Growth performance, carcass quality, meat quality and fatty acid composition of pigs fed diets containing extruded soybeans

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Van Lunen, T. A., Hurnik, D. and Jebelian, V. 2003. **Growth performance, carcass quality, meat quality and fatty acid composition of pigs fed diets containing extruded soybeans**. Can. J. Anim. Sci. **83**: 45–52. Two hundred gilts and 200 barrows, housed within sex in pens of 25, were randomly allotted to two replications of four dietary treatments to determine the effects of incorporating 30, 20, 10 or 0% extruded soybeans (ESB), displacing a commercial protein supplement, in barley-based grower and finisher diets for pigs. Growth, feed intake and carcass quality of the pigs, and meat quality and fatty acid composition of the pork from a random subset of the pigs on test were determined. No sex × diet interactions were observed. ESB inclusion rate had no effect on growth rate; however, per-pen feed consumption decreased numerically with increasing ESB resulting in an improvement in feed efficiency. The 30% ESB inclusion rate increased carcass fat content ($P < 0.05$) compared with the control, whereas lean content was unaffected. Meat colour and marbling score were similar across all treatments whereas fat and lean firmness was reduced by the 30% ESB inclusion rate ($P < 0.05$) compared with all other treatments. Increasing ESB in the diet altered the fatty acid content of the pork by decreasing the amount of short-chain saturated and monounsaturated fatty acids and increasing the amount of long-chain polyunsaturated fatty acids (PUFA). The results of this study indicate that ESB can be used as the sole source of supplemental protein in barley-based diets for pigs with no detrimental effects on performance and minimal negative effects on carcass and meat quality. Alteration of fatty acid content of pork from feeding ESB has both positive and negative implications for consumer acceptance by increasing PUFA content while concomitantly increasing the risk of premature oxidation.

Key words: Extruded soybeans, pigs, pork, growth, fatty acids, meat quality

Van Lunen, T. A., Hurnik, D. et Jebelian, V. 2003. **Croissance, qualité de la carcasse, qualité de la viande et composition en acides gras de la viande des porcs recevant du soja extrudé**. Can. J. Anim. Sci. **83**: 45–52. Les chercheurs ont réparti au hasard deux cents truies nullipares et autant de castrats, gardés en enclos par groupes de 25 sujets du même sexe, entre quatre régimes en vue d'établir ce qui se produirait si on remplaçait 30, 20, 10 ou 0 % d'un supplément protéique commercial par du soja extrudé dans une ration de croissance et de finition à base d'orge. Dans cette optique, ils ont déterminé la croissance, la prise alimentaire et la qualité de la carcasse des animaux d'un sous-échantillon ainsi que la qualité de leur viande et sa composition en acides gras. Aucune interaction n'a été relevée entre le sexe et le régime. La proportion de soja extrudé n'agit pas sur le taux de croissance, mais en augmentant la quantité de soja extrudé dans la ration, on note un recul numérique de la consommation par enclos, signe qu'il y a amélioration de l'indice de consommation. La ration contenant 30 % de soja extrudé entraîne une hausse de la quantité de gras dans la carcasse ($P < 0,05$) comparativement au groupe témoin, sans que la proportion de viande maigre en soit affectée. La couleur de la viande et le persillé restent les mêmes, quel que soit le traitement, mais l'addition de 30 % de soja extrudé à la ration réduit la fermeté des tissus adipeux et musculaires ($P < 0.05$), comparativement aux autres traitements. La composition en acides gras de la viande se transforme à mesure que la quantité de soja extrudé augmente dans la ration. En effet, on remarque une baisse de la concentration d'acides gras saturés et mono-insaturés à chaîne courte et une hausse de celle d'acides gras poly-insaturés à chaîne longue. Les résultats de l'étude indiquent qu'on peut entièrement remplacer les suppléments protéiques par du soja extrudé dans les rations à base d'orge sans que le rendement des porcs en souffre et avec des effets négatifs minimes sur la qualité de la carcasse et de la viande. L'altération du profil des acides gras attribuable à l'ingestion de soja extrudé par les animaux aura néanmoins des conséquences positives et négatives sur les consommateurs, car la hausse de la concentration d'acides gras poly-insaturés signifie un risque accru d'oxydation prématurée de la viande.

