter cultivars (Aniszewski et al., 2001). The content of other anti-nutrient substances (trypsin and chymotrypsin inhibitors, tanins, phenolic substances, lectins etc.) is relatively low and the seeds of these cultivars do not require heat treatment and may be fed unprocessed to the animals.

Existing results and experience with lupine utilisation in pig nutrition are controversial. Decreased growth and feed intake was observed in pigs fed a diet containing 150 to 430 g/kg *L. albus* seeds (Batterham, 1992; Roth-Maier and Kirchgessner, 1993; Zettl et al., 1995). By contrast Gdala et al. (1996) did not find a growth depression in pigs fed 410 g/kg *L. angustifolius* in a diet in comparison with barley and soy based diet. Beneficial effects of feeding yellow lupine, cv. Juno, were obtained by Flis et al. (1996).

The aim of the present study was to investigate the effect of white lupine, cv. Amiga, included in pig diets on the performance, health, carcass characteristics and nutritional quality of pork in comparison with diets containing animal protein or soy. A further aim was to evaluate the effectiveness of lupine containing diets supplemented with limiting amino acids or fat.

MATERIAL AND METHODS

Animals and feeding. Fifty hybrid P × (Du × LW × L) pigs in equal numbers of barrows and gilts with the initial mean live body weight of 35.6 ± 2.21 kg (V = 6.3%) were used in the study. The animals were earmarked by tattooing and housed in pens with 5 pigs to each, under good hygienic conditions of accredited animal facilities in the Veterinary Research Institute (approved project of the experiment No. 588 by the Ministry of Agriculture of the Czech Republic). Average surface space was 1.7 m^2 and the length of the feeding place was 0.3 m per pig. Straw was used as bedding. Average ambient temperature and relative humidity were 19 ± 3°C and 55 ± 10%, respectively. Before the beginning of the experiment, the animals were dewormed (Ivomec, inj., Agvet, USA) and allocated into five groups based on individual live body weight and sex. During the course of the experiment (90 days) the pigs were fed partly *ad libitum* twice a day at 7.00 and 16.00 h, the diets were mixed with drinking water 1:1. Thirty minutes after the beginning of feeding, the refusals were removed, weighed and taken into account in the calculations of feed consumption.

Live body weight of pigs was taken at weekly intervals (each time 2 h post feeding). Individual and group body weight gains (BWG) were calculated. Feed conversion rate (FCR) was calculated from feed consumption and BWG of respective groups. The health status of animals was monitored daily by observation at regular intervals. Occasional morbidity and mortality were recorded.

At the end of the trial, blood samples were drawn from *v. cava cranialis* for biochemical analysis 3 h post feeding and all experimental animals were slaughtered using electrical stunning and exsanguination.

Diets. All experimental diets were based on cereals (wheat and barley) and feed supplements. Control group diets contained animal protein – fish meal (C1) or extracted soy meal (C2). The diets for experimental groups contained lupine, cv. Amiga (Group E1), lupine and amino acids (Group E2), lupine, amino acids and sunflower oil (Group E3). Compositions of experimental diets are given in Table 1. The diets were suggested for fattening of meat type pigs with 56% proportion of lean musculature (Simecek et al., 1993).

Chemical analysis. DM, CP (N × 6.25), ether extract, raw fibre and ash of lupine seeds and di-

Table 1. Composition (%) and nutrient content in the diets

Diet with[1]	FM	ESM	L	LA	LAF
Diet No.	C1	C2	E1	E2	E3
Barley	45.00	45.00	45.50	40.40	40.00
Wheat	40.00	39.60	31.40	36.00	34.40
Extracted soy meal 48% CP	10.00	12.50	–	–	–
Fish meal 64% CP	1.50	–	–	–	–
Lupine	–	–	20.00	20.00	20.00
Sunflower oil	–	–	–	–	2.00
L-lysine 60%	–	–	–	0.20	0.20
DL-methionine 40%	–	–	–	0.10	0.10
L-threonine 20%	–	–	–	0.20	0.20
BOLIFOR MCP-F[2]	0.60	–	–	–	–
Unimak P1-M[3]	2.89	2.90	3.10	3.10	3.10
Nutrients (g/kg)					
Dry matter	880.2	877.8	883.6	883.0	884.6
Nitrogenous substances	164.2	162.7	165.7	165.6	165.6
Fat	35.3	33.1	37.4	37.4	47.4
Fibre	36.5	35.1	49.5	49.6	46.0
Ash	55.6	44.6	47.5	47.4	45.6
N-FE[4]	588.6	602.3	583.5	583.0	580.0
OM[5]	824.6	833.2	836.1	836.6	839.0
MEp (MJ/kg)[6]	13.0	13.0	12.8	12.9	13.1
Lysine/MEp (g/MJ)	0.74	0.74	0.73	0.80	0.79

