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Nutritional value of white lupins (*Lupinus albus*) for broilers: apparent metabolisable energy, apparent ileal amino acid digestibility and production performance

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*Two experiments were conducted to evaluate the nutritional value of three cultivars (Promore, Kiev mutant and Ultra) of white lupins (*Lupinus albus *L.) for broilers. In experiment 1, the apparent metabolisable energy (AME) and ileal amino acid digestibility coefficients of the three cultivars were determined. The cultivar effects were significant (*$P < 0.05$*) for AME, but the ileal amino acid digestibility coefficients were similar (*$P > 0.05$*) between cultivars. The AME value of Ultra cultivar was lower (*$P < 0.05$*) than those of Promore and Kiev mutant cultivars. In Experiment 2, using the AME and ileal digestible amino acid values determined in Experiment 1, diets containing 200 g/kg of lupin were formulated and the effects of feeding these diets on performance, digestive tract development and excreta quality of broiler starters were investigated. Weight gain, feed intake and feed per gain of broilers fed diets containing white lupins were similar (*$P > 0.05$*) to those fed the maize–soybean meal diet. The performance of birds fed diets containing different cultivars of white lupins was similar (*$P > 0.05$*). Several digestive tract parameters were influenced by the dietary inclusion of white lupins. In particular, the relative liver weight and the relative empty weights of small intestine and caeca in birds fed diets containing white lupins were higher (*$P < 0.05$*) than those fed the maize–soybean meal diet. No differences (*$P > 0.05$*) were observed in the excreta quality scores between the birds fed the maize–soybean meal diet and those fed diets containing white lupins.*

Keywords: white lupins, apparent metabolisable energy, amino acids, ileal digestibility, broilers

Implications

Although the high non-starch polysaccharide and the low metabolisable energy contents of white lupins (*Lupinus albus* L.) limit their use in broiler diets, the relatively high contents of protein, digestible amino acids and fat make it potentially beneficial. The high non-starch polysaccharide content of white lupins, however, is a nutritional concern and resulted in an increase in the relative weight of the small intestine and caeca of broilers in this study. Overall, the present results showed that, when diets are balanced in terms of metabolisable energy and digestible amino acids, white lupins can be used at a 200 g/kg inclusion level as a partial replacement for soybean meal in broiler starter diets without any adverse effects on the performance or excreta quality.

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Introduction

The search for new plant protein sources has attracted considerable attention in recent years as a result of the ban of inclusion of animal protein meals in diet formulations in some countries and the ever-increasing price of soybean meal. In addition, continued growth in the poultry industry is driving the demand for alternative protein ingredients that are locally available and economical and can be used as substitutes for conventional protein meals. Of the various possibilities (Ravindran and Blair, 1992), grain legumes such as lupins (*Lupinus* spp.) have good potential. Of the more than 200 species of Lupinus, five species (*L. albus*, *L. angustifolius*, *L. luteus*, *L. mutabilis* and *L. polyphilu*) are suitable for cultivation as high-protein crops (Gladstones, 1998).

White lupins (*Lupinus albus* L.) represent a potential grain legume with good protein quality in non-ruminant diets. The feeding value of early cultivars of lupins to poultry was poor because of the presence of high concentrations of toxic and bitter alkaloids (Olver and Jonker, 1997; Olkowski *et al.*, 2001). However, plant breeding programmes have paid considerable

attention to selecting lupin cultivars with almost zero alkaloid content and current lupin cultivars are largely alkaloid free (Cowling *et al*., 1998). Despite this development, the usefulness of lupins in poultry diets remains limited because of the uncertainty of their nutritional value and the presence of anti-nutritional factors, such as non-starch polysaccharides (NSP), tannins and protease inhibitors, which can lower nutrient digestibility and performance (Jezierny *et al*., 2010). It is also known that the level of anti-nutritional factors in grain legumes varies depending on the cultivar (Gatel, 1994).

Published data on the apparent metabolisable energy (AME; Brenes *et al*., 1993; Hughes *et al*., 1998) and the ileal amino acid digestibility (Ravindran *et al*., 2005) of white lupins for broilers are scant. Moreover, data available on the energy value and amino acid digestibility of grain legumes have often been obtained in studies that have evaluated only one sample of the legume. Knowledge of the variability of these parameters is essential to develop matrix values for more precise feed formulations. Published data on the suitability of white lupins, as a replacement for soybean meal, in broiler diets are limited and contradictory (Karunajeewa and Bartlett, 1985; Olver and Jonker, 1997; Viveros *et al*., 2007), with some studies showing adverse effects on performance and others reporting performance similar to control diets at inclusion levels of over 200 g/kg.

