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An Evaluation of The Complete or Partial Replacement of Soybean Meal With Canola Meal in Diets For Growing Swine

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An Evaluation Of The Complete Or Partial Replacement Of Soybean Meal With Canola Meal In Diets For Growing Swine

By

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ABSTRACT

A series of three trials was conducted to evaluate the performance of starting, growing and finishing pigs fed diets containing canola meal (CM) as the partial or complete supplemental protein source. In Trial 1, performance of starting pigs fed isocaloric, isolysinic and isoavailable phosphorus diets containing corn, soybean meal and CM (CM represented 10% of the diet) were similar to pigs fed control diets (using SBM as the sole supplemental protein source) for measurements of average daily gain (ADG), average daily feed intake (ADFI) and feed per unit of gain. Pigs fed diets containing 15% CM in the growing phase were less efficient ($P<.10$) than pigs fed control diets. In the finishing phase, pigs fed diets containing 17.5% CM (completely replacing SBM) gained significantly less than the control group (710 vs. 787 g/day). Subsequently, pigs fed the CM diets in the starting, growing and finishing phases had smaller loin eyes ($P<.01$) and less muscle than ($P<.05$) the control group. In Trial 3, varying levels of CM were fed to pigs in the growing and finishing phases (replacing 0, 25, 50, 75 or 100% of the SBM in the diet). As pigs were fed increasing amounts of CM in the growing phase, their F/G was linearly increased and ADG was linearly depressed. Pigs fed the same treatment in the finishing phase were able to compensate for their reduced performance in the growing stage by increasing their ADFI and ADG, but still increasing their F/G as

they were fed increasing amounts of CM. Carcass measurements between the treatment groups were not significantly different. Thus, it would appear that pigs which were fed increasing amounts of CM during the growing stage might be able to compensate for the possible nutritional deficiencies of canola meal diets (at the expense of F/G), by increasing diet intake during the finishing stage.

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

In the United States, soybean meal has been the predominant supplemental protein source in typical swine growing diets. It contains an excellent balance of amino acids and sufficiently compliments corn, sorghum, barley, or other cereal energy sources used in swine diets in supplying lysine, tryptophan, threonine, isoleucine, and the sulfur amino acids, all of which are deficient in cereal energy sources.

Canola meal is a fairly new supplemental protein source and is a by-product from the processing of canola for edible oil. Canola is another name for rapeseed which has been improved through extensive plant research and breeding. These improvements have resulted in a higher quality vegetable oil that is nutritionally similar to soybean oil. The meal by-product of canola may be included at higher levels than formerly in swine diets due to the reduction (through plant breeding and selection) of thyrotoxic substances originally present in rapeseed meal.

Like soybean meal, canola meal contains a favorable balance of amino acids which compliments the energy source (grains) in swine diets. However, canola meal is slightly lower in energy and protein and the critically limiting amino acid lysine than soybean meal. Balancing swine diets for these nutritional deficiencies has sometimes produced comparable performance to that of pigs fed diets containing soybean meal as the sole supplemental protein source, but there is some indication that other limiting factors may be associated with feeding canola meal.

There is a considerable amount of information, especially from Canada, concerning the performance of pigs fed diets containing canola meal. Most of the diets used in those trials contained barley and/or wheat as the primary energy source instead of corn (the predominant energy source in typical swine diets fed in the U.S.). Also, canola meal used in past studies was usually from either the Tower or Candle variety of canola. Today, canola meal on a commercial scale contains a wide mixture of canola varieties.

Thus, the objective of this study was to balance swine diets containing commercial canola meal for the limiting nutrients and determine if these diets could support performance of pigs equal to that of pigs fed typical corn-soybean meal diets. Varying levels of the canola meal were also fed to determine the effect of inclusion rate on subsequent pig performance.

The results from this study would then allow us to estimate the economic value of canola meal based on the price of corn and soybean meal replaced by canola meal and the performance of pigs fed that particular level of canola meal.

REVIEW OF LITERATURE

HISTORY AND DEVELOPMENT OF RAPESEED VARIETIES

The production and composition of rapeseed has changed considerably since its introduction to Canada in 1936 as an oilseed rape. These improvements and changes were made in response to the increased demand for edible oil and usage of oilseed meals in livestock diets. As a result of work by plant breeders and researchers, the new rapeseed contains substantially lower quantities of erucic acid and glucosinolates. This, in turn has resulted in an increased acceptance of rapeseed in Canada and abroad. These newer varieties of rapeseed have been termed canola, a trademark of the Canola Council of Canada.

Bell (1982, 1984) and Kondra (1985) have written extensive reviews pertaining to the development of the present canola varieties from old traditional rapeseed varieties. The highlights of these reviews will be summarized below.

Rapeseed is a member of the Cruciferae or mustard family and belongs to the *Brassica* genus. The two most common species of rapeseed are *B. napus* and *B. campestris*. These two species are well suited to the temperate and subtropical zones of the world. Because of this adaptability, rapeseed thrives as a winter or cool season crop in Canada, Europe, and Asia in areas less suited for optimum soybean production (Pond and Maner, 1984).

The *B. campestris* species of rapeseed originated in Poland and was introduced as an oilseed rape in Canada in 1936. Shortly thereafter, the species *B. napus* from Argentina was introduced in Canada. These two species served as the base from which subsequent cultivars of rapeseed were produced.

Because of the high erucic oil content of the seed, rapeseed oil served as an engine lubricant for ships during World War II. Later, as demand for edible oil increased, rapeseed oil was approved for human food consumption in Canada by the Food and Drug Directorate in 1958. During this time controversy arose concerning the presence of erucic acid in the oil (25-50% of the oil) from rapeseed. Erucic acid which is a 22 carbon, long chain fatty acid was thought to cause certain abnormalities in animals fed this oil. This concern was reviewed by the Department of National Health and Welfare in 1970 over evidence of myocardial lesions in laboratory animals associated with erucic acid consumption (Bell, 1982). This prompted the decision to limit edible oils to less than 5% erucic acid.

Thus, the concern for health and also the evidence of cost reduction in refining low erucic acid oils prompted Canadian researchers and plant breeders to initiate an extensive conversion program to low-erucic acid cultivars of rapeseed. In 1968, the variety Oro from B. napus became the first low-erucic acid cultivar of rapeseed licensed in Canada. The varieties Polar, Turret, Span, Zephyr, Torch, and Midas followed, all having oil low in erucic acid.

Another concern during the development of new rapeseed cultivars was the presence of glucosinolates in the meal by-product. It was found that rapeseed meal contained significant amounts of glucosinolates which, upon hydrolysis by myrosinase and heat, yielded thyrotoxic substances (Bell, 1955; Hussar and Bowland, 1959). In 1974, the first low glucosinolate cultivar was released as the variety Tower from B. napus. The release of Candle from B. campestris followed in 1977, and these two became the first "double low" (low erucic acid and low glucosinolate) varieties known as canola (Bowland, 1975; Bell, 1982). Subsequently the varieties Regent, Altex, and Ander from B. napus, and Candle and Tobin from B. campestris became commercially available (Bell, 1982; Aherne and Kennelly, 1985; Kondra, 1985). All of these cultivars are termed canola and must contain less than 5 per cent erucic acid in the oil and less than 3 mg of glucosinolates per gram of meal (Baidoo and Aherne, 1985).

The European countries have also developed low glucosinolate varieties of rapeseed. These include Swedish varieties Karat, Topas (*B. napus*) and Global, Danish rapeseed known as Line, Finish variety Sigga (*B. campestris*), and the European cultivars Erglu and Tandem (Singam and Lawrence, 1979; Thomke, 1984; Rundgren *et al.*, 1985; Nasi *et al.*, 1985; Bourdon *et al.*, 1985; Eggum *et al.*, 1985). Countries including the Netherlands and Western Germany utilize Canadian rapeseed meal (canola) by blending these varieties with the locally produced high-glucosinolate meals (Aherne and Kennelly, 1985).

The usage of these low-glucosinolate rapeseed varieties has increased dramatically over the last 5 years, but high-glucosinolate cultivars are still grown in Europe and China along with low-erucic acid cultivars (Fenwick, 1984; Thomke, 1984; Rundgren, 1985). Essentially all of the rapeseed grown in Canada is of the low-glucosinolate, low-erucic acid type (Kondra, 1985).

PRODUCTION OF RAPESEED

Current world rapeseed production is about 20 million acres (Leep, 1986). China is the leading producer of rapeseed and is continuing to strengthen this position while production in other countries has declined somewhat (Aherne and Kennelly, 1985). Canada is the world's second largest producer but is the largest exporter of rapeseed (Veeman, 1985). In 1983-84 Canada produced 2.6 million tonnes of canola for processing into oil and protein meal for internal and external uses.

Other rapeseed-producing countries include India, Poland, France, Great Britain, and Sweden. The United States plays a minor role in production with North Dakota, Minnesota, and the upper peninsula of Michigan producing roughly 20,000 acres of rapeseed (Leep, 1986). Although production of canola in the United States is limited, canola meal is gaining acceptance in the West in dairy and poultry diets (Blair, 1986). As research and economic studies with canola meal continue in these regions, increased production may be initiated. The recent approval of rapeseed oil for human consumption by the U.S. Food and Drug Administration (January, 1985) may also enhance production and crushing of canola in the United States (Helm and Ball, 1985; Kondra, 1985).

Most canola grown in the U.S. is grown under contract at a fixed price, production level, and specified delivery point (Helm and Ball, 1985). In Canada, price discovery of canola is based on the Winnipeg Commodity Exchange market for rapeseed futures contracts and the Chicago Board of Trade soybean meal futures contracts (Kondra, 1985). Canola is particularly affected by world edible oil demand, especially since canola contains almost twice the oil content of soybeans (Veeman, 1985).

PROCESSING OF CANOLA FOR OIL AND MEAL

The processing of canola for oil and meal by-product is similar to procedures used for other oil seeds such as soybeans. This could be expected since most crushing operations utilizing canola would most likely also refine oils from other oilseeds. In Canada, most processors utilize the prepress solvent extraction method, but direct solvent extraction and expeller pressing may also be employed (Youngs et al., 1981).

Direct solvent extraction of canola may be impractical since the high oil content seeds disintegrate into fine particles making percolation of the miscella through the meal bed extremely slow. This problem has been alleviated somewhat by a process known as "filtration-extraction" (Youngs et al., 1981; Yehya and Jelen, 1985). Expeller pressing used without any solvent extraction requires much higher pressures to insure adequate recovery of oil from seed. This added pressure has resulted in the thermal damage of lysine and caused poor growth and feed conversion of poultry fed expeller-processed rapeseed meal (Clandinin, 1967).

Although canola seed does not contain trypsin inhibitors, precautionary procedures must be employed relative to the glucosinolates still present in the seed. The intact glucosinolates are not nearly as toxic as the isothiocyanates, oxazolidine-2-thiones and thiocyanate ions produced from the hydrolysis of glucosinolates by the enzyme myrosinase (Olsen and Sorensen, 1980; Fenwick *et al*., 1982). Within the canola seed the glucosinolates are physically separated from the myrosinase enzyme. However, this barrier can be ruptured by grinding, chopping, and other mechanical forces employed during processing (Fenwick, 1984). Thus, steps to minimize hydrolysis of glucosinolates include monitoring seed moisture (8 to 8.5% optimum), rapidly raising the temperature in the cooker to 90°C, and maintaining the temperature in the cooker and desolventizer below 110°C (Reynolds and Youngs, 1964; Youngs *et al*., 1981).

Due to the slight differences in nutritional characteristics between some canola cultivars, Canadian crushing plants blend the seeds at the time of processing to obtain a more uniform product. Studies have shown that the composition of this meal is consistent between processing plants in Canada (Bell *et al*., 1976; Clandinin *et al*., 1981; Canola Council of Canada, 1984).

Another process employed by Canadian crushers is the addition of gums back to the meal fraction to increase the energy density. These gums obtained from the refining of canola oil consist mainly of glycolipids, phospholipids, and variable amounts of triglycerides, sterols, and fatty acids (Clandinin *et al*., 1981; Aherne and Kennelly, 1985). Along with increasing the metabolizable energy value of canola meal, the gums when added at the level of 1.5%, aid in reducing the dustiness of the product (Youngs et al., 1981). These gums have been included in experimental diets of pigs and other animals at levels as high as 6% and showed no adverse effects on performance (McCuay and Bell, 1981). This addition of gums (1.5%) accounts for the high ether extract content of the meal (3.8%).

Other processing procedures to improve the quality and nutrient value of canola meal have been investigated. Naczk et al. (1985) described the use of a two-phase solvent extraction system using 10% NH_3 in methanol or in methanol containing 5% water in the first phase and hexane as the second phase. The canola meal from this extraction method was similar in crude protein to soybean meal. The glucosinolates present in meals from Tower, Candle, and Altex canola varieties were reduced 82-86%.

Smithard and Eyre (1986) utilized a dry extrusion process on a mixture of canola and sunflower meal. The meals extruded at 135°C from an Insta-Pro extruder showed no improvement in biological value or anti-thyroid activity when fed to rats.

Since canola meal contains a substantially higher crude fiber value than soybean meal, procedures to dehull the canola seed before oil extraction were investigated. Bourdon et al. (1985) employed a dehulling procedure which resulted in a 15% increase in digestible energy, 17%

increase in crude protein, and a 5% increase in apparent digestibility of protein when compared to meals from conventional processes.

Although some of these procedures improved the nutritional value of canola meal, economics would seem to dictate whether or not these methods were implemented. Modifications in canola varieties and formulations of livestock diets may be the more direct approach to improving the value and utilizations of canola meal. However, as interest in canola oil for human consumption increases technological advances in processing may prove to be economical.

NUTRITIONAL VALUE OF CANOLA

Since soybean meal is considered the major supplementary protein source for swine in most of the U.S., it will serve as a standard for nutritional comparisons with canola meal in this review. In general, most of the nutritional values for canola meal reported here are taken from those published by the Canola Council of Canada while soybean meal data are from National Research Council publications.

COMPOSITION OF CANOLA (RAPESEED)

Rapeseed contains 48% oil and 23% protein compared to 20% oil and 43% protein (dry basis) in soybeans (Rutkowski and Kozlowska, 1979). The protein of rapeseed meal contains a higher fraction of nonprotein nitrogen (8-10% of crude protein) than soybean meal (Naczk et al., 1985). Included in this fraction are peptides, free amino acids, nucleic acids, glucosinolates, ammonia, nitrogen, and other nitrogen containing compounds. Rapeseed polysaccharides are composed primarily of cellulose plus lignin and hemicellulose. Insoluble polysaccharides or crude fiber are mainly concentrated in the hull which accounts for 12-20% of the seed weight (Rutkowski and Kozlowska, 1979; Bell, 1984). These hulls contain 67 and 80% acid and neutral detergent fiber, respectively, on an oil free basis (Bell and Shires, 1982). Rapeseed also contains significant amounts of phytate and glucosinolates. The amounts of these substances and their presence in the meal fraction will be discussed in a separate section.