Mots clés: Soja extrudé, porcs, viande de porc, croissance, acides gras, qualité de la viande

In regions where soybeans can be grown but oil extraction facilities are not available, extrusion offers an opportunity to eliminate anti-nutritional factors such as trypsin inhibitors (Patience et al. 1995) and thus permit the use of full fat soybeans in swine rations. Depending on variety and growing conditions, whole soybeans typically contain high levels of crude protein (380–420 g kg^{-1}) and lipid (180–220 g kg^{-1}) and are low in fibre (approx. 50 g kg^{-1}) (Morrison 1959).

Abbreviations: **ESB**, extruded soybeans; **PUFA**, polyunsaturated fatty acids

Table 1. Formulation and calculated nutrient content of experimental diets

	Grower				Finisher			
Ingredient	Soy 30	Soy 20	Soy 10	Control	Soy 30	Soy 20	Soy 10	Control
Barley	493.5	510	532	484	699.5	714.5	727.5	750
Wheat	150	160	170	250	0	0	0	0
Extruded soybeans	306	204	105	0	250	165	85	0
Supple-ment[z]	0	85.5	170	250	0	85	170	250
Lysine HCl	0.5	0.5	0.5	1	0.5	0.5	0	0
Vitamin/mineral[y]	50	35	17.5	0	50	35	17.5	0
Soybean meal (48%)	0	5	5	15	0	0	0	0
Total	1000	1000	1000	1000	1000	1000	1000	1000
Crude protein (%)	24.5	23.1	22.4	20.3	21.1	22	21	19.3
Total lysine (%)	1.09	1.08	1.04	1.02	1.00	1.00	0.96	0.94
ME (MJ kg^{-1})	4436.2	4412.8	4414.1	4392.4	4358.5	4335	4321.6	4316
Lysine/ME (g MJ^{-1})	0.81	0.81	0.81	0.80	0.76	0.77	0.76	0.76

[z]Commercial supplement for barley based diets. Contained 35% crude protein, 2.0% crude fat, 8.5% crude fibre, 3.4% Ca, 1.7% P, 0.7% Na, 1.2% K, 802 mg kg^{-1} Zn, 80 mg kg^{-1} Cu, 7.8 mg kg^{-1} I, 556 mg kg^{-1} Fe, 161 mg kg^{-1} Mn, 1.2 mg kg^{-1} Co, 43,933 IU kg^{-1} vitamin A, 4632 IU kg^{-1} vitamin D, 124 IU kg^{-1} vitamin E. Ingredients in the supplement were: canola meal, soybean meal, meat meal, calcium carbonate, salt, tater meal, vitamin/mineral mix, synthetic lysine, synthetic methionine, choline chloride, biotin, and barley as a carrier.

[y]Commercial vitamin/mineral premix. Contained 15.2% Ca, 6.1% P, 3.6% Na, 3008 mg kg^{-1} Zn, 401 mg kg^{-1} Cu, 39.1 mg kg^{-1} I, 2778 mg kg^{-1} Fe, 804 mg kg^{-1} Mn, 4168 mg kg^{-1} choline, 219 667 IU kg^{-1} vitamin A, 23 180 IU kg^{-1} vitamin D, 620 IU kg^{-1} vitamin E.

The predominant fatty acid in soya oil is linoleic acid (55–60%) while linolenic acid makes up 7 to 8% of soya oil (Messina 2000).

The response of pig adipose tissue to dietary fatty acids is dependent upon the fatty acid profile of the diet. Dietary levels of essential fatty acids will have a large effect on the levels of the corresponding fatty acids in adipose tissue, since the dietary fatty acids replace the de novo synthesis of other fatty acids (Wiseman et al. 2000). This is particularly true for the essential fatty acids linoleic and linolenic acid (Leat et al. 1964; Brooks 1967; Wahlstrom et al. 1971; Berschauer 1983; Christensen 1985; Hartman et al. 1985; Whittington et al. 1986; Phetterplace and Whatkins 1989; Osterballe et al. 1990; Ajuyah et al. 1991; Vilchez et al. 1991; Otten et al. 1993; Agunbiade et al. 1999). For example, Morgan et al. (1992) fed pigs either a diet containing 5% tallow or 5% soya oil to produce diets with large differences in fatty acid profile. The adipose tissue composition of the pigs was affected by diet resulting in significantly higher levels of linoleic and linolenic acid in the adipose tissue of pigs fed the soya oil diet.

