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Performance and intestinal responses to dehulling and inclusion level of Australian sweet lupins (*Lupinus angustifolius L.*) in diets for weaner pigs

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Abbreviations: AA, amino acid(s); ADF, acid detergent fibre; ASL, Australian sweet lupins; DM, dry matter; FCR, feed conversion ration; GIT, gastrointestinal tract; NDF, neutral detergent fibre; NSP, non-starch polysaccharides; PUN, plasma urea nitrogen; PWD, post-weaning diarrhoea; TTAD, total-tract apparent digestibility.

Abstract

A total of 180 entire male weaner pigs weighing 6.4 ± 0.1 kg (mean ± SEM) and housed in pairs was used in a completely randomised block design with 9 dietary treatments (n=10 pens). Pigs were blocked based on weaning weight. The diets were (i) a wheat-based control diet containing 240 g/kg of milk products (whey and skim milk powder), and (ii) 8 diets containing whole or dehulled lupins (cv. Coromup) that substituted the milk products at 60, 120, 180 and 240 g/kg of diet (replace 25, 50, 75, or 100 % of the milk products in the control diets). The diets were isoenergetic (15 MJ/kg), and were formulated to contain the same ileal standardised digestible lysine content (0.85 g/MJ DE) and ideal patterns of other essential amino acids. Pigs receiving 240 g/kg of dehulled lupins grew slower ($P<0.05$) than pigs fed the other diets mainly due to decreased feed intkae. Pigs fed diets containing more than 180 g/kg of dehulled lupins had a higher faecal β-haemolytic *E. coli* score on day 3 after weaning ($P<0.05$). Moreover, inclusion of 240 g/kg of whole lupin or more than 180 g/kg of dehulled lupins increased ($P<0.001$) plasma urea nitrogen (PUN) levels. Total tract apparent digestibility (TTAD) of dry matter decreased ($P<0.001$) in all lupin diets compared with the control diet. These data indicate that inclusion of dehulled lupin immediately after weaning should be limited to less than 180 g/kg while whole lupins can be included up to 240 g/kg without deleterious effects on production and intestinal health.

Keywords: Australian sweet lupins, performance, intestinal response, weaner pigs, post-weaning diarrhoea

1. Introduction

Traditionally, high quality piglet feeds have been based on using relatively high percentages of lactose, fat and (or) cooked cereals such as oats as energy sources, and a combination of whey powder, high quality fish meal and dried skim milk as sources of protein. However the cost of many of these ingredients has increased dramatically in recent times and there are certainly indications that their availability will continue to be variable.

Australian sweet lupins (*Lupinus angustifolius L.*; ASL) are less expensive than most other sources of protein available for feeding weaner pigs. Recent research in grower pigs demonstrated that ASL can be included at up to 350 g/kg in replacement of soybean meal without compromising growth, carcass composition and meat quality (Kim et al., 2011). However, the use of higher levels of lupins in a weaner diet to reduce or replace the more expensive protein sources, such as fishmeal and milk products, has not been examined to date. Lupins contain about 250 g/kg of seed coat (hull), which is mostly insoluble fibre, and its kernel contains about 300 g/kg of cell wall materials called polygalacturonans (Kim et al., 2007). Therefore, use of lupins in commercial weaner diets has been limited to 50 to 100 g/kg on the basis that pigs would have limited ability to deal with the high fibre content of whole lupins. In a previous study, however, we showed that yellow lupin seeds could be included at up to 150 g/kg in weaner diets without compromising performance of pigs (Kim et al., 2008a). In this regard, it is possible that a similar or greater amount of ASL seeds (*Lupinus angustifolius* L.) could be used in a weaner diet. Moreover, there is general perception that removal of the hull, which is indigestible, from lupins may offer the opportunity for even higher inclusion levels (i.e. > 150 g/kg) as increased amounts of insoluble fibre may physically limit the quantity of lupins that can be incorporated in a diet for weaner pigs.

The change in diet from sows' milk to solid feed at weaning disrupts the structure and function of the gastro-intestinal tract (GIT). Post-weaning diarrhoea (PWD) is often a consequence of this malaise. In this regard, the role of dietary fibre in the post-weaning period has been studied, with the source, type, structure and absolute amount of fibre in the diet all known to have effects on the structure and function of the GIT (e.g., Pluske et al., 2002; de Lange et al., 2010). Previous research by Kim et al. (2008b) showed that a small amount of insoluble fibre, as oat hulls, was beneficial for prevention of PWD, while soluble fibres are seemingly associated with proliferation of certain enteric pathogens (e.g., Pluske et al., 1996, Hopwood et al., 2004). As ASL contain two distinctive fibre sources in the hull (insoluble fibre, mostly cellulose, and xylose) and kernel (some pectin-like soluble fibres and largely fermentable fibres, polygalactouronans), increasing amounts of these fibres in diets for weaner pigs may promote or compromise GIT structure and function. No such experiments to measure the impact of lupin inclusion level on digestibility and indices of GIT function have been conducted, to our knowledge.

