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Effect of fatty acids source on growth performance, carcass characteristics, plasma urea nitrogen concentration, and fatty acid profile in meat of pigs fed standard- or low-protein diets

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Abstract

Thirty six Landrace × Yorkshire barrows with 18.6 kg of initial body weight were used to evaluate three sources of fatty acids: crude soybean oil, conjugated linoleic acid (CLA), and soybean soapstock in standard crude protein (CP) and low-protein diets for starter (21 d; 205, 160 g kg^{-1} CP), growing (28 d; 160, 145 g kg^{-1} CP), and finishing (29 d; 140, 125 g kg^{-1} CP) phases. Growth performance, carcass characteristics, plasma urea nitrogen concentration and fatty acid profile in meat were evaluated. The reduction of CP diminished average daily gain, feed:gain ratio, *longissimus* muscle area and plasma urea nitrogen concentration in nursery pigs; reduced *longissimus* muscle area and plasma urea nitrogen concentration in growing pigs; increased average daily feed intake, and reduced lean meat percentage and plasma urea nitrogen content in finishing pigs. It also increased c9, t11 and c11, t9 CLA isomers and total lipids and lowered eicosapentaenoic and docosahexaenoic acids concentrations in *semimembranosus* muscle; linolenic acid decreased with low-protein diets in *longissimus* and *semimembranosus* muscles; the oil type affected the concentration of c9, t11 and c11, t9 CLA isomers and total saturated fatty acids in *semimembranosus* muscle; CLA increased individually and total saturated fatty acids, reduced linoleic and docosapentaenoic acids, and increased total lipids in *longissimus* muscle. These results indicate that decreasing CP changes the profile of fatty acids. The soybean soapstock can replace crude soybean oil in pig diets; while conjugated linoleic acid does not improve response of pigs fed standard- or low-protein diets.

Additional key words: feed additives; feeding management; pork meat quality.

Resumen

Efecto de la fuente de ácidos grasos sobre la respuesta productiva, características de la canal, concentración de urea en plasma y perfil de ácidos grasos en carne de cerdos alimentados con dietas estándar o con baja proteína

Se utilizaron 36 cerdos machos castrados (18,6 ± 2,3 kg peso inicial) para evaluar tres fuentes de ácidos grasos: aceite crudo de soya, ácido linoleico conjugado (ALC) y aceite de soya acidulado en dietas estándar en proteína bruta (PB) y con baja proteína para iniciación (21 d; 205, 160 g kg^{-1} PC), crecimiento (28 d; 160, 145 g kg^{-1} PC), y finalización (29 d; 140, 125 g kg^{-1} PC). Se evaluó la respuesta productiva, características de la canal, urea en plasma y perfil de ácidos grasos en carne. La reducción de PB disminuyó la ganancia de peso, conversión alimenticia, área del músculo *longissimus* y urea en plasma en iniciación; redujo el área del músculo *longissimus* y urea en plasma durante el crecimiento; aumentó el consumo, disminuyó el porcentaje de carne magra y la urea en plasma en finalización. También

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Abbreviations used: ADFI (average daily feed intake); ADG (average daily gain); CLA (conjugated linoleic acid); CP (crude protein); CSO (crude soybean oil); FAME (fatty acid methyl ester); FGR (feed:gain ratio); LPD (low-protein diet); ME (metabolisable energy); MUFA (monounsaturated fatty acids); PUFA (polyunsaturated fatty acids); PUN (plasma urea nitrogen); SFA (saturated fatty acids); SS (soybean soapstock); ω-3 (omega-3 fatty acid); ω-6 (omega-6 fatty acid).

aumentó los isómeros c9, t11 y c11, t9 del ALC y lípidos totales, redujo los ácidos eicosapentaenoico y docosahexaenoico en músculo *semimembranosus* y disminuyó el ácido linolénico en ambos músculos. El tipo de aceite afectó a la concentración de isómeros c9, t11 y c11, t9 del ALC y total de ácidos grasos saturados en músculo *semimembranosus*; el ALC aumentó los ácidos grasos individualmente y total de saturados, redujo el linoleico y docosapentaenoico; aumentó el total de lípidos en músculo *longissimus*. Esto indica que reducir la PB cambia el perfil de ácidos grasos, que el aceite de soya acidulado puede reemplazar al aceite crudo de soya en dietas para cerdos y que el ALC no mejora la respuesta de cerdos alimentados con dietas estándar o con baja proteína.

Palabras clave adicionales: aditivos alimenticios; calidad de carne de cerdo; manejo alimenticio.

Introduction

The proper addition of synthetic amino acids to sorghum-soybean meal diets formulated to lower content of crude protein (CP) than the suggested by NRC (1998) does not adversely affect the growth performance of pigs (Myer & Gorbet, 2002; Figueroa *et al*., 2003) and reduces the excretion of N excess from the standard diets (Kerr *et al*., 2003a). However, these diets have negative effects on carcass traits, and there is less lean meat gain and greater accumulation of adipose tissue (Figueroa *et al*., 2002; Gómez *et al*., 2002b). The addition of conjugated linoleic acid (CLA) to pig diets could be an alternative to reduce the negative effects of low-protein diets (LPD), because CLA has a lipolytic effect on adipose tissue (Mersmann, 2002).

Due to the high cost of energy and protein ingredients used in animal feed it is necessary to use alternative feedstuffs. Soybean soapstock (SS) is a byproduct of the crude soybean oil (CSO) extraction and, if the SS is properly processed, it can be added to animal feed (Bruce *et al*., 2006; Dumont & Narine, 2007). This byproduct is a cheap source of energy and can be used in pig diets because its cost can be up to half of the CSO. However, due to its high concentration of free fatty acids, it has lower intestinal absorption due to the inadequate formation of micelles, which affects its digestibility and energy value (Mateos *et al*., 1996). It is therefore important to assess its use in LPD where a marginal deficiency of either nutrient can reduce the productive response. The objective of this study was to evaluate the effect of conjugated linoleic acid, soybean soapstock, and crude soybean oil as energy sources on growth performance, carcass characteristics, plasma urea nitrogen concentration, and fatty acid profile of meat from pigs fed standard or low-protein diets.

Material and methods

This research was conducted at the Swine Unit of the Experimental Farm of *Colegio de Postgraduados* in Tecamac, Mexico State, Mexico. Thirty six crossbred (Landrace × Yorkshire) barrows with 18.6 ± 2.3 kg of initial weight were used in a completely randomized design in a 2 × 3 factorial arrangement (Steel *et al*., 1997), with six replicates per treatment, to evaluate two levels of CP and three types of oil (crude soybean oil, conjugated linoleic acid and soybean soapstock) as energy sources in diets for starter, growing and finishing pigs. The experiment lasted 78 d: 21 d at starter (18-36 kg), 28 d in growing (36-62 kg), and 29 d for finishing (62-93 kg) phases. The pigs were housed in single 1.5 × 1.2 m pens with concrete floor, equipped with a single feeder and a nipple-type drinker. Food and water were provided *ad libitum*.

The diets were formulated to meet the requirement of amino acids on a true digestible value for each stage of fattening (NRC, 1998), using sorghum-soybean meal, with the following CP concentration: 205 and 160 g CP kg^{-1} in starter, 160 and 145 CP kg^{-1} in growing, and 140 and 125 CP kg^{-1} in finishing stage of growth (Table 1). Low-protein concentrations in each phase corresponded to those obtained by Trujillo-Coutiño *et al*. (2007; starter), Martínez-Aispuro *et al*. (2009; growing) and Figueroa *et al*. (2008; finishing), where the growth performance was similar to that of the corresponding standard diet.

The metabolizable energy (ME) of SS was calculated using the equations of Powles *et al*. (1995) and NRC (1998). The calculated energy value was 32.34 MJ ME kg^{-1}. The level of oil addition was based on its energy value to fulfill the same concentration of ME (13.66 MJ kg^{-1}; NRC, 1998) in all diets.