The present evaluation of white lupins consisted of two parts. In the first phase, the AME, nitrogen-corrected AME (AMEn) and apparent ileal amino acid digestibility values of three cultivars of white lupins were determined. In the second phase, using the AME and digestible amino acid values determined in the first phase, diets containing 200 g/kg of the three cultivars of white lupins were formulated and the effects of feeding these diets on the performance of broiler starters were investigated. The high contents of NSP in lupins, through their effect on digesta viscosity, could impact on the digestive tract development of broilers and excreta quality. For this reason, the influence of dietary treatments on these two parameters was also determined.

Material and methods

The experimental procedures were approved by the Massey University Animal Ethics Committee and complied with the New Zealand Code of Practice for the Care and Use of Animals for Scientific Purposes.

Ingredients

A total of three cultivars of white lupins, namely, Promore, Kiev mutant and Ultra, were used. These alkaloid-free cultivars are new introductions into New Zealand. White lupin seeds in raw form, with hulls, were ground to pass through a 3-mm sieve in a hammer mill before inclusion in the diets. Other ingredients were obtained from commercial suppliers in ground form. Representative samples of lupin cultivars were analysed, in triplicate, for dry matter (DM), nitrogen, ether extract, ash, starch, amino acids, NSP and trypsin inhibitor activity.

Table 1 *Composition (g/kg air dry basis) of the basal diet, Experiment 1*

Ingredient	g/kg
Maize	594.6
Soybean meal	351.8
Soybean oil	17.8
Dicalcium phosphate	21.7
Limestone	7.8
Salt	2.0
Sodium bicarbonate	2.3
Trace mineral–vitamin premix[1]	3.0

[1]Provided per kg diet: Co, 0.3 mg; Cu, 5 mg; Fe, 25 mg; I, 1 mg; Mn, 125 mg; Zn, 60 mg; choline chloride, 638 mg; *trans*-retinol, 3.33 mg; cholecalciferol, 60 μg; DL-α-tocopheryl acetate, 60 mg; menadione, 4 mg; thiamin, 3.0 mg; riboflavin, 12 mg; niacin, 35 mg; calcium panthothenate, 12.8 mg; pyridoxine, 10 mg; cyanocobalalamin, 0.017 mg; folic acid, 5.2 mg; biotin, 0.2 mg; antioxidant, 100 mg; molybdenum, 0.5 mg; selenium, 200 μg.

Experiment 1 – Metabolisable energy and digestibility assay

A maize–soybean meal basal diet was formulated (Table 1) and three assay diets were then developed by substituting 250 g/kg (w/w) of the basal diet with the three cultivars of white lupins. All diets contained titanium oxide (3 g/kg) as an indigestible marker to calculate the ileal digestibility of amino acids.

Male broilers (Ross 308) that were a day old were raised in floor pens and fed a commercial broiler starter diet (230 g/kg CP) till day 21. Feed and water were available at all times. On day 21, 64 birds of uniform BW were selected and randomly assigned to 16 cages (four birds per cage). The birds were offered a commercial broiler finisher diet (180 g/kg CP) until the introduction of assay diets on day 28. On day 28, four replicate cages were randomly assigned to each assay diet.

The AME was determined using the classical total excreta collection method. The diets, in mash form, were fed to birds from day 28. Feed intake and excreta output were measured quantitatively per cage from day 32 for 4 consecutive days. The excreta from each cage were pooled, mixed, sub-sampled and freeze-dried. The dried excreta samples, together with samples of the diets, were subsequently ground to pass through a 0.5-mm sieve and stored in airtight plastic containers for analysis of DM, gross energy (GE) and nitrogen content.