[1]FM – fish meal; ESM – extracted soy meal; L – lupine; LA – lupine + amino acids; LAF – lupine + amino acids + fat

[2]monocalcium phosphate

[3]commercial supplement contained the following per kg: 335 000 IU vitamin A, 45 000 IU vitamin D, 125 mg vitamin K, 2 665 mg vitamin E, 5.3 mg vitamin B_1, 165 mg vitamin B_2, 14 mg vitanmin B_6, 1.10 mg vitamin B_{12}, 165 mg niacin, 250 mg pant. calcium, 1 000 mg cholinchlorid, 0.8 mg biotin, 6 600 mg vitamin C, 110 g L-lysine HCl, 33 g DL-methionine, 55 g L-threonine, 15 mg Co, 65 mg J, 11 mg Se, 660 mg Cu, 1 585 mg Mn, 3 500 mg Zn, 2 080 mg Fe, 56 g Na, 12 g Mg, 80 g P, 205 g Ca, 833 mg Endox, 36×10^{12} cfu Bio-plus 2B, 2 900 mg Natuphos 5000G, 665 mg sacharin

[4]N-FE – nitrogen-free extracts

[5]OM – organic matter

[6]MEp – metabolizable energy

ets was analysed using AOAC methods (AOAC, 2001). The determination of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) was performed according to a technique described by Van Soest et al. (1991). Before the analysis of amino acids, the samples were processed with acid and oxidative analysis with HCl (6 mol/l). The samples were analysed by means of AAA 400 analyser (INGOS Prague, CR). A total content of alcaloids in lupine seeds was assessed by the gravimetric method described by Wysocka et al. (1989). Mono- and disaccharides in lupine samples were detected by high-performance anion-exchange chromatography with pulsed ampero-

Table 2. Amino acid content in white lupine cv. Amiga and in diets (g/kg DM)

Amino acid	White lupine seeds	FM[1] C1	ESM C2	L E1	LA E2	LAF E3
Cys	5.1	6.6	6.5	6.1	6.2	6.2
Asp	33.6	14.4	13.7	16.4	16.1	15.8
Met	2.6	3.2	3.1	2.7	3.1	3.1
Thr	11.6	7.4	6.9	7.8	8.2	8.2
Ser	14.6	7.7	7.1	7.9	8.1	7.9
Glu	58.6	37.7	37.3	37.8	39.7	38.4
Pro	12.8	13.7	13.5	13.1	13.5	13.4
Gly	13.4	7.4	6.8	7.8	7.7	7.3
Ala	10.2	6.9	6.1	6.8	6.6	6.5
Val	14.5	8.7	8.5	9.4	9.2	8.5
Ile	14.3	7.0	6.8	7.8	7.6	7.0
Leu	24.3	12.7	12.3	13.8	13.7	12.9
Tyr	13.4	5.0	4.4	6.1	6.0	5.9
Phe	12.4	8.6	8.0	8.7	8.7	8.4
His	8.3	4.6	4.5	5.1	5.0	4.9
Lys	16.4	11.5	10.8	11.8	13.7	13.6
Arg	38.6	12.3	12.3	15.9	16.0	15.7

[1]see Table 1

metric detection (HPAEC-PAD, Dionex). Isocratic elution chromatography was used for the detection of monosaccharides and a gradient mobile phase was employed for the detection of disaccharides (Gorecki et al., 1997; Erbas et al., 2005).

Total protein, albumin, glucose, triacylglycerols, cholesterol, HDL and LDL lipoproteins, alkaline phosphatase (ALP), aspartate and alanine aminotransferases (AST, ALT), calcium and phosphorus blood plasma levels were determined spectrophotometrically using Bio-La-Tests (PLIVA-Lachema Brno Ltd., Czech Republic).

