The University of Manitoba

The Utilization of Canola Meal by Young Growing Pigs

by

Ian Robert Seddon

A Thesis Submitted to the Faculty of Graduate Studies

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ABSTRACT

Four experiments, involving 140 pigs in performance and digestibility studies, were conducted to evaluate canola meal (CM) in comparison to soybean meal (SBM) as a protein supplement for young growing pigs. In experiments 1, 2 and 3, CM replaced 0, 50 or 100% of the SBM supplement on an isonitrogenous basis in isocaloric wheat-based diets for pigs fed from 14 to 32 kg. The effects of different lysine levels (0.74 or 0.84% total lysine) on performance were also studied. Feed intake and daily gains of pigs were reduced (P<0.05) when CM replaced 100% of the SBM supplement. Feed to gain ratios were similar (P>0.05) for all diets. Pigs fed diets formulated to contain 0.84% total lysine had nonsignificant (P>0.05) improved gains compared to pigs fed diets formulated to contain 0.74% total lysine.

In experiment 4, pigs initially weighing 6 kg were fed a prestarter diet until an average final weight of 14 kg. Following this, a starter diet was fed for the weight range of 14 to 32 kg. Four isocaloric diets were formulated for each part of the experiment. CM and synthetic lysine replaced 0, 35, 69 or 82% of the SBM in the prestarter diets whereas CM alone replaced 0, 32, 51 or 100% of the SBM on an isonitrogenous basis in the starter diets. The prestarter diets were formulated to contain similar available lysine levels. Pigs fed the prestarter diets had similar (P>0.05) feed intakes, daily gains and feed to gain ratios. However, pigs fed the wheat-SBM starter diet had improved (P<0.05) feed intakes

and daily gains compared to pigs fed the CM supplemented diets. Overall, pigs fed wheat-SBM diets from 6 to 32 kg in experiment 4 had improved ($P<0.05$) feed intakes and daily gains compared to pigs fed CM supplemented diets. Feed to gain ratios were similar ($P>0.05$) for all dietary treatments.

Digestibility studies conducted in experiments 3 and 4 indicated there were treatment differences ($P<0.05$) observed for apparent fecal dry matter, nitrogen and amino acid digestibilities. Complete replacement of SBM by CM usually resulted in lower digestibility coefficients but the results were not always consistent since increasing the level of CM in the diets did not always cause reductions in apparent digestibility. In experiment 4, dry matter and nitrogen digestibility coefficients were higher by 3.6 and 2.0% respectively when pigs were fed the starter diets as compared to the prestarter diets indicating an age (adaptation) effect for the young pig.

From these experiments it appeared complete (100%) replacement by CM caused reduced feed intakes and significantly lower gains. However partial (50%) replacement of SBM by CM (i.e. 12% in the diet) did not cause reduced performance thus CM could be included at up to 12% in diets for pigs 14 to 32 kg. The results of the prestarter period in experiment 4 indicated up to 14% CM and 0.5% added lysine could be used to replace 82% of the SBM without reducing performance of pigs over the weight range of 6 to 14 kg. The differences in digestibility coefficients did not help explain the reduced performance of pigs fed the CM supplemented diets.

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LIST OF ABBREVIATIONS

i) amino acids

Ala	alanine
Arg	arginine
Asp	aspartic acid
Cys	cystine
Glu	glutamic acid
Gly	glycine
His	histidine
Ile	isoleucine
Leu	leucine
Lys	lysine
Met	methionine
Pro	proline
Ser	serine
Thr	threonine
Tys	tyrosine
Val	valine

ii) others

CM	canola meal
d	day
DE	digestible energy
DM	dry matter
g	gram
HCl	hydrochloric acid
kg	kilogram
lysine HCl	lysine hydrochloride
M^2	square metres
ml	millilitre
mg	milligram
mg g^{-1}	milligram per gram
MJ kg^{-1}	megajoule per kilogram

N	nitrogen
NaOH	sodium hydroxide
SBM	soybean meal
ul	microliter
umol g^{-1}	micromole per gram

INTRODUCTION

The nutritive value of canola meal (CM) as a protein supplement in animal feed has increased due to improvements in breeding and processing of the seed (Bell et al., 1981; Youngs et al., 1981). CM can be used as the sole protein supplement for finishing pigs (Bell, 1984; Baidoo and Aherne, 1987b) however the optimum replacement value of CM for SBM in prestarter, starter and grower diets has not been clearly established (Bowland, 1975; McKinnon and Bowland, 1977; Narendran et al., 1981; Baidoo and Aherne, 1987a). When including CM in diets, consideration should be given to nutrient availabilities and digestibilities, especially lysine.

Lysine is considered to be the first-limiting amino acid in pig diets (Kerr et al., 1983). Guidelines have been issued suggesting the optimum levels required for growth (NRC, 1979). Nevertheless, similar to the CM situation, there is considerable disagreement regarding the optimum lysine level to include in diets for young pigs (NRC, 1979; ARC, 1981; Lewis et al., 1981).

The lack of agreement concerning the optimum levels of CM and lysine in diets for young pigs indicates further research is required on this topic. Thus, the present studies were carried out to:

a) to evaluate live performance of pigs (14-32 kg) fed diets formulated to various lysine levels.

b) evaluate the replacement value of CM for SBM in diets of young pigs (6-14 kg);

c) evaluate the replacement value of CM for SBM in diets of young pigs (6-32 kg) based on available supplemental lysine;

All diets included semidwarf wheat (cv. Oslo) as the basal energy source.

LITERATURE REVIEW

Introduction

Early weaning of pigs, most commonly at ages of 21 to 35 days, has become an increasingly common practice in commercial pig production. Consequently, the question of which are the optimum diets for pigs, initially weighing 5 to 10 kg, has resulted in more research investigating the physiological aspects of digestion in the young pig as well as its nutrient requirements. Furthermore, the suitability of various feedstuffs in the young pig's diet has been more extensively investigated. In most studies, the researchers have used young pigs with low initial weights (5 to 10 kg) and have fed them to final weights of 20-30 kg.

In this literature review, the more recent research will be discussed with respect to the following areas:

a) Digestion in the young pig.

b) Nutrients for the young pig - especially lysine.

c) The use of canola meal in growing pig diets, especially for the younger pig.

Digestion in the Young Pig

The trend of weaning pigs at a very young age, 17-35 days, has resulted in a higher incidence of poor postweaning growth encountered for up to 10 days postweaning (Bayley and Carlson, 1970; Owsley et al., 1986b). Suckling pigs receive a highly digestible liquid diet (i.e. sow's milk) containing approximately 25% lactose, 30% protein and 35% fat on a dry matter basis (Nelssen, 1986) whereas weaned pigs are frequently fed a dry cereal-soybean meal starter diet containing approximately 60% carbohydrates, 20% protein and 5% fat. With such a large change in diet-type from nursing to weaning, the ability of young pigs to quickly adapt and digest a cereal-soybean meal diet has been questioned. Therefore, it is important to establish when the early-weaned pig can adapt to a change in dietary ingredients. The following will review changes in digestive enzyme secretions and activities in early life and some of the feeding trial data related to this area.