Changes of pigs weight and feed intake were measured weekly, although the average daily gain (ADG), average daily feed intake (ADFI), and feed:gain ratio (FGR) of each stage (starter, growing, and finishing) were used for statistical analysis. At the end of the growing and finishing phases, blood samples were obtained from the vena cava using heparinised vacutainer tubes (BD Vacutainer Systems, NJ, USA) and

Table 1. Composition of experimental diets for nursery, growing and finishing pigs (g kg^{-1} as fed)

Phase[1]	Nursery II						Growing						Finishing					
Ingredient/Treatment	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Sorghum grain	623.9	623.9	621.1	767.2	767.2	765.4	771.4	771.4	770.2	819.2	819.2	818.3	836.2	836.2	835.7	883.8	883.8	883.6
Soybean meal	333.2	333.2	333.8	183.0	183.0	183.4	194.6	194.6	194.9	144.5	144.5	144.7	137.6	137.6	137.7	87.8	87.8	87.9
Crude soybean oil	**13.8**	0.0	0.0	**9.3**	0.0	0.0	**6.0**	0.0	0.0	**4.5**	0.0	0.0	**2.4**	0.0	0.0	**0.9**	0.0	0.0
Soybean soapstock	0.0	0.0	**15.9**	0.0	0.0	**10.8**	0.0	0.0	**7.0**	0.0	0.0	**5.2**	0.0	0.0	**2.8**	0.0	0.0	**1.1**
Conjugated linoleic acid[2]	0.0	**13.8**	0.0	0.0	**9.3**	0.0	0.0	**6.0**	0.0	0.0	**4.5**	0.0	0.0	**2.4**	0.0	0.0	**0.9**	0.0
Bio-Lys (L-Lysine·H_2SO_4)[3]	1.2	1.2	1.2	3.1	3.1	3.0	3.8	3.8	3.7	4.5	4.5	4.5	3.2	3.2	3.2	4.1	4.1	4.1
DL-Methionine	0.2	0.2	0.2	1.4	1.4	1.4	0.2	0.2	0.2	0.6	0.6	0.6	0.0	0.0	0.0	0.3	0.3	0.3
Tripto-Plus (L-Tryptophan)[4]	0.0	0.0	0.0	4.7	4.7	4.7	0.2	0.2	0.2	1.7	1.7	1.7	0.0	0.0	0.0	1.3	1.3	1.3
L-Threonine	0.0	0.0	0.0	1.8	1.8	1.8	0.3	0.3	0.3	0.9	0.9	0.9	0.1	0.1	0.1	0.7	0.7	0.7
Other[5]	27.8	27.8	27.8	29.4	29.4	29.4	23.4	23.4	23.4	23.9	23.9	23.9	20.4	20.4	20.4	20.9	20.9	20.9
Calculated analysis																		
Crude protein	205	205	205	160	160	160	160	160	160	145	145	145	140	140	140	125	125	125
Calcium	7.0	7.0	7.0	7.0	7.0	7.0	6.0	6.0	6.0	6.0	6.0	6.0	5.0	5.0	5.0	5.0	5.0	5.0
Available phosphorus	3.2	3.2	3.2	3.2	3.2	3.2	2.3	2.3	2.3	2.3	2.3	2.3	1.9	1.9	1.9	1.9	1.9	1.9
Lysine	10.1	10.1	10.1	10.1	10.1	10.1	8.3	8.3	8.3	8.3	8.3	8.3	6.6	6.6	6.6	6.6	6.6	6.6
Threonine	6.5	6.5	6.5	6.5	6.5	6.5	5.2	5.2	5.2	5.2	5.2	5.2	4.3	4.3	4.3	4.3	4.3	4.3
Tryptophan	2.3	2.3	2.3	2.3	2.3	2.3	1.7	1.7	1.7	1.7	1.7	1.7	1.4	1.4	1.4	1.4	1.4	1.4
Isoleucine	7.8	7.8	7.9	5.7	5.7	5.7	5.9	5.9	5.9	5.2	5.2	5.2	5.1	5.1	5.1	4.4	4.4	4.4
Leucine	16.8	16.8	16.8	13.9	13.9	13.9	14.3	14.3	14.3	13.3	13.3	13.3	13.3	13.3	13.3	12.3	12.3	12.3
Valine	8.4	8.4	8.4	6.4	6.4	6.4	6.6	6.6	6.6	5.9	5.9	5.9	5.8	5.8	5.8	5.1	5.1	5.1
Methionine + Cystine	5.8	5.8	5.8	5.8	5.8	5.8	4.7	4.7	4.7	4.7	4.7	4.7	4.0	4.0	4.0	3.9	3.9	3.9
ME MJ kg^{-1}	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66	13.66
Determined analysis																		
Crude protein	212	201	215	167	171	166	158	165	169	139	147	142	143	137	145	121	127	130

[1] Requirements suggested for pigs on a true digestible amino acid basis (NRC, 1998). [2] Conjugated linoleic acid (LutaCLA® 60 BASF Mexicana) contains: 9c, 11t methyl ester, 300; 10t, 12c methyl ester, 300; other isomers, ≤10; oleic acid, 220; palmitic acid, 60; stearic acid, 40; linoleic acid, 20; methanol, ≤100 ppm; heavy metals, ≤1 ppm. [3] Bio Lys contains (g^{-1} kg): crude protein, 750; available phosphorus, 1.6; lysine, 507; threonine, 4; tryptophan, 1.4; methionine, 2; arginine, 6; isoleucine, 4; leucine, 7; valine, 7; cystine, 1. [4] Tripto Plus contains (g^{-1} kg): crude protein, 950; lysine, 553; threonine, 1.5; tryptophan, 150; valine, 5; methionine+cystine, 17.5. [5] Other: vitamins and minerals, salt, antioxidant (ethoxyquin), dicalcium phosphate, $CaCO_3$. Each kg of feed supplied: vit. A, 6,250 IU; vit. D, 1,250 IU; vit. E, 25 IU; vit. K3, 2.5 mg; B1, 1.25 mg; B2, 6.25 g; B5, 31.25 mg; B6, 2.5 mg; B12, 0.01875 mg; folic acid, 3.75 mg; vit H, 0.225 mg; panthotenic acid, 18.75 mg; choline, 381.25 mg; Fe, 125 mg; Zn, 125 mg; Mn, 125 mg; Cu, 12.5 mg; Se, 0.25 mg; I, 0.375 mg; Co, 0.125 mg. ME: metabolisable energy.

samples of blood were kept on ice until centrifugation at 2,500 rpm (1286 *g*) for 15 min; the supernatant was transferred to polypropylene tubes and stored at –20°C until determination of plasma urea nitrogen (PUN) concentration (Chaney & Marbach, 1962). At the beginning and the end of each stage, backfat thickness and *longissimus* muscle area were measured with a real time ultrasound (Sonovet 600, Medison Inc., Cypress, CA, USA). These data and the initial and final body weights were used to calculate the fat free lean gain and the lean meat percentage in the carcass using the NPPC (1991) equation. The CP content was determined in diets (AOAC, 1990) for each stage of growth.