Total lipids of meat were extracted with chloroform-methanol (2:1 v/v) according to the method of Folch et al. (1957). Derivation of FA was based on a base-catalysed reaction using KOH-methanol as the reagent. Fatty acid methyl esters (FAME) were then extracted to hexane. FAME were analysed by gas-liquid chromatography using an SP-2560 fused silica capillary column (100 m × 0.25 mm i. d., 20 μm film thickness, Supelco, Bellefonte, USA) in a Hewlett-Packard 5890 gas chromatograph (Palo Alto, USA) equipped with a flame ionising detector (FID). The oven temperature was 175°C for 30 min, then was increased to 210°C by 1°C/min and held at that temperature for 40 min. Detector and injection port temperatures were 220°C and nitrogen carrier gas flow was 1 ml/min. For identification of FAME, the standard FAME mixtures were analysed. To confirm the identification of some FAME, GC/MS analyses was carried out on the GC/MSD system Agilent 5973 (Agilent, Palo Alto, USA) with the same column and temperature conditions as above, except helium flow was 0.6 ml/min and the detector temperature was 250°C.

Carcass and meat quality measurement. At the end of the experiment, carcass quality was determined using dressing percentage and estimated lean yield in percent (ZP method; CSN 46 6160, 2000) as criteria. Back fat thickness and *musculus longissimus lumborum et thoracis* (*MLLT*) depth were measured with a slide gauge at the location of the last thoracic vertebra. Using the WTW 720 pH meter (Inolab, Germany), pH value 1 was meas-

ured at the same location of *MLLT*, immediately (pH_1) and 24 hours (pH_{24}) after slaughter. DM, CP (N × 6.25) and fat content (petrol ether extraction in Soxhlet's extraction equipment for 6 h) were determined in *MLLT*.

Sensory evaluation. The samples (app. 500 g) of muscle tissue were collected from *MLLT* for analyses of sensory parameters. Evaluation was done by a group of 8 members meeting the requirements of CSN ISO 8586-1 (2003) in a special room for the analysis of sensory parameters (according to CSN ISO 8589, 1993). A seven-point scale was used (1 – the least desirable, 7 – the most desirable). The following attributes (descriptors) of meat were assessed: colour, texture, juiciness, odour and taste.

Statistical analysis. The results obtained were processed by statistical methods using the statistical and graphic software STAT Plus (Matouskova et al., 1992). Analysis of the obtained data was performed by one-way ANOVA, using the Tukey test and Kruskal-Wallis test.

RESULTS

Diet composition. Analysis of the investigated diets confirmed that they were isoproteinic and isoenergetic. The contents of CP and MEp ranged between 162.7 and 165.7 g/kg and 12.8 and 13.1 MJ/kg, respectively. The lysine/MEp ratio was balanced (0.73 to 0.80 g/MJ). In the lupine containing diets, higher crude fibre levels were noted (Table 1).

Seeds of white lupine, cv. Amiga, used in the experiment contained (in g/kg DM): CP 337, crude fat 108, crude fibre 134.1, NDF 225.0, ADF 155.0 and ADL 10.3. Total alkaloid content was 0.8 ± 0.02 g/kg DM. The content of amino acids in lupine seeds and respective diets is shown in Table 2. Lupine CP contained 4.9 g lysine/16 g N, methionine and threonine constituted 0.8 and 3.4 g/16 g N, respectively. Among lupine saccharides, sucrose content was the highest (36.7 g/kg DM). The content of α-galactosides were as follows: raffinose 7.1 g/kg, stachyose 30.2 g/kg, verbascose 4.9 g/kg; traces of ajugose were also detected (Table 3).

The composition of respective FA in the lipid compound of lupine and the diets is presented in Table 4. In lupine, monounsaturated FA (MUFA 52.3%) prevailed. Polyunsaturated FA (PUFA) and saturated FA (SFA) constituted 35.1% (the n-6/n-3 ratio was 1.9) and 12.5%, respectively. Lupine containing diets (E1, E2, E3) showed less SFA and a higher proportion of MUFA in comparison with fish meal (C1) and extracted soy meal (C2) containing diets. The n-6/n-3 PUFA ratio ranged between 7.9 and 8.6.