On day 35, all birds were euthanised by an intracardial injection of sodium pentobarbitone solution and the contents of the lower half of the ileum were collected according to the procedures of Ravindran *et al*. (2005). The ileum was defined as that portion of the small intestine extending from the Meckel's diverticulum to a point approximately 40 mm proximal to the ileo–caecal junction. The ileum was divided into two halves and the digesta was collected from the lower half towards the ileo–caecal junction. Digesta from birds within a cage were pooled and processed as described by Ravindran *et al*. (2005). The diet and digesta samples were then analysed for DM, titanium oxide and amino acids.

Experiment 2 – Performance trial

A total of four diets, including a maize–soybean meal control diet and three experimental diets containing 200 g/kg of the

Table 2 *Ingredient composition and calculated analysis (g/kg as fed) of experimental diets, Experiment 2*

		White lupin diets		
Ingredient	Maize–soy diet	Promore	Kiev mutant	Ultra
Maize	567	430	429	414
Soybean meal	317	235	235	237
Grain legume	–	200	200	200
Meat meal	80.0	80.0	80.0	80.0
Tallow	10.0	10.0	10.0	10.0
Soybean oil	6.0	25.1	26.0	38.8
L-lysine HCl	1.1	0.3	0.4	0.3
DL-methionine	2.9	3.0	3.0	3.1
L-threonine	0.1			
Dicalcium phosphate	10.3	11.7	11.7	11.8
Salt	1.6	1.8	1.8	1.9
Sodium bicarbonate	1.0	0.6	0.6	0.5
Trace mineral–vitamin premix[1]	3.0	3.0	3.0	3.0
Calculated analysis				
AME (MJ/kg)	12.2	12.2	12.2	12.2
CP	245	256	256	258
Digestible lysine	12.5	12.5	12.5	12.5
Digestible methionine	6.1	6.0	5.9	6.0
Digestible met + cys	8.8	8.9	9.0	8.9
Digestible threonine	7.2	7.8	7.6	7.8
Calcium	9.6	10.2	10.2	10.2
Available phosphorus	4.8	4.8	4.8	4.8
Sodium	1.6	1.6	1.6	1.6
Potassium	8.2	8.0	8.0	8.0
Chloride	1.6	1.6	1.6	1.6

AME = apparent metabolisable energy; met = methionine; cys = cysteine.
[1]Provided per kg diet: Co, 0.3 mg; Cu, 5 mg; Fe, 25 mg; I, 1 mg; Mn, 125 mg; Zn, 60 mg; choline chloride, 638 mg; *trans*-retinol, 3.33 mg; cholecalciferol, 60 μg; DL-α-tocopheryl acetate, 60 mg; menadione, 4 mg; thiamin, 3.0 mg; riboflavin, 12 mg; niacin, 35 mg; calcium panthothenate, 12.8 mg; pyridoxine, 10 mg; cyanocobalalamin, 0.017 mg; folic acid, 5.2 mg; biotin, 0.2 mg; antioxidant, 100 mg; molybdenum, 0.5 mg; selenium, 200 μg.

three cultivars of lupins, were formulated using the AME and ileal digestible amino acid values determined in Experiment 1 to contain similar levels of metabolisable energy and ileal digestible amino acids (Table 2). After mixing, the experimental diets were pelleted at 70°C.

A total of 128-day-old male broilers (Ross 308) were individually weighed and assigned to 16 cages (eight birds per cage) in electrically heated battery brooders, so that the average initial weight per cage was similar. Each of the four dietary treatments was then randomly assigned to four cages. The temperature was maintained at 32°C during the first week and was gradually decreased to approximately 23°C by the end of the third week. Ventilation was controlled by a central ceiling extraction fan and wall inlet ducts. The birds were provided with 20 h of fluorescent illumination per day. The diets were offered *ad libitum* from days 1 to 21. Water was freely available throughout the trial.

BW and feed intake were recorded at weekly intervals. Any bird that died was weighed and the weight was used to adjust feed per gain. Feed per gain was calculated by dividing the total feed intake by weight gain of live plus dead birds. Excreta was scored on day 21 for consistency on a scale of 1 to 5, with a score of 1 representing normally formed excreta and 5 representing watery and sticky excreta (Wu *et al*., 2004). On day 21, three birds, closest to the average cage weight, were selected per cage, weighed and sacrificed by cervical dislocation. The length (±0.1 mm) of the small intestine (from the pyloric junction to the ileal–caecal junction) and caeca (from the ostium to the tip of each caeca) was determined with a non-rigid tape on a wet glass surface to prevent inadvertent stretching. Following freeing of each of these components from any adherent mesentery, their full and empty weights (±0.1 g) were determined along with those of the crop, proventriculus and gizzard. The weights of the liver, spleen and pancreas were also determined.