Therefore, the purpose of this study was to examine performance and intestinal responses to whole and dehulled ASL as alternatives to more expensive animal protein sources. The hypotheses tested in this experiment were: (1) performance of weaner pigs will decline as the inclusion level of whole and dehulled lupins increases in the diet; (2) weaner pigs fed dehulled lupins will perform better than pigs fed whole lupins at the same rate; and (3) indices of GIT function such as faecal consistency and β-haemolytic *E. coli* score will be compromised when pigs are fed more than 180 g/kg whole or dehulled lupins.

2. Materials and methods

The experimental protocol used in this study was approved by the Department of Agriculture and Food Western Australia Animal Ethics committee (AEC 6-08-41). Animals were handled according to the Australian code of practice for the care and use of animals for scientific purposes (NHMRC, 2004).

2.1 Lupins, diets, animals, and experimental design

A high protein ASL, cv. Coromup, was selected for the study because it is the variety most likely to be grown in the future in Western Australia (WA). In turn, WA produces approximately 80% of the world's angustifolius lupins (FAOSTAT, 2008). The lupin was collected from the northern agricultural region of WA (Geraldton, WA) which has a reasonably generic soil type (sand over loam). The lupin contained 319 g protein, 346 g insoluble non-starch polysaccharides (NSP) and 24 g soluble NSP (Kim et al., 2009a).

A total of 180 entire male pigs weaned at 21 days of age and weighing 6.4 ± 0.1 kg (mean ± SEM) was acquired from a high health status commercial farm and be transported to the Medina Research Station. Two replicate studies using 90 pigs per replicate were conducted, with an interval of a month between each. Upon arrival, pigs were weighed, ear tagged, housed as pairs (space allowance 0.4 m^2 per pig) and were allocated to 9 dietary treatments based on weaning weight.

The experiment was a completely randomised block design with 9 dietary treatments, as follows: (i) a wheat-based control diet containing 240 g/kg of whey and skim milk powder, and (ii) 8 diets containing whole or dehulled lupins (cv. Coramup) that substituted the milk products at 60, 120, 180 and 240 g/kg of diet (replace 25, 50, 75, or 100% of the milk products in the control diets). The whole and dehulled lupins were hammermilled to a mean particle size of 700 μm and directly dumped into the mixer. Digestible energy and ileal digestible indispensable AA contents were equalised using soy protein concentrate, canola oil, full fat soya and meat meal. The diets were isoenergetic (15 MJ/kg), and were formulated to contain the same ileal standardised digestible lysine content (Sauvant 2003, 0.85 g/MJ DE) and ideal patterns of other indispensable AA. Composition and chemical contents of diets are presented in Table 1. All diets contained 2 g/kg titanium dioxide as a digestibility marker (Short et al., 1996) to estimate the total tract apparent digestibility (TTAD) of dry matter (DM). Nutrient composition of dehulled lupins was not chemically determined but used tabulated value (Table 2) reported in the previous publication (Kim et al., 2007), as chemical composition of lupin kernels are not variable.

2.2 Experimental procedure and measurements

Pigs were fed their respective diets as a mash form and on an *ad libitum* basis for 3 weeks. Fresh water was available throughout the experiment. Pigs were weighed weekly and feed intake was measured on a daily basis. Pigs having diarrhoea (score 4; see below) were treated with Trisoprim-480 (trimethropin 80 mg/ml, sulfadiazine, 400 mg/ml, 0.05 ml/kg body weight, Troy Laboratories, Smithfield, NSW, Australia) until considered healthy and the number of antibiotic treatments was recorded. The antibiotic treatment was initiated when the faecal score exceeds 4 and ceased at 3 (Kim et al., 2008b).

Faecal consistency and incidence of diarrhoea of individual pigs were visually assessed daily for the first 2 weeks. Faecal consistency was determined using the following scoring criteria: 1 = well-formed faeces, firm to cut; 2 = formed faeces, soft to cut; 3 = faeces falling out of shape upon contact with surfaces, sloppy; 4 = pasty and liquid diarrhoea. Data for faecal consistency were then expressed as the mean faecal consistency value of pigs within a diet having the score 1 (25 %), score 2 (50 %), score 3 (75 %), and score 4 (100 %). A faecal consistency score of 4 represented pigs with diarrhoea, and the incidence of PWD was express as the mean proportion of days pigs had faecal score 4 with respect to days (14 d) (after Mateos et al. 2006).

Faecal swabs from individual pigs were taken on days 0, 3, 5, 7 and 9 to examine the degree of β-haemolytic *E. coli* proliferation (Kim et al., 2008b). Swabs were cultured onto sheep blood (50 ml/L) agar plates (Columbia base, Oxoid, London, UK) and then assessed for β-haemolytic colonies displaying the characteristic morphology of *E. coli*, after overnight incubation at 37°C in air (McDonald et al. 2001). The sheep blood agar plates were given a swab score according to the number of streaked sections that contained viable haemolytic *E. coli*, where: 0 = no growth, 1 = haemolytic *E. coli* in 1st section, 2 = haemolytic *E. coli* in 2nd section, 3 = haemolytic *E. coli* in 3rd section, 4 = haemolytic *E. coli* in 4th section, 5 = haemolytic *E. coli* present right out to the 5th section of the plate.

