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Effect of Australian sweet lupin (*L. angustifolius* L.) inclusion levels and enzyme supplementation on the performance, carcass composition and meat quality of grower/finisher pigs

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Abstract.

Two hundred and twenty-four crossbred male pigs (Large White x Landrace, initial body weight 27.2 kg ± 0.22) were used to determine the influence of dietary Australian sweet lupin (ASL) inclusion level and enzyme supplementation on growth performance, carcass composition and meat quality. The experiment was a 4 x 2 factorial design with the respective factors being ASL inclusion level (*L. angustifolius* L., cv Mandelup; 200, 250, 300 and 350 g/kg, in replacement of soybean meal) and enzyme supplementation (without or with supplemental enzyme; Allzyme SSF, Alltech Biotechnology, USA). Pigs (7 pigs per pen x 4 replicates per treatment = 28 pigs per enzyme by lupin-level combination) were fed grower diets between 27 kg to 50 kg, finisher diets between 50 kg to 75 kg and pre-sale diets between 75 kg to 107 kg, and daily gain and feed intake were measured weekly. At approximately 107 kg live weight, the pigs were slaughtered at a commercial abattoir and carcass composition was measured. Meat quality (pH, surface exudate, drip loss, cooking loss, meat colour and shear force) was measured from selected pigs (n=18) fed the lowest and highest lupin diets without enzyme supplementation. Increasing ASL inclusion level to 350 g/kg did not alter ($P > 0.05$) growth performance of pigs and did not influence ($P > 0.05$) carcass composition and meat quality. Likewise, addition of supplemental enzyme had no effect ($P > 0.05$) on growth performance and carcass composition. Lack of performance response to added enzyme complex is likely due either to the use of enzyme complex that was not substrate-specific for the lupin non-starch polysaccharides or to the high specification of the experimental diets which was inevitable when increasing inclusion levels of lupins. The results show that a current variety (Mandelup) of ASL can be used in grow/finish diets up to 350 g/kg without compromising growth, carcass composition or meat quality of pigs.

Additional Key Words: Australian Sweet Lupins, Pig, Enzyme, Growth performance, Carcass composition, Meat Quality

Introduction

Despite Australian sweet lupins ASL (ASL, *Lupinus angustifolius* L.) being an economical plant protein ingredient for growing and finishing pigs in Western Australia (WA), the inclusion level of ASL in the diets for growing and finishing pigs is restricted due to the presence of anti-nutritional factors (ANF) such as oligosaccharides and non-starch polysaccharides (NSP). . In a growth trial, for example, Mullan *et al.* (1997) concluded that the maximum inclusion level of ASL for optimum grower performance was 180 g/kg. These data were obtained using ASL varieties available 5-10 years ago, such as Gungurru, which represent only a small proportion of ASL currently fed to pigs. For example, the production of Gungurru in 2008 harvest was only 1% of total lupin production in Western Australia, while production of the new variety Mandelup was 62% (Dr B. Buirchell, personal communication). Comparison of chemical composition between a newer variety Mandelup and the old variety Gungurru showed that Mandelup contains a greater amount of insoluble NSP but has a comparable amino acid composition to Gungurru as summarized in Table 1. Therefore, studies using newer and more widely grown varieties that represent a greater proportion of the ASL fed to pigs in WA needs to be conducted.

Despite research indicating that the optimum inclusion rate for whole ASL in grower pigs diets is close to 200 g/kg (e.g. Mullan *et al*. 1997), inclusion levels often exceed these suggested maximum values in commercial diets in WA. Another possible concern when pigs are fed a diet containing a high concentration of ASL is carcass composition and meat quality. Previous publications reported that feeding lupin seeds to pigs decreased the dressing percentage of pigs and decreased back fat

thickness without influencing carcass leanness and lean meat percentage in the ham (King 1981; van Nevel *et al.* 2000).

To counteract the high levels of ANF in ASL and improve their nutritive value, some researchers have used supplementary enzymes to improve energy and amino acid digestibility in lupin-fed pigs (Gdala *et al.* 1997). Adding an enzyme, or more accurately an enzyme complex, that specifically targets lupin ANF has potential to improve digestibility, and could thus allow for higher inclusion levels of ASL in diets for grower and finisher pigs.

The purpose of this experiment therefore was to identify the optimum inclusion level of the current major variety of ASL (cv. Mandelup) grown in WA for grower and finisher pigs in terms of performance, carcass composition and meat quality. Furthermore, we wished to study the effects of a supplemental enzyme complex on performance and carcass composition of pigs, and to examine any interactions between the lupin inclusion level and enzyme supplementation.