All pigs were slaughtered at the end of the finishing phase, obtaining samples in warm carcass of approximately 100 g from *semimembranosus* and *longissimus* muscles. The samples were ground and stored at –20°C until determination of fatty acid profile. The total lipid content (923.07 method), the fatty acid profile (saturated, unsaturated, polyunsaturated, and isomers of CLA) in the oils (Table 2) and in muscle tissue samples (994.10 method), and the lipid extract (methylated with a complex of 20% methanol trifluorite boron in a methanol solution) were determined (AOAC, 2000). Fatty acid profile of oil and muscle tissue samples were analysed by gas chromatography using a DB23 column (30m × 0.25 mm id) in a Varian 3400 gas chromato-

Table 2. Analysis of fatty acids in the oils included in the experimental diets

Fatty acid, g kg^{-1} FAMEs	SS	CLA	CSO
Palmitic (C16:0)	109.6	51.1	103.2
Palmitelaidic (C16:1)	1.0	ND	ND
Palmitoleic (C16:1)	1.5	ND	1.0
Heptadecanoic (C17:0)	1.0	ND	1.0
Stearic (C18:0)	32.9	42.6	41.6
Oleic (C18:1)	259.9	229.5	208.9
Cis-vaccenic (C18:1)	22.8	ND	9.6
Linoleic (C18:2)	439.6	4.6	549.4
Alpha-linolenic (C18:3)	97.6	ND	75.0
c9,t11 and c11,t9 CLA	ND	323.9	ND
t10,c12 CLA	ND	300.0	ND
Arachidonic (C20:4)	2.8	ND	3.2
Eicosaenoic (C20:1)	3.8	5.5	2.0
Eicosapentaenoic (C20:5)	3.4	6.6	3.4
Erucic (C22:1)	ND	8.2	ND
Lignoceric (C24:0)	1.3	1.4	1.1
Other fatty acids	22.8	26.5	0.8
SFA	147.6	95.1	150.0
MUFA	289.0	243.2	221.4
PUFA	540.6	635.1	627.8

FAMEs = fatty acid methyl esters; SS = soybean soapstock; CLA = conjugated linoleic acid; CSO = crude soybean oil; ND = not detectable; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

graph equipped with an autosampler and a flame ionization detector. The carrier gas used was N at a flow of 30 mL min^{-1}. The operating temperatures were: column 230°C; injector 150°C; detector 300°C. The retention times were compared with methylated fatty acids standards (Supelco 18919-1 AMP).

The data were analysed for ANOVA using the GLM procedure (SAS, 2002). The model included the effects of protein level and oil type as main factors and their interaction; the initial weight of pigs was used as covariate in the analysis of variables where this factor had a significant effect. Multiple mean comparisons were performed using Tukey's test; the alpha level for determination of significance was 0.05.

Results

Starter period

The protein level affected ($p < 0.05$) ADG and final weight (Table 3). The highest value was observed in pigs fed standard CP diet. The main factors did not affect the ADFI ($p > 0.05$), but there was an interaction between CP level and oil type ($p < 0.006$) for pigs fed standard CP diet ($p < 0.05$) with CSO (1.38 kg d^{-1}) or CLA (1.71 kg d^{-1}). The FGR was 8.5% higher in pigs fed LPD ($p < 0.05$). The interaction ($p < 0.01$) between CP and oil type affected the final backfat thickness, with the greatest thickness in pigs fed standard CP diet and CLA ($p < 0.05$). The final *longissimus* muscle area was greater ($p < 0.05$) in pigs fed the standard CP diet than in pigs fed LPD (1,424 vs. 1,297 mm^2). The pigs fed SS had the highest values (1,409 mm^2) of *longissimus* muscle area ($p < 0.05$) and the lowest (1,283 mm^2) was with CSO, irrespective of the CP level.

Growing period

The protein level or oil type did not affect growth performance or carcass characteristics ($p > 0.05$, (Table 4). However, there was a trend ($p = 0.06$) to reduce the *longissimus* muscle area when the CP decreased in the diet. The plasma urea nitrogen concentration was 14% lower in pigs fed the LPD, indicating a reduction of the amino acid excess or a better balance of them in the diet.

Finishing period

The ADFI increased by 290 g d^{-1} ($p < 0.05$) when pigs were fed LPD (Table 5). The fat free lean gain was higher (404 g d^{-1}; $p < 0.05$) in pigs fed CSO, and the lowest value (334 g d^{-1}) was observed in pigs fed CLA. The diet did not change backfat thickness or *longissimus* muscle area ($p > 0.05$). Lean meat percentage was higher ($p = 0.051$) in pigs fed standard CP diet. The plasma urea nitrogen concentration was 14.2% lower in pigs fed LPD; the interaction between CP × Oil type showed a trend ($p = 0.059$) to affect the concentration of plasma urea nitrogen concentration, with lower values in pigs fed CSO.

Fatty acid profile

Semimembranosus *muscle*

Pigs fed LPD showed the highest values ($p < 0.05$) of CLA isomers (c9, t11 and c11, t9) and eicosaenoic acid (Table 6), and also showed the lowest concentration

Table 3. Effect of crude protein level (g kg^{-1}) and oil source on growth performance and carcass characteristics of nursery pigs (18.6-35.7 kg)

TRT[1]	CP[2]	OS[3]	Growth performance[4]				Carcass characteristics[5]		
			IW (kg)	FW[6] (kg)	ADG (g d^{-1})	ADFI[6] (kg d^{-1})	FGR	BF[6] (mm)	LMA[6] (mm^2)
T1	205	CSO	18.7	35.6	809	1.38b	1.72	4.15a	1,318
T2	205	CLA	18.1	37.2	878	1.71a	1.92	5.23b	1,459
T3	205	SS	19.0	37.7	914	1.69ab	1.86	4.19ab	1,495
T4	160	CSO	18.3	34.9	772	1.60ab	2.09	4.20a	1,247
T5	160	CLA	18.6	34.1	740	1.49ab	2.02	4.17a	1,319
T6	160	SS	19.1	35.4	803	1.52ab	1.90	4.74ab	1,324
SEM[7]				0.268	0.013	0.028	0.032	0.100	19.67
Main effects									
	205		18.6	36.8a	861a	1.59	1.83a	4.52	1,424a
	160		18.5	34.8b	770b	1.54	2.00b	4.37	1,297b
		CSO	18.5	35.2	791	1.49	1.90	4.17	1,283b
		CLA	18.3	35.6	809	1.60	1.97	4.70	1,389ab
		SS	19.1	36.5	852	1.60	1.88	4.46	1,409a
Source of variation						***p* value**			
CP				0.001	0.001	0.307	0.016	0.453	0.003
OS				0.187	0.147	0.177	0.501	0.102	0.030
CP × OS				0.183	0.269	0.006	0.116	0.010	0.582
IW				0.001		0.001	0.022	0.015	0.001

[1] TRT = treatment; [2] CP = crude protein; [3] OS = oil source; CSO = crude soybean oil; CLA = conjugated linoleic acid; SS = soybean soapstock; [4] Growth performance: IW = initial weight; FW = final weight; ADG = average daily gain; ADFI = average daily feed intake; [5] Carcass characteristics: FGR = feed:gain ratio; BF = backfat thickness; LMA = *longissimus* muscle area. [6] Treatment means adjusted by initial weight as a covariate ($p \leq 0.05$) [7] SEM = standard error of the mean; [a, b, c] Treatment means or main effect with different superscript are different ($p \leq 0.05$).

($p < 0.05$) in linolenic, eicosapentaenoic and docosahexaenoic acids. Docosapentaenoic acid decreased ($p = 0.075$) and the total lipid level increased ($p = 0.062$) in pigs fed LPD. The CLA diets increased ($p < 0.05$) the isomers c9, t11 and c11, t9 of CLA. The eicosaenoic acid concentration was similar in pigs fed with CSO and SS, and less with CLA ($p < 0.05$). The total saturated fatty acids concentration was higher in pigs fed CLA, and less with CSO ($p < 0.05$). The interaction between CP level and type of oil affected the concentrations of the cis10-pentadecaenoic, cis10-heptadecaenoic, and cis-vaccenic acids ($p < 0.05$).

Longissimus *muscle*

The LPD decreased ($p < 0.05$) the concentration of linolelaidic and linolenic acids. The CLA increased ($p < 0.05$) the palmitoleic, myristic, palmitic and stearic acids, and decreased ($p < 0.05$) the elaidic, linolenic, eicosaenoic, cis-8,11,14-eicosatrienoic, and docosapentaenoic (Table 7) acids. Total saturated fatty acids were higher ($p < 0.05$) in pigs fed CLA, but similar in pigs given CSO or SS. The total lipid content was higher with CLA ($p = 0.055$). The interaction of CP level and oil type affected ($p < 0.05$) the concentration of cis10-pentadecaenoic acid, and there was a tendency to affect the cis10-heptadecaenoic acid ($p = 0.07$) and the t10,c12 isomer of CLA ($p = 0.06$).