Faecal samples were collected from the pen floor as voided by the pigs for 3 consecutive days at the end of weeks 1 and 3 to determine faecal moisture content and the TTAD of DM. Samples were pooled per pen at the end of each collection and subsamples were stored at -20°C until analyzed.

Blood samples were collected from individual pigs on days 7 and 21. Samples were collected from anterior vena cava into lithium heparin coated vacutainer. The blood samples were immediately placed on ice and then centrifuged at 2,000 × g for

10 minutes at 5°C. Plasma was stored at -20°C until analyzed for plasma urea nitrogen (PUN).

2.3 Chemical analyses

The PUN level was determined using an enzymatic (urease) kinetic method (Randox, Crumlin, Co. Antrim, UK). Dry matter was measured using the AOAC official method 930.15 (AOAC 1997). Titanium dioxide (TiO_2) was measured spectrophotometrically at 410 nm after acid hydrolysis (7·4 M-H_2SO_4; Short et al., 1996). The nitrogen (N) content was determined using combustion method 990.03 (AOAC 1997). Crude protein content was calculated as N content × 6.25. Crude fat content was determined using AOAC official method 2003.06 (AOAC, 1997). The neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined using the AOAC official method 925.10 (AOAC, 1997). Gross energy content was determined using a ballistic bomb calorimeter (SANYO Gallenkamp, Loughborough, UK). Total phosphorus (P) was determined using inductively-coupled atomic emission spectroscopy as described by McQuaker et al. (1979). Phytate-P content was determined spectrophotometrically using the principle that phytate forms stable complexes with ferric ions in dilute acid solution (Xu et al., 1992). The insoluble and soluble NSP content of the lupin samples was determined as alditol acetates by gas-liquid chromatography (GLC) using the method of Theander and Westerlund (1993). Total NSP content was calculated by adding the insoluble and soluble NSP contents. The sum of insoluble and soluble NSP was calculated using the following polymerization factors:

Sum of total, insoluble and soluble NSP = (Rha + Fuc + Rib) × 0.89 + (Ara + Xyl) × 0.88 + (Man + Gal + Glu) × 0.90,

where Rha = rhamnose; Fuc = fucose; Rib = ribose; Ara = arabinose; Xyl = Xylose; Man = mannose; Gal = galactose; Glu = glucose.

Polymerization factors were used to correct for differences in total molecular weights due to dehydration during the polymerization process. For example, each glucosidic linkage for a glucose (hexose) molecule loses one molecule of water during polymerization. Therefore, a factor of 0.9 was used in the calculation to account for differences in molecular weights between glucose (180) and water (18) [i.e., (180 − 18) / 180 = 0.9]. The same calculation was applied for deoxysugars (molecular weight 164 and hence a factor of 0.89) and pentoses (molecular weight 150 and hence a factor of 0.88).

2.4 Statistics

There were no replication effects and data were pooled for subsequent statistical analyses. The individual pig was considered as the experimental unit for all measurements (n=20) except performance indices, faecal DM content and faecal DM digestibility, in which a pen was the experimental unit (n=10). The treatment effects were assessed by one-way analysis of variance (ANOVA) and faecal score was analysed using repeated measure ANOVA as it was recorded daily for 14 days. When significant diet effect was found in the ANOVA test, then the variables were tested for Fisher's-protected least significant difference analysis to separate means where significant main effect occurred under the ANOVA analysis. Pigs were blocked based on weaning weight and the block was used as a random factor in the model for all measured experimental variables. Initial BW was used as a covariate for growth data analyses. Where significant treatment effect was evident, then the data were subjected to a simple linear regression analysis to establish linear relationship between dietary concentration of whole or dehulled lupins and TTAD DM. Statistically significant difference between treatments was accepted at $P<0.05$. The statistical analyses were conducted using the statistical package Genstat 10.0 for Windows (VSN International Ltd., Hemel Hempstead, UK).

3. Results

3.1 Post-weaning performance

Pigs fed diets containing whole lupins up to 240 g/kg and dehulled lupins up to 180 g/kg ate comparable amounts of feed and had similar feed conversion ratio (FCR) and daily gains compared to pigs fed the milk-powder-based control diet. Although FCR was comparable, pigs receiving 240 g/kg of dehulled lupins grew slower ($P<0.05$) than pigs fed the other diets, predominantly due to decreased feed intake (Table 3).

3.2 Indices of GIT function

Faecal consistency, the number of antibiotic treatments, and the incidence of PWD were generally low and unaffected by up to 240 g/kg inclusion of whole or dehulled lupins in the diet (Table 4). However, pigs fed diets containing 180 g/kg and 240 g/kg of dehulled lupins had greater faecal β-haemolytic *E. coli* scores on day 3 after weaning ($P<0.05$, Figure 1). Faecal β-haemolytic *E. coli* scores were not different in the other days. Inclusion of 240 g/kg of whole lupin or more than 180 g/kg of dehulled lupins increased (P<0.001) the PUN level. Increased dispensable amino acid levels in the diets with greater lupin concentrations showed a positive relationship to the PUN level (Figure 2).