Chemical analysis

The DM, crude fat and ash contents were calculated according to the procedures of Association of Official Analytical Chemists (AOAC, 2005). Nitrogen content was determined using an FP-428 nitrogen determinator (LECO® Corporation, St Joseph, MI, USA).

Soluble, insoluble and total NSP concentrations were determined using the Megazyme dietary fibre analysis kit (Megazyme International Ireland Ltd, Wicklow, Ireland). GE was determined using an adiabatic oxygen calorimeter (Gallenkamp Autobomb, London, UK) standardised with benzoic acid.

Amino acid concentration was determined by HPLC as described by Ravindran *et al*. (2009). Cystine and methionine were analysed as cysteic acid and methionine sulphone by oxidation with performic acid for 16 h at 0°C and neutralisation with hydrobromic acid before hydrolysis. Tryptophan was not determined. The titanium oxide content was measured using the colorimetric method described by Short *et al*. (1996). The procedure to determine trypsin inhibitor was according to the method of Valdebouze *et al*. (1980).

Calculations

The difference method approach was used to calculate the AME and apparent ileal digestibility coefficient (AIDC) of amino acids.

The AME values of the test diets and white lupin cultivars were calculated using the following formulas, with appropriate corrections made for differences in the DM content:

$$\text{AME}_{\text{diet}}\ (\text{MJ/kg}) = \frac{(\text{feed intake} \times \text{GE}_{\text{diet}}) - (\text{excreta output} \times \text{GE}_{\text{excreta}})}{\text{Feed intake}}$$

$$\text{AME}_{\text{Lupin}}\ (\text{MJ/kg}) = \frac{\text{AME of lupin diet} - (\text{AME of basal diet} \times 0.75)}{0.25}$$

Correction for zero nitrogen retention was made using a factor of 36.54 kJ per gram nitrogen retained in the body.

The AIDC of amino acids in the test diets and lupin cultivars were calculated, using titanium oxide as the indigestible marker, as follows:

$$\text{AIDC of diet} = \frac{(\text{AA/Ti})\text{d} - (\text{AA/Ti})\text{i}}{(\text{AA/Ti})\text{d}}$$

$$\text{AIDC of lupin} = \frac{\left[(\text{AIDC of lupin diet} \times \text{AA of lupin diet}) - (\text{AIDC of basal diet} \times 0.75 \times \text{AA of basal diet})\right]}{(0.25 \times \text{AA of lupin})}$$

where, (AA/Ti)d is the ratio of amino acid and titanium in the diet and (AA/Ti)i the ratio of amino acid and titanium in ileal digesta.

Statistical analysis

Data were analysed using the one-way analysis of variance according to the General Linear Models procedure of SAS (1997), with cage as the experimental unit. Differences were considered to be significant at $P < 0.05$ and significant differences between means were separated using Fisher's Least Significant Difference test.

Results

The chemical composition of white lupin cultivars is summarised in Table 3. The CP (349 to 363 g/kg) contents of the three cultivars were similar. The total NSP contents (355 to 370 g/kg) of the three cultivars were also comparable, but marked differences were found for the soluble NSP contents. The soluble NSP content of Ultra cultivar was higher than those of the other two cultivars. Differences were observed between cultivars in terms of the crude fat contents (113 to 134 g/kg), with Ultra cultivar having the lowest fat content. Trypsin inhibitor activity was found to be negligible (<1 TIU/mg) in all three cultivars.

The amino acid concentrations of the three cultivars are presented in Table 4. Arginine was the most abundant indispensable amino acid, whereas glutamic acid was the abundant dispensable amino acid. All white lupin cultivars were moderate sources of lysine, but deficient in methionine and cysteine.

Table 3 *Chemical composition (g/kg DM) of white lupin cultivars*

	Promore	Kiev mutant	Ultra
DM	883	887	888
CP (nitrogen × 6.25)	351	349	363
Crude fat	132	134	113
Ash	39.4	36.9	40.9
Starch	ND	ND	ND
Non-starch polysaccharides			
Soluble	28.8	31.1	50.1
Insoluble	339	324	320
Total	368	355	370
Trypsin inhibitor activity (TIU/mg)	0.25	0.24	0.20

DM = dry matter; ND = not detected.