Materials and Methods

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

Experimental design

Two hundred and twenty-four crossbred entire male pigs (Large White x Landrace) were transported at weaning to the Medina Research Station and, after

several weeks of acclimation, were allocated based on their live weight to one of the 8 treatment combinations [8 treatments (4 inclusion levels x 2 enzyme supplements)] at an average body weight of 27 kg ± 0.22. There were 7 pigs per pen and 4 replicates to give 28 pigs per enzyme by lupin-level combination. The experiment was a randomised design with a 2 x 4 factorial arrangement. The 8 diets were formulated to contain increasing concentrations of ASL (200, 250, 300 and 350 g/kg) without and with an added enzyme complex (Allzyme SSF added at 200 g/tonne). The enzyme complex contained minimum activities of 100 U 1,4-β-xylanase (EC 3.2.1.8), 30 U α-amylase (EC 3.2.1.1), 200 U β-glucanase (EC 3.2.1.6), 700 U protease (EC 3.4.23.18), 40 U cellulase (EC 3.2.1.4), 4000 U pectinase (EC 3.1.1.73), and 300 U phytase (EC 3.1.3.26) per kg product (Alltech Biotechnology, USA).

Diets, feeding and sample collection

All diets were formulated to contain equal amounts of ileal digestible amino acids and ileal digestible lysine to DE ratio (Tables 2 - 4). The lupin variety used was Mandelup because it comprises the greatest proportion of ASL grown in WA at the current time (Dr M. Sweetingham, DAFWA, *personal communication*), and therefore reflects the variety of lupin most likely to be in pig feeds in WA and also exported as stockfeed. Pigs were fed grower diets between 27 kg – 50 kg, finisher diets between 50 kg – 75 kg, and pre-sale diets between 75 kg – 107 kg. ASL were progressively substituted for wheat and soybean meal but diets were formulated to be isoenergetic and isonitrogenous by supplementation of canola oil and crystalline amino acids. Pigs were fed their respective diets *ad libitum* and fresh water was available throughout the experiment via swivel drinkers. The pens consisted of 60% solid concrete and 40% plastic slatted areas and had a space allowance of 0.93 m^2 per pig.

Measurements

Average daily gain and feed conversion ratio per pen were determined weekly until slaughter. Pigs were slaughtered in a commercial abattoir when their live weight reached≈107 kg, and carcass composition data were collected. Hot carcass weight was measured based on AUSMEAT trim 13 (head off, flare off, fore trotters off, hind trotters on). Dressing percentage was calculated as the ratio between live weight and hot carcass weight. P2 back fat was measured between the $12^{th}/13^{th}$ ribs of the left side of each carcass at 65 mm off the midline.

Eighteen pigs with median weight of the group were selected at slaughter from the lowest and highest lupin diets without enzyme supplementation to assess meat quality measurements. Muscle samples from the *longissimus thoracis* (LT) were taken between the $10^{th}/15^{th}$ ribs from the left side of each carcass (~ 1 kg) at 24 h post-slaughter. The pH of the LT was measured using a portable pH meter (Eutech Instruments, Cyberscan pH 3000 series, Singapore) at 24 h post-slaughter. The surface exudate of the LT was measured using the filter paper absorption method (filter paper-55 mm) (Kauffman *et al.* 1986). Forty eight hr drip loss was then calculated using the surface exudate values according to the regression equations reported by Kauffman *et al.* (1986). Meat colour was measured with a Minolta Chromameter CR-400, using D65 illumination, a 2º standard observer and 8 mm aperture in the measuring head, standardised to a white tile. Cooking loss was determined by weight differences by cooking LT muscles (~100 g) in a water bath at 80º C for 1 hr and cooled under running water for 30 min (Bouton *et al.* 1971). The cooked LT samples were stored at 4º C for 24 hrs and shear force was measured using

a Warner Bratzler shear blade fitted to an Instron Universal Testing Machine (Model 1122, Instron Pty, Ltd.; AMSA, 1978).