Growth, feed intake and feed efficiency. Growth performance, feed intake and FCR are shown in Table 5. No marked differences in feed intake were observed; the lowest feed intake (2.15 kg/day) during the entire experimental period was recorded for the lupine containing diet E2. Complete replacement of soy or animal protein with lupine in experimental diets balanced for CP content and

Table 3. Content of mono-, disaccharides and α-galactosides in white lupine cv. Amiga and ratios of respective sugars to total sugar

Sugar	Content (g/kg DM)	Portion in total (%)
Arabinose	0.15	0.12
Fructose	0.41	0.47
Glucose	0.74	0.82
Galactose	4.48	5.30
Mannose	0.10	0.12
Raffinose	7.09	8.36
Rhamnose	0.10	0.12
Sucrose	36.69	43.23
Stachyose	30.21	35.57
Verbascose	4.93	5.77
Xylose	0.13	0.12

Table 4. Fatty acid composition of white lupine cv. Amiga and of dietary lipids (% of total fatty acids)

Fatty acid	White lupine seeds	FM[1] C1	ESM C2	L E1	LA E2	LAF E3
Myristic (C 14:0)	0.07	0.37	0.11	0.15	0.11	0.13
Palmitic (C 16:0)	4.30	13.40	12.40	9.93	9.00	10.16
Palm-oleic (C 16:1)	0.30	0.32	1.00	0.54	0.42	0.38
Stearic (C 18:0)	2.28	12.40	15.90	7.53	5.85	4.27
Oleic (C 18:1 n-9)	43.90	38.34	35.16	46.60	43.99	45.00
Linoleic (C 18:2 n-6)	22.19	30.30	30.23	24.17	29.10	28.00
Linolenic (C 18:3 n-3)	12.14	3.60	3.78	2.84	3.68	3.60
Eikosanic (C 20:0)	0.99	0.15	–	–	–	0.90
Eikosenic (C 20:1 n-9)	8.14	1.13	0.70	4.17	4.64	4.43
Eikosadienic (C 20:2 n-6)	0.81	–	–	0.21	0.94	0.42
Lignoceric (C 24:0)	4.88	–	0.72	3.86	2.26	2.70
Σ SFA[2]	12.52	26.32	29.13	21.47	17.22	18.16
Σ MUFA[3]	52.34	39.79	36.86	51.31	49.05	49.81
Σ PUFA[4]	35.14	33.90	34.01	27.22	33.72	32.02
PUFA n-6/n-3	1.9	8.4	8.0	8.6	8.1	7.9

[1]see Table 1
[2]SFA – saturated fatty acids
[3]MUFA – monunsaturated fatty acids
[4]PUFA – polyunsaturated fatty acids

supplemented with lysine, methionine and threonine did not markedly adversely affect BWG. Amino acid supplementation of the diet resulted in BWG increase by 3.7% in comparison with the E1 group. Moreover, sunflower oil containing diet (Group E3) had a beneficial effect on BWG. BWG was significantly higher ($P < 0.05$) during the initial 30 days of the experiment in comparison with the cereal-lupine diet group (E1); and in comparison with the other groups (C1, C2, E2) their BWG was increased by 12.6 to 15.9%.

The effect of lupine seeds supplemented with amino acids and above all, fat (E3 diet) was shown in an increased BWG (0.88 ± 0.07 kg/day), which was non-significantly higher by 10% in comparison with the lupine only diet (E1) during the entire experimental period. The best results for FCR were found using E3 and E2 diets (2.55 and 2.58 kg/kg BWG, respectively). The use of fat and amino acid supplemented diets reduced FCR by 7.3 and 7.6%, respectively compared with C1 and E1 diets.

Biochemical analysis of pig blood plasma. The effect of the diets on pig blood plasma parameters is presented in Table 6. In most cases, non-significant differences in the investigated parameters of protein, sugar and mineral metabolism were detected between groups of animals fed respective diets. The HDL level was significantly higher in group E3 in comparison with groups C1 and E2 ($P < 0.01$, $P < 0.05$). ALT activity was significantly lower ($P < 0.01$) in group E2 in comparison with group E3. No clinical signs of disease were observed during the entire experiment and no mortality or gross changes of internal organs after slaughter were recorded. That gave evidence of the animals being in a good state of health.

Carcass characteristics, FA profile and meat quality. Evaluation of carcass quality of slaughtered pigs did not reveal any significant differences in respective parameters. The pH_{24} value in group E1 was the only decreased parameter ($P < 0.05$) in comparison with group E3 meat. Physical-chemical analyses of *MLLT* (DM, CP, intramuscular fat, ash) did not reveal a significant effect of diets on meat composition (Table 8).