Recently, emphasis has been placed on the inclusion of polyunsaturated fats in the human diet. For example, Stewart et al. (2001) reported that pork containing high levels of polyunsaturated fatty acids lowered low density lipoprotein cholesterol in women compared with pork with a more traditional fatty acid content. It has been recommended that fat in the human diet be made up of a polyunsaturated to saturated (P:S) fatty acid ratio of 1:1 (Grundy et al. 1982). Fat from retail pork has been reported to have a P:S ratio of less than 0.8 (Breidenstein 1987). More recently, it has been suggested that human dietary intake of fat be limited to 30% of total caloric intake (Grundy 1999) with that intake comprising a 1:1:1 ratio of saturated, monounsaturated and polyunsaturated fatty acids (Grundy 1997). If fatty acids such as linolenic acid can be incorporated into pork adipose tissue at higher levels, the polyunsaturated fat content of pork products may be preferentially selected in the marketplace based upon their potential contribution to human health. This trial was conducted to evaluate the growth, carcass quality, meat quality and fatty acid composition of pigs fed diets containing extruded soybeans.

MATERIALS AND METHODS

A four by two factorial with two replicates (50 replicates for gain) design was utilized for four dietary treatments and two sexes resulting in 200 barrows and 200 gilts of similar age and weight on test. The pigs were randomly assigned to pens of 25, within sex. Each pen was 2.8 m × 7.3 m with a solid floor bedded with 60 cm of sawdust and straw. Two pens shared one feeder resulting in a pen of barrows and a pen of gilts consuming feed from one feeder. The experimental grower and finisher diets were formulated to contain 306, 204, 105 and 0 g kg^{-1} and 250, 165, 85 and 0 g kg^{-1}, respectively, of extruded soybeans (ESB) replacing a commercial protein supplement. All diets contained barley and wheat (grower only) and a vitamin/mineral premix (Table 1). The diets were not formulated to be isocaloric or isonitrogenous but rather to have similar lysine energy^{-1} ratios. This resulted in dietary ME levels ranging from 13.5 to 12.8 and 13.2 to 12.4 MJ kg $^{-1}$ for the grower and finisher diets, respectively. All animals were fed and watered ad libitum via wet/dry feeders. Ambient temperature was maintained at 16°C for the entire growth period.

The ESB was supplied from a commercial grain elevator using locally grown soybeans. Extrusion was conducted using an Insta-Pro Model 2500 dry extruder (Insta-Pro Inc., Des Moines, IA, USA) with a throughput of 1 t h^{-1} at an output temperature of 300°C. The beans remained in the cooking chamber for 15 s resulting in a decrease in moisture from 12 to 9%.

Random diet samples were collected for chemical analysis. Each sample was ground through a 1-mm screen using a centrifugal force grinder (Retch Ultra-Centrifugal Mill: F. Kurt Retch, Haan, Germany). The diets were analyzed for dry matter and Kjeldahl nitrogen crude protein using standard methods described by the Association of Official Analytical Chemists (AOAC 1990).

Feed samples were prepared for fatty acid analysis by grinding through a hammer mill with a 0.5-mm screen. Twenty-four carcasses were selected for fatty acid analysis 24 h post-slaughter. Random selection occurred within each diet and gender. A 1-kg section of loin was cut from the left side of each carcass beginning at the last rib. Loin samples were packed on ice and shipped immediately to the laboratory (Toronto) by air. Transit time was less than 24 h. Samples of backfat were obtained from the subcutaneous fat layer approximately 4 cm from the midline end of the left loin. A frozen fat layer (–20°C) was sectioned with a scalpel, removing a layer of fat from all surfaces. Equal portions of inner and outer fat layers were included in the sample.

The extraction and methylation method was a modification of the method of Liu (1994). Each feed sample (300 mg) or each backfat sample (100 mg) was placed in a glass culture tube with a teflon cap. Three millilitres of methanolic 6% KOH was added under nitrogen. The sample was heated to 90°C for 1 h and then cooled. Two millilitres of saline and 5.0 mL of hexane were added and samples were shaken, then centrifuged for 4 min at 1.12 × *g*. The hexane layer was discarded. The sample was acidified with 0.3 mL of concentrated HCl. Five millilitres of hexane was added and the sample was shaken, then centrifuged for 4 min at 1.12 × *g*. The hexane layer was transferred to another tube and evaporated under nitrogen. Three millilitres of boron triflouride/methanol was added, the sample was capped under nitrogen and heated to 90°C for 30 min. Two millilitres of 0.88% NaCl and 2.0 mL of hexane were added; the sample was capped, shaken vigorously and centrifuged for 4 min at 2.57 × *g*. The hexane layer was removed for injection.