Table 4 *Amino acid concentration (g/kg DM) of the three white lupin cultivars*

Amino acids	Promore	Kiev mutant	Ultra
Indispensable			
Arginine	37.7	34.6	36.6
Histidine	8.92	8.78	8.79
Isoleucine	14.2	13.2	12.8
Leucine	26.5	25.3	26.3
Lysine	16.9	16.4	16.9
Methionine	2.96	2.77	2.73
Phenylalanine	13.3	12.6	13.4
Threonine	14.2	13.1	13.9
Valine	14.2	13.2	13.8
Dispensable			
Alanine	12.4	12.0	11.7
Aspartic acid	35.4	33.9	33.8
Cysteine	5.27	5.53	5.02
Glycine	13.4	12.1	12.7
Glutamic acid	68.1	62.6	63.3
Proline	11.7	11.0	12.9
Serine	16.3	14.4	14.4
Tyrosine	15.6	11.5	14.4

DM = dry matter.

Cultivar differences ($P < 0.05$) were observed in the AME and AMEn of white lupins (Table 5). The AME values were determined to range between 8.05 and 9.68 MJ/kg DM. The AME and AMEn values of the Ultra cultivar were lower ($P < 0.05$) than those of the Promore and Kiev Mutant Broad cultivars. The AIDC of amino acids, however, was found to be similar ($P > 0.05$) between cultivars (Table 5). Amino acids in white lupins were well digested. The average ileal digestibility coefficients of the 17 amino acids in the three lupin cultivars were high (0.86 to 0.87).

The effects of feeding diets containing 200 g/kg of the three lupin cultivars on the performance, excreta score and digestive tract development of broilers are presented in Table 6. The weight gain, feed intake and feed per gain of birds fed diets containing lupins did not differ ($P > 0.05$) from those fed the maize–soybean meal diet and there were no cultivar differences. The excreta scores of birds fed lupin-based diets were found to be similar ($P < 0.05$) to those fed the maize–soy diet.

Digestive tract parameters were affected by the dietary inclusion of 200 g/kg white lupin (Table 6). Birds fed diets containing lupins had higher ($P < 0.05$) relative liver weights. The relative weight of the pancreas in birds fed the Kiev mutant diet was lower ($P < 0.05$) than that in birds fed the maize–soy diet. The relative empty weight of the proventriculus of birds receiving the Kiev mutant-based diet was lower ($P < 0.05$) than those fed the maize–soy and Ultra-based diets, but similar ($P > 0.05$) to that of the Promore-based diet. The birds fed diets containing lupins had higher

Table 5 *AME, AMEn and AIDC of amino acids in three cultivars of white lupins for broilers*[1]

	Promore	Kiev mutant	Ultra	Pooled s.e.m.
AME (MJ/kg DM)	9.68[a]	9.58[a]	8.05[b]	0.430
AMEn (MJ/kg DM)	7.67[a]	8.38[a]	6.34[b]	0.380
AIDCs				
Indispensable amino acids				
Arginine	0.945	0.944	0.949	0.009
Histidine	0.808	0.805	0.816	0.031
Isoleucine	0.864	0.895	0.874	0.014
Leucine	0.877	0.911	0.894	0.019
Lysine	0.891	0.905	0.908	0.017
Methionine	0.803	0.866	0.822	0.036
Phenylalanine	0.908	0.933	0.929	0.021
Threonine	0.829	0.828	0.850	0.017
Valine	0.841	0.821	0.879	0.048
Mean	0.863	0.879	0.880	0.018
Dispensable amino acids				
Alanine	0.814	0.875	0.850	0.029
Aspartic acid	0.849	0.886	0.863	0.019
Cysteine	0.808	0.811	0.797	0.044
Glycine	0.851	0.862	0.868	0.019
Glutamic acid	0.904	0.944	0.927	0.011
Proline	0.831	0.855	0.870	0.028
Serine	0.852	0.843	0.842	0.023
Tyrosine	0.882	0.862	0.892	0.019
Mean	0.849	0.867	0.864	0.018
Overall mean[2]	0.856	0.873	0.872	0.018

AME = apparent metabolisable energy; AMEn = nitrogen-corrected apparent metabolisable energy; AIDCs = apparent ileal digestibility coefficients.
[a,b]Means in a row with different superscripts differ ($P < 0.05$).
[1]Each value represents the mean of four replicates (four birds per replicate).
[2]Average digestibility of 17 amino acids.