Digestive enzymes and activities

i) Proteolytic enzymes

Much research has been conducted in recent years studying protein digestion in the young pig. Hartman et al. (1961) and Lindemann et al. (1986) reported low gastric proteolytic activity for the first two weeks of life, followed by a rapid increase.

Lindemann et al. (1986) also reported that pigs weaned at 4 weeks of age had almost twice the gastric peoteolytic activity by 6 weeks of age that comparable nursing pigs had. Thus, they concluded that enzyme production and activity was responsive to the diet.

The activities of pancreatic enzymes increase with the age of the pig (Corring et al., 1978; Efird et al., 1982a,b; Lindemann et al., 1986; Owsley et al., 1986a). Efird et al. (1982a) reported that pigs (3.5 kg) weaned at 16 days of age had significantly higher intestinal activities of chymotrypsin and trypsin by day 22 compared to nursing pigs, whereas the nursing pigs had higher pancreatic activities of the same enzymes. Since total activities of these enzymes were similar for both sow-reared and weaned pigs, Efird et al. (1982a) suggested weaning affects the intestinal and pancreatic enzyme levels. Similar conclusions were reported by Lindemann et al. (1986).

ii) Lactase and amylase

Lactase, an enzyme which hydrolyzes lactose, shows high activity at birth and decreases with age (Nelssen, 1986). Pancreatic amylase has been reported to increase in pigs up to six weeks of age for both nursing and weaned pigs (Corring et al., 1978; Lindemann et al., 1986). The pigs used in these studies had access to either creep feed or sow's feed thus, the increase in amylase secretion and activity was probably due to the need for amylase to digest starch.

iii) Lipase

Corring et al. (1978) and Lindemann et al. (1986) reported an increase in pancreatic lipase up to six weeks of age for nursing pigs, however Lindemann et al. (1986) reported pancreatic lipase activity in weaned pigs, 4 weeks old, significantly decreased by one week after weaning and remained low. The post weaning diet of Lindemann et al. (1986) contained less than 4% fat thus, the decline in lipase activity is not unexpected since lipase secretion and activity is usually adjusted to the dietary fat content.

Feeding experiments

i) Antigenic responses in young pigs

Lindemann et al. (1986) and Owsley et al. (1986a) reported that pigs weaned at 4 weeks of age had sufficient pancreatic enzyme activities to digest typical starter diets however, both reported a decrease in pancreatic amylase, trypsin and chymotrypsin activities during the first week postweaning, followed by a subsequent increase of activity. Reasons for this are unclear, but Newby et al. (1984) suggested early weaned pigs (3 weeks old) may have an antigenic response to their diets at weaning, especially if the pigs receive small amounts of creep feed prior to weaning. Miller et al. (1986) suggested the possibility of an interaction between the gut immune system, activated by absorbed food antigens, and the intestinal epithelium. Based on this one study, it appears as if absorptive capacity of the intestine is impaired by protein antigens for a period of up to 11 days postweaning (Newby et al., 1984) after which time absorptive function returns to normal. This may partially explain the postweaning lag often associated with early-weaned pigs.

ii) Protein utilization

Walker et al. (1986a, b) reported significantly higher dry matter digestibilities and amino acid availabilities for pigs (5.8 kg) weaned at 21 days fed diets with a milk protein supplement compared to a soy protein supplement. Such differences, especially for lysine, accounted for the significant differences noted in daily gain and feed efficiency for these pigs. The apparent digestibility of SBM increased over time to the extent that differences among SBM and milk diets were nonsignificant by 35 days of age. Similar results were obtained by Wilson and Leibholz (1981 a, b, c, d).

iii) Fat utilization

Many studies have been conducted using a wide range of fats or oils added to diets of young pigs less than 28 days old. Conflicting results have been reported but the most recent evidence seems to indicate that when protein, vitamin and mineral levels of the diet are increased as the energy level of the diet increases, then pigs weaned at 21 to 35 days appear to utilize energy from fat as well as that of carbohydrates (Leibbrandt et al., 1975a, b; Wolfe et al., 1978; Aherne et al., 1982).

In summary, the current practice of weaning pigs at 17 to 35 days of age in order to improve overall pig productivity has made it necessary to understand the development of digestive function in the young pig so that optimum diet compositions can be obtained for specific weaning ages. Based on enzyme studies and practical feeding trials it appears that a period of 7 to 10 days is required for the digestive system of the newly weaned pig to adapt from a highly digestible liquid diet to a usually lower digestible dry diet.

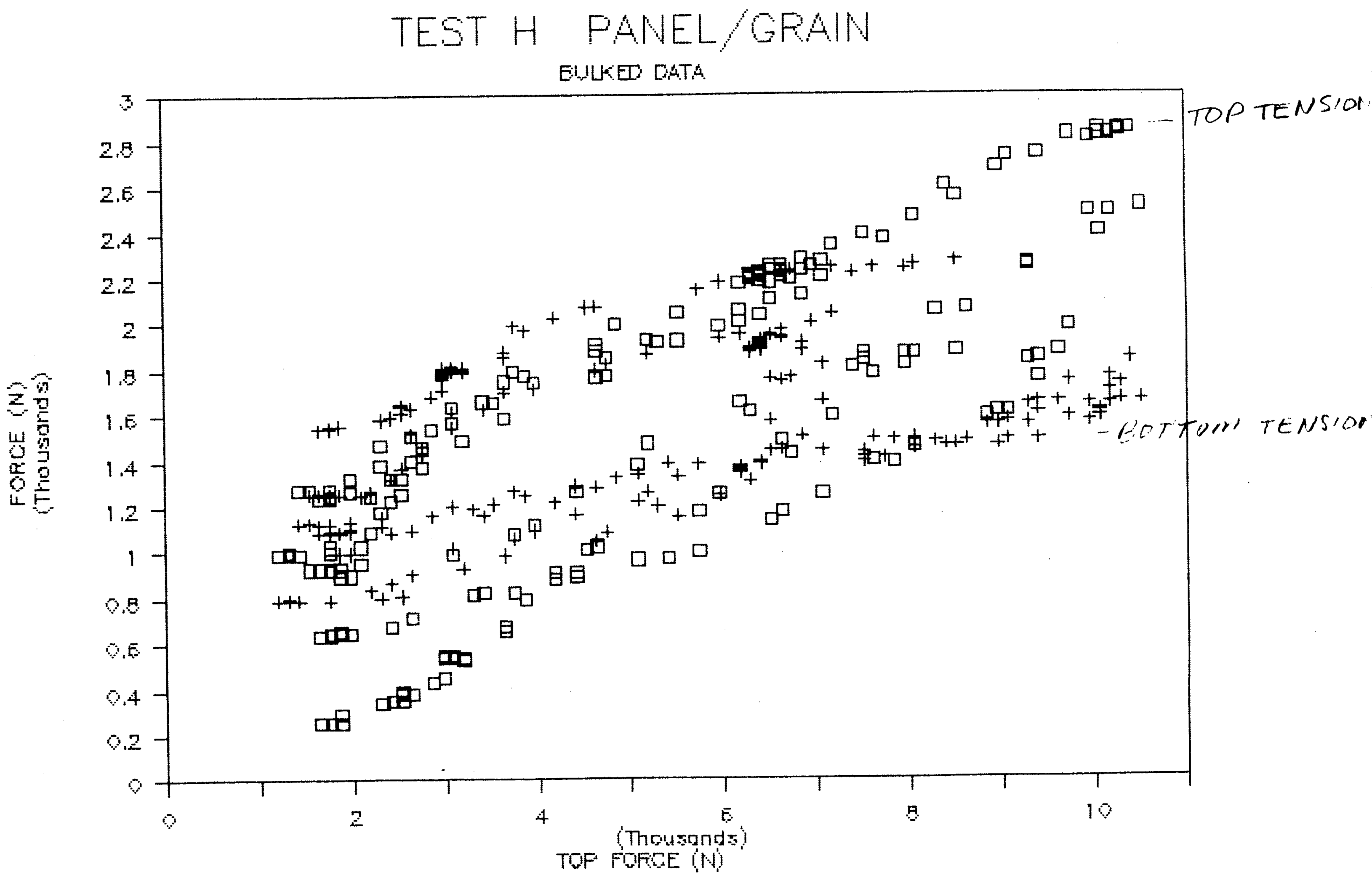
Nutrients for the Young Pig - Especially Lysine