Discussion

Growth performance

The reduction of CP level lowered growth performance of pigs during the starter period, although the CP can be reduced by 40 (Hansen *et al*., 1993a), 55 (Le Bellego & Noblet, 2002), and up to 60 g kg^{-1} (Kerr

Table 4. Effect of crude protein level (g kg^{-1}) and oil source on growth performance, carcass characteristics, and plasma urea nitrogen concentration of pigs for growing period

TRT[1]	CP[2]	OS[3]	Growth performance[4]				Carcass characteristics[5]					
			IW (kg)	FW[6] (kg)	ADG[6] (g d^{-1})	ADFI[6] (g d^{-1})	FGR	FFLG (g d^{-1})	BF (mm)	LMA (mm^2)	LMP[6]	PUN (mg/100 mL)
T1	160	CSO	35.4	62.9	965	2.50	2.59	342	7.60	2,119	39.2	16.74
T2	160	CLA	36.5	62.8	962	2.52	2.65	346	8.16	2,257	39.5	16.88
T3	160	SS	38.1	62.8	962	2.39	2.53	338	8.20	2,314	39.7	18.98
T4	145	CSO	35.5	63.9	998	2.56	2.57	348	7.80	2,065	38.7	14.75
T5	145	CLA	34.1	63.5	986	2.47	2.48	340	7.33	2,124	39.4	14.62
T6	145	SS	35.9	61.7	922	2.33	2.53	323	7.60	2,072	39.1	15.91
SEM[7]				0.444	0.015	0.034	0.043	0.001	0.170	37.39	0.134	0.530
Main effects												
	160		36.7	62.9	963	2.47	2.59	342	8.00	2,232	39.5	17.49a
	145		35.1	63.0	969	2.45	2.52	337	7.56	2,089	39.1	15.06b
		CSO	35.5	63.4	982	2.53	2.58	345	7.70	2,092	38.9	15.75
		CLA	35.3	63.2	974	2.50	2.56	343	7.75	2,190	39.5	15.75
		SS	37.0	62.3	942	2.36	2.53	331	7.90	2,193	39.4	17.44
Source of variation								***p* value**				
CP				0.873	0.872	0.797	0.462	0.755	0.240	0.067	0.159	0.030
OS				0.603	0.602	0.159	0.910	0.682	0.889	0.475	0.286	0.348
CP × OS				0.615	0.612	0.732	0.684	0.845	0.445	0.613	0.834	0.914
IW				0.001	0.022	0.001					0.003	

[1] TRT = treatment. [2] CP = crude protein. [3] OS = oil source; CSO = crude soybean oil; CLA = conjugated linoleic acid; SS = soybean soapstock. [4] Growth performance: IW = initial weight; FW = final weight; ADG = average daily gain; ADFI = average daily feed intake. [5] Carcass characteristics: FGR = feed:gain ratio; FFLG = fat free lean gain; BF = backfat thickness; LMA = *longissimus* muscle area. LMP = lean meat percentage; PUN = plasma urea nitrogen concentration. [6] Treatment means adjusted by initial weight as a covariate ($p \leq 0.05$). [7] SEM = standard error of the mean. [a, b] Treatment means or main effect with different superscript are different ($p \leq 0.05$).

et al., 1995), adding synthetic amino acids for this phase of growth.

In the growing stage, the decrease of CP did not affect the growth performance in pigs fed sorghum- (Hansen *et al*., 1993b) or corn-soybean meal with 140 (Tartrakoon *et al*., 2004), 130 (Tuitoek *et al*., 1997a) and 120 g CP kg^{-1} (Kerr *et al*., 1995, 2003a,b; Figueroa *et al*., 2002). However, Kendall *et al*. (1998) found that reducing the CP up to 122 g kg^{-1} decreased ADG and feed efficiency; this effect can be avoided by the addition of synthetic valine and isoleucine to diet (Le Bellego *et al*., 2001; Zervas & Zijlstra, 2002). The variability of the results in growing pigs may be due to: 1) the genetic potential of pigs, because there was a great variation of genotypes of pigs used between studies; 2) the feedstuffs of the diets (corn, sorghum, or wheat- soybean meal), because the amount and type of soluble carbohydrates in the diet influence the growth performance of pigs (Atakora *et al*., 2003); 3) the variation in the initial weight of pigs; and 4) the duration of the evaluation period.

In finishing pigs, reducing the CP in the diet increased ADFI, but did not affect ADG and FGR, as in pigs fed corn-soybean meal diet with 30 g kg^{-1} less CP (Kerr *et al*., 2003b), supplemented with synthetic amino acids (Kerr *et al*., 1995). However, this result has not been consistent since Tuitoek *et al*. (1997a) and Panetta *et al*. (2006) indicated that ADG and feed efficiency are adversely affected with a similar reduction in the CP.

Addition of CLA to diets does not have an effect on growth performance of pigs. This result differs from other studies where CLA addition improved some growth response variables (Ramsay *et al*., 2001; Wiegand *et al*., 2002; Sun *et al*., 2004; Lauridsen *et al*., 2005; Martin *et al*., 2008a).

Diets supplemented with SS maintained growth performance at similar levels as with CSO or CLA (Starkey *et al*., 2002a). In finishing pigs fed 60 g kg^{-1} of SS for 70 d improved ADG and feed efficiency (Starkey *et al*., 2002b).

Table 5. Effect of crude protein level (g kg^{-1}) and oil source on growth performance, carcass characteristics, and plasma urea nitrogen concentration of pigs for finishing period

TRT[1]	CP[2]	OS[3]	Growth performance[4]				Carcass characteristics[5]					
			IW (kg)	FW[6] (kg)	ADG[6] (g d^{-1})	ADFI[6] (g d^{-1})	FGR	FFLG[6] (g d^{-1})	BF (mm)	LMA[6] (mm^2)	LMP	PUN (mg 100 mL)
T1	140	CSO	62.3	94.3	1,105	3.26	2.98	414	11.40	3,294	38.6	20.51
T2	140	CLA	63.7	91.4	1,003	3.02	3.05	339	13.00	3,074	37.6	24.57
T3	140	SS	65.8	91.2	995	2.98	3.02	341	12.40	3,052	37.7	21.28
T4	125	CSO	59.6	95.6	1,151	3.46	2.98	395	13.66	3,117	37.5	18.69
T5	125	CLA	61.0	92.5	1,041	3.15	3.02	329	12.66	2,857	36.9	17.56
T6	125	SS	61.8	95.1	1,130	3.53	3.12	393	13.20	3,160	37.6	21.21
SEM[7]				0.598	0.020	0.065	0.055	0.001	0.439	54.98	0.162	0.593
Main effects												
	140		63.9	92.3	1,034	3.09b	3.02	365	12.31	3,140	37.9	22.27[a]
	125		60.7	94.4	1,107	3.38a	3.04	372	13.17	3,045	37.3	19.03b
		CSO	60.8	95.0	1,128	3.36	2.98	404a	12.63	3,205	38.0	19.51
		CLA	62.4	91.9	1,022	3.08	3.04	334b	12.83	2,965	37.3	21.06
		SS	63.8	93.1	1,063	3.25	3.07	367ab	12.80	3,106	37.7	21.24
Source of variation								***p* value**				
CP				0.103	0.102	0.042	0.824	0.682	0.310	0.414	0.051	0.019
OS				0.124	0.124	0.226	0.812	0.010	0.954	0.209	0.187	0.478
CP × OS				0.591	0.593	0.398	0.874	0.234	0.477	0.448	0.496	0.058
IW				0.001	0.009	0.006		0.032		0.003		

[1, 2, 3, 4, 5, 6, 7]: See Table 4.