ENERGY AND DIGESTIBILITY OF CANOLA MEAL

The digestible and metabolizable energy values of canola meal for swine are reported as 2900 and 2700 kcal/kg, respectively, by the Canola Council of Canada (1984). These as-fed values are based on past research using rapeseed and canola meals (Saben et al., 1971; May and Bell, 1971; Bell and Jeffers, 1976). Other work evaluating the energy digestibility of rapeseed meals showed lower values (Bayley et al., 1969; Bell, 1975), but later research by Bell and Jeffers (1976) suggested that the cultivars of rapeseed used in those experiments could have been immature and of poor quality.

Various Swedish experiments reviewed by Rundgren (1983) showed a range of metabolizable energy values for pigs of 2300 to 2700 kcal/kg air dry basis (assuming 10% moisture). Later work done by Rundgren et al. (1985) using the Swedish low-glucosinolate cultivar Topas found metabolizable energy values ranging from 2600-2800 kcal/kg air dry. This particular study found metabolizable energy values for high-glucosinolate varieties to be slightly lower when compared to Topas. French work done by Bourdon et al. (1985) compared the digestible energy values of the low-erucic acid variety Jetneuf and the double low (low-erucic acid and low-glucosinolate) rapeseed variety Tandem. Pigs fed the two varieties showed that the digestible energy of meals from Jetneuf and Tandem varieties were 3111 and 2930 kcal/kg of solvent extracted meal, respectively.

These experiments show some deviations from the published Canola Council energy values for canola meal. Differences in processing, cultivar used, and collections for energy determinations may account for some of the variance. The Swedish and French work quoted earlier showed slightly improved energy digestion coefficients for low-glucosinolate cultivars of rapeseed in swine diets compared to high-glucosinolate types. Saben _et al_. (1971) found no significant differences in metabolizable energy values between commercial rapeseed meals (older high-glucosinolate types) and the low glucosinolate Bronowski type (the cultivar which became the source of the low-glucosinolate character of Tower; Bell, 1982).

Differences in digestible energy between varieties of canola appear to be minimum. Bell _et al_. (1981) evaluated meals from Candle and Tower rapeseed varieties and found Candle to have a digestible energy value for pigs of 3030 kcal/kg (air dry). This slightly improved energy value may be attributed to the reduced hull content in the meal from Candle varieties.

Research has been conducted to evaluate the influence of fiber on the digestibility of canola meal. Canola meal contains approximately 11-13% fiber (as fed) compared to 6-7% fiber in soybean meal (Clandinin _et al_., 1981; Rundgren, 1983; Bell, 1984). The higher fiber in canola meal undoubtedly accounts for the lowered digestible and metabolizable energy values (May and Bell, 1971; Bell, 1984).

Rapeseed meal contains about 30% hulls. These hulls contain approximately 20% cellulose, 23% lignin, 9% pectin, 20% protein, 5% ash, and very little free carbohydrates or lipids (Bell and Shires, 1982; Bell, 1984). Thus, it would seem that the hulls present in canola meal probably limit the digestibility of energy and protein fractions by the pig. While some studies have shown that the removal of hulls from canola meal may increase energy and protein digestibility by the rat and chick (Leslie et al., 1973; Bayley and Hill, 1975; Sarwar et al., 1981), studies with pigs showed limited improvement in digestibility of energy and protein (Bayley and Hill, 1975; Kennelly et al., 1978). Mitaru and Blair (1985) evaluated hulls from Tower and R500 rapeseed and compared them to soybean hulls. They found starter pigs fed diets with Tower and soybean hulls had similar digestibility values while R500 rapeseed hulls had higher digestibility ($P < 0.05$) values for dry matter, energy, and protein. This would seem to indicate that hulls may not be the only factor limiting the digestible and metabolizable energy values of canola meal.

Canadian plant breeders have worked to develop cultivars of canola with reduced fiber and seed coat thickness. The variety Candle was developed which contained a thinner hull and a yellow seed coat (Bell et al., 1981). Although Candle was found to have a slightly higher digestible energy value (Bell et al., 1981), pig performance was not significantly improved over that observed when using other low-glucosinolate varieties (Kennelly et al., 1978). Continued work is being done to reduce the fiber and hull content of canola using the R500 variety of rapeseed from B. campestris (Bell and Shires, 1982; Mitaru and Blair, 1985).

Past Canadian work has shown that dehulling rapeseed meal by means of an air classification and sieving technique resulted in a product similar in metabolizable energy and protein to soybean meal (Clandinin and Robblee, 1981). However, problems with palatability associated with the finely ground meal were seen. French and Swedish work showed that removal of the hull from the seed before oil extraction resulted in a high protein product with no apparent palatability problems in pigs. Bourdon et al., (1985) found that this process reduced crude fiber approximately 50% and increased energy and protein digestibility. However, the added heat treatment of dehulling may have affected the lysine availability in the low-glucosinolate meal.

It would appear from these studies that increasing the energy digestibility of canola would require a reduction in fiber, seed coat, hulls or removal of hulls, but the energy composition of the embryo may also need to be considered. Dehulling may increase the energy value if economics warrants this process.

PROTEIN AND AMINO ACID AVAILABILITY OF CANOLA MEAL

The protein and amino acid profile of canola meal in comparison to soybean meal is presented in Table 1 (values from the Canola Council of Canada, 1981). These are average values based on canola meal produced in Canadian processing plants. Older, high-glucosinolate varieties of rapeseed and newer canola varieties have similar protein and amino acid profile when processed using the prepress solvent extraction method (Clandinin and Robblee, 1981; Sauer, 1982).

Like soybean meal, canola meal contains an excellent balance of amino acids for utilization in swine diets (Clandinin et al., 1981; Bell, 1984; Aherne and Kennelly, 1985). From Table 1, we can see that canola meal is lower in lysine than soybean meal (2.27 vs. 2.80%), but canola meal is a better source of the sulfur-containing amino acids cystine + methionine. Canola meal is also lower in crude protein than soybean meal. This value may vary depending on the variety of canola used. Meals from Candle contain approximately 35% crude protein, while meals from Tower, Regent, and Altex contain 38-39% crude protein (Clandinin and Robblee, 1981). Again, these cultivars are usually blended together before processing to obtain a more uniform product.

Canadian work has shown that the average protein digestibility of canola meal for pigs is 80% (Bell and

Table 1. Proximate and amino acid composition of canola[a] meal and soybean meal[b].

	Canola meal		Soybean meal	
	as fed %	in protein %	as fed %	in protein %
Proximate composition				
Moisture	7.49		11.00	
Crude fiber	11.09		7.3	
Ether extract	3.78		.8	
Protein (N x 6.25)	37.96		45.01	
Amino acid composition				
Alanine	1.73	4.56	1.89	4.20
Arginine	2.32	6.11	3.30	7.50
Aspartic acid	3.05	8.03	5.04	11.20
Cystine	.47	1.23	.70	1.59
Glutamic acid	6.34	16.69	8.10	18.00
Glycine	1.88	4.96	2.07	4.60
Histidine	1.07	2.81	1.20	2.73
Isoleucine	1.51	3.98	2.40	5.45
Leucine	2.65	6.97	3.50	7.95
Lysine	2.27	5.98	2.80	6.22
Methionine	.68	1.78	.70	1.59
Phenylalanine	1.52	4.01	2.30	5.23
Proline	2.66	7.00	2.20	4.89
Serine	1.67	4.39	2.25	5.00
Threonine	1.71	4.50	1.81	4.11
Tryptophan	.44	1.16	.62	1.41
Tyrosine	.93	2.46	1.30	2.95
Valine	1.94	5.11	2.30	5.23

[a] Values reported from Canola Council Publication No. 59, 1981.

[b] Values reported from **Nutrient Requirements for Swine**, NRC, 1979.

Aherne, 1981). Rundgren (1983) summarized Swedish work which showed that apparent digestibility of protein in low-glucosinolate rapeseed meal fed to pigs varied from 72-86%. Average values, however, were close to the 80% digestibility values reported by Canadian workers.

French work (Bourdon, 1985) using the double zero (low glucosinolate, low erucic acid) Tandem and Regent varieties of rapeseed found that the average digestibility of nitrogen by pigs was approximately 81.7%. Although this value is lower than the 87-89% protein digestibility of soybean meal, dehulling increased the value of low-glucosinolate rapeseed meal to 85.8% apparent digestibility of nitrogen when fed to pigs.

While digestible protein values may be useful in assessing the nutritive value of canola meal, these values may be somewhat misleading. Hodgdon et al. (1974) determined the hepatic portal blood ammonia concentrations in pigs fed either rapeseed meal or soybean meal. This study found more ammonia was formed in the large intestine of pigs fed rapeseed meal, indicating a possible overestimation of the digestible nitrogen values. Perhaps a more useful assessment of canola meal protein quality may be amino acid digestibility and availability.

Work done by Cho and Bayley (1970) showed that apparent digestibility of total amino acids in soybean meal was

88.53% while rapeseed meal apparent availability averaged 82.44%. Lysine availability was 90.4% in soybean meal and 87% in rapeseed meal. These values were determined using fecal analysis of 60 kg barrows fed semipurified diets containing either soybean meal or rapeseed meal (older, high-glucosinolate varieties). Later work by Cho and Bayley (1971) found significant differences in the concentrations of several amino acids between samples of ileal digesta and feces from animals fed rapeseed meal or soybean meal. Holmes et al. (1974) also found that differences in amino acid digestibility were greater at the ileum than in the feces of pigs fed low-erucic acid rapeseed meal and soybean meal. Sauer et al. (1982) compared the ileocecal analysis to fecal analysis of available amino acids and found that the fecal analysis method overestimated the availabilities of amino acids in canola meal and soybean meal.

Utilizing the ileocecal method of collection, Sauer et al. (1982) compared the apparent and true amino acid availabilities of canola meal and soybean meal in swine. These values are reported in Table 2. From the table we can see that there were no significant differences between amino acid availabilities of canola meal and rapeseed meal. However, significantly higher values for lysine, arginine, isoleucine, aspartic acid, glycine,

Table 2. Apparent ileal availabilities of amino acids in soybean meal, canola meal, and rapeseed meal for pigs[a].

	SBM	CM		RSM[c]
		Regent	Candle	Turret
	%	%	%	%
Dry matter	78.3	69.8	67.2	69.0
Crude protein	80.6	70.3	68.2	69.5
<u>Amino acids: Indispensible</u>				
Arginine	90.3	81.2	81.7	85.6
Histidine	82.1	79.8	82.9	85.1
Isoleucine	85.5	76.1	76.0	78.0
Leucine	84.2	79.8	79.3	81.3
Lysine	85.6	75.4	73.5	73.5
Methionine	86.3	82.2	81.4	84.3
Phenylalanine	86.3	77.5	79.8	81.8
Threonine	75.8	67.2	65.6	67.3
Valine	74.3	66.3	67.3	69.8
<u>Dispensible</u>				
Alanine	80.1	76.6	75.4	76.2
Aspartic acid	83.8	71.4	72.9	73.6
Cysteine	82.1	88.0	90.0	90.2
Glutamic acid	85.2	84.3	82.3	82.8
Glycine	72.3	66.5	63.0	66.4
Proline	75.1	62.4	75.2	74.6
Serine	81.9	69.1	70.8	71.0
Tyrosine	83.8	71.4	72.2	73.6

[a] Taken from Sauer *et al.*, 1982.

[b] Canola meal.

[c] Rapeseed meal.

serine, and tyrosine were obtained with soybean meal compared to canola meal and rapeseed meal. The same magnitude of difference was seen using true ileal amino acid availabilities. McIntosh and Aherne (1985) used starter pigs to determine true availabilities of amino acids in canola meal and found values almost identical to those of Sauer (1982).

These various trials seem to indicate a need for consideration of amino acid availability when balancing diets for swine using canola meal. Although availabilities in canola meal are apparently lower for some essential amino acids, the causes may be associated with a number of factors. Nesheim (1965) as reviewed by Nwokolo et al. (1976) suggested some factors associated with lowered amino acid availabilities in certain feedstuffs. These include protein-sugar interactions in feedstuffs with low levels of protein, inhibitors of plant origin, and damage from heat during processing. The effects of phytate on protein may account for some of the reduced amino acid availability in canola meal (Rutkowski and Kozlowska, 1979; Thompson and Cho, 1984; Serraino et al., 1985). This is especially true due to the high percentage of phytic acid present in canola meal (2.7% phytate; Keith and Bell, 1984). Phenolic compounds such as sinapic acid found in canola meal may also limit the value of protein (Rutkowski and Kozlowski, 1979).

From the previous discussion on canola meal protein and availability of amino acids, it would appear that these limiting factors need to be considered when formulating diets which utilize canola meal. As more accurate procedures are developed for rapid amino acid availability determinations, balancing diets on these bases may be justified.

MINERALS AND VITAMINS IN CANOLA MEAL

The major and trace minerals along with some vitamins present in canola meal are shown in Table 3. In general canola meal is a richer source of minerals than soybean meal (Clandinin and Robblee, 1981). The effects of phytate, however, may reduce the availability of some minerals. Nwokola and Bragg (1976, 1980) reported that phytate and fiber reduced the availabilities of six minerals in canola meal (Table 4) when fed to chicks. They also found that the crude fiber reduced the availability of copper and manganese. Jones (1979) found that zinc supplementation reduced the incidence of anorexia in pregnant rats fed rapeseed protein concentrate and attributed this to the high phytate content (5-8% of the protein concentrate). Thus zinc supplementation was recommended for animals fed rations containing rapeseed meal.

Values for phytic acid in canola meal have been reported by Nwokolo and Bragg (1977) to be 1.92% and 2.7%

Table 3. Mineral and vitamin content of canola meal and soybean meal (as fed)[a].

	Canola meal	Soybean meal
Major minerals		
Calcium, %	.68	.29
Phosphorus, %	1.17	.65
Sodium, %	.03	.03
Chloride, %	.02	.04
Potassium, %	1.29	2.0
Magnesium, %	.64	.27
Trace minerals		
Copper, mg/kg	10.4	21.5
Iron, mg/kg	159.2	120.0
Iodine, mg/kg	.8	.15
Manganese, mg/kg	53.9	29.3
Selenium, mg/kg	1.0	.1
Zinc, mg/kg	71.4	27.0
Vitamins		
Vitamin E (-tocophenol), mg/kg	14.50	13.30
Pantothenic acid, mg/kg	9.50	16.00
Niacin, mg/kg	160.00	29.00
Choline equivalents, mg/kg	6700.00	2700.00
Riboflavin, mg/kg	5.80	2.90
Thiamin, mg/kg	5.20	4.50
Biotin, mg/kg	1.07	.28
Folic acid, mg/kg	2.30	1.30
Pyridoxine, mg/kg	7.20	8.00

[a] Values reported from Canola Council Publication No. 59, 1981.