Gas chromatography was conducted using a Hewlett Packard 3650 G.C. with a flame ionization detector. Injector and detector temperatures were 200 and 250°C, respectively. The oven temperature began at 45°C with a 3 min initial delay. The oven temperature was ramped up to 180°C at a rate of 5°C per minute. The temperature was held constant at 180°C for 5 min, then ramped up further to 220°C at a rate of 3°C per minute. Fatty acid peaks were identified by retention time, using reference standards (NU CHEK PREP INC. CLC #463).

All pigs were individually identified and weighed at the beginning and end of the trial. Feed consumption, on a feeder basis, was monitored daily and any mortalities or morbidity were recorded. At slaughter, carcass P-2 back fat depth, loin depth, carcass weight, predicted lean yield and grade index were recorded using the Animal Productivity and Health Information Network (APHIN) automated data collection system developed and operated by the University of Prince Edward Island. Twenty-four hours post slaughter 51 carcasses, in addition to the 24 carcasses selected for fatty acid analysis, were randomly selected from pigs on the study, as they were being sectioned into primal cuts. The loins were sectioned at the P-2 site and the cross section of the loin was scored visually for marbling (1 = no marbling, 5 = extreme marbling), manually for fat and muscle firmness (1= soft, 5 = firm) and for muscle light reflectance using a chromameter (Minolta Cl -CR-300, Minolta Canada, Mississauga, ON).

The animal care protocol for this trial followed the guidelines of the Canadian Council on Animal Care (1993) and was approved by the University of Prince Edward Island Animal Care Committee. All animals were slaughtered in a commercial slaughter facility using electrical stunning and exsanguination.

Economic returns per pig were calculated by subtracting feed costs per pig (using feed ingredient costs per tonne of mixed feed divided by feed consumption per pig) from revenue per pig [market price of \$1.60 kg^{-1} × carcass weight × (grade index 100^{-1})]. Based on previous studies in the same facility, using the same genotype, it was assumed that the grower and finisher diets accounted for 33 and 67% of total feed consumption, respectively.

Each pig was an experimental unit for growth parameters. Growth performance data were analyzed by ANOVA using Genstat 5 (Genstat Committee 1993). The effect of increasing the concentration of ESB on growth parameters was assessed using polynomial regression analysis and testing for significant linear or quadratic relationships. The effect of starting weight was removed by analysis of covariance. Missing values were generated by Genstat 5. Feed consumption data were not statistically analyzed due to the low level of replication.

The fatty acid analysis data were analyzed using linear regression analysis controlling for gender to test for a linear relationship between fatty acid content and level of dietary ESB. A correlation coefficient between fatty acid content and level of extruded soybeans fed was generated.

The loin quality measurements were analyzed using a random effects regression model that controlled for pen variation (the random effect) and for gender. Each diet was compared to the control diet (0 g kg^{-1} soybeans).

All meat and fatty acid composition and quality data were analyzed by regression using Intercooled Stata®, Stata Corp. College Station, TX.

RESULTS

There were no sex × diet interactions observed in this study and therefore combined sex effects are presented. Start weight (mean = 20.5 kg) was not significantly (P >0.05) affected by treatment (Table 2); however, to remove any influence of start weight on other parameters, analysis of covariance was employed.

End weight, days on test, total gain and gain d^{-1} were unaffected by soybean inclusion rate and no linear or quadratic effects were observed. Overall, for all dietary treatments, the pigs reached a mean end weight of 108.7 kg within 97 d resulting in a mean gain d^{-1} value of 915 g. Such performance results are considered to be very good by industry standards.

Feed consumption data are presented in Table 3. Due to lack of replication, no statistical analyses were performed on these data. There was a numerical increase in feed consumption with decreasing levels of ESB so that pigs fed the highest ESB inclusion rate diet consumed 10% less feed

Table 2. Growth performance of pigs fed diets containing extruded soybeans

	Start wt (kg)	End wt (kg)	Days on test	Total gain (kg)	Gain/day (g d^{-1})
Soy 30	19.6	108.1	96.8	87.6	911
Soy 20	20.4	109.1	97.1	88.5	919
Soy 10	21.3	109.3	97.8	88.7	916
Control	20.9	108.4	97	87.8	913
SEM	0.37	0.41	0.7	0.14	7.4
Contrasts	*Significance probability of contrast*				
Diet	0.525	0.374	0.459	0.374	0.792
ESB — linear	0.213	0.716	0.276	0.716	0.392
ESB — quadratic	0.519	0.109	0.346	0.109	0.999

Table 3. Feed consumption of pigs fed diets containing extruded soybeans

	Feed pig^{-1} (kg)	Feed pig^{-1} d^{-1} (kg d^{-1})	Feed gain^{-1} (g g^{-1})
Soy 30	216.8	2.24	2.49
Soy 20	230.1	2.37	2.58
Soy 10	238.6	2.44	2.66
Control	239.6	2.47	2.71

than those fed a diet containing no ESB. Because all pigs grew at a similar rate it appears that feed gain^{-1} may have improved with increasing ESB inclusion.