Carcass traits

The CP levels analysed in this research did not influence carcass characteristics even when CP was reduced by 40 g kg^{-1} in sorghum-soybean meal (Myer & Gorbet, 2002) or corn-soybean meal (Le Bellego *et al*., 2002; Kerr *et al*., 2003a) diets supplemented with synthetic amino acids. This amino acids addition is necessary because of deficiency of some of them, such as valine and isoleucine, may produce a greater accumulation of lipids (Kerr *et al*., 1995; Atakora *et al*., 2003) and decreases protein in body tissues (Gómez *et al*., 2002b), reflected in less fat free lean gain and *longissimus* muscle area in carcass (Figueroa *et al*., 2002). It has been suggested that a greater reduction of CP in the diet could negatively affect the growth performance and carcass composition (protein and lipid deposition; Tuitoek *et al*., 1997b).

Addition of CLA increased *longissimus* muscle area in starter pigs (Wiegand *et al*., 2002), but had no effect on carcass traits in growing and finishing pigs (Eggert *et al*., 2001; Averette-Gatlin *et al*., 2002; Martin *et al*., 2008a), although some reports have indicated an increase in carcass quality adding 5 to 20 g kg^{-1} of CLA in growing (Ramsay *et al*., 2001) and growing-finishing pigs (Lauridsen *et al*., 2005), and a decrease in backfat thickness (Thiel-Cooper *et al*., 2001).

Supplementing SS increased *longissimus* muscle area in starter pigs, and improved fat-free lean gain in finishing pigs. Therefore, the inclusion of SS to meet the energy requirement for fattening pigs fed sorghum-soybean meal diets is a good choice because there is no negative effect on growth response of pigs and it is a cheaper ingredient than CSO.

Plasma urea nitrogen concentration

The reduction of plasma urea nitrogen concentration in pigs fed LPD evaluated in this study indicated a lower N excretion in urine (Gómez *et al*., 2002a; Tartrakoon *et al*., 2004) and lower production of ammonia, which is proportional to the reduction of CP in the diet (Powers *et al*., 2007). Plasma urea nitrogen content and N excretion were linearly reduced (Figueroa *et al*., 2002) up to 60% when the CP decreases by 40 g kg^{-1}, with the risk of affecting negatively growth performance and carcass characteristics (Kendall *et al*., 1998). This problem could be solved by adding limiting essential amino acids

Table 6. Effect of crude protein concentration and oil source on total lipids and fatty acid profile (g kg^{-1}) in pork *semimembranosus* muscle

Fatty acids, g kg^{-1} FAMEs[1]	CP[2]		Source of oil[3]			SEM[4]	*p* value		
	Control	LPD	CSO	CLA	SS		CP	Oil	CP × Oil
Myristic (C14:0)	8.8	9.6	8.8	10.2	8.7	0.4	0.086	0.176	0.425
Cis 10-Pentanoic (C15:1)	7.5	11.4	6.5	11.9	10	1.3	0.15	0.247	0.001
Palmitic (C16:0)	219.3	221.5	212.2	230.3	218.8	3	0.724	0.073	0.231
Palmitelaidic (C16:1)	2.7	2.3	2.5	2.1	3.0	0.2	0.314	0.218	0.624
Palmitoleic C16:1	27.0	27.3	26.8	30.0	24.7	1.1	0.87	0.157	0.534
Heptadecaenoic (C17:0)	3.4	2.7	2.7	3.1	3.2	0.3	0.265	0.829	0.899
Cis 10-heptadecaenoic (C17:1)	4.1	3.2	3.0	3.4	4.5	0.4	0.205	0.27	0.001
Stearic (C18:0)	107.7	111.3	104.2	112.7	111.6	1.6	0.275	0.079	0.586
Elaidic (C18:1trans)	3.0	2.5	3.1	3.0	2.1	0.2	0.251	0.243	0.019
Oleic (C18:1)	327.8	362.6	361.2	326	348.3	9.6	0.086	0.338	0.572
Cis-vaccenic (C18:1)	35.1	32.2	31.1	34.7	35.1	1.6	0.364	0.527	0.116
Linolelaidic (C18:2 trans)	0.2	0.3	0.2	0.3	0.2	0.1	0.564	0.948	0.71
Linoleic (C18:2ω6)	133	113.1	118.8	132.9	117.4	7.6	0.207	0.662	0.376
c9,t11 and c11,t9 CLA	1.5[a]	2.5b	1.7b	3.1a	1.3b	0.2	0.033	0.005	0.083
t10,c12 CLA	0.3	0.0	0.0	0.5	0.0	.001	0.164	0.151	0.151
Other CLA-isomers	0.1	0.2	0.3	0.1	0.2	0.1	0.793	0.443	0.053
Gamma-linolenic (C18:3)	1.2	0.7	1.8	0.5	0.7	0.2	0.278	0.09	0.462
Alpha-linolenic (C18:3ω3)	3.9a	2.8b	3.7	3.2	3.1	0.3	0.045	0.618	0.631
Arachidic (C20:0)	1.7	1.5	1.8	1.4	11.7	0.2	0.747	0.761	0.156
Eicosaenoic (C20:1)	5.8b	6.7a	6.7a	5.3b	6.7a	0.2	0.008	0.002	0.09
Cis-11, 14-eicosadienoic (C20:2)	4.5	4.1	4.3	4.1	4.5	0.2	0.254	0.701	0.375
Cis-11,14,17-eicosatrienoic (C20:3)	1.5	0.9	1.1	1.5	1.1	0.2	0.122	0.651	0.255
Cis-8,11,14-eicosatrienoic (C20:3)	4.5	3.8	4.4	3.8	4.2	0.3	0.272	0.755	0.911
Arachidonic (C20:4 ω6)	34.0	27.8	29.7	28.3	34.7	2.5	0.225	0.55	0.26
Eicosapentaenoic (EPA, C20:5 ω3)	1.0a	0.2b	1.0	0.4	0.4	0.2	0.033	0.255	0.848
Docosapentaenoic (DPA C22:5 ω3)	4.0	2.9	3.1	3.4	3.9	0.3	0.075	0.474	0.149
Docosahexaenoic (DHA, C22:6 ω3)	2.0a	0.11b	1.5	1.6	1.5	0.2	0.044	0.942	0.757
Other fatty acids	47.1	41.0	53.5	40.4	38.3	4.3	0.482	0.315	0.363
SFA, %	341.4	346.7	330b	358a	344ab	4.2	0.532	0.047	0.286
MUFA, %	413.6	448.5	441.2	417.0	434.9	10.2	0.103	0.612	0.949
PUFA, %	197.7	163.6	175.1	184.5	182.4	10.9	0.135	0.934	0.481
TL, g/100 g	28.0	35.6	30.7	31.1	33.6	1.9	0.062	0.806	0.718

[1] FAMEs = fatty acid methyl esters; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; TL = total lipids. [2] CP = crude protein; LPD: low-protein diet. [3] CSO = crude soybean oil; CLA = conjugated linoleic acid; SS = soybean soapstock. [4] SEM = standard error of the mean. [a, b] Means of main factors with different superscript indicate differences ($p \leq 0.05$).

(Zervas & Zijlstra, 2002) and adjusting energy concentration (Herr *et al*., 2000; Le Bellego *et al*., 2002), because, with this type of diet, there is a lower energy requirement for deamination, transamination and urea synthesis (Gómez *et al*., 2002b). It is important not reducing too much the CP to prevent negative effects on pigs response, but it is a cheaper strategy to control the production of gases in intensive pig production (Hayes *et al*., 2004).