Young growing pigs require a palatable, highly digestible diet because of the rate of growth that such a young pig can achieve. Compared to older growing and finishing pigs, the young growing pig requires in its diet higher levels of essential amino acids, digestible energy, vitamins and minerals. Among the essential amino acids to be considered in most pig diet formulation, lysine is the first-limiting amino acid. Since 1980, considerable research has been done on the lysine requirement of the young growing pig. Some of the interest in the requirement was created by the difference in lysine recommendations by NRC (1979) and ARC (1981).

The National Research Council (NRC, 1979) suggested lysine requirements of 0.95% for 5 to 10 kg pigs and 0.79% for 10 to 20 kg pigs. By comparison, the Agriculture Research Council (ARC, 1981) suggested a lysine requirement of 7 g lysine/100 g crude protein or 1.44% of the diet for pigs 3 to 8 weeks of age. Since lysine is the first-limiting amino acid in typical starter and grower pig diets, the establishment of accurate requirement data is of great importance to the swine industry.

<u>Dietary lysine requirement for 5 to 20 kg pigs</u>

Several studies have been reported in recent years suggesting optimum lysine levels for young pigs. Campbell (1977, 1978) suggested that pigs weighing 5 to 20 kg, fed wheat-SBM diets, required a crude protein content of 19 or 20% and 1.01 to 1.10% lysine. Lewis et al. (1981) suggested that pigs weighing 5 to 15 kg, fed corn-SBM diets containing 19% crude protein, required 1.15 to 1.25% lysine. Rosell and Zimmerman (1983, 1984) suggested a minimum lysine requirement of 1.12% for weanling pigs (initial weight 5 kg) fed sorghum-soybean diets; and 1.15 or 1.20% for weanling pigs (initial weight 5 kg) fed corn-soybean or sorghum-soybean diets containing 17 and 18.5% crude protein respectively. Aherne and Neilsen (1983) suggested that pigs weighing 7 to 19 kg, fed wheat-barley-SBM-based diets, required


TEST H PANEL/GRAIN
BULKED DATA
FORCE (N)
(Thousands)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
(Thousands)
TOP FORCE (N)
TOP TENSION
BOTTOM TENSION

20% crude protein and approximately 1.15% lysine. The above studies reported crude protein levels similar to NRC (1979) and ARC (1981) recommended levels (20 and 20.5% for young pigs respectively). Digestible energy of the diets reported above ranged from 14.1 MJ kg^{-1} (Aherne and Nielsen, 1983) to 14.9 MJ kg^{-1} (Campbell, 1978) which are similar to NRC (1979) and ARC (1981) recommendations of 14.6 and 14.6 MJ kg^{-1} respectively.

Amino acid imbalances and antagonisms in typical starter pig diets

Currently, pig diets are formulated to contain the recommended crude protein and lysine levels. Such formulation may result in other amino acids being present in excess or deficient amounts and, at least one possible antagonism between lysine and arginine has been identified (Southern and Baker, 1984).

Aherne and Nielsen (1983) suggested a lysine requirement of 1.15% for pigs 7-19 kg. A further increase to 1.30% tended to decreased performance. Rosell and Zimmerman (1984) noticed reduced feed intake when adding synthetic lysine to a low protein (17%) starter diet, suggesting a second amino acid may be limiting. If the protein level was increased (to 18.5%), no reduction occurred. However, Lewis et al. (1986) indicated lysine levels between 1.15 and 1.75% in a simple corn-soybean (18.5% protein) diet did not affect feed intake or daily gains regardless of the source of supplemental lysine (either synthetic lysine or SBM). Feed efficiencies increased in response to SBM, between

1.15-1.75% lysine, but not in response to synthetic lysine. These researchers concluded that 6 kg pigs had a lysine requirement of 1.15% and that increasing lysine up to 1.75% did not adversely affect pig performance.

Use of synthetic amino acids in typical pig diets

Supplementing lower protein diets with synthetic amino acids may reduce feed costs. Studies have shown that only lysine is deficient when crude protein levels of starter, grower and finisher diets are reduced two percentage units below NRC (1979) recommendations (Lunchick et al., 1978; Easter and Baker, 1980). However, further reductions in crude protein caused decreased gains in grower pigs even with supplemental synthetic lysine (Kerr et al., 1983) which suggested other amino acids became limiting. Research conducted to date has indicated crude protein levels in starter, grower and finisher diets can be reduced by 4 percentage units in corn-SBM based diets if supplemented with lysine, tryptophan and threonine (Russell et al., 1980; Corley and Easter, 1983; Cromwell et al., 1983).

The lysine requirement of pigs 20-30 kg

As with young starter pigs, there is considerable interest in the lysine requirement of older starter pigs. Baker et al. (1975) suggested a requirement of 0.77% lysine for pigs 18-31 kg. fed a typical corn-soybean diet containing 16% protein. This requirement was in good agreement with the NRC (1973) suggested level of 0.79% lysine and a 16% protein diet for pigs 20-35 kg, however it is higher than the current NRC (1979) recommendation of 0.70% lysine for the same diet. Henry (1984) suggested a lysine requirement of 0.85% for gilts (17-43 kg) fed a typical corn-soybean diet. Thus, it appears as though current NRC (1979) recommendations are below those necessary for optimum performance.