Carcass quality parameters of the pigs on test are presented in Table 4. Dressed weight showed a positive linear response (P = 0.022) to ESB inclusion rate. Loin depth at the P-2 site was unaffected by level of ESB inclusion rate while a positive linear response (P = 0.008) in P-2 fat depth with increasing ESB was observed. Estimated percent lean yield showed a negative linear response (P = 0.003) with increasing ESB inclusion resulting in a small, non-significant (P = 0.074) reduction in carcass grade index. The data appear to indicate that high rates of dietary ESB inclusion resulted in increased fat deposition while lean tissue deposition was unaffected. Although there were no diet × sex interactions for carcass measurements, sex differences were apparent. P-2 loin and fat depth measurements, across all diets, were 59.1 and 20.4 mm for barrows and 60.4 and 17.1 mm for gilts, respectively.

Feed costs were calculated based on ingredient prices as described in the footnote of Table 5. Feed costs increased with increasing ESB inclusion; however, lower levels of feed consumption with increasing ESB resulted in feed savings of \$2.81 pig^{-1} for the highest ESB diet as compared to the diet without ESB inclusion. Despite higher backfat levels and slightly lower carcass grade index values associated with increasing ESB, the higher dressed weight of the ESB fed pigs resulted in higher monetary returns for the highest ESB inclusion rate compared with the diet containing no ESB. Combined with lower feed consumption, this resulted in a marginal increase in profitability of \$5.23 pig^{-1} for the highest ESB inclusion rate compared with the diet containing no ESB.

Table 6 describes the meat quality parameters measured for the pigs on test. Colour, as measured by percent reflectance, and marbling scores were unaffected by ESB inclusion while lean tissue and fat firmness scores were significantly lower (P < 0.05) for the highest dietary ESB inclusion rate compared with all other treatments.

The fatty acid profile of the experimental diets and pork samples are presented in Tables 7 and 8. Increasing inclusion rates of ESB resulted in decreasing dietary levels of short chain, saturated and monounsaturated fatty acids while polyunsaturated fatty acids, such as n-6 and n-3 fatty acids increased in the diet with increasing ESB inclusion (Table 7).

As in dietary fatty acid composition, the fatty acid composition of the pork samples was altered with dietary ESB inclusion level. Levels of n-3 and n-6 fatty acids, as well as PUFA significantly (P < 0.05) increased with increasing dietary ESB while conjugated linoleic acid (CLA), SFA and MUFA decreased with increasing dietary ESB (Table 8).

Table 4. Carcass characteristics of pigs fed diets containing extruded soybeans (n = 13)

	Dressed wt (kg)	P-2 loin depth (mm)	P-2 fat thickness (mm)	Estimated lean yield (%)	Carcass grade index[z]
Soy 30	85.2	59.8	19.8	60	110.1
Soy 20	84.9	58.6	19.6	60	110.1
Soy 10	85.1	60.7	18	60.8	110.7
Control	83.6	59.7	17.8	60.9	110.4
SEM	0.34	0.79	0.51	0.19	0.2
Contrasts	*Significance probability of contrast*				
Diet	0.044	0.328	0.03	0.01	0.074
ESB — linear	0.022	0.564	0.008	0.003	0.069
ESB — quadratic	0.113	0.999	0.824	0.905	0.268

[z]Determined from hot carcass weight and P-2 fat thickness measurement using the 2000 Prince Edward Island Hog Settlement Grid.

Table 5. Costs and revenue when feeding diets containing extruded soybeans to pigs[z]

	Feed cost t^{-1} grower	Feed cost t^{-1} finisher	Feed pig^{-1} (kg)	Feed cost pig^{-1}	Revenue pig^{-1}	Revenue – feed cost
Soy 30	$231.36	$216.94	216.8	$48.06	$150.09	$102.03
Soy 20	$227.44	$216.78	230.1	$50.69	$149.56	$98.87
Soy 10	$224.76	$211.16	238.6	$51.60	$150.73	$99.13
Control	$221.31	$207.88	239.6	$50.87	$147.67	$96.80

[z]Feed consumption assumed to be 33% grower and 67% finisher. Costs are for feed ingredients only and do not include milling, mixing or transportation. Ingredient prices (per tonne): barley, $130; wheat, $150; lysine HCl, $10 000; ESB, $334; Soybean meal, $367; vitamin/mineral mix, $750; protein supplement, $441.50. Revenue per pig based on a market price of $1.60 kg^{-1} dressed wt × dressed wt × (grade index/100).