3.3 Total tract apparent digestibility of dry matter

The TTAD of DM decreased (P<0.001) as inclusion of lupins was increased, and the extent of the reduction was greater in the whole lupin diet than in the dehulled lupin diet (Figure 3). The TTAD of DM was negatively correlated to the NDF and ADF concentration of the diets (P<0.001, Figure 3).

4. Discussion

It was hypothesised that feed intake, daily gain and FCR of weaner pigs would be significantly reduced when both whole and dehulled lupins above the current recommended level of 150 g/kg were included. This expectation was based on the previous findings that (1) lupins contain greater levels of NSP in hulls and kernels, which may alter the physiological properties of digesta and influence digestibility (Gdala et al., 1997; Kim et al., 2007); (2) ileal digestibility of energy decreased linearly with increasing lupin kernel concentration in 45 kg grower pigs (van Barneveld et al., 1995); (3) feeding lupins increased endogenous protein loss due mainly to higher NSP contents (Salgado et al., 2002; Rubio et al., 2005); and (4) inclusion of slowly-digestible insoluble NSP in a weaner pig diet limits the physical capacity of the GIT and hence limits voluntary feed intake (Kyriazakis and Emmans, 1995).

In the present study, weaner pigs responded differently to insoluble NSP (hulls) and partly soluble NSP (kernels) of the lupin variety fed. Lupin hulls contain 880 g/kg

NSP with 500 g/kg being cellulose, whereas lupin kernels contain 300 g/kg NSP with more than 200g/kg being galacturonic acids (Evans et al., 1993). Pigs fed 240 g/kg dehulled lupins ate less feed and hence grew slower than other pigs, although their short-term growth retardation disappeared in the growing-finishing phases of growth, whereas pigs fed 240 g/kg whole lupins showed comparable intake and daily gain to the pigs fed the milk powder-based control diet. As FCR was not affected by any of the experimental diets, reduced daily again in pigs fed 240g/kg dehulled lupins was caused by decreased feed intake. Inclusion of lupin kernels, containing approximately 300 g fermentable NSP, can decrease the net energy value of the diet (Taverner et al., 1983; Kim et al., 2007). However, decreased feed intake but not FCR indicates that dietary energy was not a limiting factor in the 240 g/kg dehulled lupin diet (Ferguson et al., 2003). Rather, the results suggest that ASL in either form (i.e., dehulled or whole) does not influence nutrient utilisation efficiency but excess inclusion of fermentable lupin kernel fibre limits the physical capacity of the GIT and hence reduces feed intake. This is most likely due to the greater amount of structural cell wall component of lupin kernel endosperms (Vincken et al., 2003). These structural polysaccharides may have altered the physico-chemical properties of the digesta (i.e., increased viscosity and fermentation by-products) in the GIT and limited feed intake, possibly by increasing gastric distension and increasing digesta transition time once the inclusion levels of the dehulled lupin exceeded 180 g/kg (Kyriazakis and Emmans, 1995; Choct et al., 1996; Choct and Kocher, 2000; Dunshea et al., 2001). On the other hand, these findings also indicate that supplementation of lupin hulls, which is mostly insoluble NSP, can remove the deleterious effect of lupin kernel endosperm polysaccharides, although the mechanism behind this was not explored herein. Nevertheless and based on these findings, it is clear that inclusion of dehulled lupins in the diet for young pigs should be limited to current recommended inclusion level of 150 g/kg, while inclusion of whole lupins can be increased up to 240 g/kg.

Although NDF content of the diets were not analysed and used calculated values from previous publications, it is worth to discuss possible impact of dietary NDF due to increasing lupin concentration on the TTAD of DM. A linear reduction in TTAD of DM was expected with the increased amounts of both whole and dehulled lupins in the diet, as dietary NDF increases with increasing inclusion of dehulled and whole lupins. However and as Figure 3 shows, only whole lupin concentration linearly decreased the TTAD of DM whereas increasing dehulled lupin concentration decreased TTAD DM in a non-linear manner. This finding indicates that a significant proportion of lupin kernel fibre was fermented in the large intestine while fermentation of lupin hull fibre was minimal, as previously reported (Taverner et al., 1983; Kim et al., 2009b). Therefore, the significantly decreased TTAD of DM in ASL-supplemented diets can be attributed to the dilution effect of insoluble fibre but not to the fermentable lupin kernel endosperm structural fibre, as found in the relationship between fibre content and the TTAD of DM (Figure 3). A similar relationship between NDF and the TTAD of energy was reported previously (Le Goff et al., 2002), where TTAD of energy was decreased by 0.1% per 1 g increase in dietary NDF. Our study showed a 0.19 and 0.23% reduction in TTAD DM per gram increase in dietary NDF and ADF, respectively.