Statistical analyses

The General Linear Model (GLM) procedure of SPSS (version 14, SPSS Inc, Chicago, Illinois) was used to analyse the main effects of lupin inclusion level (L) and enzyme (E) and their interactions on growth performance and carcass composition. Meat quality, measured from selected pigs fed the lowest and highest lupin diets without enzyme supplementation, was assessed using GLM procedure. Pen was considered as the experimental unit for growth performance and pig was the experimental unit for analyses of carcass composition and meat quality. Slaughter weight was used as a covariate for carcass composition and meat quality assessment. Linear and quadratic effects of lupin inclusion level on these measurements were also examined.

Results

Growth performance

Dietary inclusion of up to 350g ASL per kg of grower, finisher and pre-sale diets did not alter ($P > 0.05$) growth performance of pigs. Consequently, days to reach 107 kg was similar ($P > 0.05$) regardless of the lupin concentration in the experimental diets. Moreover, with the lack of negative effects of lupin inclusion level on performance, supplementation of an enzyme complex did not improve ($P > 0.05$) growth performance and carcass characteristics. However, supplementation of the enzyme complex tended to increase feed intake without increasing growth rate during the pre-sale period ($P=0.054$, Table 5).

Carcass composition

Although increasing lupin inclusion level numerically decreased dressing percentage (not significant, linear effect P= 0.283), carcass composition was not influenced (P > 0.05) by either lupin inclusion level or by enzyme supplementation (Table 6).

Meat quality

The meat quality traits of pigs fed 350 g ASL/kg were not different (P > 0.05) from those of pigs fed 200 g ASL/kg (Table 7). However, the meat from pigs fed the 350 g/kg lupin diet showed a trend to be more tender (P=0.102) than that from pigs fed the 200 g/kg lupin diet.

Discussion

Chemical composition

Although there was a slight increase in the essential amino acid content in Mandelup, chemical composition of the old variety Gungurru and a newer variety Mandelup were comparable except that Mandelup had higher insoluble NSP than the older variety Gungurru. This change reflects the lupin breeding program that has targeted yield, drought tolerance and disease tolerance which have subsequently increased the amount of structural polysaccharides. This was also evident in the increased acid detergent fibre content of Mandelup compared with the old variety Gungurru. Increased insoluble NSP may have negative effects on nutrient utilization as a greater inclusion of insoluble NSP is associated with loss of amino acids through increased endogenous secretion such as mucins (Kim et al., 2007).

Growth performance

Using an older variety of *L angustifolius* (cv. Gungurru), previous Australian research showed that the maximum inclusion level that pigs could digest lupin kernel NSP and galactose in the small intestine of 45 kg pigs was 200g/kg, which is equivalent to 260 g/kg of whole lupin seeds (van Barneveld *et al.* 1995a). A concurrent digestibility study with the same cultivar showed that inclusion of ASL above this level significantly decreased ileal energy and lysine digestibilities and increased fermentation of NSP in the large intestine (van Barneveld *et al.* 1995b; 1995c). Based on these and other experiments, the maximum inclusion level of ASL in pig diets was recommended as 100-150 g/kg for weaners, 200-250 g/kg for growers and 300-350 kg for finishers (van Barneveld 1994). Despite the apparent negative nutritional influences of ASL in the GIT of pigs that have been reported, however, other research showed that if diets were formulated based on equal amounts of ileal digestible amino acids, ASL could be included to 400 g/kg in diets for weaner and grower pigs without compromising growth performance. For example, Fernandez and Batterham (1995) and Gdala *et al.* (1996) used 20 kg and 14 kg pigs, respectively, and fed diets containing more than 400 g ASL/kg (cv. Gungurru and Saturn, respectively) with supplementation of essential amino acids, and found no significant differences in growth performance of these pigs compared with pigs fed soybean meal-based diets. However, simple replacement of other protein sources such as soybean meal with angustifolius lupin seeds without adjustments for levels of ileal digestible amino acids showed an inferior production response due to the low lysine and sulphur amino acid contents in ASL (Hale and Miller 1985; McNiven and Castell 1995). Collectively, it is evident that ASL can be included up to 400 g/kg in grower/finisher diets as long as

the diets are formulated based on ileal digestible amino acids. Chemical analysis of Mandelup showed that the major difference between the old variety Gungurru and the newer variety Mandelup is the greater insoluble NSP content in Mandelup (Table 1). This increased insoluble NSP content may not influence nutrient utilization efficiency in the diets supplemented with greater amounts of angustifolius lupin according to the finding by Ferguson et al. (2003). This particular research demonstrated that the major ANF in angustifolius ASL is soluble NSP whereas addition of insoluble NSP had no effect on performance of pigs. Therefore, changes in chemical composition in the newer variety Mandelup may not have influenced the growth of pigs in this experiment.