Table 6. Meat quality parameters of pigs fed diets containing extruded soybeans

	Colour reflectance	Marbling score	Lean firmness score	Fat firmness score
Soy 30	57.1	1.4	1.6	1.2
Soy 20	54.5	2.1	2.3	1.8
Soy 10	56.8	2.1	2.2	2.1
Control	58.1	2.1	2.3	2.1
SEM	1.61	1.93	0.22	0.22
Contrasts	*Significance probability of contrast*			
Diet	0.526	0.099	0.010	0.017
ESB — linear	0.583	0.017	0.001	0.003
ESB — quadratic	0.565	0.027	0.003	0.003

DISCUSSION

Growth

Growth performance of the pigs in this study was unaffected by inclusion level of ESB. Pigs on all treatments grew at similarly rapid rates approaching 1 kg d^{-1}. Despite similar growth rates, it appeared that feed intake may have decreased with increasing ESB inclusion rate resulting in improved feed conversion ratios. Because of the low replication achieved for feed consumption in this study it is risky to place emphasis on this observation; however, it is appears that the variations in energy density of the diets may have played a role. The experimental diets were formulated to contain similar lysine/ME ratios; however, energy density according to treatment with high ESB inclusion resulted in higher dietary ME. The overall energy efficiency (MJ of ME kg^{-1} of growth) of the four diets was similar at 33.07, 33.25, 33.89 and 33.90 MJ kg^{-1} for diets 1 through 4, respectively. It is possible, therefore, that the pigs fed the higher energy diets consumed slightly more energy and protein per day during the early stages of growth when gut fill is the first limiting factor to feed intake (Chadd et al. 1993). This additional energy may have been in excess of lean growth requirements since pigs on all treatments had similar growth rates and carcass lean contents. As the growing/finishing pig consumes feed to primarily meet its energy requirements (Chadd et al. 1993), one would expect feed consumption of high ESB diets to be lower than diets containing lower levels or no ESB. The additional fat content of the pigs fed the high ESB diet further suggests that dietary energy levels were in excess of requirements for lean growth.

Carcass Quality

Carcass quality parameters, as measured in this study, indicated that the pigs had similar rates of lean deposition since

Table 7. Fatty acid composition (% of total fatty acids) of diets containing varied amounts of extruded soybeans

	Grower				Finisher			
Fatty acid	Soy 30	Soy 20	Soy 10	Control	Soy 30	Soy 20	Soy 10	Control
C14:0	0.15	0.25	0.35	0.61	0.21	0.36	0.51	0.78
C16:0	13.3	14.24	15.08	17.76	14.46	15.68	16.87	19.39
C16:1	0.03	0.05	0.07	0.13	0.04	0.06	0.11	0.14
C16:1n7	0.12	0.27	0.41	0.88	0.21	0.37	0.92	1.01
C17:0	0.11	0.12	0.15	0.2	0.12	0.15	0.2	0.24
C17:1	0.08	0.08	0.09	0.15	0.06	0.09	0.11	0.14
C18:0	2.8	3.05	3.58	4.13	2.99	3.35	4.03	4.53
C18:1n7	1.1	1.56	1.71	2.91	1.1	1.44	1.67	2.98
C18:1n9	18.53	19.44	19.49	23.55	15.66	17.47	20.86	22.8
C18:2n6	54.13	51.76	50.08	42.16	54.88	51.57	46.49	40.32
C18:3n3	8.39	7.87	7.5	4.99	8.88	7.8	6.18	4.62
C20:0	0.24	0.26	0.26	0.27	0.27	0.27	0.31	0.3
C20:1n9	0.31	0.35	0.39	0.63	0.3	0.4	0.43	0.62
C20:5n3	0.28	0.29	0.29	0.25	0.33	0.3	0.29	0.26
C22:1n9	0.16	0.16	0.19	0.26	0.18	0.2	0.21	0.26
C22:5n3	0.12	0.12	0.13	0.16	0.13	0.13	0.16	0.2
SFA[z]	16.6	17.92	19.41	22.96	18.04	19.8	21.92	25.23
MUFA[y]	20.31	21.91	22.34	29.08	17.54	20.26	24.57	28.8
PUFA[x]	62.91	60.04	58	47.55	64.22	59.79	53.12	45.39

[z]Saturated fatty acids.
[y]Polyunsaturated fatty acids.
[x]Monounsaturated fatty acids.