A purported benefit of feeding greater amounts of highly-digestible milk powder in diets after weaning is amelioration of the post-weaning growth check (e.g., increased daily gain in the first week after weaning; Kim et al., 2010) and improved ‘health’ of the GIT. Inclusion of lactose through dietary milk products has been shown to improve indices of intestinal health, for example by reducing digesta pH through production of lactic acid (Pierce et al., 2006), increasing *Lactobacilli* populations (Dillon et al., 2010; Kim et al., 2010) and decreasing the coliform population (Kim et al., 2010), although supplementation of lactose did not prevent villous atrophy (Vente-Spreeuwenberg et al., 2003). With this in mind, the current experiment attempted to replace milk products with a mixture of insoluble (whole lupins) and partly soluble (dehulled lupins) fibres or partly soluble fibre solely, and examined indices of GIT function and whole-of-life performance. Only a very small number of pigs developed PWD, and therefore a definitive conclusion as to whether these different types of fibre affected intestinal health cannot be made. However, the significant increase in the faecal β-haemolytic *E. coli* score in pigs fed more than 180 g dehulled lupins/kg diets (Figure 1) suggests that fermentable lupin fibre may have negative effects on GIT function, however this was not observed in more PWD. It is likely that polygalacturonans (major polysaccharides in lupin kernel) increased water holding capacity and increased digesta retention time in the GIT, which is evident in the decreased feed intake in 240 kg/kg dehulled lupin-fed pigs. In turn, increased retention time and availability of fermentable fibre contributed to higher proliferation of β-haemolytic *E. coli*.

5. Conclusions

Use of whole Australian sweet lupins up to 240 g/kg in diets for weaner pigs did not affect performance and indices of intestinal health most likely because of a insoluble NSP in the hull, that in turn possibly altered physico-chemical property of the digesta. However, feeding a diet containing greater than 180 g/kg dehulled lupins significantly compromised feed intake and hence growth of the pigs, and stimulated the proliferation of β-haemolytic strains of *E. coli* in the gastrointestinal tract.

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Table 1

Composition and calculated analysis of the experimental diets (g/kg, as-fed basis)

Ingredient	Control[a]	Whole lupin, g/kg				Dehulled lupin, g/kg			
		60	120	180	240	60	120	180	240
Wheat	417	407	407	411	397	430	453	448	446
Cooked oats	150	150	150	150	150	150	150	150	150
Whole lupin	0	60	120	180	240	-	-	-	-
Dehulled lupin	-	-	-	-	-	60	120	180	240
Full fat soya	25	50	43	24	19	30	3	11	9
Soycomil[b]	53	26	10	10	10	24	10	10	7
Meat meal	4	11	23	22	38	15	26	10	19
Fishmeal	100	100	100	100	100	100	100	100	100
Skim milk	120	90	60	30	-	90	60	30	-
Whey	120	90	60	30	-	90	60	30	-
Canola oil	-	5	15	27	34	-	5	6	5
L-Lysine	0.4	1.1	1.9	2.6	2.6	1.4	2.4	2.6	2.6
DL-Methionine	0.7	0.9	1.2	1.4	1.4	1.0	1.3	1.4	1.4
Threonine	-	0.08	0.47	0.79	0.80	0.22	0.72	0.87	0.89
Tryptophane	-	-	0.04	0.17	0.24	-	0.09	0.11	0.15
Vitamin/Mineral Premix[c]	1	1	1	1	1	1	1	1	1
Limestone	3.7	3.3	1.6	3.8	0.4	2.3	0.9	8.8	7.6
Dicalcium Phosphate	-	-	-	-	-	-	-	3.9	4.6
Salt	1	1	1	1	1	1	1	1	1
Znic oxide	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Choline Chloride	-	-	-	-	-	-	0.22	0.47	0.65
TiO_2[d]	2	2	2	2	2	2	2	2	2
Calculated composition [g/kg as-fed]									
DE [MJ/kg]	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
NE [MJ/kg]	10.2	10.3	10.5	10.7	10.8	10.2	10.4	10.4	10.5
Crude protein	230	230	230	230	240	230	230	234	245
Crude fat	34	47	60	71	81	40	45	49	52
Calcium	9.0	9.0	9.0	9.2	9.0	9.0	9.0	10.8	11.0
FD P[e]	5.2	5.0	5.0	4.5	4.7	5.1	5.0	4.5	4.5
NDF	70	85	99	112	124	77	83	87	92
ADF	15	28	39	49	60	1.6	16	16	16
Lignin	4.6	5.7	6.6	7.4	8.2	4.8	4.7	4.8	4.7
Calculated SID[f] AA content [g/kg as-fed]									
Indispensable AA									

Lysine	14.4	14.4	14.5	14.5	14.6	14.4	14.3	14.2	14.3
Methionine	5.4	5.3	5.3	5.3	5.2	5.3	5.3	5.2	5.1
Threonine	9.5	9.3	9.3	9.3	9.4	9.3	9.3	9.3	9.4
Tryptophan	3.1	3.0	2.9	2.9	2.9	2.9	2.8	2.8	2.9
Isoleucine	10.6	10.2	9.8	9.4	9.5	10.0	9.4	9.4	9.5
Leucine	17.8	17.3	16.6	16.1	16.4	17.1	16.3	16.2	16.5
Valine	11.9	11.5	11.2	10.9	11.1	11.4	10.9	10.7	10.8
Arginine	12.3	13.7	15.0	16.3	18.4	13.6	14.8	16.6	18.8
Histidine	5.8	5.8	5.7	5.7	5.9	5.7	5.6	5.7	6.0
Phenylalanine	10.3	10.1	9.8	9.6	9.9	9.9	9.5	9.7	10.0
Dispensable AA									
Alanine	8.2	9.2	9.8	9.8	10.6	9.1	9.6	9.5	10.2
Aspartic	13.8	16.2	17.3	17.5	18.8	15.8	16.3	17.4	18.8
Glutamine	33.9	38.4	41.3	42.7	45.5	38.6	41.4	44.1	47.8
Glycine	8.5	9.9	11.1	11.4	12.9	10.0	11.1	10.9	12.2
Proline	12.8	13.6	14.0	13.7	14.2	13.6	13.8	13.3	13.6
Serine	8.5	9.5	9.9	9.9	10.5	9.4	9.7	10.1	10.7
Tyrosine	6.6	7.1	7.2	7.1	7.2	7.1	7.2	7.4	7.7
Cystine	3.3	3.4	3.4	3.5	3.7	3.4	3.4	3.6	3.8