Using the current variety *Mandelup* in the present experiment demonstrated that ASL could be used successfully up to 350 g/kg in diets for grower/finisher pigs without any signs of growth depression. However, and considering the higher NSP content of ASL seeds, supplementation of exogenous NSP-degrading enzymes to improve nutrient digestibility and hence performance of pigs was examined. The use of enzymes targeting specific types of NSP in ASL such as polygalacturonans in the kernels of ASL seeds is a probable strategy to improve the nutritive value of ASL. The NSP in ASL kernels are mostly pectic substances and are complex links within and between polygalacturonans (homogalcturonan, xylogalacturonan, rhamnogalacturonans) and neutral polysaccharides such as arabinans and arabinogalactans. Also, galactose residues of the polygalacturonans are methyl-esterfied at C-6 which protects access of pectinase as found in an *in vitro* study (Ali et al., 2005). This study showed that polygalacturonase supplementation breaks only 11% of the bonds due to the presence of the methyl-esterfied galactose residues which block the binding sites of polygalacturonans to the glucosidic bonds along the pectin

chain. Consequently, supplementation of pectin methyl esterase and polygalacturonase in combination with ground dehulled ASL (*L* angustifolius in 70 mL acid buffer) efficiently reduced the length of pectin chains by 65% and molecular weight of pectin by 56% (Ali et al., 2005). However, currently a commercial enzyme product targeting these complex structures is not available. Therefore, a commercial enzyme complex was selected which contains the enzymes thought to have the greatest positive effect on ASL, including pectinase.

Supplementation of the enzyme complex in ASL diets at all inclusion levels did not improve performance response of pigs throughout the entire growth period. This suggests either: (1) the dietary specifications used in this experiment (240 g, 180 g, and 180 g CP/kg for grower, finisher and pre-sale diets, respectively) exceeded the animal's requirements (180 g, 155 g, and 132 g/kg, respectively), (2) pigs between 27 kg to 107 kg could utilise nutrients from ASL without any negative effects caused by ASL oligosaccharides and NSP, and (or) (3) the enzyme complex was not sufficiently substrate-specific for the ASL kernel NSP. To formulate diets that were isoenergetic and isonitrogenous, including the diet containing 350 g ASL/kg, formulation of high-specification diets was inevitable because the simple addition of 350 g ASL and 600 g barley in the pre-sale diet resulted in a diet containing 170 g/kg of crude protein. Therefore, addition of enzymes may not be effective because pigs were already being supplied with sufficient nutrients to maximise growth. The finding that supplementation of the enzyme complex tended to increase feed intake during the pre-sale period but did not increase growth rate and hence feed efficiency could support this notion, at least in part.

Carcass composition

Feeding ground *angustifolius* and *albus* lupin seeds to pigs decreased dressing percentage of carcass and decreased back fat thickness without influencing carcass leanness and lean meat percentage in the ham (King 1981; King *et al*., 2000; van Nevel *et al.* 2000). This is mainly due to the extensive fermentation of dietary energy in the large intestine that causes: (1) higher intestinal tissue growth; and (2) modulation of energy digestion (Taverner *et al.* 1983). King (1981) and van Nevel *et al.* (2000) showed that every 100 g/kg inclusion of *albus* lupin seeds in grow/finish diets reduced dressing percentage by 0.7 to 1.4 percentage units. Albeit not significant in the present study, increasing ASL concentration from 200 g/kg to 350 g/kg decreased dressing percentage by 0.5 percentage units.

Meat quality

The purpose of the meat quality assessments in this experiment was to ascertain whether increasing dietary inclusion levels of ASL influenced meat quality as the source of dietary protein had a significant effect on meat quality of lambs (Ponnampalam et al., 2003). In that experiment the meat from lambs fed ASL was more tender mainly because lambs fed ASL had more intramuscular fat (Ponnampalam et al., 2003). This is probably due to conversion of pectins from lupin kernels to short-chain fatty acids in the rumen which may have increased the energy pool of the lambs. Our data showed that feeding high-ASL diets influenced none of the meat quality traits measured. The trend showing that the meat from pigs fed 350 g/kg ASL tended to be more tender than that from pigs fed 200 g/kg ASL was not expected, as utilization of fermentable fibre such as pectins are less efficient than ruminant animals, and all diets were formulated to be isoenergetic in this experiment. In a previous experiment, pigs fed either a 200 g/kg ASL-based diet or soybean meal-

based diets from 40 kg to 107 kg showed no effect on meat quality traits including tenderness (Moore 2001).