The FA profile in *MLLT* samples is presented in Table 7. Significantly lower content of palmitic acid

Table 5. Feed intake, body weight gain and feed efficiency

Indices	Day	FM[1] C1	ESM C2	L E1	LA E2	LAF E3	SEM
Initial BW[2] (kg)	0	35.7	35.5	35.4	35.3	35.0	0.30
Final BW (kg)	90	109.9	113.0	108.1	110.0	114.0	1.16
Feed intake (kg/day)	0–30	1.60	1.58	1.49	1.45	1.62	0.03
	30–60	2.43	2.43	2.32	2.29	2.44	0.02
	60–90	2.82	2.82	2.84	2.70	2.69	0.01
	0–90	2.28	2.27	2.22	2.15	2.25	0.03
BW gain (kg/day)	0–30	0.69	0.71	0.66	0.69	0.80[i]	0.02
	30–60	0.98	1.01	0.89	0.95	0.98	0.01
	60–90	0.82	0.85	0.86	0.87	0.87	0.02
	0–90	0.83	0.86	0.80	0.83	0.88	0.01
Feed:BW gain (kg/kg)	0–30	2.33	2.22	2.26	2.11	2.03	–
	30–60	2.47	2.40	2.60	2.42	2.50	–
	60–90	3.44	3.32	3.31	3.11	3.10	–
	0–90	2.75	2.66	2.76	2.58	2.55	–

[1]see Table 1; [2]body weight; [i]$P < 0.05$ E1:E3

(C 16:0) was detected in experimental groups fed lupine supplemented diets (Group E2, E3) in comparison with control groups C1, C2 and experimental group E1 ($P < 0.05$, $P < 0.01$). The effect of diets on the total content of SFA was not significant. Oleic acid was dominant among FA in all groups; the highest level (42.2%) was detected in animals fed lupine containing diet supplemented with fat

Table 6. Selected biochemical characteristics of blood plasma

Parameter	FM[1] C1	ESM C2	L E1	LA E2	LAF E3	SEM
Total protein (g/l)	73.4	72.3	69.4	72.1	72.0	0.55
Albumin (g/l)	34.1	33.9	33.0	32.4	34.2	0.54
Glucose (mmol/l)	5.21	5.09	5.30	5.65	5.00	0.13
Triacylglycerols (mmol/l)	0.29	0.34	0.37	0.36	0.35	0.02
Cholesterol (mmol/l)	2.34	2.40	2.45	2.40	2.61	0.06
HDL lipoproteins (mmol/l)	0.74	0.85	0.84	0.81	0.99[D,j]	0.02
LDL lipoproteins (mmol/l)	1.09	1.10	1.02	0.98	1.00	0.02
ALT (μkat/l)	0.65	0.60	0.63	0.49	0.72[J]	0.02
AST (μkat/l)	0.57	0.45	0.47	0.47	0.47	0.04
ALP (μkat/l)	4.38	4.67	3.90	3.63	3.67	0.25
Ca (mmol/l)	2.53	2.71	2.68	2.67	2.88	0.05
P (mmol/l)	2.63	2.69	2.79	2.60	2.83	0.05

[1]see Table 1; [D]$P < 0.01$ C1:E3; [j]$P < 0.05$ E2:E3; [J]$P < 0.01$ E2:E3

Table 7. Fatty acid composition of *MLLT* lipids (% of total fatty acids)

Fatty acid	FM[1] C1	ESM C2	L E1	LA E2	LAF E3	SEM
Myristic (C 14:0)	1.14	1.40[a]	1.30	1.17	1.42[d,j]	0.03
Palmitic (C 16:0)	23.7	25.0	25.1	22.9[f]	21.4[D,G,I,J]	0.31
Palm-oleic (C 16:1)	2.98	3.65[a]	3.38	2.94[f]	2.15[d,G,I,j]	0.12
Stearic (C 18:0)	11.8	12.0	11.9	11.8	13.8	0.36
Petroselic (C 18:1 n-6)	4.58	5.12	5.21	4.60	4.55	0.09
Oleic (C 18:1 n-9)	37.7	38.2	36.0	37.7	42.2	0.85
Linoleic (C 18:2 n-6)	10.7	7.99	9.36	10.0	9.10	0.63
Linolenic (C 18:3 n-3)	1.06	0.89	1.05	1.35[f]	1.67[D,G,I]	0.07
Eikosenic (C 20:1 n-9)	0.28	0.23	0.37	0.31	0.27	0.02
Arachidonic (C 20:4 n-6)	2.22	1.86	1.86	2.24	0.78	0.20
Eikosatrienic (C 20:5 n-3)	0.26	0.17	0.26	0.34	0.09	0.04
Dokosatetraenic (C 22:4 n-6)	0.40	0.22	0.22	0.32	0.14	0.04
Dokosapentaenic (C 22:5 n-3)	0.49	0.35	0.38	0.51	0.50	0.04
Dokosahexaenic (C 22:6 n-3)	0.35	0.09	0.10	0.14	0.27	0.03
Others	2.25	2.85	3.50	3.66	1.65[I,J]	0.20
Σ SFA[2]	36.7	38.4	38.3	35.9	36.6	0.50
Σ MUFA[3]	45.5	47.2	44.9	45.5	49.2	0.80
Σ PUFA[4]	15.5	11.6	13.2	14.9	12.35	0.93
PUFA n-6	13.4	10.1	11.4	12.6	10.02	0.82
PUFA n-3	2.15	1.51	1.79	2.34	2.53	0.14
PUFA n-6/n-3	6.23	6.66	6.37	5.38	3.97[d,g]	0.30