[a] Basal diet contained none of either whole or dehulled lupins

[b] Soycomil, soy protein concentrate (ADM Specialty Ingredients, Netherlands)

[c] Provided the following nutrients (per kg of air-dry diet):

Vitamins: A 7000 IU, D_3 1400 IU, E 20 mg, K 1 mg, B_1 1 mg, B_2 3 mg, B_6 1.5 mg, B_{12} 15 µg, Calcium pantothenate 10.7 mg, Folic acid 0.2 mg, Niacin 12 mg, Biotin 30 µg.

Minerals: Co 0.2mg (as cobalt sulphate), Cu 10 mg(as copper sulphate), Iodine 0.5 mg (as potassium iodine), Iron 60 mg (as Ferrous sulphate), Mn 40 mg (as manganous oxide), Se 0.3 mg (as Sodium Selenite). Zn 100 mg (as zinc oxide). (BJ Grower 1, BioJohn Pty Ltd., WA, Australia)

[d] Titanium dioxide (TiO_2; Sigma Chemical Company, St. Louis, MO, USA)

[e] FD P: faecal digestible phosphorus

[f] SID: standardised ileal digestible

Table 2. Analysed chemical composition (g/kg, as-fed basis) of Australian sweet lupin cultivar Coromup and tabulated chemical composition of dehulled lupins.

Item	Whole lupin, Coromup	Dehulled lupin[b]
Dry matter	916	900
Gross energy, MJ/kg	18.4	18.9
Crude protein	319	380
Crude fat	62	71
Neutral detergent fibre	244	58
Acid detergent fibre	222	32
Lignin	19	0.8
Total NSP[a]	370	270
Rhamnose	2.8	7.2
Fucose	1.1	-
Ribose	0.9	-
Arabinose	54	35
Xylose	41	6
Mannose	8	1.8
Galactose	159	181
Glucose	146	13.5
Insoluble NSP	346	231
Rhamnose	2.5	5.4
Fucose	1.1	-
Ribose	0.6	-
Arabinose	49	31.4
Xylose	37	5.1
Mannose	4.7	-
Galactose	146	154
Glucose	146	12.6
Soluble NSP	24	39
Rhamnose	0.3	1.8
Fucose	-	-
Ribose	0.3	-
Arabinose	5.1	3.6
Xylose	4.1	0.9
Mannose	3.4	1.8
Galactose	13	27
Glucose	0.5	0.9
Total phosphorus	3.5	1.0
Phytate phosphorus	2.2	

[a] NSP: non-starch polysaccharides

[b] Tabulated value (Evans et al., 1993; King et al., 2000; Kim et al., 2007)

Table 3

Effect of dehulling and concentration of lupins in the diet for weaner pigs on performance of weaner pigs measured for 21 days after weaning.

Item	Control[a]	Whole lupin, g/kg				Dehulled, g/kg				SEM[b]	P- value[c]
		60	120	180	240	60	120	180	240		
Average daily gain	324	351	342	364	344	362	359	326	305	6.4	0.040
Average daily feed intake	509	523	524	519	498	516	502	507	424	10.6	0.202
Feed conversion ratio	1.56	1.46	1.55	1.43	1.43	1.44	1.36	1.52	1.49	0.029	0.734

[a] Basal diet contained none of either whole or dehulled lupins.

[b] Pooled standard error of mean.

[c] Significance level: NS: Not significant.

Table 4

Effect of dehulling and concentration of lupins in the diet for weaner pigs on faecal consistency, faecal dry matter, incidence of PWD and number of antibiotic treatment.

Item	Control[a]	Whole lupin, g/kg				Dehulled lupin, g/kg				SEM[b]	P-value[c]
		60	120	180	240	60	120	180	240		
n=	20	20	20	20	20	20	20	20	20		
Faecal consistency[d], %											
d 1-7	22.1	22.6	22.0	21.6	24.4	24.6	22.6	24.1	22.3	0.410	NS
d 8-14	22.4	23.7	21.6	20.6	21.9	22.9	22.6	22.9	22.6	0.355	NS
Faecal DM, %[e]											
d 7	31.8	37.1	34.0	30.6	35.3	31.3	34.4	32.9	35.2	0.69	NS
d 21	29.5	28.4	28.2	29.2	30.9	28.4	27.5	29.3	30.1	0.26	NS
Incidence of PWD[f], %											
d 1-7	2.1	0.7	0.7	0.7	2.9	2.9	2.9	2.1	0.7	0.42	NS
d 8-14	0.0	0.7	0.0	0.0	0.7	0.7	0.0	0.0	1.4	0.21	NS
Number of antibiotic treatments[g]											
d 1-7	0.1	0.1	0.1	0.0	0.3	0.2	0.2	0.2	0.1	0.03	NS
d 8-14	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.01	NS

[a] Basal diet contained none of either whole or dehulled lupins.