($P < 0.05$) relative empty weights of the small intestine and caeca. The relative digesta weights of the small intestine of birds fed diet containing all cultivars of lupins were higher ($P < 0.05$) than that of the basal diet. With the exception of Promore, feeding broilers with diets containing lupins resulted in marked increases ($P < 0.05$) in the relative length of the caeca.

Discussion

The compositional data showed that white lupins are valuable sources of protein (>300 g/kg DM) and fat (>100 g/kg DM). The CP and crude fat contents determined for the three cultivars were within the range of 300 to 410 and 59 to 146 g/kg, respectively, reported in the literature (Gatel, 1994; Petterson *et al*., 1997). The amino acid profiles of the lupin cultivars are in agreement with those reported by Green and Oram (1983) and Ravindran *et al*. (2005). White lupins were moderately good sources of lysine, but were poor in sulphur-containing amino acids, which are characteristics of grain legumes in general (Gatel, 1994). The level of trypsin inhibitor activity found in these faba bean cultivars tested was negligible, suggesting that these cultivars could be incorporated in raw form in poultry diets without the need for thermal processing.

Virtually no starch was found in white lupins, in contrast to other grain legumes such as field peas and faba beans (Petterson *et al*., 1997; Nalle *et al*., 2010a and 2011). The carbohydrate reserves in white lupins were the NSP. White lupins contained 355 to 370 g/kg total NSP, which is in agreement with those reported by Kocher *et al*. (2000). The high contents of soluble NSP (29 to 50 g/kg DM) determined in white lupins can be a concern in poultry nutrition and may have implications for digesta viscosity and nutrient utilisation in birds (Smits and Annison, 1996).

The AME values of the three cultivars were determined to range between 8.05 and 9.68 MJ/kg DM, which are comparable to those reported by Brenes *et al*. (1993), but considerably lower than the values (13.3 to 14.9 MJ/kg DM) reported by Hughes *et al*. (1998) for white lupins (cv. Kiev Mutant). Lupin kernels were evaluated in the latter study, whereas seeds with hulls were used in this study and the dilution effect of hulls may explain, at least partly, the observed discrepancy. The proportion of hulls in the lupin seeds can be as high as 0.32, and Nalle *et al*. (2010b) reported that dehulling of Australian sweet lupin seeds resulted in marked reductions in NSP contents and improved AME values.

Amino acids in white lupins were well digested, with all amino acids having digestibility coefficients over 0.80. No cultivar effects were observed on the AIDC of amino acids. Only one previous study has reported the ileal amino acid digestibility of white lupins for broilers (Ravindran *et al*., 2005). On average, the apparent ileal digestibility values determined in this study were higher than those reported by Ravindran *et al*. (2005), which may be explained by differences in the assay methodology. The difference method was used in this study, whereas the direct method was used in the study by Ravindran *et al*. (2005) to determine amino acid digestibility. It has been suggested that the use of the direct method to determine the amino acid digestibility of ingredients with low-to-moderate protein contents will result in underestimation because of greater proportions of amino acids from endogenous sources, relative to amino acids of dietary origin, in ileal digesta at low dietary amino acid intakes (Ravindran and Bryden, 1999; Lemme *et al*., 2004).

It was evident that feeding diets containing 200 g/kg white lupins had no deleterious effects on the performance of broiler starters. Similarly, Karunajeewa and Bartlett (1985) reported that broiler starter diets could contain 220 g/kg white lupins (cv. Hamburg), with no adverse effects on growth. However, the present findings are in contrast with those of Olver and Jonker (1997) and Viveros *et al*. (2007), who showed that the use of 200 g/kg white lupins reduced the growth rate and feed efficiency of broiler starters. The observed discrepancy between studies may reflect differences in cultivars or feed formulation strategies, especially failure to balance for AME and digestible amino acids. In the study of Viveros *et al*. (2007), the diets were not balanced for

Table 6 *Effects of diets containing 200 g/kg white lupins on the performance (1 to 21 days post hatch), digestive tract development and excreta quality of broilers*[1]