Table 4. Availability of minerals in rapeseed (canola) meal.

Mineral	Percent mineral availability Rapeseed meal	Soybean meal
Phosphorus	75	89
Calcium	68	86
Magnesium	62	78
Zinc	44	67
Copper	74	51
Manganese	54	76

[a] Taken from Nwokola *et al.*, 1976.

by Keith and Bell (1984). Nwokolo and Bragg (1977) also found phytate phosphorus was .24% in soybean meal and .54% in rapeseed meal.

Despite the effects of fiber and phytate, canola meal has been shown to be a better source of available calcium, iron, manganese, phosphorus, selenium, and magnesium than soybean meal. In comparison, soybean meal is a better source of copper, zinc, and potassium (Clandinin and Robblee, 1981).

Canola meal contains higher amounts of many of the B vitamins, except pantothenic acid, than soybean meal.

GLUCOSINOLATES IN CANOLA MEAL

Possibly the most limiting factor associated with the older varieties of rapeseed was the glucosinolates present in the meal. Earlier studies recommended limiting the inclusion of rapeseed meal in swine diets to 5% of the diet (Fenwick, 1984). Above this level, problems with intake and gain were seen in pigs. These problems were associated with the pungent taste associated with isothiocyanates and goitrogenic effects of the thiocyanate and oxazolidine-2-thione antithyroid agents (Hussar and Bowland, 1959; Bell et al., 1972; Castell, 1977a; Bell, 1984; Fenwick, 1984; Eggum et al., 1985). These older varieties of rapeseed contained approximately 4%

glucosinolates (dry basis) in the seed (Ohlson and Anjou, 1979) while the meal from B. napus and B. campestris contained 8.5 and 6.3 mg glucosinolates per gram, respectively (Bell and Jeffers, 1976).

Earlier methods to reduce the glucosinolates by processing were somewhat inadequate and costly (Bell, 1984). As the development of low erucic acid cultivars of rapeseed was initiated, Canadian plant scientists began developing low-glucosinolate varieties of rapeseed. Subsequently, Tower and Candle rapeseed varieties were released and contained only 1/8 the glucosinolate content of the older meals. Analysis of meals from these varieties showed glucosinolates represented 1.04 mg/g and .62 mg/g in Tower and Candle rapeseed meals, respectively (Aherne and Kennelly, 1985).

These new varieties of rapeseed which were low in erucic acid and glucosinolates became known as "Canola" to distinguish them from older rapeseed varieties. When compared to traditional rapeseed meal, the inclusion of canola meal in swine diets improved intake and pig performance (Bowland, 1975; McKinnon and Bowland, 1977; Eggum et al., 1985), resulted in higher triiodothyronine and thyroxine levels (McKinnon and Bowland, 1979; Christison and Laarveld, 1981) and lower thyroid weights (McKinnon and Bowland, 1979; Nasi et al., 1985).

While the superiority of canola varieties is well documented, there may still be some remaining goitrogenicity associated with the meals. Trials have shown increasing levels of canola meal in swine diets may still reduce serum T_3 and T_4 levels and increase thyroid weights, though not nearly to the extent of older rapeseed meals fed to swine and rats (Bowland, 1975; McKinnon and Bowland, 1979; Thomke, 1984; Nasi et al., 1985; Bourdon, 1985). Other trials showed slight depressions in performance of starter and grower swine fed canola meal. Part of the reductions were attributed to the remaining glucosinolates present (Castell, 1977a, 1977b; Grandhi, 1974; Ochetim, 1980; Singam and Lawrence, 1979; Kennelly, 1978). Estimates by Castell (1977a) suggested that for each .1 g total glucosinolates/kg diet, the average daily gain for pigs ranging in liveweight from 25 to 89 kg was reduced by approximately 3.5%.

The two classes of glucosinolate hydrolysis products which appear to be goitrogenic are the thiocyanates and oxazolidine-2-thiones (Fenwick, 1984; Bell, 1984). These products have been shown to be capable of depressing iodine uptake, iodification, and increasing T_3/T_4 ratios and thyroid epitheliazation (Bell et al., 1972; Fenwick, 1984; Bell, 1984). The other class of hydrolysis products is the isothiocyanates. These compounds are present in other

Brassica members and are associated with the pungent taste of mustard, radish, and horseradish. This pungency may have reduced intake of pigs fed older rapeseed meal and may still be present in the newer varieties of rapeseed (Fenwick, 1982; Rundgren, 1983).

These factors associated with glucosinolates may affect pig performance but other interactions may also be present. More work needs to be done in the area of glucosinolates to pinpoint non-toxic levels on pig performance and thyroid hormones.

CANOLA MEAL IN THE DIETS OF SWINE

Prior to the introduction of the first canola cultivar in 1974 (Tower), the use of rapeseed meal was limited in all classes of swine. Hussor and Bowland (1959) fed rapeseed meal to pigs from 3 weeks of age to market. Diets contained 0, 2, and 10% expeller extracted rapeseed meal. Pigs fed the rapeseed meal at the 10% level gained significantly less than soybean meal controls and were not as efficient. These pigs also showed hypertrophy and abnormalities of the thyroid gland. Manns et al. (1963) also found reduced protein bound iodine and significant thyroid hypertrophy in pigs fed increasing amounts of rapeseed meal. Using rapeseed meal, Bowland (1971) found that the inclusion of 10% in the diet of swine reduced intake and promoted slower gains along with reduced carcass dressing percentages. Bowland (1971) concluded that a depression of approximately 2% in feed intake could be expected for each one percent dietary rapeseed, regardless of protein and digestible energy adjustments. Fenwick (1982) reviewed work which showed that high-glucosinolate rapeseed meal fed at levels greater than 6% of the diet to gestating and lactating gilts subsequently led to reduced litter sizes and lowered conception rates.

Based on these and other experiments with swine, it was recommended that rapeseed meal should be limited to no more than 5% of the diets of finishing swine and 3% in breeding swine (Bell, 1975; Rundgren, 1983).

With the development of low-glucosinolate cultivars, trials were conducted to compare performance of pigs fed diets using these cultivars compared with that of pigs fed high-glucosinolate rapeseed meal and soybean meal. Bowland (1975) found improvements in feed intake, weight gain, and efficiency in pigs fed low-glucosinolate varieties of rapeseed meal compared to that of pigs fed diets with low-erucic acid rapeseed meal (span). Thyroxine and protein bound iodine values were lowest for those pigs fed span rapeseed meal.

Using isocaloric (digestible energy basis) and isonitrogenous diets, McKinnon and Bowland (1977) varied the levels of Tower rapeseed meal or commercial (high-glucosinolate) rapeseed meal in combination with soybean meal in the diets of starting, growing, and finishing swine. Feeding the commercial rapeseed meal based diets resulted in reduced pig performance in all phases of growth, but with the Tower rapeseed meal there was depressed performance only in starter pigs fed the diets. Later work using Tower and other canola varieties showed similar performance improvements and reduced goitrogenic effects in swine compared to that of older rapeseed meals, confirming the superiority of the low glucosinolate varieties (McKinnon and Bowland, 1979; Thomke, 1984; Rundgren, 1985; Bourdon, 1985).

STARTER STUDIES

Feeding trials using starter pigs from weaning to 20 kg have produced varying responses (Baidoo and Aherne, 1985). Castell (1977b) formulated isonitrogenous diets using soybean meal and/or Tower canola meal. Starter pigs fed diets containing 7.5% canola meal gained less (518 vs. 546 g/day) and were not as efficient (2.51 vs. 2.38 kg diet/kg gain) as pigs fed the soybean meal control diets. Feed intake was not significantly affected by dietary treatment. McKinnon and Bowland (1977) formulated isonitrogenous, isocaloric diets using 0, 11.9, and 25.3 percent canola meal. Performance was similar for those starter pigs fed 0 or 11.9% canola meal but complete substitution of canola meal (25.3%) resulted in depressed feed intake when compared to soybean meal control diets.

Ochetim et al. (1980) observed a reduction in feed intake and growth rate by approximately .10 and .14 kg per day, respectively, in starter pigs fed 24% Tower canola meal diets compared to soybean meal control diets. Reviewing a trial conducted at the University of Alberta, Bell and Aherne (1981) saw no significant reduction in performance of pigs fed a 50/50 mixture of canola meal and soybean meal as the protein supplement. When canola meal replaced all of the dietary soybean meal, gain, intake, and feed efficiency were reduced in the starter pigs.

Reviewing work done by McIntosh (1983) and Baidoo (1984), Baidoo and Aherne (1985) indicated for every 1% inclusion of canola meal in starter pig diets, there was a 4 gram reduction in daily feed intake and a 2 gram reduction in daily liveweight gain. Thus, based on previous starter performance data, Bell and Aherne (1981) recommended that canola meal be limited to 12% of the starter pig diet while Baidoo and Aherne (1985) later recommended dietary levels of 6-8% canola meal.

GROWING PIGS

There has been considerably more work done in the grower-finisher phases using canola meal, yet results in the grower phase are still somewhat inconsistent. These variable responses may be attributed to nutrient values of the meals used, glucosinolate level, level of canola meal inclusion, feeding regime and calculated requirements, amino acid availability and type of cereal and diet used. Some of these interactions will be considered in separate sections of the review.

McKinnon and Bowland (1977) found that complete substitution of dietary soybean meal with canola meal resulted in lower average daily gains and inferior feed efficiencies of growing swine. This level of canola meal (19.8%) was formulated in isocaloric and isonitrogenous swine grower diets. However, when canola meal replaced one half of the supplemental protein (9.3% canola meal), no significant reduction in pig performance was observed. Narandaran et al. (1981) found that isocaloric, isonitrogenous diets containing up to 25% canola meal gave pig performance similar to that of the soybean meal control diets fed to swine. Using Swedish low-glucosinolate rapeseed meal (Karat), Thomke (1984) found levels as high as 18% did not affect gain or efficiency of pigs fed these diets compared to that of pigs fed soybean meal-fishmeal control diets.

Although the latter two experiments demonstrated that high levels of canola meal could be fed to grower swine without depressions in performance, a number of studies indicate lower levels may be optimum. Castell (1977b) found diets fed to growing swine containing 12.5% canola meal resulted in reduced growth rates and feed efficiencies compared to pigs fed soybean meal control diets. Kennelly (1978) observed reductions in intake, gain, and efficiency in pigs fed 10% Tower or 10% Candle canola meal. When Tower canola meal composed 9 or 19% of the diet in grower pigs, significant reductions in growth rate and feed efficiency were observed by Aherne and Lewis (1978). Baidoo et al. (1983) found that diets fed to pigs (20-60 kg) containing canola meal gave pig performance similar to that of soybean meal controls until the level of canola meal replaced 75% or more of the soybean meal in the diet (10.9-16.8% canola meal), at which point growth rate was significantly reduced. Feed efficiency was significantly depressed when canola meal replaced 25% or more of the soybean meal in the diet.

Based on these and other grower phase studies, it is generally recommended that canola meal should not constitute more than 12% of the diets of grower swine (Baidoo and Aherne, 1985).

FINISHING STUDIES

There are also numerous studies evaluating canola meal in the finishing phase (50-100 kg liveweight). Most of these studies show that canola meal may completely substitute for soybean meal in pig diets with little or no depression in performance, though the actual level of canola meal may need to be considered.

Narandaran et al. (1981) found that levels of 25% Tower canola meal in isocaloric, isonitrogenous diets supported finishing pig performance similar to that of corn-soybean meal diets. Thomke (1984) also found similar results using Swedish low-glucosinolate rapeseed meal at the level of 18% in finishing swine diets. Aherne and Lewis (1978) found that partial or total replacement of soybean meal by Tower canola meal (19%) did not significantly affect growth rate or feed efficiency of finishing gilts. Work done by McKinnon and Bowland (1977) showed 12.6% Tower canola meal as the sole source of supplementary protein did not affect finishing pig performance compared to controls.

These trials indicate that canola meal can be effectively utilized by the finishing pig whose nutritive requirements are not as demanding as the starting or growing pig. Although most studies have shown that complete replacement of soybean meal with canola meal gave comparable performance to that of control diets, some trials showed a slight tendency for gain, intake, or efficiency to be depressed by high levels of canola meal (Bell *et al*., 1981; Narandian *et al*., 1981; Castell and Spurr, 1984). Thus, it has been recommended that canola meal can be used as the only supplemental protein source in finishing swine at levels as high as 12% of the diet (Baidoo and Aherne, 1985).

CARCASS COMPOSITION AND EVALUATION

The majority of the data regarding carcass measurements have shown that the inclusion of canola meal in swine diets does not adversely affect percent muscle, loineye area, backfat, dressing percentage, and other carcass measurements (Aherne and Lewis, 1978; Narandaran, 1980; Bell *et al*., 1981; Eggum *et al*., 1985; Baidoo and Aherne, 1985).

McKinnon and Bowland (1977) found that pigs fed Tower canola meal as the sole source of supplementary protein from 5.3 kg to market had significantly smaller loineye areas than soybean meal control pigs. The levels of canola meal used in the starter, grower, and finisher phases were 25.3%, 19.8%, and 12.6%, respectively. Bourdon *et al*. (1985) found that pigs fed 20% of low-glucosinolate Swedish rapeseed meal in the dehulled form had a significantly reduced muscle content.

Other carcass characteristics including backfat composition, pH, color, and flavor of meat from pigs fed canola meal have been measured. Aherne *et al*. (1980) noticed an overall high incidence of pale, soft, and exudative pork in pigs fed both soybean meal or canola meal diets, but there was no significant trend for either diet to be greater than the other. Although Dransfield *et al*. (1985) found no indication of PSE in pigs fed Tower canola meal, high levels of canola meal increased pigmentation and produced slightly darker meat compared to carcasses from pigs fed soybean meal control diets. In this study, texture, juiciness, and flavor of the lean from pigs fed both protein sources were measured and no significant differences were found.

Thacker and Bowland (1980) found that pigs fed diets containing canola meal had higher levels of odd-chained and unsaturated fatty acids in their backfat compared to control pigs. Castell and Falk (1980) also found that pigs fed increasing levels of Candle canola (0-15% of the diet) had carcasses with a marked increase in unsaturated fatty acids; noticeably linoleic and linolenic.

SUMMARY OF GROWTH TRIALS

Because of the variability of previous results from feeding canola meal in swine diets, particularly the starter and grower phases, some dietary interactions may need to be considered. Among those to be considered include amino acid availability, possible goitrogens still in the meal, and intake of canola meal.