Conclusions

Results of the present experiment showed that if diets are formulated based on the ileal digestible amino acid content, a current variety of ASL (cv Mandelup) can be used up to 350 g/kg in diets for grower/finisher pigs without compromising growth performance, carcass composition or meat quality. A simple mix of wheat, barley and ASL with essential amino acid supplements supported daily gains of over 1 kg with an FCR of 2.7 kg/kg between 27 kg and 107 kg live weight without showing deleterious effects. It is unknown whether other ASL varieties grown in WA having different chemical compositions would respond in the same way.

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411 Table 1. Comparison of the chemical composition (g/kg, air-dry basis) between the
412 older variety (cv. Gungurru) and newer variety (cv. Mandelup) of Australian
413 sweet lupins (ASL).

	Chemical composition, g/kg	
Variety	Mandelup	Gungurru[A]
DM,	914	920
GE, MJ/kg	18.3	18.1
CP	294	320
Crude fat	61	53
Neutral detergent fibre	247	260
Acid detergent fibre	236	172
Total NSP	393	224
Insoluble NSP	366	204
Soluble NSP	27	20
Essential Amino Acids		
Arginine	29.1	30.2
Histidine	8.2	7.9
Isoleucine	13.3	11.5
Leucine	20.8	18.9
Lys ine	15.2	12.9
Methionine	1.7	1.6
Phenylalanine	11.9	11.6
Threonine	10.3	9.0
Valine	13.3	10.5

414 [A]van Barneveld (1997).
415

Table 2. Dietary and nutritional composition (g/kg, air-dry basis) of grower diets.

Lupin (g/kg)	200	250	300	350
Ingredient (g/kg)				
Barley 10% CP	150	150	150	150
Wheat 12% CP	390.0	333.3	307.7	283.4
Lupins (ASL)	200	250	300	350
Soybean meal	210.8	215.7	187.5	157.6
Canola oil	20.4	23.4	26.9	30
Lysine	1.5	0.7	1	1.2
Methionine	1	1	1.1	1.3
Threonine	0.1	-	-	-
Tryptophan	-	-	-	0.6
Dicalcium Phosphate	15	15	15	15
Limestone	8.8	8.6	8.5	8.5
Salt	1	1	1	1
Vit & Min[A]	0.7	0.7	0.7	0.7
Choline	0.6	0.6	0.6	0.6
Enzyme[B]	-(+)	-(+)	-(+)	-(+)
Total	1000	1000	1000	1000
Calculated Nutrient composition				
AID Lysine[C]	1.1	1.1	1.1	1.1
AID Methione+Cysstein	0.7	0.7	0.7	0.7
AID Threonine	0.7	0.7	0.7	0.7
AID Tryptophane	0.2	0.2	0.2	0.3
AID Luecine	1.4	1.4	1.4	1.4
AID Isoleucine	0.8	0.9	0.9	0.9
AID Phenylalanine+Tyrosine	1.6	1.6	1.6	1.6
AID Valine	0.9	0.9	0.9	0.9
AID Hisstidine	0.5	0.5	0.5	0.5
AID Lysine (g/MJ DE)	0.8	0.8	0.8	0.8
DE (MJ/Kg)	14.0	14.0	14.0	14.0
Ca	0.9	0.9	0.9	0.9
AFD P[D]	0.4	0.4	0.4	0.4
Crude fibre	6.0	6.7	7.2	7.7
Crude fat	4.8	5.3	5.8	6.3
Crude protein	23.1	24.0	24.0	24.0
Neutral Detergent Fibre	16.7	17.1	17.5	17.8
Diet cost (Aus$/tonne)[E]	462.8	463.5	458.7	454.9
Saving (Aus$/head)[F]		-0.04	0.24	0.47

[A]Provided the following nutrients (per kg of air-dry diet):Vitamins: A 4900 IU, D_3 980 IU, E 14 mg, K 0.7 mg, B_1 0.7 mg, B_2 2.1 mg, B_6 1.05 mg, B_{12} 10.5 µg, Calcium pantothenate 7.5 mg, Folic acid 0.13 mg, Niacin 8.4 mg, Biotin 21 µg; Minerals: Co 0.14 mg (as cobalt sulphate), Cu 7 mg (as copper sulphate), Iodine 0.35 mg (as potassium iodine), Iron 42 mg (as Ferrous sulphate), Mn 28 mg (as Manganese oxide), Se 0.21 mg (as Sodium Selenite), Zn 70 mg (as zinc oxide), Antioxident 14 mg. (BJ Grower 1, BioJohn Pty Ltd., WA, Australia).