In summary, considerable research has been conducted to determine the optimum dietary lysine level for young pigs. Reports suggest a level of 1.10-1.20% is necessary for optimum performance of pigs fed from 5-20 kg (Campbell, 1978; Lewis et al., 1981; Rosell and Zimmerman, 1984) and a level of at least 0.77-0.85% for pigs 20-30 kg (Baker et al., 1975; Henry, 1984). Both levels are well in excess of current NRC (1979) recommendations. Crude protein recommendations (NRC, 1979) appear adequate to ensure that the other essential amino acids are present at required levels. Present formulation procedures based on a total lysine and crude protein content tend to result in some amino acids present in excess quantities but such levels do not seem to cause reduced performance.

Canola Meal for Growing Pigs

Soybean meal (SBM) is considered to be the major source of supplementary protein in pig diets in North America (Aherne and Kennelly, 1982). However, alternative protein sources are continually being investigated for their suitability in pig diets in comparison to soybean meal. Canola meal (CM), the residual material following oil extraction of low erucic acid, low glucosinolate cultivars of Brassica napus or B. campestris, would seem to be a logical replacement for SBM in Western Canada where canola is a major crop.

Much interest has been expressed about the use of CM as a protein supplement for starting (7-35 kg), growing (35-60 kg) and finishing (60-100 kg) pigs. Evidence suggests CM can be used as the sole protein supplement for finishing pigs (Bell, 1984; Castell and Spurr, 1984), however there is a lack of consensus regarding the replacement potential of CM for SBM in starter and grower diets (Bowland, 1971; Bowland et al., 1975; Castell, 1977; McKinnon and Bowland, 1977; Baidoo and Aherne, 1987a).

Effect of protein quality and amino acid availability on pig performance

Of the various factors believed to influence pig performance when comparing diets containing CM and SBM, protein quality and amino acid availability are considered extremely important. CM usually contains 37-38% protein and has a very good balance of amino acids, especially the sulfur-containing amino acids (Table 1). Special attention should be given to the content of lysine, threonine and the sulfur-containing amino acids and their availabilities since they are the first-, second- or third limiting in most pig diets.

Fecal samples have been used extensively for many years to determine amino acid availability (Walker et al., 1986a). However, several reports suggested microbial fermentation in the hind gut alters the amino acid profile and more accurate estimates of amino acid availability may be obtained from digesta collected at the terminal ileum (Hodgson et al., 1977; Sauer et al., 1982). For example, fecal analysis has overestimated threonine availability by as much as 11.6% in CM (Sauer et al., 1982).

Sauer et al. (1982) compared the total and available lysine content of barley-based CM or SBM diets for growing pigs. This study indicated only small differences (2.08 to 0.80%) in total lysine supply existed as the protein level of the diet decreased from 18 to 13% whereas much larger differences (10.01 to 3.65%) were noticed for available lysine supply over the same range of protein levels. These results led to the conclusion that, for grower diets containing 18 and 16% protein, CM should not replace more than half of the supplemental protein from SBM in order to minimize differences in available lysine supply without a reduction in pig performance. Where complete replacement of SBM

TABLE 1

Chemical analysis of canola meal (CM) and soybean meal (SBM)*

	CM		SBM	
	as-fed %	in protein %	as-fed%	in protein%
Proximate analysis				
Dry matter (%)	7.5		11.0	
Crude fiber (%)	11.1		7.3	
Ether extract (%)	3.8		0.8	
Protein (Nx6.25)	38.0		45.0	
Amino acid composition (%)				
Essential				
Arginine	2.32	6.11	2.90	6.44
Histidine	1.07	2.81	1.08	2.40
Isoleucine	1.51	3.98	2.11	4.69
Leucine	2.65	6.97	3.37	7.49
Lysine	2.27	5.98	2.80	6.22
Methionine & cystine	1.15	3.01	0.92	2.05
Phenylalanine	1.52	4.01	2.16	4.80
Threonine	1.71	4.50	1.71	3.80
Tryptophan	0.44	1.16	0.54	1.20
Valine	1.94	5.11	2.25	5.50
Non-essential				
Alanine	1.73	4.56	1.89	4.20
Aspartic acid	3.05	8.03	5.04	11.20
Glutamic acid	6.34	16.69	8.10	18.00
Glycine	1.88	4.96	2.07	4.60
Proline	2.66	7.00	2.20	4.89
Serine	1.67	4.39	2.25	5.00
Tyrosine	0.93	2.46	1.26	2.80

*Adapted from Clandinin et al. (1981).

with CM is desired (for economic reasons), then the crude protein level of a barley-CM diet should be increased relative to a barley-SBM diet, or synthetic lysine could be added, to create equivalent available lysine. Thus, Sauer et al. (1982) concluded the available lysine supply could be a critical factor when using CM as a replacement for SBM in pig diets.

Effect of digestible energy and fiber content in CM on pig performance

CM contains more hulls than SBM (Sauer et al., 1982) which is undoubtedly related to the lower energy and protein digestibility in CM than SBM when fed to pigs. Moreover, canola hulls contain more protein of low digestibility than soybean hulls (Cichon and Sauer, 1980). Thus the higher level of hulls in CM results in CM having a higher fiber content than SBM, helping explain the digestibility differences that may affect pig performance (Sauer et al. 1982; McIntosh et al., 1987).

Castell (1977) suggested the energy content of diets may be affected by including canola meal in the diet. CM and RSM are known to contain less energy per unit than SBM (U.S.-Can. Table of Feed Comp., 1982), thus it seems that CM diets should be formulated to minimize any effect the lower energy may have on pig performance. Narendran et al. (1981) reported growing and finishing pigs (18-105 kg) fed isocaloric CM or SBM-based diets showed similar performance.

Effect of glucosinolate content of CM in pig performance

Early rapeseed cultivars had high levels of glucosinolates, approximately 150 umol g^{-1} oil-free meal (Bell, 1984), which caused reduced pig performance and led to the recommendation that rapeseed not exceed a 5% inclusion rate in swine diets (Bowland, 1971).

Subsequent development of low erucic acid, low glucosinolate rapeseed cultivars, i.e. canola cultivars with approximately 25 umol g^{-1} oil-free meal (Bell, 1984), allowed for higher inclusion rates in pig diets without usually reducing performance, especially feed intake (Ochetim et al., 1980a). Furthermore, the proper processing of canola reduces the activity of myrosinase, an enzyme which hydrolyzes glucosinolates into toxic compounds, such as isothiocyanates, oxazolidinethiones (goitrin), nitriles and thiocyanates, that have detrimental effects on thyroid function (Ochetim et al. 1980a, b).

While some studies showed the addition of CM to growing and finishing pig diets (Narendran et al., 1981) or just finishing diets alone (McKinnon and Bowland, 1977), did not cause reduced performance, the inclusion rate of CM in the diets varied from study to study. Confounding these results, is the fact that glucosinolate levels of the meals used varied (Castell, 1977; Kennelly et al., 1978; Narendran et al., 1981).