The addition of CLA did not change plasma urea nitrogen concentration, which was observed in growing pigs fed 10 g kg^{-1} of CLA (Ramsay *et al*., 2001) or pigs that weighed between 105 and 153 kg fed 7.5 g kg^{-1} of CLA (Corino *et al*., 2008). This indicates that the main effect of CLA is on lipid metabolism, not on productive variables.

Fatty acid profile in meat

The accumulation of CLA isomers in intramuscular fat of *longissimus* and *semimembranosus* muscles has also been reported mainly for *longissimus* muscle (Eggert *et al*., 2001) and this concentration is directly related to CLA concentration in the diet (Ramsay *et al*., 2001; Joo *et al*., 2002). Isomers of CLA

Table 7. Effect of crude protein concentration and oil source on total lipids and fatty acid profile (g kg^{-1}) of pork *longissimus* muscle

Fatty acids, g kg^{-1} FAMEs[1]	CP[2]		Source of oil[3]			SEM[4]	*p* value		
	Control	LPD	CSO	CLA	SS		CP	Oil	CP × Oil
Myristic (C14:0)	11.1	10.7	9.8b	12.9a	9.9b	0.3	0.525	0.001	0.371
Cis 10-Pentaenoic (C15:1)	5.2	7.3	4.8	8.1	5.9	1.3	0.452	0.598	0.006
Palmitic (C16:0)	240.6	236.4	226.4b	259.5a	229.7b	2.1	0.319	0.001	0.185
Palmitelaidic (C16:1)	2.4	2.2	2.4	1.8	2.7	0.2	0.569	0.115	0.655
Palmitoleic C16:1	30.9	28.6	27.4b	34.5a	27.3b	0.8	0.184	0.003	0.284
Heptadecaenoic (C17:0)	2.8	2.4	2.7	2.6	2.4	0.2	0.495	0.873	0.998
Cis 10-heptadecaenoic (C17:1)	3.6	4.4	4.0	4.5	3.6	0.6	0.499	0.829	0.077
Stearic (C18:0)	119.6	121.3	115.4b	128.4a	117.7ab	1.9	0.652	0.026	0.81
Elaidic (C18:1trans)	2.3	1.9	2.7a	1.1b	2.5a	0.2	0.398	0.007	0.16
Oleic (C18:1)	370.6	386.9	379.4	372.8	384	5.9	0.18	0.743	0.809
Cis-vaccenic (C18:1)	34.6	34.3	35.4	33.3	34.6	0.9	0.902	0.654	0.902
Linolelaidic (C18:2 trans)	0.8a	0.3b	0.5	8.0	0.4	0.1	0.044	0.215	0.726
Linoleic (C18:2ω6)	94.8	92	104.7	84	91.5	5.1	0.787	0.273	0.662
c9,t11 and c11,t9 CLA	2.3	1.3	1.6	2.7	1.1	0.3	0.099	0.092	0.287
t10,c12 CLA	0.4	0.1	0.0	0.7	0.0	0.1	0.092	0.008	0.067
Other CLA-isomers	0.1	0.5	0.5	0.3	0.1	0.1	0.094	0.431	0.279
Gamma-linolenic (C18:3)	0.6	0.4	0.8	0.4	0.5	0.2	0.683	0.669	0.335
Alpha-linolenic (C18:3ω3)	3.5a	2.5b	3.5a	2.3b	3.1ab	0.2	0.004	0.017	0.964
Araquidic (C20:0)	2.1	1.6	1.9	1.7	2.0	0.2	0.176	0.825	0.525
Eicosaenoic (C20:1)	6.2	6.0	6.4ab	4.9b	6.8a	0.3	0.72	0.045	0.738
Cis-11,14-eicosadienoic (C20:2)	3.6	3.2	4.0	2.4	3.9	0.2	0.207	0.003	0.963
Cis-11,14,17-eicosatrienoic (C20:3)	0.6	0.3	0.5	0.4	0.4	0.1	0.335	0.938	0.243
Cis-8,11,14-eicosatrienoic (C20:3)	2.8	2.6	3.4a	1.6b	3.1a	0.2	0.62	0.003	0.684
Araquidonic (C20:4 ω6)	19.8	20	22.4	14.4	22.8	1.5	0.948	0.051	0.567
Eicosapentaenoic (EPA, C20:5 ω3)	0.7	0.3	0.8	0.2	0.5	0.1	0.177	0.267	0.994
Docosapentaenoic (DPA C22:5 ω3)	2.5	2.0	2.8a	1.3b	2.6ab	0	0.376	0.028	0.676
Docosahexaenoic (DHA, C22:6 ω3)	1.0	0.8	1.3	0.3	1.1	0.2	0.56	0.938	0.529
Other fatty acids	31.0	26.4	32.2	21.1	32.7	2.1	0.28	0.061	0.047
Total ω3	7.7	5.6	8.4	4.1	7.3				
Total ω6	114.6	110.0	127.1	98.4	114.3				
Ratio ω3: ω6	6.3: 93.7	4.8: 95.2	6.2: 93.8	4.0: 96.0	6.0: 94.0				
SFA, %	376.2	372.6	356.1b	405.3a	361.8b	3.3	0.604	0.001	0.371
MUFA, %	456.0	471.9	462.8	461.4	467.7	6.5	0.234	0.916	0.824
PUFA, %	136.6	128.9	148.5	112.0	137.7	6.8	0.58	0.108	0.906
Ratio sat: unsat	38.8: 61.2	38.3: 61.7	36.8: 63.2	41.4: 58.6	37.4: 62.6				
TL, g/100 g	40.9	41.2	36.0	49.0	38.1	2.2	0.95	0.055	0.682

[1, 2, 3, 4]: See Table 6.

with more accumulation are c9,t11 and c11,t9 (Thiel-Cooper *et al*., 2001; Lauridsen *et al*., 2005; Martin *et al*., 2008b). It could also be a greater accumulation of the isomer t10,c12 (Ramsay *et al*., 2001) due to the proportion of CLA isomers in the product added to the diet.

The increase in total saturated fatty acids and the reduction of total monounsaturated fatty acids in intramuscular fat has also been reported in pigs fed 10 g kg^{-1} CLA replacing sunflower oil (Eggert *et al*., 2001), corn oil (Averette-Gatlin *et al*., 2002) or CSO (Wiegand *et al*., 2002). Dietary addition of CLA increased the saturated fatty acids both individually and total concentration in meat of *longissimus* muscle, and reduced linolenic and docosapentaenoic acids. A similar concentration (2.5 g kg^{-1}) of CLA used in growing pigs resulted in a decrease of oleic, linoleic, linolenic and arachidonic acids in fat tissue, but only decreased linolenic acid in muscle tissue (Ramsay *et al*., 2001). This indicates that prolonged periods of treatment may

affect the amount and type of fat in the meat of fattening pigs. The increase in saturated fatty acids (such as stearic acid) and the reduction of unsaturated fatty acids (such as oleic acid) in muscle from pigs fed CLA may be due to the inhibition and downregulation of the enzyme Δ-9-steroil-CoA desaturase (Ramsay *et al*., 2001), which is involved in synthesis of monounsaturated fatty acids (Lee *et al*., 1998), reducing its activity in response to higher concentrations of linolenic acid, increasing lipogenesis and the activity of enzymes such as acetyl-CoA-carboxylase (Kouba & Mourot, 1997). For this reason it was important to analyse the fatty acid profile of the oils used in this study (Table 2) and to verify the presence of linolenic acid, because, with the reduced activity of the enzyme Δ-9-esteroil-CoA desaturase, the endogenous synthesis of CLA is inhibited, enhanced by some precursors in the diet such as the C18:1 trans (Gläser *et al*., 2000).

The changes in fatty acids composition due to the higher CLA levels increased the ratio of saturated: unsaturated fatty acids in intramuscular fat, which could improve the quality of meat, such as water holding capacity that increases when the CLA concentration is lower (Joo *et al*., 2002). The reduction of this fatty acid is observed in some cases, but has a negative impact on the nutritional value of meat (Teye *et al*., 2006).