[B]Allzyme SSF 200g/tonne diet (minimum activities 100 U 1,4-β-xylanase/kg, 30 U α-amylase, 200 U b-glucanase, 700 U protease, 40 U cellulose, 4000 U pectinase, and 300 U phytase; Alltech Biotechnology, USA), enzyme addition was exchanged with wheat.

[C]AID: apparent ileal digestible.

[D]AFD: apparent faecal digestible.

[E]Current diet cost (June 2008).

[F]Based on average feed intake of 60 kg/pig between 20 kg and 50 kg body weight.

Table 3. Dietary and nutritional composition (g/kg, air-dry basis) of finisher diets.

Lupin (g/kg)	200	250	300	350
Ingredient (g/kg)				
Barley 10% CP	545	524	503	488
Wheat 12% CP	100	100	100	100
Lupins (ASL)	200	250	300	350
Soybean meal	107	75	43	10
Canola oil	20.2	22.2	24.2	22.1
Lysine	1.2	1.6	1.9	2.2
Methionine	0.7	0.8	1.0	1.1
Threonine	0.0	0.0	0.1	0.2
Dicalcium Phosphate	14.3	14.3	14.3	14.3
Limestone	10.0	10.0	10.0	10.0
Salt	1.0	1.0	1.0	1.0
Vit & Min[A]	0.7	0.7	0.7	0.7
Choline	0.6	0.6	0.6	0.6
Enzyme[B]	-(+)	-(+)	-(+)	-(+)
Total	1000	1000	1000	1000
Calculated Nutrient composition				
AID Lysine[C]	0.8	0.8	0.8	0.8
AID Methione+Cysstein	0.5	0.5	0.5	0.5
AID Threonine	0.5	0.5	0.5	0.5
AID Tryptophane	0.2	0.2	0.2	0.1
AID Luecine	1.1	1.1	1.1	1.0
AID Isoleucine	0.6	0.6	0.6	0.6
AID Phenylalanine+Tyrosine	1.2	1.2	1.2	1.1
AID Valine	0.7	0.7	0.7	0.6
AID Hisstidine	0.4	0.4	0.4	0.4
AID Lysine (g/MJ DE)	0.6	0.6	0.6	0.6
DE (MJ/Kg)	13.3	13.3	13.3	13.2
Ca	0.9	0.9	0.9	0.9
AFD P[D]	0.4	0.4	0.4	0.4
Crude fibre	6.6	7.1	7.6	8.0
Crude fat	4.6	5.0	5.4	5.3
Crude protein	18.2	18.2	18.2	18.2
Neutral Detergent Fibre	19.2	19.5	19.7	20.0
Diet cost (Aus$/tonne)[E]	419.7	413.7	407.8	397.8
Saving (Aus$/head)[F]		0.39	0.77	1.42

[A]Provided the following nutrients (per kg of air-dry diet):Vitamins: A 4900 IU, D_3 980 IU, E 14 mg, K 0.7 mg, B_1 0.7 mg, B_2 2.1 mg, B_6 1.05 mg, B_{12} 10.5 μg, Calcium pantothenate 7.5 mg, Folic acid 0.13 mg, Niacin 8.4 mg, Biotin 21 μg; Minerals: Co 0.14 mg (as cobalt sulphate), Cu 7 mg (as copper sulphate), Iodine 0.35 mg (as potassium iodine), Iron 42 mg (as Ferrous sulphate), Mn 28 mg (as Manganese oxide), Se 0.21 mg (as Sodium Selenite), Zn 70 mg (as zinc oxide), Antioxident 14 mg. (BJ Grower 1, BioJohn Pty Ltd., WA, Australia).

[B]Allzyme SSF 200g/tonne diet (minimum activities 100 U 1,4-β-xylanase/kg, 30 U α-amylase, 200 U b-glucanase, 700 U protease, 40 U cellulose, 4000 U pectinase, and 300 U phytase; Alltech Biotechnology, USA), enzyme addition was exchanged with wheat.

[C]AID: apparent ileal digestible.

[D]AFD: apparent faecal digestible.

[E]Current diet cost (June 2008).

[F]Based on average feed intake of 65 kg/pig between 50 kg and 75 kg body weight.