The critical level for swine is unclear. Castell (1977) noticed similar performance for growing and finishing swine fed diets containing 15% CM (3.4 mg g^{-1} (26.8 umol g^{-1}) glucosinolate content). Kennelly et al. (1978) noticed reduced performance for similar pigs fed diets containing 10% CM (0.94 mg g^{-1} glucosinolate content). Narendran et al. (1981) reported similar performances for growing-finishing pigs fed diets with up to 25% CM (2.2 mg g^{-1} (17.6 umol g^{-1}) glucosinolate content). Thus, two of three studies indicated that differences in glucosinolate content of CM did not likely contribute to differences in pig performance.

CM in early-weaned pig diets

Recent trends have shown a move by producers to earlier weaning of pigs as young as 17 days, but more frequently at 21-35 days of age. There is a paucity of information regarding the optimum replacement level of CM for SBM with these younger pigs.

McIntosh and Aherne (1981) evaluated CM as a protein supplement for starter pigs weaned at 3 weeks of age. Their results indicated pigs fed wheat-barley-SBM-based diets consumed more feed and had higher daily gains compared to pigs fed diets in which CM was 50 or 100% of the supplemental protein source. Feed efficiencies were similar for all diets. It appeared as if a reduced feed intake of the CM diets caused the poorer average daily gains.

In a similar study using pigs 3 weeks of age, fed wheat-barley-SBM-based diets, McIntosh et al. (1986) demonstrated that replacing SBM with CM significantly reduced feed intakes and daily gains by 4 g and 2 g for every 1% addition of CM in the diet. Feed efficiencies were similar regardless of the source of supplemental protein. The reduction in feed intake of CM supplemented diets compared to the SBM diets caused the reduced growth rates of the CM supplemented pigs. The exact causes of the reduced intakes were unclear however Castell (1977), Ochetim et al. (1980b), Chubb (1982) and Baidoo and Aherne (1987a) suggested fiber, meal palatability or hydrolytic products of glucosinolates affected the feed intake of CM diets.

In these studies with young growing pigs, the primary energy sources have been corn and wheat with supplemental tallow where required with higher levels of CM. Frequently, corn and wheat have been expensive energy sources so they have been partially replaced by good quality barley. Pond and Maner (1984) suggested that wheat usually has a feeding value of 109-114% of that for barley.

In recent years, semi-dwarf wheats, including winter and spring cultivars, have become popular because of their high yield of digestible energy per unit area planted and fewer lodging problems. However, these higher yielding cultivars have been associated with lower protein contents and therefore poorer milling quality. While the protein content of semi-dwarf wheats may be lower, the data of Stothers et al. (1986) indicated that for feeding purposes, its protein quality is similar to that for milling wheats. In addition, both Stothers et al. (1986) and Salmon et al. (1987) found the energy values of semidwarf wheat to be similar to those for milling wheats. Excellent performance data for both growing pigs and broiler chicks fed diets containing semidwarf wheats were reported by Stothers et al. (1986).

To date, the CM diets used by researchers for the young growing pig have been formulated based on total lysine content. The most recent studies have incorporated total lysine levels in line with those proposed by Lewis et al. (1981) and Rosell and Zimmerman (1984), that is 1.15-1.25% total lysine. Sauer et al. (1982) reported lysine availability was lower in CM than SBM thus, when formulating diets with CM for very young pigs, more emphasis should be placed on available lysine rather than total lysine.

In summary, CM can be an attractive alternative to SBM in pig diets. CM can serve as the sole protein source in finisher diets, however the optimum replacement level of CM for SBM in starter and grower diets is not clearly established. Most evidence suggests CM can replace up to 50% of the supplemental protein source in grower diets without a reduction in live performance whereas for starter diets the replacement value of CM for SBM is less clearly defined.

MATERIALS AND METHODS

Animals and Management

i) Experiment 1

Forty two (Managra and Managra x Yorkshire) pigs were randomly allotted on an initial weight (19.5 $\pm$ 1.6 kg) basis to one of six treatments, 4 barrows and 3 gilts per treatment. Treatments were set up in a 3 x 2 factorial design with three levels of CM and two lysine levels. The pigs were housed in an environmentally controlled barn in pens 5.22 m^2 with ad libitum access to feed and water. Chemical analysis of the major dietary ingredients used in all experiments is listed in Table 2. This experiment was designed to examine the replacement value of CM for SBM and to examine the live performance of pigs fed diets formulated at two lysine levels. Isocaloric diets (DE basis) were formulated to meet or exceed NRC (1979) recommendations for pigs 10 to 20 kg and contain either 0.74 or 0.84% total lysine (Table 3). CM replaced 0,50 or 100% of the SBM supplement on an isonitrogenous basis. All diets were made into pellets 6 mm in diameter.

Individual pig weights and feed consumption on a per pen basis were recorded weekly until the mean treatment weight of one of the treatments was 32 kg at which time all pigs were taken off test.

Table 2 Proximate analysis and amino acid composition of oslo wheat (OW), canola meal (CM) and soybean meal (SM) (as-fed basis)

Proximate Analysis	OW	CM	SBM
Dry Matter (%)	88.9	91.2	87.3
Crude Protein (Nx6.25)(%)	17.1	38.6	49.7
Acid-detergent Fiber (%)	3.2	16.5	4.5
Ether Extract (%)	3.0	4.3	1.6
Amino acid composition			
Alanine	0.55	1.69	2.22
Arginine	0.63	2.38	3.73
Aspartic acid	0.75	2.79	6.25
Glutamic acid	5.21	6.80	7.50
Glycine	0.68	1.90	2.13
Histidine	0.36	0.94	1.20
Isoleucine	0.39	1.03	1.58
Leucine	0.92	2.28	3.40
Lysine	0.37	2.02	3.07
Methionene & cystine	0.56	1.46	1.31
Phenylalanine	0.78	1.50	2.51
Proline	1.68	2.37	2.45
Secine	0.80	1.76	2.81
Threonine	0.41	1.76	2.81
Tyrosine	0.39	0.90	1.49
Valine	0.65	1.35	1.66
Total Glucosinolates			
(um g^{-1} oil-free meal)	--	14.95	--

Table 3 Composition of diets, as-fed basis. Experiment 1

Diets	1	2	3	4	5	6
Ingredients (%)						
Wheat	83.5	80.3	79.2	75.0	76.0	70.0
SBM	13.5	17.2	6.80	8.75	0.0	0.0
CM	0.0	0.0	9.50	11.75	18.0	24.0
Tallow	0.5	0.0	2.0	2.0	3.5	3.5
Ground Limestone	1.0	1.0	1.0	1.0	1.0	1.0
Calcium Phosphate	1.0	1.0	1.0	1.0	1.0	1.0
T-M salt *	0.25	0.25	0.25	0.25	0.25	0.25
V-M-A **	0.25	0.25	0.25	0.25	0.25	0.25
Chemical Analysis***						
Dry matter (%)	90.0	89.8	90.1	90.5	90.5	91.1
Crude Protein (Nx6.25)(%)	21.2	22.3	20.8	21.6	20.2	21.7
Digestible energy (kcal kg^{-1} calculated)	3412.8	3406.4	3395.8	3430.3	3383.0	3351.6
Acid-detergent Fiber(%)	3.66	4.18	5.42	4.98	7.27	6.11
Ether Extract (%)	1.35	1.17	3.21	3.38	4.64	4.97
Total lysine (%)	0.72	0.79	0.68	0.74	0.64	0.75

* T-M salt is trace-mineralized salt containing the following (expressed as % $unit^{-1}$ of salt): NaCl 96.4, I 0.01, Co 0.004, Fe, 0.16, Cu 0.033, Mn 0.12, and Zn 0.4.