Total lipids concentration tended to increase in longissimus muscle of pigs fed CLA. In this regard, the addition of 5 g kg^{-1} of CLA in substitution of sunflower oil does not change the content of intramuscular fat (Lauridsen *et al*., 2005), even with 20 g kg^{-1} of inclusion (Joo *et al*., 2002). However, in finishing pigs increased intramuscular fat (3.6 *vs* 2.6%) with 10 g kg^{-1} of CLA in the diet; but with 20 g kg^{-1}, the concentration was similar as in pigs fed sunflower oil (Martin *et al*., 2008a). With 12.5 g kg^{-1} of CLA increased the marbling score compared to CSO (Wiegand *et al*., 2002). The variability of results could be due to the concentration of CLA used in the diet and the length of treatment period (Sun *et al*., 2004). Furthermore, the concentration of intramuscular fat is reduced when CLA increases in the diet to 8.3 g kg^{-1} in growing-finishing pigs (Thiel-Cooper *et al*., 2001).

The fatty acid profile of meat in pigs fed CSO or SS was similar, probably due to the low level of addition. This indicates that the oil added was mainly used to meet the energy requirements of pigs, so, the accumulation of intramuscular fat derived from dietary oil was minimal.

The LPD in this experiment did not affect total lipids concentration in meat; this result did not agree with previous research (Teye *et al*., 2006; Doran *et al*., 2006). The increased lipid accumulation occurs when pigs are fed LPD without meeting the requirement of essential amino acids (Kerr *et al*., 2003b). Also, when pigs are fed LPD, the concentration of ω-6 and ω-3 acids is reduced (Teye *et al*., 2006), as is the linolenic acid in *longissimus* muscle and the linolenic, eicosapentaenoic, docosapentaenoic, and docosahexaenoic acids in *semimembranosus* muscle. Another effect of LPD is the increase of saturated and monounsaturated fatty acids (Teye *et al*., 2006), and has been hypothesised that a lower concentration of CP could stimulate the expression of lipogenic enzymes in muscle, such as esteroil-CoA desaturase, which increases *de novo* synthesis of fatty acids (Doran *et al*., 2006). This premise is supported by the increase in the enzyme fatty acid synthase and the expression of acetyl-CoA carboxylase, involved in the biosynthesis of fatty acids, which increases in response to LPD (Doran *et al*., 2006). However, in this study, there was an increase of myristic, oleic, and eicoesaenoic acids, indicating that the addition of amino acids was adequate for pigs.

As conclusions, reduction of CP up to 160 g kg^{-1} for starter pigs adversely affects growth performance; however, 145 g kg^{-1} in growing pigs and 125 g kg^{-1} in finishing pigs are suitable for an acceptable productive performance and carcass characteristics, and reduces plasma urea nitrogen concentration. The addition of conjugated linoleic acid to standard diets or to low-protein diets for fattening pigs does not improve growth performance or carcass characteristics, therefore, their incorporation in the diet could be based on its cost. Due to the cheaper cost of soybean soapstock, it can be used to replace crude soybean oil in diets without affecting the response of pigs.

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References

AOAC, 1990. Official methods of analysis, 15th ed. Association of Official Analytical Chemists, Arlington, VA, USA.

AOAC, 2000. Official methods of analysis, 17th ed. Association of Official Analytical Chemists, Washington DC, USA.

Atakora JKA, Mohn S, Ball RO, 2003. Low protein diets reduce greenhouse gas production in finisher pigs while maintaining animal performance. Proc 9th Int Symp on Digestive Physiology in Pigs. Banff, AB, Canada, May 14-18, Vol 2, pp: 296-298.

Averette-Gatlin L, See MT, Larick DK, Lin X, Odle J, 2002. Conjugated linoleic acid in combination with supplemental dietary fat alters pork fat quality. J Nutr 132: 3105-3112.

Bruce KJ, Karr-Lilienthal LK, Zinn KE, Pope LL, Mahan DC, Fastinger ND, Watts M, Utterback PL, Parsons CM, Castaneda EO, Ellis M, Fahey GC, 2006. Evaluation of the inclusion of soybean oil and soybean processing by-products to soybean meal on nutrient composition and digestibility in swine and poultry. J Anim Sci 84: 1403-1414.

Chaney AL, Marbach EP, 1962. Modified reagents for determination of urea and ammonia. Clin Chem 8: 130-132.

Corino C, Musella, M, Pastorelli G, Rossi R, Paolone K, Constanza L, Manchisi A, Maiorano G, 2008. Influences of dietary conjugated linoleic acid (CLA) and total lysine content on growth, carcass characteristics and meat quality of heavy pigs. Meat Sci 79: 307-316.

Doran O, Moule SK, Teye GA, Whittington FM, Hallett KG, Wood JD, 2006. A reduced protein diet induces stearoyl-CoA desaturase protein expression in pig muscle but not in subcutaneous adipose tissue: relationship with intramuscular lipid formations. Brit J Nutr 95: 609-617.

Dumont MJ, Narine SS, 2007. Soapstock and deodorizer distillates from North American vegetable oils: Review on their characterization, extraction and utilization. Food Res Int 40: 957-974.

Eggert JM, Belury MA, Kempa-Steczko A, Mills SE, Schinckel AP, 2001. Effects of conjugated linoleic acid on the belly firmness and fatty acid composition of genetically lean pigs. J Anim Sci 79: 2866-2872.

Figueroa JL, Lewis AJ, Miller PS, Fischer RL, Gomez RS, Diedrichsen RM, 2002. Nitrogen metabolism and growth performance of gilts fed standard corn-soybean meal diets or low-crude protein, amino acid-supplemented diets. J Anim Sci 80: 2911-2919.

Figueroa JL, Lewis AJ, Miller PS, Fischer RL, Diedrichsen RM, 2003. Growth, carcass traits, and plasma amino acid concentrations of gilts fed low-protein diets supplemented with amino acids including histidine, isoleucine, and valine. J Anim Sci 81: 1529-1537.

Figueroa JL, Martinez M, Trujillo JE, Zamora V, Cordero JL, Sanchez-Torres MT, 2008. Plasma urea nitrogen concentration and growth performance of finishing pigs fed sorghum-soybean meal, low-protein diets. J Appl Anim Res 33: 7-12.

Gläser KR, Scheeder MRL, Wenk C, 2000. Dietary C18:1 trans fatty acids increase conjugated linoleic acid in adipose tissue of pigs. Eur J Lipid Sci 102: 684-686.

Gomez RS, Lewis AJ, Miller PS, Chen HY, 2002a. Growth performance, diet apparent digestibility, and plasma metabolite concentrations of barrows fed corn-soybean meal diets or low-protein, amino acid-supplemented diets at different feeding levels. J Anim Sci 80: 644-653.

Gomez RS, Lewis AJ, Miller PS, Chen HY, Diedrichsen RM, 2002b. Body composition and tissue accretion rates of barrows fed corn-soybean meal diets or low-protein, amino acid-supplemented diets at different feeding levels. J Anim Sci 80: 654-662.

Hansen JA, Knabe DA, Burgoon KG, 1993a. Amino acid supplementation of low-protein, sorghum-soybean meal diets for 5- to 20-kilogram swine. J Anim Sci 71: 452-458.

Hansen JA, Knabe DA, Burgoon KG, 1993b. Amino acid supplementation of low-protein, sorghum-soybean meal diets for 20- to 50-kilogram swine. J Anim Sci 71: 442-451.

Hayes ET, Leek ABG, Curran TP, Dodd VA, Carton OT, Beattie VE, O'Dohert JV, 2004. The influence of diet crude protein level on odour and ammonia emissions from finishing pig houses. Biores Tech 91: 309-315.

Herr CT, Kendall DC, Bowers KA, Richert BT, 2000. Evaluating variable feed energy levels for grow-finish pigs. Purdue Univ Swine Day, West Laffayette, IN, USA, pp: 35-38.