	Maize–soy diet	Promore	Kiev mutant	Ultra	Pooled s.e.m.
Performance					
Weight gain (g/bird)	933	963	973	911	16.5
Feed intake (g/bird)	1240	1327	1320	1265	31.7
Feed per gain (g/g)	1.328	1.379	1.358	1.388	0.024
Excreta score	2.94	2.75	2.94	2.75	0.25
Relative organ weight (g/kg BW)					
Liver	26.8^{c}	30.2^{ab}	29.4^{b}	32.2^{a}	0.740
Spleen	0.967	0.850	0.958	0.883	0.064
Pancreas	3.09^{a}	2.90^{ab}	2.67^{b}	2.86^{ab}	0.08
Relative empty weight (g/kg BW)					
Crop	2.65	2.62	2.76	2.94	0.120
Proventriculus	4.54^{a}	4.22^{ab}	3.59^{b}	4.96^{a}	0.284
Gizzard	10.28	11.00	10.32	11.53	0.450
Small intestine	24.4^{b}	27.0^{a}	26.9^{a}	27.6^{a}	0.804
Caeca	1.28^{b}	1.53^{a}	1.52^{a}	1.52^{a}	0.063
Relative digesta content (g/kg BW)					
Crop	2.59	1.95	3.58	3.97	0.675
Proventriculus	1.99	2.99	2.41	2.42	0.467
Gizzard	3.56	5.86	4.94	5.60	0.650
Small intestine	45.3^{b}	54.7^{a}	55.7^{a}	54.5^{a}	1.985
Caeca	1.69	2.38	2.04	2.05	0.227
Relative length (cm/kg BW)					
Small intestine	157	159	162	167	3.010
Caeca	15.0^{b}	15.9^{ab}	16.8^{a}	17.2^{a}	0.507

^{a,b,c}Means in a row with different superscripts differ ($P < 0.05$).
[1]Each value represents the mean of four replicates (eight birds per replicate).

AME and digestible amino acids. An old cultivar of white lupins with a relatively high alkaloid content was used in the study of Olver and Jonker (1997), whereas alkaloid-free modern cultivars were used in this study.

Some authors have suggested that the inclusion of white lupins in broiler diets should not exceed 100 g/kg due to the possible incidence of wet-sticky droppings, which may be caused by its high NSP contents (Edwards and van Barneveld, 1998). In this study, however, no evidence of negative effects on excreta quality was observed even at a 200 g/kg inclusion level.

The higher relative weights of the small intestine and caecum in birds fed diets containing lupin cultivars may be related, at least in part, to the effects of dietary NSP. High NSP levels may also explain the longer caecum in birds fed diets containing lupins compared with those fed the maize–soy diet. These findings are in agreement with those of Brenes *et al.* (2002), who observed that increasing lupin content in the diet resulted in an increase in the relative size of several sections of the gastrointestinal tract. These findings are also in general agreement with those of Jørgensen *et al.* (1996), who reported that feeding high-fibre diets increased visceral organ mass and intestinal length relative to empty BW compared with birds fed low-fibre diets. The negative effects of NSP on the physiology and morphology of the digestive tract have been attributed to their viscous nature and interaction with gut microflora (Smits and Annison, 1996; Gabriel *et al.*, 2006). The higher relative digesta content in the small intestine of birds fed white lupin diets may be explained by the increase in gut viscosity caused by dietary soluble NSP, which could lead to a lower gastric emptying rate of solids and liquids and transit time in the small intestine (Smits and Annison, 1996). However, the observed effects of lupin diets on digestive tract development had no adverse influence on the performance of birds.

Inclusion of 200 g/kg lupins in broiler diets increased the relative weight of liver. As alkaloid-free lupin cultivars were used in the study, the significance of this finding is unclear.

Overall, the present results showed that white lupins are a good source of digestible amino acids and a moderate source of AME. It is concluded that, when diets are balanced in terms of metabolisable energy and digestible amino acids, white lupins can be included at a level of 200 g/kg in broiler starter diets, with no detrimental effect on performance. Further studies are warranted to investigate the possibility of higher levels of inclusion of white lupins in broiler diets through the removal of hulls (Nalle *et al.*, 2010b) and/or the use of NSP-degrading enzymes.

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