Table 4. Dietary and nutritional composition (g/kg, air-dry basis) of pre-sale diets.

Lupin (g/kg)	200	250	300	350
Ingredient (g/kg)				
Barley 10% CP	671	641	622	601
Lupins (ASL)	200	250	300	350
Soybean meal	99	77	45	13
Canola oil	3.2	5.0	6.1	8.1
Lysine	-	0.05	0.4	0.7
Methionine	0.4	0.5	0.6	0.8
Dicalcium Phosphate	12.9	13.1	13.4	13.7
Limestone	11.0	10.8	10.6	10.4
Salt	1.0	1.0	1.0	1.0
Vit & Min[A]	0.7	0.7	0.7	0.7
Choline	0.8	0.8	0.8	0.8
Enzyme[B]	-(+)	-(+)	-(+)	-(+)
Total	1000	1000	1000	1000
Calculated Nutrient composition				
AID Lysine[C]	0.7	0.7	0.7	0.7
AID Methione+Cysstein	0.5	0.5	0.5	0.5
AID Threonine	0.5	0.5	0.5	0.5
AID Tryptophane	0.2	0.2	0.2	0.1
AID Luecine	1.1	1.1	1.0	1.0
AID Isoleucine	0.6	0.6	0.6	0.6
AID Phenylalanine+Tyrosine	1.2	1.2	1.2	1.1
AID Valine	0.7	0.7	0.7	0.6
AID Hisstidine	0.4	0.4	0.4	0.4
AID Lysine (g/MJ DE)	0.6	0.6	0.6	0.6
DE (MJ/Kg)	12.7	12.7	12.7	12.7
Ca	0.9	0.9	0.9	0.9
AFD P[D]	0.4	0.4	0.4	0.4
Crude fibre	7.0	7.4	7.9	8.4
Crude fat	2.9	3.3	3.6	3.9
Crude protein	17.6	17.9	17.9	17.9
Neutral Detergent Fibre	20.4	20.5	20.8	21.0
Diet cost (Aus$/tonne)[E]	395.5	391.3	384.5	378.7
Saving (Aus$/head)[F]		0.37	0.99	1.51

[A]Provided the following nutrients (per kg of air-dry diet):Vitamins: A 4900 IU, D_3 980 IU, E 14 mg, K 0.7 mg, B_1 0.7 mg, B_2 2.1 mg, B_6 1.05 mg, B_{12} 10.5 μg, Calcium pantothenate 7.5 mg, Folic acid 0.13 mg, Niacin 8.4 mg, Biotin 21 μg; Minerals: Co 0.14 mg (as cobalt sulphate), Cu 7 mg (as copper sulphate), Iodine 0.35 mg (as potassium iodine), Iron 42 mg (as Ferrous sulphate), Mn 28 mg (as Manganese oxide), Se 0.21 mg (as Sodium Selenite), Zn 70 mg (as zinc oxide), Antioxident 14 mg. (BJ Grower 1, BioJohn Pty Ltd., WA, Australia).

[B]Allzyme SSF 200g/tonne diet (minimum activities 100 U 1,4-β-xylanase/kg, 30 U α-amylase, 200 U b-glucanase, 700 U protease, 40 U cellulose, 4000 U pectinase, and 300 U phytase; Alltech Biotechnology, USA), enzyme addition was exchanged with wheat.

[C]AID: apparent ileal digestible.

[D]AFD: apparent faecal digestible.

[E]Current diet cost (June 2008).

[F]Based on average feed intake of 90 kg/pig between 75 kg and 105 kg body weight.

Table 5. Effects of Australian sweet lupin concentration and enzyme supplementation on the performance of grower pigs[A].