[b] Pooled standard error of mean.

[c] Significance level: NS: Not significant.

[d] Faecal consistency was expressed as % cumulative score per day of pigs having more liquid faeces; higher values are associated with more liquid faeces.

[e] The pen was experimental unit for faecal DM analysis (n=10).

[f] A faecal consistency score of either 4 or 5 represented pigs with PWD, observed during the first14-days after weaning, is expressed as the mean percentage of days with diarrhoea relative to the total 14 days after weaning. Data are mean values per treatment combination assessed between days 1-14.

[g] Mean for total number of pigs injected with antibiotics with respect to the number of pigs in each feeding group.

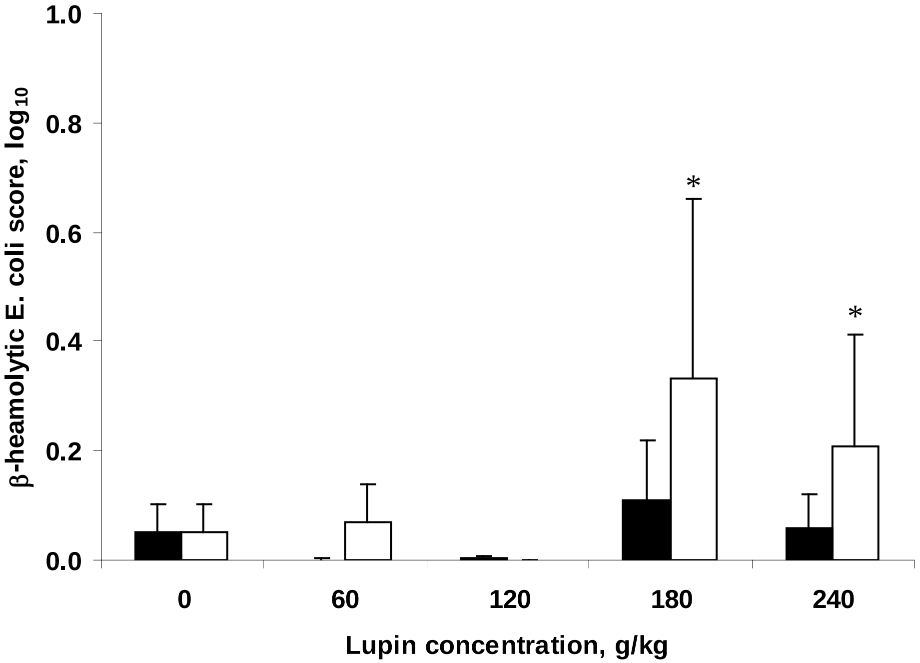

Figure 1 Effect of dehulled (☐) or whole (■) lupin concentration on faecal β-haemolytic *E. coli* score ($\log_{10}$) at day 3 after weaning.