Table 8. Fatty acid composition (% of total fatty acids)of subcutaneous backfat from pigs fed diets containing varied amounts of extruded soybeans

Fatty acid	Soy 30	Soy 20	Soy 10	Control	Correlation coefficient[z]
C14:0	1.03	1.16	1.25	1.34	–0.5459
C16:0	19.09	21.31	23.07	23.87	–0.6704
C16:1	0.28	0.28	0.35	0.37	–0.5226
C16:1n7	1.24	1.52	1.74	1.98	–0.7712
C17:1n7	1.24	1.52	1.74	1.98	–0.7499
C18:0	10.5	12	13.38	13.6	–0.562
C18:1n7	1.42	1.83	1.99	2.64	–0.7687
C18:1n9	31.87	34.6	39.44	41.19	–0.8598
C18:2n6	27.06	21.03	13.87	10.63	0.8893
C18:3n6	3.82	2.78	1.46	0.96	0.9139
C20:1n9	0.65	0.75	0.94	0.94	0.585
C20:2n6	1.17	0.97	0.73	0.57	0.7927
CLA[y]	0.09	0.1	0.11	0.13	–0.5396
n-3	4.3	3.17	1.7	1.11	0.9168
n-6	28.6	22.36	14.98	11.58	0.8871
SFA[x]	31.29	35.12	38.37	39.52	–0.6646
MUFA[w]	35.66	39.18	44.75	47.47	–0.9041
PUFA[v]	32.94	25.61	16.76	12.88	0.89

[z]Correlation between fatty acid content and dietary ESB inclusion rate.
[y]Conjugated linoleic acid. The standard used for fatty acid analysis did not define individual isomers of CLA.
[x]Saturated fatty acids.
[w]Monounsaturated fatty acids.
[v]Polyunsaturated fatty acids.

their growth rates and loin depth measurements were similar for all treatments. Fat deposition rate appears to have been higher for the high ESB diets resulting in higher dressed weights and lower lean yields. P-2 fat depth measurements were 2.4 mm thicker for pigs fed the high ESB diets compared with the non-ESB fed pigs. As discussed above, the available energy from the high ESB diets may have been greater than for the lower or non-ESB diets and this may have resulted in dietary energy levels in excess of lean gain requirements which, in turn, would result in greater fat deposition.

Economic Returns

Due to experimental design, we were unable to statistically analyze feed conversion ratio; however, the feed conversion data indicated a linear relationship between the inclusion rate of soybeans and feed efficiency (Table 3). Despite the lack of significance for this parameter, the economic return results of this study illustrate the importance of feed conversion ratio and energy density to overall feed costs. Despite the fact that the highest ESB (i.e., highest energy density) diet cost $10.05 and $9.06 more per tonne (grower and finisher diets, respectively) than the non-ESB diet, the improved feed conversion of the high ESB diet resulted in a feed cost saving per pig of $2.81 compared with the non-ESB diet. As discussed above, this may partly be due to the differences in energy density between the diets. The cost per MJ of ME for each diet was similar at $0.0171, $0.0172, $0.0173, and $0.0173 (grower) and $0.0165, $0.0168, $0.0167, and $0.0168 for the highest to the lowest ESB inclusion rate, respectively. This suggests that the difference in the per-tonne cost of the complete diets was, in large part, a reflection of the energy density of the diets.

Even with a slightly reduced carcass grade index for the high ESB pigs the per-tonne feeding cost advantage, along with a higher dressed weight, still resulted in an increased profitability of $5.23 per pig compared with pigs fed diets without ESB. These results suggest that higher energy diets, with optimum lysine/ME ratios, may be more cost effective than lower density diets provided the source of extra energy is inexpensive.

Fatty Acids

The pork from the pigs fed high levels of ESB contained higher levels of linoleic and linolenic acids as compared to pigs fed diets without ESB. This represents both a benefit and a hindrance to the consumer acceptability of such a product. The protective effects of n-3 fatty acids against cardiovascular diseases, cancer and rheumatoid arthritis (Addis 1989; Fernandes and Venkatraman 1993) have caused researchers to study the dietary enrichment of animal products, including pork, with n-3 fatty acids. Wood and Enser (1997) investigated the fat content and composition of steaks or chops from the loins of beef cattle, pigs and lambs. The results indicated that lean red meat is low in fat in all three species, but especially so in pigs. The fatty acid composition of the total lipid extracted from the lean tissue showed clear species differences with pigs having a higher n-6:n-3 fatty acid ratio than beef cattle or lambs due mainly to the high linoleic acid content of pork. Recommended n-6:n3 ratios are below 4.0 (Wood and Enser 1997) while pork lean typically contains ratios of 7.0 and above. With such high n-6:n3 fatty acid ratios in pork, researchers have focused on ways to correct this imbalance. In the trial reported here we were able to reduce the n-6:n-3 ratio from 10.4 to 6.7 by inclusion of high levels of ESB.