	Lupin concentration (g/kg)				Enzyme[B]		s.e.m.	Main effects		
	200	250	300	350	-	+		Lupin	Enzyme	LxE
Grower										
Initial wt	27.3	27.2	27.0	27.2	27.2	27.2	0.22	0.978	0.899	0.994
Final wt	53.7	53.5	53.2	53.4	53.3	53.6	0.42	0.986	0.802	0.970
ADG[C]	0.94	0.94	0.95	0.94	0.94	0.94	0.011	0.989	0.986	0.797
VFI	2.02	2.05	2.06	2.05	2.04	2.05	0.018	0.867	0.863	0.858
FCR	2.14	2.19	2.18	2.18	2.17	2.17	0.014	0.628	0.808	0.446
Finisher										
Initial wt	53.7	53.5	53.2	53.4	53.3	53.6	0.42	0.986	0.802	0.970
Final wt	76.1	75.6	75.2	75.8	75.4	76.0	0.50	0.948	0.576	0.952
ADG	1.07	1.05	1.04	1.08	1.05	1.07	0.012	0.645	0.504	0.713
VFI	2.64	2.65	2.65	2.64	2.63	2.66	0.033	0.999	0.656	0.767
FCR	2.49	2.52	2.56	2.44	2.50	2.50	0.036	0.749	0.958	0.824
Pre-sale										
Initial wt	76.1	75.6	75.2	75.8	75.4	76.0	0.50	0.948	0.576	0.952
Final wt	107.9	107.8	107.5	107.9	107.7	107.9	0.18	0.896	0.565	0.464
ADG	0.99	1.04	1.01	1.02	1.01	1.02	0.013	0.544	0.803	0.582
VFI	3.38	3.41	3.39	3.23	3.28	3.44	0.041	0.376	0.054	0.795
FCR	3.43	3.30	3.39	3.19	3.26	3.39	0.056	0.499	0.262	0.762
Total										
Initial wt	27.3	27.2	27.0	27.2	27.2	27.2	0.22	0.978	0.899	0.994
Final wt	107.9	107.8	107.5	107.9	107.7	107.9	0.18	0.896	0.565	0.464
ADG	1.00	1.01	1.01	1.03	1.01	1.01	0.008	0.694	0.602	0.791
VFI	2.72	2.74	2.76	2.68	2.69	2.76	0.020	0.505	0.079	0.322
FCR	2.73	2.71	2.74	2.62	2.68	2.72	0.027	0.459	0.447	0.751
Days to 104 kg	77.8	76.7	77.4	76.3	77.4	76.6	0.65	0.871	0.588	0.883

[A]There were 7 pigs per pen and 4 replicates to give 28 pigs per enzyme by lupin-level combination.

[B]Allzyme SSF 200g/tonne diet (minimum activities 100 U 1,4-β-xylanase/kg, 30 U α-amylase, 200 U b-glucanase, 700 U protease, 40 U cellulose, 4000 U pectinase, and 300 U phytase; Alltech Biotechnology, USA), enzyme addition was exchanged with wheat.

[C]Abbreviations: ADG-average daily gain; VFI: voluntary feed intake; FCR: feed conversion ratio.

Table 6. Effects of Australian sweet lupin concentration and enzyme supplementation on carcass composition[A].

	Lupin concentration (g/kg)				Enzyme			Main effects			Lupin effect	
	200	250	300	350	-	+	s.e.m.	Lupin	Enzyme	LxE	Linear	quadratic
Hot carcass weight[B]	69.9	70.0	69.7	69.5	69.7	69.9	0.18	0.824	0.710	0.793	0.392	0.749
Dressing %[C]	65.0	64.9	64.8	64.5	64.8	64.8	0.18	0.771	0.876	0.984	0.283	0.750
P2 Back fat[D]	13.6	13.5	14.0	14.0	13.7	13.9	0.23	0.821	0.719	0.532	0.397	0.937

[A]There were 7 pigs per pen and 4 replicates to give 28 pigs per enzyme by lupin-level combination.
[B]Hot carcass weight: AUSMEAT trim 13, head off, flare off, fore trotters off, hind trotters on.
[C]Based on hot carcass weight (AUSMEAT trim 13).
[D]Measured between $12^{th}/13^{th}$ rib.

474 Table 7. Effects of Australian sweet lupin concentration on meat quality measured in
475 the *Longissimus thoracis* muscle 24 hour after slaughter.

	Lupin inclusion rate			
	200 g/kg	350 g/kg	s.e.m.	Significance
n=	18	18		
Relative lightness (L*)	49.2	50.1	0.53	0.403
Relative redness (a*)	6.84	6.46	0.214	0.377
Relative yellowness (b*)	3.41	3.44	0.157	0.942
Ultimate pH	5.23	5.23	0.017	0.862
Surface exudates (mg)	58.3	53.9	3.11	0.486
48 h drip loss (%)[A]	3.40	3.13	0.186	0.486
Cook loss	36.5	35.9	0.32	0.348
WB shear-force (kg)[B]	6.91	5.96	0.290	0.102

476 [A]Calculated from the surface exudates (Kauffman *et al*., 1986).
477 [B]Shear force was measured using the Instron Universal Testing Machine.
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