INTAKE

The limitations imposed on intake have been altered by the introduction of low-glucosinolate cultivars of rapeseed. The effect of isothiocyantes on intake in relation to the pungent taste associated with these compounds appears to have been reduced. However, Castell (1980) found that pigs fed two levels of canola meal (10.7 and 18.8%) free choice with barley or wheat preferred the diet containing the lower level of canola meal. McIntosh and Aherne (1982) found that pigs which had free access to a soybean meal control diet and four other canola meal diets (5, 10, 15, or 20% canola meal) preferred the diets with the lowest level of canola meal (reviewed by Rundgren, 1983). Comparing high and low levels of glucosinolates, Lee and Hill (1980) and Lee et al. (1980) showed that intake was lowered by the presence of glucosinolates in the diets of young growing pigs.

These studies indicate that even lowglucosinolate rapeseed meal may still have some remaining pungency associated with the isothiocyanates present in the meal but most Canadian work has shown that intake was not adversely affected.

Certainly the lower digestible and metabolizable energy values of canola meal would influence the intake of pigs in studies using non-isocaloric diets. Since intake is partially regulated by energy density (Henry, 1984), pigs consuming canola meal diets should have higher feed intakes compared to soybean meal diets if these diets were not balanced for energy. Baidoo et al. (1983) used isonitrogenous, non-isocaloric diets of canola meal and soybean meal with growing swine. This study showed that intake was increased and feed efficiency was depressed in pigs as the level of canola meal in the diet increased from 3.6 to 16.8%. Thus, it would appear that metabolizable energies should be closely evaluated when formulating diets with canola meal.

AMINO ACID AVAILABILITY AND SUPPLEMENTATION

Work evaluated earlier in this review showed that availabilities of some essential and non-essential amino acids were lower than those of soybean meal (Cho and Bayley, 1970; Sauer et al., 1982; McIntosh and Aherne, 1985). Most studies using canola meal have not balanced swine diets on this basis and this may account for the lowered performance of pigs in the earlier phases of growth. Sauer et al. (1982) showed the magnitude of differences in available lysine between canola meal-barley and soybean meal-barley diets. When these two diets were balanced to contain 13% protein, available lysine in the barley-soybean meal diet was 3.98 g/kg and 3.84 g/kg in the barley-canola meal diet. When these two diets were balanced to contain 18% protein, available lysine was 7.36 g/kg in the barley-soybean meal diet and only 6.69 g/kg in the barley-canola meal diet. The extent of this difference may be supported by the poorer performance of pigs fed canola meal in the starting and growing phases compared to that in the finishing phases.

While these studies seem to indicate a need to balance canola meal on an available lysine basis, work using supplemental amino acids has been somewhat inconclusive.

Bell (1975) used soybean meal or rapeseed meal (Bronowski) in isocaloric, isonitrogenous diets to test the effects of .1% methionine and .5 or .1% supplemental lysine in growing-finishing swine. They obtained a 15% improvement in growth with pigs fed rapeseed meal supplemented with methionine, but found no effect of either level of lysine supplementation. Aherne and Lewis (1978) added .05% lysine to grower swine diets containing Tower rapeseed meal and did not observe a response to this supplementation.

Bell _et al_. (1981) later found that supplementation with .15% lysine and .05% methionine significantly improved feed utilization of pigs fed Tower or Candle canola meal

(5, 10, or 15% of the diet). Rowan and Lawrence (1979) found that the addition of lysine to growing swine diets containing 25% Tower or Erglu rapeseed meal significantly improved nitrogen retention.

From the results of amino acid supplementation and availability studies of canola meal, it would appear that considerations for amino acid availability may be in order when formulating swine diets with canola meal. The varied responses of amino acid supplementation may show a need to consider other essential amino acids in addition to lysine. At any rate, amino acid availability appears to be a contributing factor which limits the use of canola meal in the early and subsequent stages of pig growth.

EFFECTS OF GLUCOSINOLATES ON PERFORMANCE AND THYROID HORMONE SYNTHESIS

The effects of glucosinolates and their goitrogenic properties may need to be evaluated in assessing the worth of canola meal. Although the glucosinolates of canola are only 1/8 that found in older, traditional varieties of rapeseed, most studies measuring thyroid hormones found that levels were still depressed somewhat compared to values from soybean meal based diets (Bowland, 1975; Grandhi et al., 1976; McKinnon and Bowland, 1979; Ochetim, 1980; Thomke, 1984; Bourdon, 1985).

Christison and Laarveld (1981) infused thyroid releasing hormone into pigs fed 15% Tower canola meal or soybean meal. The pigs weighed 13 kg initially and were infused for 58 days. The basis of the experiment was to determine the effects of thyroid releasing hormone and the subsequent release of thyroid stimulating hormone from the pituitary on the capacity of the thyroid to produce and release T_3 and T_4. These workers found that the pigs fed canola meal were unable to increase the output of T_4 in response to an external TRH stimulus while those fed soybean meal diets were able to increase T_4 production. From these results, it was suggested that the compensatory hypertrophy of the thyroid in pigs fed canola meal was not sufficient to maintain full thyroid function.

The importance of the small goitrogenic properties still apparently present in canola meal may not be of any relative economic importance when considering subsequent performance of pigs fed canola meal. However, Grandhi (1980) observed that pigs fed canola meal in the cooler months of the year had slightly lower average daily gains than those fed soybean meal control diets, but gains were not affected during warmer periods. This observation could be a factor in the reduced thyroid hormone function and the magnitude of this reduction in colder environments (Christison and Laarveld, 1981), but actual thyroid hormones were not determined in the trial by Grandhi et al. (1981).

Supplemental iodine or iodinated casein to diets containing varying levels of canola meal has shown mixed responses in swine performance. Bell *et al*. (1981) found additions of iodine (calcium iodate, to supply .14 mg iodine/kg diet) to diets containing 15% Candle canola meal were not effective in improving pig performance compared to that of controls. Rundgren (1983) reviewed earlier work done by Bell (1980) which showed iodine or iodinated casein had no significant effect on performance characteristics of pigs fed low-glucosinolate rapeseed meal. However, Ochetim *et al*. (1980) showed that starter pigs (6.8 to 14.0 kg liveweight) responded to iodinated casein (44 mg/kg diet) when fed 20% Tower canola meal.

SUMMARY

The improvements made in rapeseed meal during the past 15 years have produced a viable protein source for swine. There may still be some limitations imposed during the early growth phases of swine. These limitations may be a result of amino acid availability, glucosinolates, or other factors. If the use of canola meal in the United States is increased, these factors may need to be either eliminated or corrected depending on economics.

Based on past Canadian work, the value of canola meal in comparison to soybean meal has been assessed. The economic worth of canola meal is about 70% of that of soybean meal in the starter and grower periods of swine and 75-80% in the finishing period (Bell, 1984). As improvements are made in canola varieties and processing of the meal, this value may be increased.

MATERIALS AND METHODS

Performance and balance trials were conducted to evaluate the use of canola meal in growing swine diets. The objective of these trials was to compare the performance of pigs fed diets which completely or partially replaced soybean meal as the supplementary protein source to pigs fed standard corn-soybean meal diets.

Realizing that canola meal is lower in energy and lysine and higher in phosphorus than soybean meal, diets were balanced to be isocaloric, isolysinic, and to contain isoavailable phosphorus in Trial 1. In Trial 2, balance studies were conducted to evaluate the diets used in Trial 1 and to determine digestibility of for energy and protein and retention of calcium and phosphorus of pigs fed those diets. The results from those two trials would then support data from Trial 3 which compared performance of pigs fed increasing levels of canola meal in place of soybean meal to determine the optimum level of usage.

TRIAL 1

Forty-eight York X Landrace X Duroc weanling pigs (4 weeks) were lotted randomly from litters to 6 pens of 8 pigs. The pens were then adjusted for sex and nearly equal pen weight. Three pens were randomly assigned to each of the starter diets in Table 5. These diets were formulated to meet NRC requirements for the starter pig.

Table 5. Starter diets (Trial 1).

Ingredients	Corn-soy control	Corn-soy-canola
Tallow	--	10
Corn, ground shelled	660	631
Soybean meal (44%)	300	220
Canola meal	--	100
Mono-dicalcium phosphate	11	10
Calcium carbonate	13	13
Sodium chloride	3.5	3.5
MSU vitamin-trace mineral premix[a]	5	5
Vitamin E-selenium premix[b]	5	5
Aureo-SP 250[c]	2.5	2.5
	1000	1000
Calculated values[d]		
ME, kcal/kg	3175	3175
Crude protein, %	19.0	19.0
Lysine, %	1.0	1.0
Tryptophan, %	.19	.19
Calcium, %	.79	.83
Phosphorus, %	.60	.63
Available phosphorus, %	.35	.35
Analyzed values		
GE, kcal/kg	3960	3990
Crude protein, %	20.2	19.2
Calcium, %	1.08	1.09
Phosphorus, %	.54	.60

[a] See nutrient values in Table 7.

[b] Vitamin E-selenium premix supplies 20 mg of Se and 1100 IU of vitamin E per kilogram of premix.

[c] Supplied 110 mg of chlortetracycline, 110 mg of sulfamethazine, and 55 mg of penicillin per kg of diet.

[d] See nutrient values in Table 6.

The diets were also balanced to be isocaloric, isolysinic, and to contain the same amount of available phosphorus (assuming the phosphorus in canola meal and soybean meal to be 1/3 as available as an inorganic source such as dicalcium phosphate). Subsequent diets fed in the growing and finishing phases were also formulated on these bases and were balanced to meet NRC requirements of swine at those stages. The nutrient values of feedstuffs used to balance these diets are shown in Table 6. Table 7 shows the level of nutrients supplied by the vitamin-trace mineral premix used in all trials of this study.

The average initial weight of the pigs in this study was 6.5 kg. These pigs remained on the starter diets for 4 weeks during the time period 9/24/84-10/22/84. After 4 weeks the pigs were continued on their respective starter diets for an additional week before being moved to the growing unit.

During the starter period, the pigs were housed in the environmentally controlled nursery unit at the Michigan State University swine research farm. The nursery pens were 1.2 x 2.4 m with partially slotted floors and heated with hot water running through coils in the solid concrete portions of the floor. Each pen had an adjustable stainless steel feeder which accomodated 4 pigs eating simultaneously. The pens also had nipple waterers located above the slotted portions of the floor.

Table 6. Nutrient values used for ingredients in calculations of diets for this study[a].

Ingredient	ME, kcal/kg	Crude protein %	Lysine %	Trypto-phan %	Calcium %	Phos-phorus %
Corn	3400	8.6	.25	.05	.02	.26
Soybean meal (44%)	3100	44.0	2.80	.54	.29	.65
Canola meal	2700	38.0	2.30	.44	.68	1.17
Mono-dicalcium phosphorus	--	--	--	--	18.00	21.00
Calcium carbonate	--	--	--	--	38.00	--
Tallow	7900	--	--	--	--	--

[a] As-fed values based on NRC, 1979 and Canola Council of Canada, 1984.

Table 7. Nutrients supplied by vitamin-trace mineral premix to all diets.

Nutrient	Amount supplied per kg diet
Vitamin A	3300 IU
Vitamin D	660 IU
Vitamin E	5.5 IU
Menadione	2.2 mg
Riboflavin	3.3 mg
Niacin	17.6 mg
d-pantothenic acid	13.2 mg
Choline	110 mg
Vitamin B_{12}	20 μg
Zinc	75 mg
Iron	60 mg
Manganese	37 mg
Copper	10 mg
Iodine	.5 mg

Each pig was weighed initially and then weekly during the 4-week starter period. Feeders were also weighed at this time and feed consumption of the pen was determined. These values were used to determine average daily feed intake, average daily gain, and feed efficiency for the pens of pigs between each weighing. These measurements were compiled at the end of the 4-week study to determine overall performance of each pen during the period.

After the one week adjustment period, the pigs were moved, with pens intact, to the MSU growing and finishing unit. Pens received the same treatment diets as in the starting phase and the diets were formulated to meet NRC requirements. The composition and nutrient analysis of the diets fed in the growing phase are shown in Table 8. The corn-soybean meal-canola meal diet contained a higher level of canola meal than that of the starter diet (15% canola meal vs. 10% canola meal).

The average initial weight of pigs in the growing phase was 17.2 kg. During the growing phase, pigs were housed in the environmentally controlled grower and finisher unit. Pens were 1.37 x 4.27 m with completely slotted floors (concrete slats). Each pen contained a nipple waterer and a Smidley (Marting Mfg, Co., Wash. C.H., OH 43160) two-hole feeder. Pigs were individually weighed bi-weekly and feeders were also weighed at this time.

Table 8. Grower diets (Trial 1).

Ingredients	Corn-soy control	Corn-soy-canola
Tallow	--	15
Corn, ground shelled	766	722
Soybean meal (44%)	200	80
Canola meal	--	150
Mono-dicalcium phosphate	10	9
Calcium carbonate	10	10
Sodium chloride	3.5	3.5
Vitamin-trace mineral premix	5	5
Vitamin E-selenium premix	5	5
Antibiotic premix[a]	.5	.5
	1000 kg	1000 kg
<u>Calculated values</u>		
ME, kcal/kg	3225	3225
Crude protein, %	15.4	15.4
Lysine, %	.75	.75
Tryptophan, %	.14	.14
Calcium, %	.63	.68
Phosphorus, %	.54	.60
Available phosphorus, %	.32	.32
<u>Analyzed values</u>		
GE, kcal/kg	3820	4070
Crude protein, %	15.3	15.2
Calcium, %	.69	.70
Phosphorus, %	.52	.58

[a] Aureo-50 supplies 55 mg of chlortetracycline per kg of diet.

These measurements were taken during the 8-week grower period to determine overall feed efficiency, average daily gain, and average daily feed intake for each pen treatment. These same measurements were taken during the 8-week finishing period. The growing phase was conducted during the time period of 10/29/84-12/24/84.

After the 8-week grower period, pigs remained housed in the same unit but were moved to larger pens. The pens receiving the diets containing canola meal in the first two periods remained on this treatment during the finishing phase. Canola meal completely replaced soybean meal as the supplementary protein source for pigs receiving this treatment (17.5% canola meal). The composition and nutrient analyses of the diets fed in the finishing phase are shown in Table 9.

The average initial weight of pigs in the finishing phase was 55.3 kg. The pigs remained on the finishing dietary treatments for 8 weeks during the time period of 12/24/84-2/18/85. During this period pig weight and pen feed consumption was monitored bi-weekly. The finishing pens were partially slotted and measured 1.8 x 4.3 m. Each pen contained a three-hole feeder and a nipple waterer.

At the end of the eight weeks in the finishing period, overall pen feed efficiency, average daily gain, and average daily feed intake were determined for each pen. These

Table 9. Finishing diets (Trial 1).