** V-M-A is a vitamin-mineral-additive premix which provided the following (kg^{-1} of diet): 5000 IU vitamin A, 500 IU vitamin D, 84 mg vitamin B_{12}, 40 IU vitamin E, 123 mg Zn O, 11 mg oxytetracycline HCl, 400 mg $CuSO_4$.

*** As-fed basis.

ii) Experiment 2

Experiment two was designed and set up similar to the method of experiment 1 with the following exceptions:

a) There were 4 gilts and 3 barrows per treatment and

b) average initial weight of pigs was 14.0 $\pm$ 1.1 kg

Diet formulations are given in Table 4.

iii) Experiment 3

Twenty four (Managra and Managra x Yorkshire) pigs were randomly allotted, on an initial weight (13.9 $\pm$ 1.1 kg) basis, to one of three treatments, 4 barrows and 4 gilts per treatment.

Isocaloric (DE basis) and isolysinic (total lysine diets) were formulated on an as-fed basis to meet or exceed NRC (1979) requirements for pigs 10 to 20 kg (Table 5). This experiment was designed to determine the replacement value of CM for SBM and to measure digestibility coefficients and their relationship to the level of CM in the diet. CM replaced 0,50 or 100% of the SBM supplement on an isonitrogenous basis. All diets were made into pellets 6 mm in diameter. Pigs were housed in an environmentally controlled barn in pens 5.22 m^2 with ad libitum access to feed and water.

Individual pig weights and feed consumption on a per pen basis were recorded weekly until the mean treatment weight of one of the treatments was 32 kg at which time all pigs were taken off test.

Table 4 Composition of diets, as-fed basis. Experiment 2

Diets	1	2	3	4	5	6
Ingredients (%)						
Wheat	83.5	80.3	79.2	75.0	76.0	70.0
SBM	13.5	17.2	6.80	8.75	0.0	0.0
CM	0.0	0.0	9.50	11.75	18.0	24.0
Tallow	0.5	0.0	2.0	2.0	3.5	3.5
Ground Limestone	1.0	1.0	1.0	1.0	1.0	1.0
Calcium Phosphate	1.0	1.0	1.0	1.0	1.0	1.0
T-M salt *	0.25	0.25	0.25	0.25	0.25	0.25
V-M-A **	0.25	0.25	0.25	0.25	0.25	0.25
Chemical Analysis***						
Dry matter (%)	89.3	89.4	89.9	89.8	90.3	90.7
Crude Protein (Nx6.25)(%)	21.5	22.8	20.7	21.7	20.2	21.4
Digestible energy (kcal kg^{-1} calculated)	3412.8	3406.4	3395.6	3430.3	3383.0	3351.6
Acid-detergent Fiber(%)	3.77	4.36	5.19	5.12	6.20	6.92
Ether Extract (%)	1.54	1.26	3.24	3.41	5.65	5.85
Total lysine (%)	0.70	0.80	0.65	0.75	0.65	0.73

* T-M salt is trace-mineralized salt containing the following (expressed as % $unit^{-1}$ of salt): NaCl 96.4, I 0.01, Co 0.004, Fe, 0.16, Cu 0.033, Mn 0.12, and Zn 0.4.

** V-M-A is a vitamin-mineral-additive premix which provided the following (kg^{-1} of diet): 5000 IU vitamin A, 500 IU vitamin D, 84 mg vitamin B_{12}, 40 IU vitamin E, 123 mg Zn 0, 11 mg oxytetracycline HCl, 400 mg $CuSO_4$.

*** As-fed basis.

Table 5 Composition of diets, as-fed basis. Experiment 3

Diets	1	2	3
Ingredients (%)			
Wheat	83.25	78.95	75.75
SBM	13.5	6.8	0.0
CM	0.0	9.5	18.0
Tallow	0.5	2.0	3.5
Ground Limestone	1.0	1.0	1.0
Calcium Phosphate	1.0	1.0	1.0
T-M salt *	0.25	0.25	0.25
V-M-A **	0.25	0.25	0.25
Chromic oxide	0.25	0.25	0.25
Chemical Analysis* **			
Dry matter (%)	88.7	89.8	90.7
Crude Protein (Nx6.25)(%)	20.8	20.5	20.1
Digestible energy (kcal kg^{-1} calculated)	3404.3	3387.1	3374.6
Acid-detergent Fiber(%)	3.90	5.09	6.50
Ether Extract (%)	1.74	3.78	5.62
Total lysine (%)	0.71	0.71	0.66

* T-M salt is trace-mineralized salt containing the following (expressed as % $unit^{-1}$ of salt): NaCl 96.4, I 0.01, Co 0.004, Fe, 0.16, Cu 0.033, Mn 0.12, and Zn 0.4.

** V-M-A is a vitamin-mineral-additive premix which provided the following (kg^{-1} of diet): 5000 IU vitamin A, 500 IU vitamin D, 84 mg vitamin B_{12}, 40 IU vitamin E, 123 mg Zn 0, 11 mg oxytetracycline HCl, 400 mg $CuSO_4$.

*** As-fed basis.

Chromic oxide was incorporated into each diet as an inert digestibility marker. Fecal samples were collected from each pig on day 12 and 26 of the test period using the following procedures:

a) each pen of pigs was moved to a small, recently washed area where,

b) freshly voided feces was collected from each pig, stored in polyethylene bags and frozen for subsequent analysis.

iv) Experiment 4

Thirty-two (Managra) pigs were randomly allotted on an initial weight (6.1 ± 0.7 kg) basis to one of four treatments, 4 barrows and 4 gilts per treatment. This experiment included two feeding phases, a prestarter for pigs 6-14 kg followed by a starter for pigs 14-32 kg. The objectives of this experiment were to determine the replacement value of CM for SBM in diets for young pigs, especially 6 to 14 kg pigs, based on available lysine supplies. Also, digestibility coefficients were determined to attempt to relate the digestibility of the diets to the performance of the pigs fed the various diets. All diets were formulated on an as-fed basis to be isocaloric (DE basis) and isolysinic (total lysine basis) during each feeding phase. Prestarter diets met or exceeded NRC (1979) requirements for pigs 5 to 10 kg (Table 6) whereas starter diets met or exceeded NRC (1979) requirements for pigs 10-20 kg (Table 7). CM and lysine

Table 6 Composition of diets, as-fed basis. Experiment 4 (prestarter).