[1]see Table 1; [2, 3, 4] see Table 4; [a]$P < 0.05$ C1:C2; [d]$P < 0.05$ C1:E3; [D]$P < 0.01$ C1:E3; [f]$P < 0.05$ C2:E2; [g]$P < 0.05$ C2:E3; [G]$P < 0.01$ C2:E3; [I]$P < 0.01$ E1:E3; [j]$P < 0.05$ E2:E3; [J]$P < 0.01$ E2:E3

(E3). The concentration of n-3 PUFA increased non-significantly after lupine supplementation of the diet in comparison with the soy containing diet (C2). The linolenic acid (C 18:3 n-3) level was significantly higher in group E2 ($P < 0.05$) and group E3 ($P < 0.01$) in comparison with groups C1, C2 and E1. The ratio of n-6/n-3 PUFA was significantly lower in experimental diet E3 (3.97) in comparison with control diets C1 and C2 containing animal protein or soy ($P < 0.05$). Long-chain SFA of 24 carbon units were not detected in measurable amounts in any of the analysed samples.

Sensory analysis. Comparison of sensory analysis results from an aspect of the investigated diets showed differences in the following descriptors: colour, texture and juiciness. Meat of control group pigs (C1) fed a diet containing animal protein showed the best colour in comparison with groups C2, E1 ($P < 0.01$) and E3 ($P < 0.05$). Meat from animals fed a lupine containing diet supplemented with fat (E3) was more tender than that from groups C1 ($P < 0.01$), C2 and E1 ($P < 0.05$) and more juicy than that from groups C1, C2 and E1 ($P < 0.01$). No significant differences were found for odour descriptor despite that group E3 meat was of best taste and was assigned the highest scores (Table 8). From an aspect of sex of the animals, a difference was found only for the colour of meat; meat from barrows significantly more approached the requirements than meat from gilts ($P < 0.01$).

Table 8. Carcass characteristics of pigs fed different diets

Indices	FM[1] C1	ESM C2	L E1	LA E2	LAF E3	SEM
BW[2] before slaughter (kg)	113.6	114.9	112.0	113.1	117.1	0.91
Dressing percentage (%)	79.3	79.1	78.9	79.2	79.2	0.06
Estimated lean yield (%)	57.9	57.1	57.8	58.6	56.2	0.34
Backfat thickness (mm)	19.0	19.1	18.1	17.3	20.5	0.45
MLLT depth (mm)	64.6	61.8	62.6	63.2	62.7	0.43
pH_1	6.21	6.18	6.12	6.27	6.24	0.03
pH_{24}	5.45	5.43	5.40	5.47	5.46^{i}	0.01
Contents in *MLLT*						
Dry matter (%)	25.49	25.40	25.58	25.46	25.54	0.06
Crude protein (%)	21.88	22.11	22.17	22.17	21.99	0.05
Intramuscular fat (%)	2.30	1.94	2.07	1.96	2.24	0.06
Ash (%)	1.18	1.18	1.18	1.19	1.17	0.01
Sensory evaluation						
Colour	5.27	4.46^{A}	4.56^{B}	4.95	4.69^{d}	0.13
Texture	4.45	4.64	4.57	4.80	$5.27^{D,g,i}$	0.14
Juiciness	3.97	4.30	4.14	4.54	$5.02^{D,G,I}$	0.13
Odour	4.92	5.01	5.02	4.96	4.94	0.13
Taste	4.62	4.70	4.67	4.66	4.99	0.13