Ingredients	Corn-soy control	Corn-canola
Tallow	--	15
Corn, ground shelled	828	779
Soybean meal (44%)	140	--
Canola meal	--	175
Mono-dicalcium phosphate	9.5	8
Calcium carbonate	9	9.5
Sodium chloride	3.5	3.5
Vitamin-trace mineral mix	5	5
Vitamin E-selenium premix	5	5
Antibiotic premix	--	--
	1000	1000
Calculated values		
ME, kcal/kg	3225	3225
Crude protein, %	13.3	13.3
Lysine, %	.60	.60
Tryptophan, %	.11	.11
Calcium, %	.57	.62
Phosphorus, %	.50	.58
Available phosphorus, %	.30	.30
Analyzed values		
GE, kcal/kg	3820	4060
Crude protein, %	13.13	13.02
Calcium, %	.72	.61
Phosphorus, %	.50	.59

performance measurements were also compiled for the combined growing and finishing period (16 weeks). The trial was terminated and five pigs were taken from each pen and slaughtered. There were 10 barrows and 5 gilts from the corn-soybean meal-canola meal treatment group and 9 barrows and 6 gilts from the corn-soybean meal control treatment group. The average slaughter weight of these pigs was 103.3 kg.

At the packing plant, hot carcass weight was measured (head off). One day later, the carcasses were measured for length, 10th rib backfat, and loineye area at the 10th rib according to procedures outlined by the National Pork Producers Council, 1983. These values were also used to calculate adjusted backfat, adjusted loineye area, grams of lean gain per day on test, and percent muscle. This would allow us to determine if there were carcass differences between treatment groups on an equal slaughter weight basis (104.5 kg). The equations for these determinations are shown in Table 10. Carcass water and firmness characteristics (pale, soft, and exudative pork) were monitored at the packing plant according to procedures outlined by the National Pork Producers Council, 1983.

The carcass and performance data were statistically analyzed in a completely randomized design, one-way analysis of variance. The triplicate pen means of average daily

Table 10. Carcass adjustment equations[a,b]

1. Backfat at 230 pounds =

   actual backfat, in. + [(230 - actual weight, lb.) (actual backfat/actual weight, lb. - 25)]

2. Loineye area at 230 pounds =

   actual loineye area, in. + [(230 - actual weight, lb.) (.013)]

3. Length at 230 pounds =

   actual length, in. + [(230 - actual weight, lb.) (.033)]

4. Pounds of lean pork gain per day on test =

   .9 - (.0044 x initial live weight on test, lb) - (.007 x hot carcass weight, lb) - (.15 x fat depth, in.) + (.018 x loineye area, $in._2$) + (.0047 x hot carcass weight, lb)

5. Percent muscle =

   [2 + (hot carcass weight, pounds x 0.45) + (10th rib loineye area, $in.^2$ x 5) - (10th rib fat depth, inches x 11)]/hot carcass weight

---

[a] Equations 1, 2, 3, and 5 from **Guidelines for Uniform Swine Improvement Programs**, USDA, 1981.

[b] Equation 4 from **Procedures to Evaluate Market Hog Performance**, NPPC, 1983.

gain (ADG), average daily feed intake (ADFI), and feed required per unit of gain (F/G) were also analyzed in a completely randomized design, one-way analysis of variance.

Trial 2

Our objective in Trial 2 was to determine, using balance trials, the metabolizable energy, apparent digestibility of protein, biological value of protein, net protein utilization, and retention of calcium and phosphorus of the corn-soybean meal control diets and the corn-soybean-canola meal diets fed in the starting, growing, and finishing phases of Trial 1. These diets are shown in Tables 5, 8, and 9.

In the starter balance trial, 12 York X Landrace X Duroc weanling pigs (4 weeks) were placed in collection cages and randomly assigned to the two experimental starter diets in Trial 1. The average initial weight of these pigs was 7.36 kg. Six pigs were fed each of the two starter diets through a 10-day adjustment period and a 4-day collection period. These pigs were fed 2% of their body weight (initial body weight at the beginning of the trial) twice daily during the adjustment and collection periods.

The pigs were removed from the stainless steel collection cages and placed in a separate feeding pen to prevent feed contamination of the feces and urine.

The diets were finely ground and mixed with an equal amount of water to encourage rapid consumption. Additional water was added to the slurry to allow the pigs to clean the feed cup thoroughly. After 5-10 minutes, the pigs were immediately transferred back to their respective collection cages.

Within the cages, feces were collected on a fine wire screen beneath a stainless steel slotted floor. Urine was collected on a stainless steel tray located beneath the wire screen and directed towards the plastic urine collection containers. Approximately 20 ml of a 50:50 mixture of deionized water and hydrochloric acid was added to the urine containers to help prevent nitrogen release by microbial degradation.

At the end of the 4-day collection period in all of the balance trials, final urine weight was taken before a filtered 150 ml sample from each pig was stored in a plastic bottle and retained for analysis. Total feces for each pig was dried in an oven at 70°C and then weighed and finely ground for laboratory analysis. These same procedures were employed for all three of the balance trials.

In the grower balance trial, 12 York X Landrace X Duroc pigs with an average initial weight of 9.3 kg were randomly assigned to one of the two grower diets in Table

8. There were 5 barrows and 1 gilt fed each of the two grower diets. In the finishing balance trial, 12 York X Landrace X Duroc pigs were randomly assigned to one of the two finishing diets used in Trial 1 shown in Table 9. The average initial weight of these pigs was 12.6 kg. It was felt that using smaller pigs for this finishing balance trial as opposed to 50-100 kg pigs would be more accurate since the larger balance cages were more likely to pose contamination problems with feed in the feces (pigs would not be fed in separate feeding areas using the larger balance cages). Therefore, the finishing diets were evaluated with the same cages used in the starting and growing swine balance trials.

Samples of the fecal matter, urine, and feed were analyzed in duplicate for gross energy, nitrogen, calcium, and phosphorus. In determining gross energy, .8-.9 g of feces or feed was pelleted and analyzed using an adiabatic bomb calorimeter (Parr Instrument Co., Moline, IL) standardized with benzoic acid. Urine samples were put on cotton balls of known weight and energy content and freeze dried before being placed in the bomb calorimeter for energy determinations.

Calcium determinations were made using atomic absorption spectrophotometry (Model 951, Instrument Laboratory Inc., Lexington, MA). Feed, feces, and urine samples were measured for phosphorus using a colorimetric procedure (Gomori, 1942). The nitrogen content of feed, feces, and urine was determined by a semi-micro Kjeldahl method (A.O.A.C., 1980).

These laboratory determinations were used to calculate the following values for the diets fed to swine.

1. Digestible energy (DE) =

$$\frac{\text{Gross energy (GE) of total grams (g) of feed (4 days)} - \text{GE of total feces (4 days)}}{\text{Total g of feed}}$$

2. Metabolizable energy (ME) =

$$\frac{\text{GE of total g of feed fed} - \text{GE of total g of feces} - \text{GE of total g of urine}}{\text{Total g of feed}}$$

3. Apparent protein or nitrogen (N) digestibility, % =

$$\frac{\text{Total feed N} - \text{total fecal N}}{\text{Total feed N}} \times 100$$

4. Apparent biological value (BV) of protein, % =

$$\frac{\text{Total feed N} - \text{total feces N} - \text{total urinary N}}{\text{Total feed N} - \text{total fecal N}} \times 100$$

5. Apparent net protein utilization (NPU), % =

Apparent protein digestibility x apparent biological value X 100

6. Mineral retention (for calcium and phosphorus, %) =

$$\frac{\text{Total mineral intake (from feed)} - \text{total mineral in feces} - \text{total mineral in urine}}{\text{Total mineral intake (from feed)}} \times 100$$

The data in the balance trials were analyzed using one-way analysis of variance test for significant dietary effect on each of the measures.

TRIAL 3

After conducting Trials 1 and 2, the objective of Trial 3 was to determine the effect of increasing the proportion of supplemental protein supplied by canola meal on pig performance and carcass characteristics in growing and finishing swine. This would allow us to determine the optimum levels of canola meal and soybean meal used in swine diets based on economics.

One hundred and sixty York X Landrace X Duroc pigs were randomly lotted into 5 treatment groups replicated four times. The average initial weight of the pigs on study was 24.5 kg. Pigs remained on the same treatment during the growing (8 weeks) and finishing (8 weeks) phases. Pigs were housed in the same environmentally controlled growing and finishing unit in Trial 1 except pigs remained in the same pens throughout the growing and finishing study (1.37 x 4.27 m). As in Trial 1, pigs and feeders were weighed every two weeks to determine pen ADG, ADFI, and F/G for the period. These parameters were determined for each pen for the growing and finishing periods and for the two periods combined.

The diets used in this study were formulated to meet the NRC requirements of pigs in each phase and were balanced on an isolysinic basis. The five dietary treatments consisted of replacing 0, 25, 50, 75, or 100% of the soybean meal with canola meal. The composition and calculated nutrient analysis of these diets in both phases are shown in Tables 11 and 12.

Because of limited pen space, this trial was conducted during three different time periods (4/15/85-8/5/85; 5/13/85-9/2/85; 9/12/85-1/3/86). In the first two time periods, one pen (8 pigs) was tested for each of the five treatments. The last time period had two pens per treatment, but one group of five treatments were separated from the other group being on different sides of the building. There were a total of 7 barrows and 25 gilts in each of treatments 1, 3, and 4. There were 6 barrows and 26 gilts in treatments 2 and 5.

After the sixteen week test period, the average ending weight of the pigs was 104.5 kg. Four pigs were taken from each pen to be slaughtered and measured according to procedures of Trial 1. There was a total of 4 barrows and 12 gilts slaughtered in each of treatments 1, 2, 3, and 4 and 3 barrows and 13 gilts slaughtered from treatment 5.

The performance and carcass data were statistically analyzed using time as a blocking variable. There were four blocks used since in the last period, one group of five treatments was separated from the other giving a total of four different groups. For several of the

Table 11. Grower diets fed in Trial 3.

	Treatments				
	1	2	3	4	5
	Percent replacement of soybean meal				
Ingredients	0	25	50	75	100
Corn, ground shelled	766	757	746	736	725
Soybean meal (44%)	200	150	100	50	0
Canola meal	0	61	122	183	244
Mono-dicalcium phosphate	10	9	9	8	7
Calcium carbonate	10	9	9	9	10
Sodium chloride	3.5	3.5	3.5	3.5	3.5
Vitamin-trace mineral premix	5	5	5	5	5
Vitamin E-selenium premix	5	5	5	5	5
Antibiotic premix	.5	.5	.5	.5	.5
	1000.0	1000.0	1000.0	1000.0	1000.0
Calculated values					
ME, kcal/kg	3225	3200	3175	3150	3125
Crude protein, %	15.4	15.4	15.4	15.4	15.4
Lysine, %	.75	.75	.75	.75	.75
Tryptophan, %	.14	.14	.14	.14	.14
Calcium, %	.63	.62	.64	.64	.66
Phosphorus, %	.54	.58	.59	.60	.62
Available phosphorus, %	.32	.32	.32	.32	.32
Actual analysis					
Gross energy, kcal/kg	4080	4010	4000	3985	3910
Crude protein, %	15.8	15.5	15.7	15.3	15.4
Calcium, %	.72	.68	.66	.76	.88
Phosphorus, %	.51	.51	.53	.56	.57

Table 12. Finishing diets fed in Trial 3.

	Treatment				
	1	2	3	4	5
	Percent replacement of soybean meal				
Ingredients	0	25	50	75	100
Corn, ground shelled	828	821.5	814.5	807.5	800.5
Soybean meal (44%)	140	105	70	35	0
Canola meal	0	42	85	128	170
Mono-dicalcium phosphate	9.5	9	8.5	8	8
Calcium carbonate	9	9	8.5	8	8
Sodium chloride	3.5	3.5	3.5	3.5	3.5
Vitamin-trace mineral premix	5	5	5	5	5
Vitamin E-selenium premix	5	5	5	5	5
	1000.0	1000.0	1000.0	1000.0	1000.0
Calculated values					
ME, kcal/kg	3250	3235	3220	3200	3185
Crude protein, %	13.3	13.3	13.3	13.3	13.3
Lysine, %	.60	.60	.60	.60	.60
Tryptophan, %	.12	.12	.12	.12	.12
Calcium, %	.56	.55	.55	.56	.57
Phosphorus, %	.50	.52	.53	.55	.57
Available phosphorus, %	.30	.30	.30	.30	.30
Actual analysis					
Gross energy, kcal/kg	4010	3970	3960	3985	3980
Crude protein, %	13.1	13.2	13.1	13.0	13.2
Calcium, %	.67	.69	.66	.64	.60
Phosphorus, %	.51	.53	.53	.54	.53

performance measures, blocking was effective in reducing the experimental errors. Therefore, a completely randomized block design was utilized with fixed block effects to test for significant treatment differences according to procedures outlined by Gill (1978). The treatments were also tested for linear and quadratic effects using orthogonal polynomials for five equally-spaced treatments. The simple t-test was used to determine significant effects.

CANOLA MEAL USED IN THE TRIALS

The canola meal used in this study was supplied by Maple Leaf Monarch, Ontario, Canada through a grant from the Canola Council of Canada. The canola meal was prepared by a prepress-solvent extraction process. Before processing, the canola from different varieties was blended to obtain a more uniform product. The processing of this meal resulted in a product with a nutrient analysis similar to those published by the Canola Council of Canada.

Actual lysine analysis of canola meal and soybean meal was determined in acid (6N HCl) hydrolysates by resin column chromatography. The procedure using an amino acid analyzer was described by Makdani, Huber, and Bergen (1971). Actual lysine analysis was 2.27% for canola meal and 2.80% for soybean meal. These values were quite close to those published values used in the formulations of diets in our trials.

Periodic feed samples were taken throughout all three trials in this study and were refrigerated in air-tight polyethylene bags for later use. Gross energy, nitrogen, calcium, and phosphorus determinations were made on the feed samples according to procedures outlined earlier.

RESULTS AND DISCUSSION

Results: Trial 1

The performance results of pigs fed the two treatment diets in Trial 1 through the starting, growing, and finishing periods are shown in Table 13. The carcass data are shown in Table 14.

During the 4-week starter phase, pigs fed the diet containing canola meal (canola meal represented 10% of the diet) had performance (rate and efficiency of gain) similar to that of pigs fed the corn-soybean meal control diet. The overall average daily gain for the two treatment groups was 260 g for the control corn-soybean meal treatment (CS) and 243 g for the pigs fed the cornsoybean meal-canola meal starter diet (CSC). The average daily feed intake and feed per unit of gain for pigs fed the CS diet was 470 g and 1.83, respectively, while pigs fed the CSC diet consumed 460 g of feed daily and had an overall feed to gain ratio of 1.86 during the starter period. There were no significant differences between mean values of any of these measurements for the two treatment groups. The final weights of these pigs at the end of the 4-week starter period were 13.7 and 13.3 kg for pigs fed the CS and CSC diets, respectively.