Joo ST, Lee JI, Ha YL, Park GB, 2002. Effects of dietary conjugated linoleic acid on fatty acid composition, lipid oxidation, color, and water-holding capacity of pork loin. J Anim Sci 80: 108-112.

Kendall DC, Lemenager KM, Richert BT, Sutton AL, Frank JW, Belstra BA, Bundy D, 1998. Effects of intact protein diets versus reduced crude protein diets supplemented with synthetic amino acids on pig performance and ammonia levels in swine buildings. Purdue Univ Swine Day, West Laffayette, IN, USA, pp: 141-146.

Kerr BJ, McKeith FK, Easter RA, 1995. Effect on performance and carcass characteristics of nursery to finisher pigs fed reduced crude protein, amino acid-supplemented diets. J Anim Sci 73: 433-440.

Kerr BJ, Yen JT, Nienaber JA, Easter RA, 2003a. Influences of dietary protein level, amino acid supplementation and environmental temperature on performance, body composition, organ weights and total heat production of growing pigs. J Anim Sci 81: 1998-2007.

Kerr BJ, Southern LL, Bidner TD, Friesen KG, Easter RA, 2003b. Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. J Anim Sci 81: 3075-3087.

Kouba M, Mourot J, 1997. Effect of a high linoleic acid diet on Delta-9-desaturase activity, lipogenesis and lipid composition of pig subcutaneous adipose tissue. Reprod Nutr Dev 38: 31-37.

Lauridsen C, Mu H, Henckel P, 2005. Influence of dietary conjugated linoleic acid (CLA) and age at slaughtering on performance, slaughter and meat quality, lipoproteins, and tissue deposition of CLA in barrows. Meat Sci 69: 393-399.

Le Bellego L, Noblet J, 2002. Performance and utilization of dietary energy and amino acids in piglets fed low protein diets. Livest Prod Sci 76: 45-58.

Le Bellego L, Van Milgen J, Dubois S, Noblet J, 2001. Energy utilization of low-protein diets in growing pigs. J Anim Sci 79: 1259-1271.

Le Bellego L, Van Milgen J, Noblet J, 2002. Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. J Anim Sci 80: 691-701.

Lee KN, Pariza MW, Ntambi JM, 1998. Conjugated linoleic acid decreases hepatic stearoyl-CoA desaturase mRNA expression. Biochem Biophys Res Commun 248: 817-821.

Martin D, Muriel E, Gonzalez E, Viguera J, Ruiz J, 2008a. Effect of dietary conjugated linoleic acid and monounsaturated fatty acids on productive, carcass and meat quality traits of pigs. Livest Sci 117: 155-164.

Martin D, Muriel E, Antequera T, Perez-Palacios T, Ruiz J, 2008b. Fatty acid composition and oxidative susceptibility of fresh loin and liver from pigs fed conjugated linoleic acid in combination with monounsaturated fatty acids. Food Chem 108: 86-96.

Martinez-Aispuro M, Figueroa-Velasco JL, Trujillo-Coutiño JE, Zamora-Zamora V, Cordero-Mora JL, Sanchez-Torres MT, Reyna-Santamaria L, 2009. Respuesta productiva y concentración de urea en plasma de cerdos en crecimiento alimentados con dietas sorgo-pasta de soya con baja proteína. Vet Mex 40: 27-38.

Mateos GG, Garcia-Rebollar P, Medel P, 1996. Utilización de grasas y productos lipídicos en alimentación animal: grasas puras y mezclas. XII Curso de Especialización FEDNA. Madrid, España, 18 p.

Mersmann HJ, 2002. Mechanisms for conjugated linoleic acid-mediated reduction in fat deposition. J Anim Sci 80: 126-134.

Myer RO, Gorbet DW, 2002. Crystalline amino acid supplementation of grain sorghum-based, low protein diets for growing and finishing swine. J Anim Sci 80: 41 (Abstr.).

NPPC, 1991. Procedures to evaluate market hogs, 3rd ed. National Pork Producers Council, Des Moines, IA, USA.

NRC, 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington DC, USA.

Panetta DM, Powers WJ, Xin H, Kerr BJ, Stalder KJ, 2006. Nitrogen excretion and ammonia emissions from pigs fed modified diets. J Environ Qual 35: 1297-1308.

Powers WJ, Zamzow SB, Kerr BJ, 2007. Reduced crude protein effects on aerial emissions from swine. Appl Eng Agr 23(4): 539-546.

Powles J, Wiseman J, Cole DJA, Jagger S, 1995. Prediction of the apparent digestible energy value of fats given to pigs. Anim Sci 61: 149-154.

Ramsay TG, Evock-Clover CM, Steele NC, Azain MJ, 2001. Dietary conjugated linoleic acid alters fatty acid composition of pig skeletal muscle and fat. J Anim Sci 79: 2152-2161.

SAS, 2002. The SAS system for windows V9. SAS Inst Inc., Cary, NC, USA.

Starkey CW, Hancock JD, Kropf DH, Jones CL, Hachmeister KH, Dunn JD, 2002a. Acidulated soapstock and restaurant grease in diets for finishing pigs. J Anim Sci 80(2): 39 (Abstr.).

Starkey CW, Hancock JD, Jones CL, Lee DJ, 2002b. Acidulated soapstock and restaurant grease in diets for nursery pigs. J Anim Sci 80(2): 9 (Abstr.).

Steel DRG, Torrie JH, Dickey DA, 1997. Principles and procedures of statistics: a biometrical approach, 3rd ed. McGraw-Hill, NY, 356 pp.

Sun D, Zhu X, Qiao S, Fan S, Li D, 2004. Effects of conjugated linoleic acid levels and feeding intervals on performance, carcass traits and fatty acid composition of finishing barrows. Arch Anim Nutr 58(4): 277-286.

Tartrakoon W, Wuthijaree K, Udomsri K, 2004. Reduction of N-excretion in growing-finishing pigs using low protein diets. Rural poverty reduction through research for development. Deutscher Tropentag, October 5-7, Berlin. pp. 211 (Abstr.).

Teye GA, Sheard PR, Whittington FM, Nute GR, Stewart A, Wood JD, 2006. Influence of dietary oils and protein level on pork quality. 1. Effects on muscle fatty acid composition, carcass, meat and eating quality. Meat Sci 73: 157-165.

Thiel-Cooper RL, Parrish Jr, FC, Sparks JC, Wiegand BR, Ewan RC, 2001. Conjugated linoleic acid changes swine performance and carcass composition. J Anim Sci 79: 1821-1828.

Trujillo-Coutiño JE, Figueroa-Velasco JL, Martinez-Aispuro M, Zamora-Zamora V, Cordero-Mora JL, Sanchez-Torres MT, Cuca-Garcia M, Cervantes-Ramirez M, 2007. Plasma urea concentration and growth performance of nursery pigs fed sorghum-soybean meal, low-protein diets. Agrociencia (Mexico) 41(6): 597-607.

Tuitoek K, Young LG, De Lange CFM, Kerr BJ, 1997a. The effect of reducing excess dietary amino acids on growing-finishing pig performance: an evaluation of the ideal protein concept. J Anim Sci 75: 1575-1583.

Tuitoek K, Young LG, De Lange CFM, Kerr BJ, 1997b. Body composition and protein and fat accretion in various body components in growing gilts fed diets with different protein levels but estimated to contain similar levels of ideal protein. J Anim Sci 75: 1584-1590.

Wiegand BR, Sparks JC, Parrish Jr, FC, Zimmerman DR, 2002. Duration of feeding conjugated linoleic acid influences growth performance, carcass traits, and meat quality of finishing barrows. J Anim Sci 80: 637-643.

Zervas S, Zijlstra RT, 2002. Effects of dietary protein and fermentable fiber on nitrogen excretion patterns and plasma urea in grower pigs. J Anim Sci 80: 3247-3256.