Diets	1	2	3	4
Ingredients (%)				
Wheat	69.25	62.65	9.97	70.5
SBM	25.9	17.4	8.0	4.0
CM	0.0	12.6	13.0	14.0
Tallow	1.5	4.0	5.3	6.65
Lysine HCl	0.0	0.0	0.38	0.5
Ground Limestone	1.3	1.3	1.3	1.3
Calcium Phosphate	1.3	1.3	1.3	1.3
T-M salt *	0.25	0.25	0.25	0.25
V-M-A **	0.25	0.25	0.25	0.25
Chromic oxide	0.25	0.25	0.25	0.25
Chemical Analysis***				
Dry matter (%)	89.9	90.5	90.6	91.7
Crude Protein (Nx6.25)(%)	22.8	23.1	22.0	21.5
Digestible energy (kcal kg^{-1} calculated)	3496.7	3499.3	3493.1	3490.1
Acid-detergent Fiber(%)	4.95	5.93	5.42	5.96
Ether Extract (%)	3.00	5.25	6.60	8.51
Total lysine (%)	1.02	1.02	1.13	1.18
Available Lysine ****	0.74	0.71	0.74	0.75

* T-M salt is trace-mineralized salt containing the following (expressed as % $unit^{-1}$ of salt): NaCl 96.4, I 0.01, Co 0.004, Fe, 0.16, Cu 0.033, Mn 0.12, and Zn 0.4.

** V-M-A is a vitamin-mineral-additive premix which provided the following (kg^{-1} of diet): 5000 IU vitamin A, 500 IU vitamin D, 84 mg vitamin B_{12}, 40 IU vitamin E, 123 mg Zn 0, 11 mg oxytetracycline HCl, 400 mg $CuSO_4$.

*** As-fed basis.

**** Available lysine refers to the available lysine supplied by the protein supplements.

Table 7 Composition of diets, as-fed basis. Experiment 4 (starter).

Diets	1	2	3	4
Ingredients (%)				
Wheat	80.7	76.0	74.5	66.9
SBM	16.8	11.25	8.75	0.0
CM	0.0	8.75	12.0	25.6
Tallow	0.0	1.75	2.25	4.75
Ground Limestone	1.0	1.0	1.0	1.0
Calcium Phosphate	1.0	1.0	1.0	1.0
T-M salt *	0.25	0.25	0.25	0.25
V-M-A **	0.25	0.25	0.25	0.25
Chromic oxide	0.25	0.25	0.25	0.25
Chemical Analysis***				
Dry matter (%)	90.0	91.1	91.0	90.7
Crude Protein (Nx6.25)(%)	20.9	21.7	21.7	21.5
Digestible energy (kcal kg^{-1} calculated)	3407.7	3406.2	3404.5	3392.0
Acid-detergent Fiber(%)	5.24	5.21	5.42	6.95
Ether Extract (%)	1.56	3.29	4.23	6.32
Total lysine (%)	0.82	0.84	0.85	0.81
Available Lysine ****	0.48	0.46	0.45	0.44

* T-M salt is trace-mineralized salt containing the following (expressed as % $unit^{-1}$ of salt): NaCl 96.4, I 0.01, Co 0.004, Fe, 0.16, Cu 0.033, Mn 0.12, and Zn 0.4.

** V-M-A is a vitamin-mineral-additive premix which provided the following (kg^{-1} of diet): 5000 IU vitamin A, 500 IU vitamin D, 84 mg vitamin B_{12}, 40 IU vitamin E, 123 mg Zn 0, 11 mg oxytetracycline HCl, 400 mg $CuSO_4$.

*** As-fed basis.

**** Available lysine refers to the available lysine supplied by the protein supplements.

HCl replaced 0, 35, 69 or 82% of the SBM supplement in the prestarter diets and CM alone replaced 0, 32, 51 or 100% of the SBM supplement on an isonitrogenous basis in the starter diets. These inclusion rates of the protein supplements were calculated so as to obtain similar available lysine supplies in each diet, assuming lysine HCl (100% available) and SBM and CM having lysine availabilities of approximately 90 and 75% respectively (Sauer et al., 1982). All diets were made into pellets 6 mm in diameter. Pigs were housed in an environmentally-controlled barn with *ad libitum* access to feed and water. The feeding pattern of diets is listed below:

t_1: prestarter 1 - starter 1

t_2: prestarter 2 - starter 2

t_3: prestarter 3 - starter 3

t_4: prestarter 4 - starter 4

Individual pig weights and feed consumption on a pen basis were recorded weekly. Pigs were placed on the starter diets when mean pen weights reached 14 kg and were taken off test when the mean pen weight of one of the treatments was 32 kg.

Chromic oxide was incorporated into all diets as an inert digestibility marker. Fecal samples were collected from each pig on day 14 of the prestarter test period and days 14 and 21 of the starter test period using the procedure described in experiment 3.

Three pigs were removed from their respective diets during the test period due to illness which was diagnosed as swine dysentry. Fecal samples of treatment 1 obtained during the day 21 collection period of the starter test period were analyzed and found to contain unexpectedly low levels of chromic oxide, thus only results from the day 14 collection period were statistically analyzed for the starter test period.

For all of the experiments described, fat was added to the diets to counter the lower digestible energy values of Cm and maintain an isocaloric status among the diets used in each experiment. However, there were limits to the amount of fat which could be added to the diets because the addition of too high fat levels reduced the ability to pellet the diets. This was especially iportant for the prestarter diets used in experiment 4 where high energy, high lysine diets were required. Thus it was necessary to use combinations of CM, SBM and synthetic lysine to obtain the required dietary lysine and digestible energy levels for those diets. All other diets were made isocaloric and isolysinic by addition of CM and no synthetic lysine.

Sampling Techniques and Chemical Analysis

Grab samples were obtained from diets in all experiments and for the major dietary ingredients. Samples were ground using a 1 mm screen in a Wiley mill No. 2 grinder. Dry matter, crude protein (N x 6.25), ether extract and acid-detergent fiber were determined as described in AOAC (1984). Chromic oxide was determined according to the procedure of Williams et al. (1962). Total glucosinolate contents of CM were determined according to the procedure of Slominski and Campbell (1987).

The fecal samples obtained in experiments 3 and 4 were frozen, lyophilized and then, due to small sample volumes, pooled into two samples per treatment and ground through a 1 mm screen using a Wiley Mill No. 2 grinder prior to determination of chromic oxide, dry matter and nitrogen as outlined above. Digestibilities of amino acids, dry matter and nitrogen were calculated according to the equation of Maynard et al. (1979).