The initial weights of pigs during the growing phase were 17.5 kg for the CS treatment group and 16.9 kg for

Table 13. Performance comparisons of Trial 1.

Item	Corn-soy[a]	Corn-soy canola[a]	MSE[b]	P
No. of pigs	24	24		
Initial weight, kg				
Starter	6.50	6.50	---	--
Grower	17.50	16.90	.44	NS[c]
Finisher	55.67	53.90	14.15	NS
Final weight, kg				
Starter	13.70	13.30	.53	NS
Grower	55.67	53.90	14.15	NS
Finisher	100.70	93.63	22.89	NS
Average daily feed intake, g				
Starter	470	460	1900	NS
Grower	1770	1860	20100	NS
Finisher	2860	2790	7600	NS
Grower & Finisher[d]	2310	2320	3400	NS
Average daily gain, g				
Starter	260	243	500	NS
Grower	700	660	3500	NS
Finisher	787	710	600	.05
Grower & Finisher[d]	743	687	1600	NS
Feed/Gain				
Starter	1.83	1.91	.033	NS
Grower	2.53	2.82	.0173	.10
Finisher	3.63	3.94	.0416	NS
Grower & Finisher[d]	3.11	3.40	.0144	.05

[a] Using diets from Tables 5, 8, and 9.
[b] Mean squares of error.
[c] NS = not significant (P > .10).
[d] Grower and finisher data combined.

Table 14. Comparisons of carcass measurements in Trial 1.

Items	Corn-soy	Corn-soy-canola	MSE[a]	P
No. of pigs	15	15		
Live wt., kg	104.43	100.22	9.43	NS[b]
Hot carcass wt., kg (head off)	78.49	74.51	7.32	NS
Dressing percent	75.15	74.30	.796	NS
Carcass length, cm	79.04	79.15	4.00	NS
Backfat thickness, cm	2.46	2.46	.0139	NS
Loineye area, cm^2	31.22	28.17	.0717	.01
Percent muscle	54.37	53.43	.1056	.05
Adjusted length, cm[c]	80.47	80.62	.577	NS
Adjusted average backfat, cm[c]	2.85	2.95	.0042	NS
Adjusted loineye area, cm^2[c]	31.24	29.0	.201	.01
Kilograms of lean gain per day on test[d]	.316	.295	.0001	.10

[a] Mean squares of error.

[b] NS = not significant (P > .10).

[c] Adjusted to 104.5 kg weight basis (see Table 10).

[d] This value estimates muscle to comprise 40% of the pig's weight at the beginning of the test. Actual lean (muscle) is calculated in the final test weight. Initial test weights used were the initial weights of the pigs in the grower phase and ending test weights were taken the day of slaughter. For more information see **Guidelines for Uniform Swine Improvement Programs, 1981.**

the pigs fed the CSC diet. For the overall 8-week growing period, there were no significant differences between treatment groups for average daily gain (ADG) (700 g for pigs fed the CS diet vs. 660 g for the CSC treatment group) or average daily feed intake (ADFI) which was 1770 g for the CS treatment vs. 1860 g for the CSC treatment group. However, there was an increase ($P < .10$) in feed to gain (F/G) of pigs fed the CSC diet (2.83 vs. 2.53). At the end of the 8-week growing period, the pigs fed the CS diet had an average weight of 56.7 kg compared to 53.9 kg for the CSC treatment group.

During the 8-week finishing period, overall ADFI was essentially the same for both treatment groups (2860 g for the CS group vs. 2790 g for the corn-canola (CC) treatment group). Feed per unit of gain between the two groups was not significantly different, but pigs fed the CC diet tended to be less efficient (3.94 for pigs fed the CC diet vs. 3.63 for the CS treatment group). The CC treatment group gained less ($P < .05$) than the pigs fed the CS diet (710 vs. 787 g per day). Though not significantly different, the ending weights of the pigs in the CC treatment group were lower at the end of the finishing phase (93.6 kg) compared to 100.7 kg for the CS treatment group.

For the combined 16-week growing and finishing phase, overall F/G was increased ($P < .05$) for the pigs fed the

CSC diet (3.40 vs. 3.11). ADG was also lower for the CSC treatment group (687 vs. 743 g), but this difference was not significant. ADFI was essentially the same between the two treatment groups for the combined periods (2310 for CS pigs vs. 2320 g for the CSC group).

At the end of Trial 1, five pigs were taken from each pen and slaughtered for carcass measurements. The average slaughter weights for the CS and CSC treatment groups were 104.4 and 102.3 kg, respectively. Hot carcass weight (head off), dressing percentage, carcass length, and backfat thickness at the 10th rib, were all similar for pigs in the two treatment groups. Pigs fed the CSC diet had smaller loineye areas ($P < .01$) than the pigs fed the control diet (28.17 vs. 31.22 cm^2).

Since not all pigs weighed the same at the time of slaughter, carcass measurements were adjusted to a 104.5 kg weight basis according to the equations outlined earlier. These adjusted values for length of carcass and average backfat at the 10th rib were similar between both treatment groups. Adjusted loineye areas of pigs fed the CSC diet were still smaller ($P < .01$) than the loineye areas of pigs consuming the CS diet (29.0o vs. 31.24 cm^2). Percent muscle of pigs fed the CS diet was greater ($P < .05$) than that of the CSC treatment group (54.4 vs. 53.4%). Using an equation from **Guidelines for Uniform Swine Improvement**

Programs (1981), kilograms of lean gain per day on test was calculated for each pig slaughtered. The CS treatment group gained .316 kg of lean per day on test, while those pigs fed the CSC diet gained .295 kg daily ($P < .10$).

When the carcass measurements were taken, the carcasses were also visually examined for quality and three pigs from each treatment group exhibited signs of PSE (pale, soft, and exudative pork). These examinations were based on guidelines outlined by the National Pork Producers Council, 1983. Since both groups had the same number of PSE carcasses, one may conclude that diet was without effect upon this parameter.

Trial 2

Diets used in Trial 1 were evaluated using balance studies. The results of these trials are shown in Tables 15, 16, and 17 for the starting, growing, and finishing diets, respectively.

The digestible and metabolizable energy values of the three diets fed in the starting, growing, and finishing phases were determined. For the starter diet, the inclusion of 1% tallow in the CSC diet resulted in higher ($P < .05$) digestible (DE), metabolizable (ME), and N-corrected metabolizable energy (ME_N) values than those of the starter CS diet (3559, 3457, and 3334 kcal/kg, for DE, ME, and ME_N, respectively, for the CSC diet vs. 3469, 3351, and

Table 15. Balance trial starter diet results.

Parameter	Corn-soy	Corn-soy-canola	MSE	P
No. of pigs	6	6		
Initial weight, kg	7.47	7.25	---	--
Total feed intake, g[a]	1195	1160	22.60	NS
Total feces excreted, g	136	143	536.7	NS
Total urine collected, g	869	708	71231	NS
<u>Energy density</u>				
GE of total feed consumed, kcal	4737	4734	360100	NS
GE of total feces, kcal	584	605	9752	NS
GE of total urine, kcal	140	119	507	NS
DE, kcal/kg diet	3469	3559	4700	.05
ME, kcal/kg diet	3351	3457	5094	.05
ME_N, corrected, kcal/kg diet	3226	3334	4051	.05
<u>Protein utilization</u>				
Nitrogen (N) of total feed fed, g	38.61	35.64	23.11	NS
N of total feces, g	5.66	5.54	1.06	NS
N of total urine, g	10.57	9.12	2.39	NS
App. digest. of N, %	85.09	84.14	8.07	NS
App. biol. value of protein, %	67.37	69.66	23.49	NS
App. net protein utilization, %	57.43	58.79	22.93	NS
<u>Phosphorus</u>				
Total phosphorus (P) intake, g	6.56	6.75	.699	NS
Total feces P, g	2.82	2.96	.172	NS
Total urine P, g	.033	.039	.0004	NS
P balance, g	3.70	3.75	.477	NS
Percent retention	55.92	55.67	30.56	NS
<u>Calcium</u>				
Total calcium (Ca) intake, g	12.007	11.484	2.267	NS
Total feces Ca, g	4.178	4.383	.405	NS
Total urine Ca, g	1.504	1.313	.153	NS
Ca balance, g	6.324	5.787	2.029	NS
Percent Ca retention	52.06	50.44	54.07	NS

[a] Total values for feed, urine, and feces are the averages of the 6 pigs in each treatment for the 4-day collection period.

Table 16. Balance trial grower diet results.

Parameter	Corn-soy	Corn-soy-canola	MSE	P
No. of pigs	6	6		
Initial weight, kg	9.28	9.17	---	--
Total feed intake, g	1485	1453	9873	NS
Total feces excreted, g	213	231	2041	NS
Total urine collected, g	1492	1477	78987	NS
Energy density				
GE of total feed consumed, kcal	5781	5784	154060	NS
GE of total feces, kcal	898	987	36285	NS
GE of total urine, kcal	133	145	221.3	NS
DE, kcal/kg diet	3291	3300	11788	NS
ME, kcal/kg diet	3203	3200	11485	NS
ME_N, corrected, kcal/kg diet	3115	3112	12696	NS
Protein utilization				
Nitrogen (N) of total feed fed, g	37.73	36.48	6.27	NS
N of total feces, g	7.40	7.65	2.79	NS
N of total urine, g	11.80	11.45	.616	NS
App. digest. of N, %	80.52	78.91	18.39	NS
App. biol. value of protein, %	61.05	60.08	6.29	NS
App. net protein utilization, %	49.20	47.45	15.07	NS
Phosphorus				
Total phosphorus (P) intake, g	7.724	8.333	.312	.10
Total feces P, g	3.648	4.167	.367	NS
Total urine P, g	.096	.122	.0025	NS
P balance, g	3.980	4.044	.372	NS
Percent retention	51.77	48.33	48.92	NS
Calcium				
Total calcium (Ca) intake, g	10.694	11.103	.554	NS
Total feces Ca, g	5.561	6.121	1.611	NS
Total urine Ca, g	.454	.523	.0335	NS
Ca balance, g	4.679	4.459	1.598	NS
Percent Ca retention	43.99	39.73	123.51	NS

Table 17. Balance trial finishing diet results.

Parameter	Corn-soy	Corn-soy-canola	MSE	P
No. of pigs	6	6		
Initial weight, kg	10.32	10.37	---	--
Total feed intake, g	1981	1861	81742	NS
Total feces excreted, g	194	221	2067	NS
Total urine collected, g	890	881	42158	NS
Energy density				
GE of total feed consumed, kcal	7767	7534	1301798	NS
GE of total feces, kcal	832	940	35784	NS
GE of total urine, kcal	116	108	859.0	NS
DE, kcal/kg diet	3490	3545	5544	NS
ME, kcal/kg diet	3430	3487	7061	NS
ME_N, corrected, kcal/kg diet	3369	3425	8331	NS
Protein utilization				
Nitrogen (N) of total feed fed, g	36.87	34.48	27.45	NS
N of total feces, g	6.24	6.60	1.86	NS
N of total urine, g	11.01	10.36	3.54	NS
App. digest. of N, %	82.93	80.95	8.99	NS
App. biol. value of protein, %	62.65	62.70	27.47	NS
App. net protein utilization, %	51.77	50.83	35.18	NS
Phosphorus				
Total phosphorus (P) intake, g	10.184	10.458	2.491	NS
Total feces P, g	3.522	4.311	.645	NS
Total urine P, g	.116	.141	.0032	NS
P balance, g	6.545	6.005	1.057	NS
Percent P retention	64.42	57.35	17.35	.05
Calcium				
Total calcium (Ca) intake, g	12.657	13.417	4.002	NS
Total feces Ca, g	4.789	6.084	1.470	NS
Total urine Ca, g	.452	.625	.0775	NS
Ca balance, g	7.416	6.708	1.485	NS
Percent Ca retention	58.87	49.98	39.434	.05

3226 kcal/kg for the CS diet). The correction for nitrogen (6.77 kcal/g of nitrogen retention) was based on work by Diggs et al. (1965). These three energy values (DE, ME, and ME_N) were also determined for the growing and finishing diets and did not differ significantly between the two treatment groups.

Apparent digestion of nitrogen (protein) was compared between treatment groups and was essentially the same for both of the diets (CS and CSC) for each of the starting, growing, and finishing phases of the trial. The same trend was observed when apparent biological value of protein and net protein utilization values were calculated for each of the diets.

Values for apparent digestion of nitrogen were 85.1, 80.5, and 82.9% for pigs fed the starting, growing, and finishing CS diets, respectively. Pigs fed the CSC starting, growing, and finishing diets had values of 84.4, 78.9, and 81.0%, respectively, for apparent digestion of nitrogen. Apparent biological value of protein for the CS starting, growing, and finishing diets were 67.4, 61.1, and 62.7, while pigs fed the respective CSC diets gave values of 69.7, 60.1, and 62.7%. The apparent net protein utilization (NPU) values of the three CS diets were 57.4, 49.7, and 51.8% while the respective CSC diets had NPU values of 58.8, 47.5, and 50.8%.

The percent calcium and phosphorus retained by pigs fed both diets in each phase was evaluated. Phosphorus retention was not significantly different between pigs fed either the CS or the CSC starting and growing diets (55.9 and 51.8% retention for the starting and growing CS diet vs. 55.7 and 48.3% for the starting and growing CSC diets). The pigs fed the CC finishing diet retained less phosphorus ($P < .05$) than pigs fed the finishing CS diet (57.4 vs. 64.4%).

Calcium retention did not differ significantly between treatment groups fed the starting and growing diets. Pigs fed the CC finishing diet retained significantly less calcium than the CS control group (50.0 vs. 58.9%).

DISCUSSION

Trials 1 and 2

Performance of pigs fed the corn-soy-canola (CSC) diet during the starting phase of Trial 1 was essentially the same as the control group (CS). The balance trial data confirmed these results and showed no significant differences between treatment groups for protein utilization measurements and phosphorus and calcium retention. The significantly higher ($P < .05$) values for digestible and metabolizable energy obtained with the CSC starter diet would seem to indicate that the addition of 1% tallow was more than adequate to bringing the diet to an isocaloric basis with the CS diet.

The average daily feed intake (ADFI) of pigs consuming the two treatment diets was not significantly different during the starting phase. This is in agreement with McKinnon and Bowland (1977) who found that pigs fed isocaloric and isonitrogenous diets containing 11.9% canola meal had feed intakes similar to those of the pigs fed soybean meal control diets. However, as the level of canola meal in that trial was increased to 25.3% of the diet (completely replacing soybean meal as the supplementary protein source), significant reductions in feed intake were observed for the starter pigs compared to controls. Bowland (1975) found that dietary levels as high as 19% Tower canola meal did not significantly reduce feed intake in starter pigs compared to the soybean meal control groups. These diets were also balanced to be isonitrogenous and isocaloric. Later work done by McIntosh and Aherne (1981) showed that 3-week-old pigs
fed diets based on wheat and barley with either 0, 50, or 100% of the supplemental protein supplied by canola meal consumed less feed as the level of canola meal increased (reviewed by Rundgren, 1983).