Significance: * $P < 0.05$

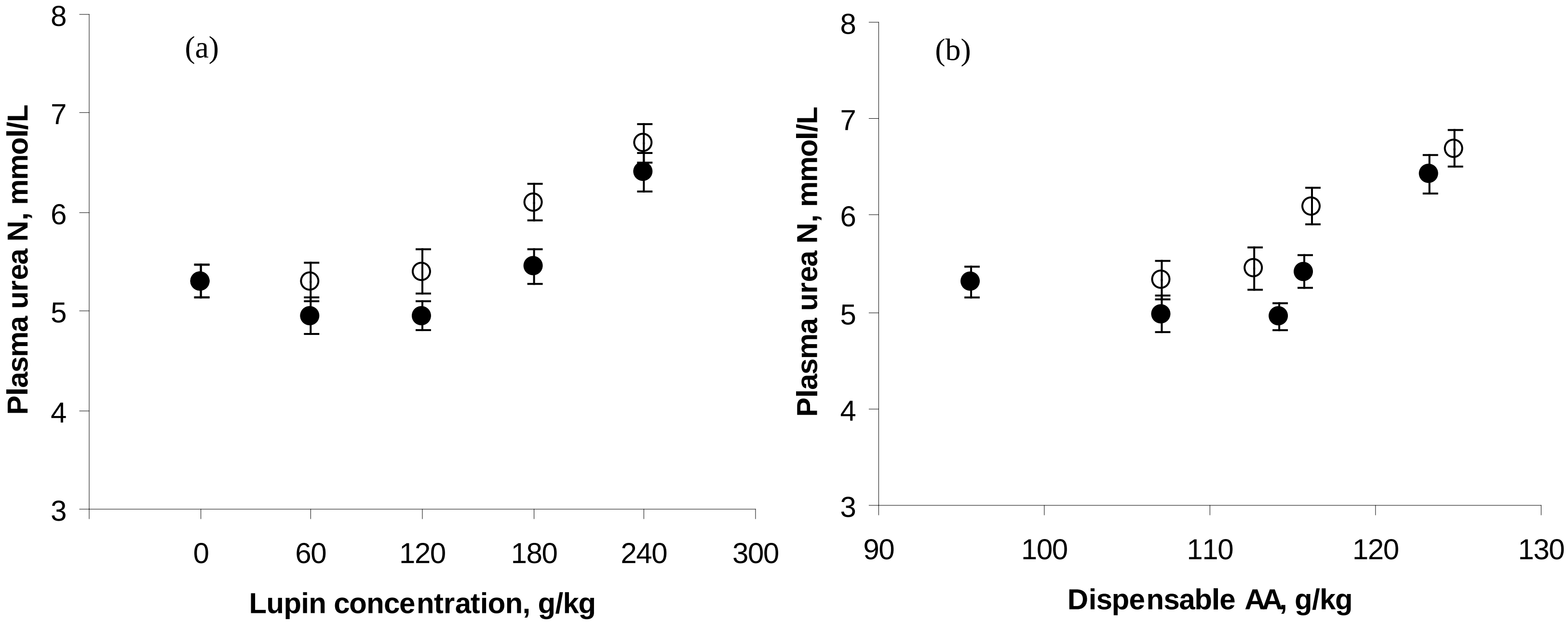

Figure 2

(a) Effect of dehulled (○) or whole (●) lupin concentration on plasma urea nitrogen (PUN) concentration ($P < 0.001$); and (b) relationship between dietary dispensable amino acids (AA) and PUN concentration ($P<0.001$). The PUN concentration was measured on day 6 and 12 after weaning from 20 pigs per treatment ($n=40$).

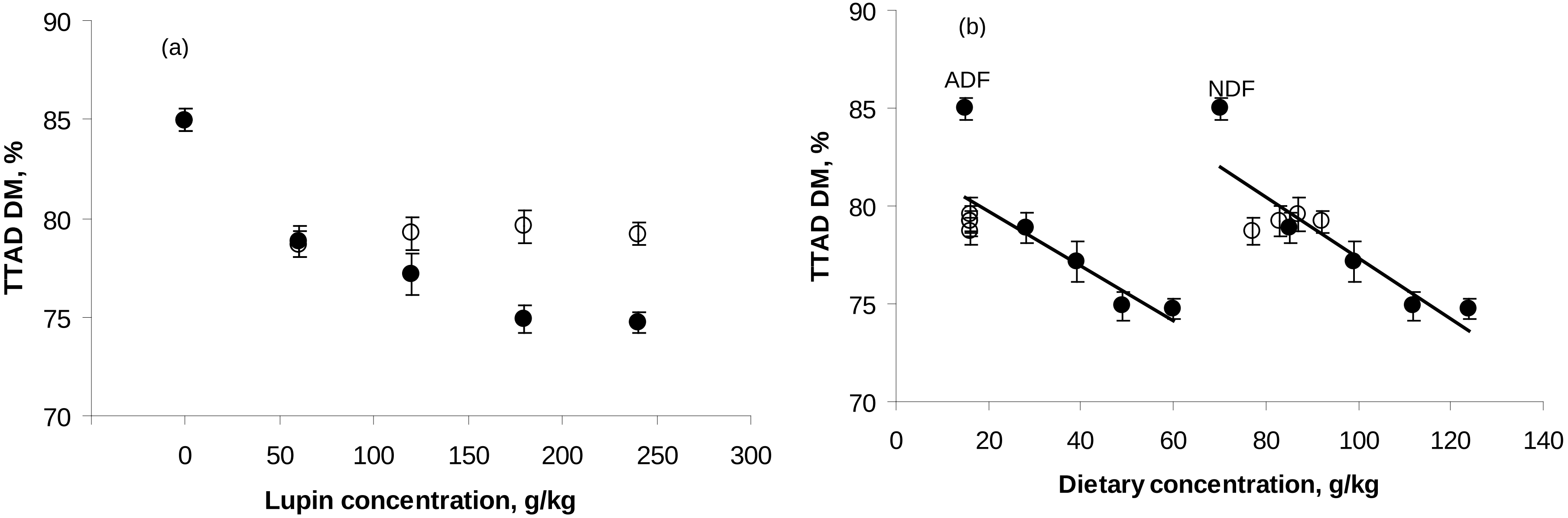

Figure 3. (a) Effect of dehulled (○) or whole (●) lupin concentration on total tract apparent digestibility (TTAD) of dry matter (DM) ($P < 0.001$); and (b) linear relationship between TTAD of DM and dietary fiber concentration [Acid detergent fibre (ADF): $y = -0.14x + 82.6$, $R^2 = 0.63$; Neutral detergent fibre (NDF): $y = -0.16x + 92.9$, $R^2 = 0.77$] ($P<0.001$). Total tract apparent digestibility of DM was repeatedly measured on day 7 and 21 after weaning from 10 pens per treatment (n = 20).