[1]see Table 1; [2]body weight; $^{A}P < 0.01$ C1:C2; $^{B}P < 0.01$ C1:E1; $^{d}P < 0.05$ C1:E3; $^{D}P < 0.01$ C1:E3; $^{g}P < 0.05$ C2:E3; $^{G}P < 0.01$ C2:E3; $^{i}P < 0.05$ E1:E3; $^{I}P < 0.01$ E1:E3

DISCUSSION

Diet compositions. Recently, scientifically bred lupine cultivars with a low content of quinolizidine alkaloids represent an alternative source of protein that is attractive to the nutritionists as a replacement for meat-and-bone meal or soy, particularly in diets for monogastric animals. The total content of alkaloids in the used white lupine, cv. Amiga, was low (0.8 g/kg DM) and was consistent with the results obtained by Zdunczyk et al. (1996a), Aniszewski et al. (2001) and others. The contents of CP, fat and crude fibre in the used lupine seeds were comparable with those described for cv. Amiga, Hetman and Bardo (Brenes et al., 1993; Gdala et al., 1996; Mieczkowska and Smulikowska, 2005). Likewise, the contents of NDF and ADF in whole non-dehulled seeds were within the ranges published by the above-mentioned authors and gave evidence of quite a high percentage of hulls in the seeds (16%). NDF and ADF contents in extracted soy meal were much lower (157.1 and 93.4 g/kg DM) than in lupine; this is in accordance with Flis et al. (1996). Accordingly, increase of CP by dehulling of seeds is currently being investigated. In the studies by Brenes et al. (1993), dehulled sweet lupine seeds contained 72% less ADF and 73% less NDF than whole seeds.

The flatulence-producing soluble oligosaccharides are an important component of lupine seeds. The total content of the raffinose family of oligosaccharides (α-galactosides – raffinose, stachyose, verbascose, ajugose) was 42.2 g/kg DM, their ratio to sucrose was 0.86 and the proportion of the sum of soluble sugars was 49.7% (Table 3). Comparable data for the white lupine was obtained by Zdunczyk et al. (1996b). Veldman et al. (1993) noted adverse effects of 27.5 g/kg white lupine in a diet on health status. Presence of α-galactosides caused fluid retention and enhanced microbial fermentation in the gut. Besides 20% reduction of ileal digestibility by crude

protein and nitrogen free extractives, they found stimulated gut motility and damaged gut wall.

Nutrient content was in agreement with requirements for fattening of meat type pigs with 56% proportion of lean musculature (Simecek et al., 1993). From an aspect of the content of CP and concentrations of metabolisable energy, they were isonitrogenic and isoenergetic, with a balanced lysine to MEp ratio. Inclusion of 20% of the tested lupine in the diet for experimental groups was twice that suggested by Simon and Jeroch (1999) for fattened pigs. The concentration of calculated energy in the tested white lupine was 14.6 MJ ME/kg DM and was comparable with data obtained by Roth-Maier and Kirchgessner (1993). The content of amino acids gave evidence of a decreased protein quality in lupine seeds (Table 2). The contents of lysine, methionine and threonine were 4.9, 0.8 and 3.4 g/16 g N, respectively, which is in accordance with the findings of Roth-Maier and Kirchgessner (1993) and Zdunczyk et al. (1996b). The content of sulphur amino acids was lower in experimental diet E1 than in control diets C1 and C2. In contrast to the tested soybeans, cv. Korado and Vision, we detected low contents of methionine and contrariwise high contents of arginine (Suchy et al., 2005). Due to this fact, these amino acids were supplemented in experimental diets E2 and E3. FA composition (Table 4) was in accordance with the range of values mentioned in the studies focused on white lupine (Roth-Maier and Kirchgessner, 1993; Zdunczyk et al., 1996b; Erbas et al., 2005). Higher proportions of MUFA (61%) have been recorded for white lupine, cv. Bardo by Mieczkowska and Smulikowska (2005). Fat supplementation of experimental diet E3 with the aim to enhance energy content was reflected in n-6/n-3 PUFA ratio reduction.