These trials would seem to indicate that high levels of canola meal in starter diets may contain sufficient

quantities of glucosinolates (namely, isothiocyanates) to reduce the palatability of the diets (Singam and Lawrence, 1979; McIntosh and Aherne, 1984). The level of canola meal in the present experiment (10%) did not appear to reduce the feed intake of the pigs consuming the CSC diet. The addition of tallow may have enhanced the palatability of the CSC diet to suppress the possible pungency associated with isothiocyanates or other glucosinolate products still present in the meal. However, other studies using similar levels of canola meal in starter diets have generally shown intake to be unaffected (McKinnon and Bowland, 1977; Ochetim et al., 1980; Bell and Aherne, 1981; Bell, 1984).

Feed per unit of gain (F/G) and average daily gain (ADG) of the starter pigs fed the two treatment diets were not significantly different. McKinnon and Bowland (1977) fed isonitrogenous, isocaloric starter diets containing 11.9% canola meal and found similar F/G and ADG of those pigs compared to soybean meal control pigs, but significant reductions in gain and efficiency were seen when the level of canola meal was increased to 25.3% of the diets. Castell (1977) fed isonitrogenous diets to swine containing 7.5% canola meal and found reduced gain ($P < .05$) and efficiency of those pigs compared to soybean meal controls. Bowland (1975) did not find differences in gain or efficiency of starter pigs fed either soybean meal control diets or diets containing 19% canola meal.

The results from these trials are rather inconsistent as to the level of canola meal which can be used in starter diets without significant reductions in performance. Based on data from this trial and previous studies, it would appear that diets for starter pigs containing 10% canola meal and balanced for energy and lysine may support performance equal to that of corn-soybean meal diets. Since canola meal is lower in metabolizable energy (2700 kcal/kg) than soybean meal, the addition of tallow (or some other high energy source) in starter diets containing canola meal may be warranted, especially if levels above 10% (of the diet) are used.

The nitrogen and protein digestibility of the two treatment diets in the starter phase, along with biological value and net protein utilization were similar. Bowland (1975) found diets fed to starter pigs containing up to 19% canola meal were similar in nitrogen digestibility, biological value, and net protein utilization as the control (soybean meal) treatment group. Similar results were found by McKinnon and Bowland (1977) using starter pigs and replacing 50% or all of the soybean meal with canola meal in the starter diet.

GROWING STAGE

After pigs in Trial 1 were allowed a one week adjustment period (after the starting phase) the diets fed in the growing phase were adjusted accordingly to NRC requirements. The level of canola meal used in the growing CSC diet was increased to 15% of the diet. Tallow was added at the level of 1.5% of the diet to maintain the isocaloric status of the two treatment grower diets.

Although the ADG of pigs fed the two diets was not significantly different, pigs fed the CSC diet tended to gain less during the growing phase (660 vs. 700 g/day). Subsequently, a reduction in efficiency was seen in the pigs fed the CSC diet compared to pigs receiving the control (CS) diet.

Previous work has also shown that pigs fed canola meal in the growing stages, especially at high levels (greater than 15% of the diet) may limit performance of those pigs compared to diets using soybean meal as the sole supplemental protein source. Using isocaloric, isonitrogenous diets, various researchers have found significant depressions in average daily gain and gain per unit of feed when canola meal comprised 15% or more of the diet of growing swine (McKinnon and Bowland, 1977; Aherne and Lewis, 1978; Singam and Lawrence, 1979; Castell, 1980; Bourdon et al., 1984; Baidoo and Aherne, 1985). Feed intake has not consistently been shown to be depressed when canola meal diets were fed to growing swine and balanced for energy.

Although most researchers have found performance of pigs fed grower diets containing less than 15% canola meal comparable to pigs fed soybean meal control diets, some workers have reported depressions in gain and feed efficiency of pigs fed diets containing 12.5% canola meal (Castell, 1977) or levels as low as 10% canola meal (Kennelly et al., 1978).

Several explanations have been reported in the literature in reference to the lowered performance of pigs fed high levels of canola meal in the growing phase. Differences in the amino acid availabilities of soybean meal and canola meal have been reported by Sauer et al. (1982) and other workers. These differences (especially lysine) are more evident when diets are formulated for growing swine due to the higher requirement of protein (as a % of the diet) compared to that of the finishing swine diet. Sauer et al. (1982) found available lysine in canola meal to be 77.7%. Soybean meal (48%) was significantly higher in available lysine ($P < .05$) at 88.3% availability. Availability of other indispensable amino acids in soybean meal were also significantly higher than those in canola meal. Since diets in this study were formulated on an isolysinic basis instead of an isoavailable lysine basis, differences in performance of the two treatment groups may be attributed to amino acid availability differences of the two supplemental protein sources.

Earlier work done by Bell (1975) and other workers did not show a response in performance of growing swine fed diets containing canola meal supplemented with lysine. Later work by Bell et al. (1981) and Bell (1984b) showed improved performance of pigs fed diets containing canola meal supplemented with additional lysine. These improvements were especially prevalent during the first half of the growing period. These studies would seem to suggest the need for additional lysine (above the levels formulated based on total lysine of canola meal) in the diets of growing swine containing higher levels of canola meal.

Average daily feed intakes of pigs fed the two treatment diets were not significantly different in this study. However, pigs consuming the CSC diet showed a slight tendency to waste feed. Feeder adjustments were made daily to curtail their wastage but no corrections were made to account for the possible overestimatation of feed intake. One possible explanation for this behavior may be related to the palatability of the CSC diet. Although the presence of isothiocyanates and other glucosinolate hydrolysis products have been dramatically reduced in canola meal, problems with intake of grower swine diets containing canola meal have still been seen. These problems were discussed earlier for the starter pig and may also be applied to the early growing stage of swine. Bell (1984b) noticed that growing pigs first introduced to diets containing canola meal consumed less feed initially, but would subsequently adjust to the diets and increase feed intake.

The goitrogenic properties of glucosinolate hydrolysis products (thiocyanate ion and oxazolidine-2-thiones) still present in canola meal may also be limiting performance in swine. Grandhi et al. (1976) fed growing and finishing swine diets containing 17.5% canola meal and found reductions in gain and subsequent final body weights of those pigs compared to the soybean meal control treatment group. Thyroid gland weights and iodine uptake were greater in the pigs receiving the canola meal diets along with lower thyroid hormone levels and higher monoiodotyrosine to diiodotyrosine ratios. Christison and Laarveld (1981) showed that 13 kg pigs fed diets containing 15% canola meal had no detectable ability to increase the output of T_4 in response to an external thyroid releasing hormone stimulus. The pigs receiving the soybean meal control diet were able to increase T_4 output. It was concluded that the compensatory hypertrophy of pigs fed high levels of canola meal was not sufficient to maintain full thyroid function.

Although the former studies suggest that feeding high levels of canola meal in the starting and growing phase may reduce thyroid hormone synthesis, reductions were not nearly as great as those from feeding the older rapeseed varieties. The effects of glucosinolates may be an additional deterrent on the feeding value of canola meal for swine, but it appears that lowered levels now present are not nearly as toxic in limiting pig performance (Bell, 1984).

FINISHING SWINE

The performance results of Trial 1 during the finishing phase showed a reduction ($P < .05$) in average daily gain of pigs fed the corn-canola (CC) diet in which canola meal completely replaced soybean meal at the level of 17.5%. These results are surprising considering past Canadian work which has shown little or no reduction in gain of pigs fed canola meal during the finishing stages (McKinnon and Bowland, 1977; Narandaran *et al.*, 1981). Though not statistically significant, feed efficiency and final weights of the pigs in the CC treatment groups were reduced compared to control pigs (CS).

It should be noted that pigs entering the finishing phase in the CSC treatment group tended to weigh less, 53.9 kg vs. 55.7 kg for the CS group, since these same pigs tended to gain less and were not as efficient when fed the CSC diet in the growing phase. From the carcass data, we can see that the loineye areas of pigs fed the CSC diets throughout the starting, growing, and finishing phases were significantly smaller than those of pigs of the control group. This would suggest a possible protein deficiency of those pigs fed the canola diets in comparison to the CS treatment group. Since diets were not balanced on an isoavailable lysine basis (according to values obtained by Sauer et al., 1982) the smaller loineye areas of pigs fed diets containing canola meal may be a result of a lower supply of available amino acids.

Most studies using canola meal in isocaloric, isonitrogenous swine diets have not shown significant differences in loineye areas and other carcass characteristics of those pigs compared to control pigs. However, McKinnon and Bowland (1977) and Bourdon et al. (1984) found that pigs fed dietary levels of canola meal above 10% throughout the starting, growing, and finishing phases, had significantly smaller loineye areas and muscle content than that of control pigs in those studies. These results agree with the present study which used levels of 10% or more canola meal in the diets of starting, growing, and finishing swine.

If protein deficiency were the primary factor which reduced the gain and efficiency of pigs fed canola meal in this study, we might expect the pigs in the later stages of growth to compensate for this deficiency. As mentioned earlier, Sauer et al. (1982) showed that the lowered availability of amino acids in canola meal might be more detrimental (more likely to cause an amino acid deficiency) in the earlier stages of pig growth. If this were the case, we might have expected the pigs during the finishing phase to compensate for this possible deficiency, as shown in other studies of pigs fed lysine deficient diets in the starting or growing phases (Wahlstrom and Libal, 1983; Thaler et al., 1986). However, pigs in the finishing phase fed the CC diet, did not show signs of a compensatory response. This would seem to indicate that if protein (lysine) deficiency were a factor, the level of lysine supplied by the CC diet containing 17.5% canola meal was not sufficiently available to support growth equal to that of the control group.

Results from the finishing diet balance trial showed that the metabolizable energy (corrected for nitrogen) was 3425 kcal/kg compared to 3369 kcal/kg for the CS diet. These values were not significantly different. However, the energy of the CC diet could have prevented the additional intake required to obtain equal performance of the CS treatment group if lysine deficiency was the reason for their (CC treatment group) lower performance and smaller loineye areas.

Although the possible role of amino acid availabilities in the use of canola meal swine diets has been theorized, one should not overlook the possible affect of the glucosinolates still present in canola meal on pig performance. As reviewed earlier, canola meal has still been shown to produce goitrogenic properties in swine and this may also be a limiting factor on finishing pig performance. This could be especially true with high dietary levels of canola meal.

MINERAL UTILIZATION

Calcium and phosphorus retention values for the starting and growing diets were not significantly different between treatment groups (CS vs. CSC). Calcium and phosphorus retention values for the finishing canola diet (CC) were significantly lower than the values for pigs fed the control diet (CS).

For purposes of this experiment, the phosphorus in canola and soybean meal was assumed to be only 1/3 as available as monodicalcium phosphate. Since canola meal represented a greater percentage of the finishing CC diet than soybean meal in the CS diet, the total phosphorus was somewhat higher for the CC diet (.592 vs. .50% phosphorus in the CS diet) so that both diets would be similar in isoavailable phosphorus. From the results, it would appear that the finishing CC diet contained somewhat greater amounts of unavailable phosphorus than the CS diet.

Nwokolo and Bragg (1977) reported that values for phytate phosphorus in rapeseed meal were .54% and .24%

in soybean meal. Bell (1984) reported values which were as high as .8 to .9% phytic phosphorus in canola meal. It is quite possible that the available phosphorus of the CC diet was overestimated which could account for the lowered retention of pigs fed this diet. Calcium retention of pigs fed the CC might also have been reduced due to the high percentage of phytate in canola meal. The presence of phytate may have tied up some of the calcium, making it unavailable to the pig.

Results: Trial 3

The performance of pigs fed the five diets (0, 25, 50, 75, and 100% replacement of soybean meal with canola meal) in the growing and finishing stages is shown in Table 18. Carcass data for Trial 3 are shown in Table 19.

The average initial weights of pigs in the five treatment groups were not statistically different. In the growing phase, average daily feed intakes (ADFI) and average daily gains (ADG) were not statistically different between the treatment groups. There was a linear ($P < .025$) decrease in ADG in pigs as the level of canola meal was increased in the diet (766 g/day for the control group to 697 g/day for the group receiving the grower diet which contained 24.4% canola meal. Feed required per unit of gain (F/G) was significantly different between treatment groups. Pigs fed the diet containing 24.4% canola meal

Table 18. Performance measurements: Trial 3.

Treatment % replacement of SBM Item	1 0 Control	2 25%	3 50%	4 75%	5 100%	MSE[a]	P	Linear	Quadratic
No. of pigs	32	32	32	32	32				
Grower period									
Initial wt., kg	24.51	24.32	24.61	24.51	24.58		--	--	--
Daily feed intake, g	2260	2310	2450	2380	2400	24200	NS[b]	NS	NS
Daily gain, g	766	756	708	714	697	1800	NS	.025	NS
Feed per unit of gain	2.95	3.05	3.18	3.33	3.45	.044	.05	.01	NS
Ending wt., kg	67.43	66.75	64.25	64.52	63.60	3.69	.10	.01	NS
Finishing period									
Daily feed intake, g	2920	3010	2910	3180	3260	67000	NS	.10	NS
Daily gain, g	690	691	702	706	714	1800	NS	NS	NS
Feed per unit of gain	4.23	4.34	4.15	4.51	4.55	.0725	NS	.10	NS
Final wt., kg	106.1	105.4	103.6	104.0	103.5	7.53	NS	NS	NS
Combined grower and finisher periods									
Daily feed intake, g	2590	2660	2580	2780	2830	34000	NS	.10	NS
Daily gain, g	727	723	705	709	705	20700	NS	NS	NS
Feed per unit of gain	3.56	3.66	3.67	3.91	4.01	.0356	.03	.01	NS

[a] Mean squares of error

[b] NS = not significant (P > .10).

Table 19. Carcass measurements: Trial 3.

Treatment	1	2	3	4	5				
% replacement of SBM	0	25%	50%	75%	100%				
Item	Control					MSE[a]	P	Linear	Quadratic
No. of pigs	16	16	16	16	16				
Slaughter wt., kg	108.4	107.8	111.8	110.1	109.0	4.74	NS[b]	NS	NS
Carcass wt., kg	84.1	83.1	86.5	84.7	83.7	3.86	NS	NS	NS
Loineye area, cm^2	31.95	31.84	31.93	31.49	31.28	4.12	NS	NS	NS
Adjusted loineye area, cm^2	31.22	31.26	30.60	30.46	30.46	4.83	NS	NS	NS
10th rib backfat, cm	3.03	2.75	2.86	2.94	2.91	.043	NS	NS	NS
Adjusted 10th rib backfat, cm	3.06	2.93	2.87	2.96	2.98	.129	NS	NS	NS
Length, cm	81.67	81.95	83.18	83.32	82.23	1.268	NS	NS	NS
Muscle, %	52.89	53.84	53.73	53.20	53.16	.794	NS	NS	NS
kg lean gain per day on test	.264	.270	.280	.267	.266	.00008	NS	NS	NS

[a] Mean squares of error.