In pigs it is well established that fatty acids can be absorbed across the intestinal lumen unchanged and incorporated into adipose tissue (Agunbiade et al. 1992). A change in diet will result in a modification of the type of triglycerides produced from anabolism, and over a period of time as lipid in adipose tissue is recycled, the fatty acid profile of the adipose tissue will change in response to the new diet. Agunbiade et al. (1999) reported that between 60 and 70% of this change has been shown to occur in a 2-wk period following the dietary change. Koch et al. (1968) reported a complete change in adipose composition occurring within 4–5 wk of a dietary change.

Early work by Ellis and Isbell (1926) showed that linoleic acid could be readily incorporated into adipose tissue in pigs; however, high levels of this fatty acid resulted in soft fat. The melting point of fats plays an important role in the firmness of adipose and lean tissue. The melting point of saturated straight chain fatty acids increases with increasing chain length and thus the fat becomes firmer at room temperature. Double bonds result in fatty acids having a lower melting point compared to the saturated fat with the same chain length. The presence of more double bonds softens fat at room temperature and results in a softer texture in the meat and fat of a primal cut. This explains the significant reduction of fat and muscle firmness in the pork from pigs fed high levels of ESB in our study. As ESB contains high levels of lipid, and that lipid is high in PUFA, feeding high dietary concentrations of ESB will increase the PUFA concentration in pork adipose tissue and thus reduce fat and lean firmness. This reduction in firmness is considered a negative attribute by the consumer.

Wiseman et al. (2000) reported that loin samples from pigs fed linseed oil (high in PUFA) had higher abnormal lean and fat odour intensity than pigs fed palm oil or tallow, which are high in saturated fatty acids. Colour intensity of the lean meat of pigs fed tallow was higher and juiciness was decreased compared with pigs fed linseed oil. Colour intensity, as measured by reflectance was not affected by dietary treatment in our study and consumer acceptance parameters such as juiciness and odour are the subject of a subsequent study.

Although consumer acceptability and shelf life were not measured in this study, the increased levels of linoleic and linolenic acid in the adipose tissue of the pork from pigs fed high levels of ESB suggest that the risk of rancidity and off flavours could be higher than for pork from pigs fed a diet with a lower level of PUFA. Ahn et al. (1996) reported that pork from pigs fed diets rich in linolenic acid had an increased oxidation value, as measured by the presence of thiobarbituric acid, which resulted in detrimental effects on the acceptability of cooked pork loins held for 2 d at 4°C. As pork from pigs fed high levels of ESB contained higher levels of linoleic acid than linolenic acid, oxidation may not be a serious concern as linoleic acid is much less prone to oxidation than linolenic acid (Ahn et al. 1996). Wood and Enser (1997) suggested that dietary inclusion of antioxidants, such as vitamin E, may partially overcome the increased risk of oxidation in pork containing high levels of PUFA. This suggests that even though feeding high levels of ESB may result in softer lean and fat, the shelf life of the pork can be maintained by supplementation with an antioxidant such as vitamin E. Further work, including an economic analysis of the cost of increasing dietary vitamin concentrations, is necessary to verify this hypothesis and to evaluate its practical potential. The increased PUFA content of the pork from the pigs fed high levels of ESB suggests that it may be a more acceptable product for the consumer than "conventionally fed" pork.

In conclusion, the results of this trial indicate that a high level of ESB (30% of the diet) leads to improved economics of production in a region where oil extraction is unavailable to value the raw beans at a higher level. Care must be taken to ensure optimum energy density of the diet to optimise feed efficiency and optimise carcass fat level and carcass grade index. It is clear from the data, and from previously published work, that the fatty acid composition of pork can be altered by dietary means. Inclusion of high levels of ESB into the diet of the pig offers a simple way of altering the fatty acid profile of pork to more fully meet the expectations of the health-conscious consumer. The risk of lipid oxidation with high PUFA content must be considered prior to feeding such diets. Care must be taken to overcome the potential reduction in shelf life which this may impose.

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