Animal performance and health status. The effect of lupine seeds on daily body weight gain and feed consumption in market pigs is controversial as shown by literature data. Beneficial effect of white lupine seeds documented in the present study suggested their potential use in pig nutrition in the future. Significantly increased ($P < 0.05$) BWG in the first part of our experiments (days 0 to 30) obtained with lupine containing diet supplemented with amino acids and fat (group E3) in comparison with group E1 gave evidence that the effect of increased energy level in the diet was positive. The highest BWG during the entire experimental period was obtained in the case where animal protein (C1) or soy (C2) was fully replaced with lupine, amino acids and fat. However, total replacement of animal protein or soy with lupine only (E1) caused a decreased BWG by 3.7 and 7.5% in comparison with C1 and C2, respectively; that is in accordance with Flis et al. (1996) who found reduction by 7.5% in the case where they replaced soy. The quoted authors likewise demonstrated that it was inevitable to increase the energy level of a diet by either dehulling of seeds or supplementation with fat and limiting amino acids. Donovan et al. (1993) obtained relatively good results in fattened pigs after replacement of 75% soy with dehydrated white lupine. In contrast Van Nevel et al. (2000) and King et al. (2000) observed growth depression, lower feed intake and FCR reduction after 30% inclusion of white lupine in a diet. Moreover, King et al. (2000) did not demonstrate a positive effect of seed dehulling and amino acid supplementation, they suggested a potential adverse effect of anti-nutritional substances such as alkaloids, α-galactosides or a high manganese level. The total carbohydrate profile seems to suppress the nutritional value of lupine, and after all, to influence digestion of energetic and nutritional substances.

A positive effect of a lupine containing diet supplementation with limiting amino acids on market pig performance and FCR confirmed lupine deficiency, particularly in sulphurous amino acids (Table 2). These results were in accordance with the findings of Batterham (1992) concerning lower content and availability of amino acids in lupine seeds and low digestibility of methionine by pig digestive tract. Effectiveness of experimental diets E2 and E3 (2.58 and 2.55 kg/kg of BWG) was consistent with results obtained by Flis et al. (1996).

It is well known that a good state of health is reflected in the performance of the animals. Neither signs of a clinical disease during the experiment were observed, nor were gross changes of organs after slaughter recorded. Biochemical parameters of blood plasma were found to be within physiological reference ranges (Tluchor, 2001) and gave evidence of a balanced homeostasis of the organisms.

FA profile, carcass characteristics and meat quality. Little information on the effects of lupine seeds on FA composition of pork can be found in the literature. Despite differences in FA composition of diets, MUFA, followed by SFA, is dominated in the fat deposited in the *MLLT*. Comparable results were obtained by Van Nevel et al. (2000) and Leikus et al. (2004). The data is in accordance with the results obtained by Skrivan et al. (2000)

in broiler chickens and gave evidence that the lipid content of SFA and MUFA depend rather on the *de novo* synthesis than on dietary lipid intake. Lupine inclusion in the diets caused a significant increase of linolenic acid levels in groups E2 and E3. A decreased n-6/n-3 FA ratio was found mainly in lupine containing diet supplemented with fat (E3); that is consistent with the results in broilers obtained by Mieczkowska and Smulikowska (2005). The PUFA concentrations and n-6/n-3 FA ratio in all tissues depend on their dietary supply because pigs cannot *de novo* synthesise FA of n-6 and n-3 families (Wiseman et al., 2000).

Lupine inclusion in the diets for experimental pigs did not significantly affect carcass characteristics in comparison with control group animals. These results were consistent with the findings of Donovan et al. (1993) and Flis et al. (1996). Decreased carcass weight and dressing percentage of animals receiving the highest amount of lupine seeds were observed by Batterham (1979), King et al. (2000) and Van Nevel et al. (2000) due to a larger gut fill caused by higher fibre content in the diet. Besides significantly increased weight of the small and large intestine, King et al. (2000) found that the weight of livers, kidneys and hearts were significantly higher in comparison with animals fed on an animal protein containing diet. Further carcass parameters were in accordance with Leikus et al. (2004). No significant effect of experimental diets on the *MLLT* CP and intramuscular fat content was demonstrated and the obtained data approached the requirements for the best quality of pork (Fernandez et al., 1999).

Literature data concerning the effect of lupine on sensory parameters of pork is scarce. Leikus et al. (2004) documented a reduction in colour intensity of meat from animals fed on a 15% sweet lupine containing diet. The results of the present study confirmed a positive effect of a 20% white lupine inclusion in pig diets on texture, juiciness and taste of the meat in comparison with control groups; those are to a certain degree comparable with the conclusions of sensory assessment of dehulled lupine *L. angustifolius* (Zraly et al., 2006).

CONCLUSIONS

It follows from the present study that animal protein or soy in the diet for market pigs may be completely replaced with white lupine, cv. Amiga, in case the diet is balanced by supplementation with amino acids and nutritional value is increased by supplementation with fat. Lupine inclusion in pig diets may have a beneficial effect on pork FA composition and its sensory parameters.

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