[b] NS = not significant (P > .10).

had the highest values for F/G while pigs fed the soybean meal control diet had the lowest values. Therefore, feed efficiency (G/F) was linearly depressed ($P < .01$) as the level of canola meal in grower diets was increased from 0 to 24.4% of the diet. At the end of the 8-week grower period, the final weights of pigs in the five treatments were significantly different. The weights decreased linearly ($P < .01$) from the control treatment group to the group receiving canola meal as the sole supplemental protein source. The range of these weights was 67.4 kg for the control treatment group to 63.6 kg for the group receiving the highest level of canola meal.

During the 8-week finishing period, pigs remained on the same treatment diets (0, 25, 50, 75, and 100% replacement of soybean meal with canola meal) but the diets contained lower amounts of canola meal for each treatment and were formulated to meet finishing pig nutrient requirements. ADFI was not significantly different between treatment groups during this period by analysis of variance. However, there was a linear increase ($P < .10$), as determined by regression analysis, in feed intake of pigs as they consumed treatment diets containing a higher percentage of canola meal (range of 2920 g/day for the control group to 3260 g/day for the group receiving 100% of the supplemental protein source from canola meal). ADG was not significantly different between treatment groups by analysis of variance. F/G was also not significantly different between treatment groups by analysis of variance, but there was a linear increase ($P < .10$) in F/G of pigs as they consumed diets containing a higher level of canola meal (4.23 for the control group to 4.55 for the pigs consuming the diet containing the highest level of canola meal, representing 17% of the diet). The final weights of pigs in the 8-week finishing study were not significantly different between treatment groups.

For the combined 16-week growing and finishing phases, pigs consuming the control diets had the lowest F/G (3.56) while the pigs fed canola meal as the sole supplemental protein source during the period were least efficient (F/G = 4.01). F/G was linearly increased ($P < .01$) in pigs as the level of canola meal in the diet was increased. There were no significant differences in ADG of pigs fed the five treatment diets for the combined period. ADFI was linearly ($P < .10$) increased by pigs as the level of canola meal increased in the diet (2590 g for the control diet to 2830 g for the group receiving the highest level of canola meal throughout the period).

Four pigs were slaughtered from each pen and carcass measurements were taken using procedures outlined in Trial 1. There were no significant differences in any of the mean values of the carcass parameters measured among pigs between the five treatment groups.

Discussion: Trial 3

As in Trial 1, the diets fed in the growing and finishing periods of Trial 3 were balanced to be isolysinic and contain isoavailable phosphorus. The diets were balanced to be nearly isocaloric, but as the level of canola meal increased in the diet the metabolizable energy was slightly lower (3225 to 3125 kcal/kg for diets in the growing phase and 3250 to 3185 kcal/kg for diets in the finishing phase).

The results of pigs fed the five diets in the growing phase showed that increasing the percentage of canola meal in the diet depressed feed efficiency and tended to limit gain of those pigs. Feed intake was not significantly affected by treatment, but tended to increase as the level of canola meal was increased in the diet. The final weights of the pigs in the growing phase showed that pigs receiving increasing amounts of canola meal in place of soybean meal in the diet weighed less at the end of the growth stage.

In a very similar trial, Baidoo _et al_. (1983) fed isonitrogenous, nonisocaloric diets containing canola meal to growing swine (20-60 kg). Five diets were fed which replaced 0, 25, 50, 75, or 100% of the soybean meal in the diet with canola meal. The growth rate of pigs fed these diets was not significantly reduced until canola meal replaced 75% or more of the soybean meal in the diet. Feed conversion efficiency was significantly reduced when canola meal replaced 25% or more of the soybean meal supplement.

From Table 18, we can see that pigs fed increasing levels of canola meal in the finishing phase consumed more feed. Subsequently, feed efficiency was linearly depressed as the level of canola meal in the diet increased. Though not significant, there was a trend for pigs to gain more (relative to control pigs) as the percentage of canola meal replacing soybean meal was increased.

The results of the carcass data showed no significant differences in backfat, loineye area, percent muscle, or any other parameters comparing pigs in the five treatment groups.

These results along with the performance data of pigs in the finishing phase that were fed canola meal are somewhat different from the data seen in Trial 1. The slightly lower energy content of the diets containing high levels of canola meal in the finishing phase of Trial 3 and to some extent in the growing phase may have caused these pigs to regulate their energy intake by increasing feed consumption. Henry (1985) reviewed past work done by other researchers and himself, which showed that pigs will increase consumption of a lower energy diet (relative to control diets) to meet their energy needs. Kennelly _et_ _al_. (1978) found pigs consuming diets containing 10% canola meal consumed more feed than pigs receiving soybean meal control diets and attributed this increased intake to the higher fiber and lower digestible energy of canola meal diets (even though diets were balanced to be isocaloric).

If the lower amino acid availabilities in canola meal (shown by Sauer _et_ _al_., 1982) are sufficiently depressed to cause a slight protein deficiency of canola meal swine diets, increased intake by pigs in response to this deficiency could be seen. Henry (1985) indicated that earlier work (Henry, 1983) showed that growing pigs fed diets made slightly deficient in lysine or threonine, will increase feed intake per unit of metabolic weight (compared to a control diet) in an attempt to meet more closely its daily requirement.

Pigs fed increasing levels of canola meal in the finishing phase tended to have increased gains relative to the control treatment group. ADFI of these pigs (fed increased levels of canola meal) in the finishing phase was linearly increased. This could be explained as a compensatory response to a marginally low protein level in the growing phase (Wahlstrom and Libal, 1983). Since carcass measures, such as loineye areas, were not significantly different between the treatment groups, the lowered gain of pigs fed increasing levels of canola meal in the growing stage and the possible effect on protein deposition was negated at the time of slaughter.

In contrast, pigs fed diets containing 15% canola meal in the growing stage and 17.5% canola meal in the finishing stage of Trial 1, had significantly smaller loineye areas than the control pigs. Feed intake of these pigs was not significantly increased, therefore, one might conclude that the diets were not able to support protein deposition equal to that from the soybean meal control diets. These diets were balanced to be isocaloric; therefore, it is quite possible that energy was more important than lower amino acid availability in regulating feed intake. One should also not overlook the effect of glucosinolates on intake and this may have also interacted with the consumption of the canola meal diets. The energy levels of the canola meal diets in Trial 3 may have been sufficiently low to cause a response in feed intake, thereby increasing the amounts of amino acids ingested by the pigs. Therefore, in Trial 1, the possible lowered amino acids available in the canola meal diet may not have been sufficiently low to elicit a response in feed intake or the presence of glucosinolates in the meal may have prevented this response.

The results from Trial 3 have shown that growing pigs fed increasing levels of canola meal may be less efficient than pigs fed soybean meal control diets and may tend to gain less. When these same diets (percent of canola meal replacing soybean meal) are fed in the finishing phase, gain of those pigs fed increasing levels of canola meal may be compensated. Feed efficiency may be depressed as the percentage of canola meal is increased in the diet, however. If pigs are allowed to compensate for the possible nutritional deficiencies in canola meal by increasing their intake, overall performance of these pigs and subsequent carcass measurements may be the same as control pigs at the expense of feed efficiency.

CONCLUSIONS

When balanced for energy, total lysine and phosphorus, diets containing canola meal at levels as high as 10% appear to support pig performance equal to that of corn-soybean meal diets that are fed to starter pigs.

Pigs which have been fed a 10% canola meal starter diet and continue on a corn-soybean meal-canola meal diet containing 15% canola meal in the growing phase may be less efficient and tend to gain less than those pigs receiving soybean meal as the sole supplemental protein source.

When the same pigs receiving canola meal in the starting and growing phase (at levels previously mentioned) are fed diets containing canola meal as the sole supplemental protein source in the finishing phase, average daily gain of those pigs may be reduced and feed required per unit of gain may tend to increase compared to the performance of control pigs. Consequently, the loineye areas of pigs fed the canola meal diets in the starting, growing, and finishing phases may be smaller than loineyes of control pigs.

The results from the first trial seem to indicate a slight amino acid deficiency of pigs fed canola meal diets. Glucosinolate hydrolysis products present in canola meal may also have limited the gain and efficiency of these pigs.

Growing and finishing diets fed in Trial 3 were formulated on an isolysinic, isoavailable phosphorus and nearly isocaloric basis. As the percentage of canola meal replacing soybean meal was increased (0, 25, 50, 75, to 100% replacement of soybean meal with canola meal) in the diets of growing pigs, feed required per unit of gain was increased for those pigs. Daily gain of those pigs decreased linearly as the level of canola meal was increased in the diet. Feed intake of pigs consuming increasing levels of canola meal also tended to increase.

During the finishing stage, pigs fed increasing levels of canola meal (0, 25, 50, 75, and 100% replacement of soybean meal with canola meal) increased feed intake linearly. Average daily gain of these pigs tended to increase as the level of canola meal in the diet was raised.

The above results suggest that the apparent nutritional deficiencies associated with the feeding of diets containing canola meal in the growing phase may be compensated for in the finishing stage. When intake is not limited due to energy density or glucosinolates, pigs consuming canola meal diets may be able to increase feed consumption to more nearly meet their dietary nutrient requirements.

It is not clear whether glucosinolates, reduced amino acid availability, or other factors associated with feeding canola meal were responsible for the reduced performance of pigs fed these diets. In order to make recommendations as to the optimum level of canola meal in the growing and finishing swine diet, more work needs to be done in the areas of amino acid availability and glucosinolates in canola meal. When the effects of these and possibly other factors are more fully understood, canola meal in typical swine diets may be more adequately utilized.

At the present time, it appears canola meal can partially replace soybean meal in the starting and growing diets of swine and may completely replace soybean meal in the finishing phase. Some reductions in gain and efficiencies of these pigs could be expected, especially if pigs are not allowed to compensate for possible nutrient deficiencies in canola meal diets by increasing their feed consumption.

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APPENDIX

Trial 3 was conducted to evaluate the performance of pigs fed different levels of canola meal (replacing part or all of the soybean meal in the diet). Based on the performance of these pigs, an estimate of the economic value of canola meal may be determined. This estimate is based on the amount and price of the corn and soybean meal replaced by canola meal in the diet.

Tables 11 and 12 show the composition of the control growing and finishing diets used in Trial 3. These control diets will serve as the base for economic evaluation. For purposes of this analysis) dietary ingredients other than corn, soybean meal and canola meal will remain constant (such as monodicalcium phosphate and calcium carbonate). This is due to the results found in Trial 2, which showed that the available phosphorus and calcium in canola meal may have been slightly overestimated.

The general equation to be used for this evaluation (based on the control diet) is as follows:

$$\frac{\text{(lbs corn replaced)x(corn price)+(lbs SBM replaced)x(SBM price)}}{\text{(lbs of canola meal in the diet)}}$$

The pounds of corn, soybean meal and canola meal included in the diet are based on a ton of this diet. For example, the control finishing swine diet contains 1656 lbs of corn and 280 lbs of soybean meal on a ton basis. If we replace 75% of the soybean meal in the diet with canola meal (as in Trial 3) and balance the diet for lysine, the amount of corn, soybean meal and canola meal in the diet is 1602, 70 and 264 lbs, respectively. Using this level of canola meal in the finishing swine diet, we find that 54 lbs of corn and 210 lbs of soybean meal were replaced with 264 lbs of canola meal. These values can then be used in our equation:

$$\frac{54\ (C) + 210\ (S)}{264} = \text{value per pound of canola meal}$$

Where C = price per pound of corn
S = price per pound of soybean meal

The value of canola meal is the price per pound of canola meal which can be paid to equal the cost of the corn and soybean meal which it replaces. For example, if corn is 3.8 cents/lb pound and soybean meal is 9 cents/lb, the value of canola meal at this level of the diet (264 lbs in a ton) is 7.9 cents/lb.

The present formula, however, is not balanced for energy. Since canola meal is lower in lysine than soybean meal, the amount of canola meal (relative to soybean meal) is increased at the expense of corn. Subsequently, diets containing canola meal and balanced for lysine will be lower in energy.

In Trial 3, diets with increasing levels of canola meal were fed to swine. Intake, especially in the finishing phase was increased as the level of canola meal in the diet was increased. Feed per unit of gain was also increased for pigs fed higher levels of canola meal. This response in intake was likely due to the slightly lower energy density of diets containing higher levels of canola meal.

Since the diets used in this evaluation were not balanced for energy, we need to include this factor in determining the value of canola meal. This may be done in two ways. First, we may use the energy in the diet containing canola meal (at any level to be used) to determine a correction factor. Using energy values from our previous example we find a coefficient of .98 (3188 kcal/kg for the diet with 75% replacement of SBM with CM divided by 3250 kcal/kg for the control diet. This gives us a corrected value of 7.74 cents/lb for canola meal.

Another correction factor which may be used for our equation is the feed to gain of the pigs fed the control diet divided by that of the pigs fed a particular level of canola meal (the level used in the evaluation).

Based on the performance of pigs in Trial 3, a regression equation was developed for pigs in the growing and finishing phases fed varying levels of canola meal. This equation, based on our data, predicts the feed to gain ratio of pigs fed a certain level of canola meal (assuming the diets are balanced for lysine).

Prediction of feed/gain in the growing phase. Linear regression, where $Y = a + bx$

y = feed to gain ratio	x = level of canola meal (%)
$a = 2.936$	$r = .99$
$b = .0206$	

Using a level of 18.6% canola meal in the growing phase (75% replacement of SBM) the coefficient would be:

$$2.94/3.32 = .89$$

Prediction of feed/gain in the finishing phase. Linear regression, where $Y = a + bx$

y = feed to gain ratio x = level of canola meal (%)

$a = 4.194$ $r = .74$

$b = .0184$

Using our previous example the feed to gain ratio in the finishing phase for the control and canola meal diets (75% replacement of SBM) were 4.19 and 4.44. This gives a correction factor of .94. The corrected value of canola meal in the diet at this level is:

$$7.9 \times .94 = 7.43 \text{ cents/lb.}$$

This equation should give an estimate of the value of canola meal used at different levels in the growing and finishing phases. It should be noted that the increased intake of pigs fed diets containing higher levels of CM in the growing phase may not have been sufficient in maintaining equal growth to the control pigs. We may want to consider this factor when evaluating the value of canola meal in the growing phase. Pigs in the finishing phase, however, were able to compensate for their possible nutritional deficiencies (possibly due to lower energy or amino acid availability) by increasing intake. Therefore, the use of energy or feed to gain coefficients may be adequate in correcting for the lower energy in the canola meal finishing diet.