Amino acid analysis of feed and fecal samples was determined using the following procedures:

a) for amino acids other than methionine and cystine:

1. weigh 100 mg of sample into 19 mm hydrolysis tubes.
2. add 4 ml of 6 N HCl to the sample.
3. evacuated the sample and hydrolyze at 110°C for 24 hours.
4. after hydrolysis, neutralize with 4.1 ml NaOH (25%)
5. bring volume to 50 ml using a sodium citrate buffer (pH = 2.2)
6. shake mixture and filter using a Whatman filter paper No. 40.
7. apply 50 ul of filtered sample to an amino acid analyzer (LKB-4151 alpha plus) and determine amino acid content using a Hewlett Packard 3393 A integrator.

The above procedure is a revision of that described by Sauer (1976).

b) methionine and cystine were determined according to the procedure of Hirs (1967) with the following modifications:

1. after oxidation, add 0.5 ml conc. HCl, mix and let stand for 3 hours.
2. add 2 ml 6 N HCl.
3. evacuate and hydrolyze at 110°C for 16 hours.
4. after hydrolysis, neutralize solution with 2.3 ml NaOH (25%)
5. proceed with steps 5-7 above.

Statistical Analysis

Experiments 1 and 2 were set up in a completely randomized design using a 3 x 2 factorial arrangement of treatments, with 3 levels of canola meal and 2 levels of lysine. Average daily gains for each animal were determined by analysis of variance using linear regression procedures (SAS Inc., 1985) then subjected to analysis of variance using general linear model (GLM) procedures (SAS Inc., 1985). Student-Newman-Kuel's (SNK) multiple range test (Steele and Torrie, 1980) was used for multiple comparison of means.

Experiment 3 was set up as a completely randomized design with three treatments. Average daily gains for each animal were determined for animals as reported for experiments 1 and 2. SNK's multiple range test (Steele and Torrie, 1980) was used for multiple comparison of means.

Experiment 4 was set up as a completely randomized design with four treatments. Average daily gains for each animal were determined separately for each test period (prestarter and starter) and analyzed as reported in experiments 1 and 2.

Overall average daily gains in experiment 4 were subjected to analysis of variance using a split-plot design with repeated measurements over time by GLM procedures (SAS Inc., 1985) for unbalanced data. Individuals within treatment (Error A) were used to test for significance of treatment effects; animals within treatments within experimental period (residual, Error B) were used to test sub-plot effects of period and treatment x period interaction for significance (Snedecor and Cochran, 1980). Type III sum of squares was used to provide the highest level of protection against error (SAS Inc., 1985).

Feed intakes and feed:gain ratios for each experiment were subjected to analysis of variance using linear regression procedures (SAS Inc., 1985). The values obtained for each treatment represented the main feed consumption and feed to gain ratios for that treatment because individual pig feed consumption was not recorded. Also, there was only one replicate of each treatment for each experiment. Therefore, only one experimental unit was reported per treatment in each experiment and statistical comparisons of treatment means for feed consumption and feed to gain ratios in each experiment were not possible

Analysis of variance procedures were used in experiments 3 and 4 to determine amino acid, dry matter and nitrogen digestibility differences using GLM procedures (SAS Inc., 1985) and SNK's multiple range test (Steele and Torrie, 1980) for multiple comparison of means.

RESULTS

A. Performance Data

In experiments 1, 2 and 3, pigs fed from 14 to 32 kg with diets which contained CM as the sole protein supplement had reduced daily gains compared to pigs fed diets with 0 or 50% replacement of the SBM (Tables 8a, 9a, 10). The daily gains were significantly reduced (P>0.05) where pigs were fed diets containing 50% CM on an isonitrogenous basis with SBM (Tables 8a, 9a, 10). These diets actually contained 9.5 and 11.75% CM (Tables 3, 4, 5). The present studies are in agreement with Baidoo and Aherne (1987b) who reported growing pigs (20 to 60 kg) had no reduction in daily gains when fed diets containing up to 9% CM in barley-wheat-SBM based diets formulated to contain 0.75% lysine.

In experiments 1 and 2, the diets formulated to contain 0.84% total lysine supported nonsignificant (p>0.05) but improved daily gains compared to diets formulated to contain 0.74% total lysine. NRC (1979) recommended 0.79% and 0.70% total lysine for pigs 10 to 20 kg and 20 to 35 kg respectively. Henry (1984) suggested gilts from 18 to 43 kg had a lysine requirement of 0.85%. Thus, it appears the NRC (1979) recommendations may be underestimated and pigs weighing 15 to 30 kg have a higher lysine requirement than 0.74%. The use of more pigs and/or replications in experiments 1 and 2 would have helped give a more definite answer.

Table 8a Comparison of average daily gains for pigs (19-32 kg) fed diets supplemented with soybean meal and canola meal. Experiment 1

Main effect	level	n	mean (g)
Canola meal**	0	14	681.0
	50	14	679.0
	100	14	629.0
SEM*			20.8
Lysine content	0.74	21	638.0
	0.84	21	688.0
SEM*			16.4

* Standard error of the means

** Canola meal refers to the % of supplemental protein provided by canola meal in the diet. SBM provides the remainder.

Table 8b Comparison of feed consumption and feed efficiency for pigs (19-32 kg) fed diets supplemented with soybean meal and canola mal. Experiment 1

Diets*	1	2	3	4	5	6
Canola Supplementation % **	0	0	50	50	100	100
Total lysine (calculated %)	0.74	0.84	0.74	0.84	0.74	0.84
Daily feed intake (g)	1526 ±89.7[1]	1599 ±127.7	1277 ±70.7	1587 ±95.1	1427 ±94.3	1409 ±84.1
Feed:gain	2.34 ±0.09	2.25 ±0.24	2.02 ±0.06	2.18 ±0.04	2.24 ±0.23	2.25 ±0.09

[1]Standard error of the mean

* Diets contain the following sources of supplemental protein (% of total diet)

1. 13.5% SBM 0.0% CM
2. 17.2% SBM 0.0% CM
3. 6.8% SBM 9.50% CM
4. 8.75% SBM 11.75% CM
5. 0.00% SBM 18.00% CM
6. 0.00% SBM 24.00% CM

** See Table 8a.

Table 9a Comparison of average daily gains for pigs (14-32 kg) fed diets supplemented with soybean meal and canola meal. Experiment 2

Main effect	level	n	mean
Canola meal**	0	14	607.0^{a}
	50	14	591.0^{a}
	100	14	487.0^{b}
	SEM*		10.4
Lysine content	0.74	21	533.0
	0.84	21	590.0
	SEM*		8.8

* Standard error of the means

a, b Means in the same column with the same superscript do not differ (P<0.05)

** Canola meal refers to the % of supplemental protein provided by canola meal in the diet. SBM provides the remainder.

Table 9b Comparison of feed consumption and feed efficiency for pigs (14-32 kg) fed diets supplemented with soybean meal and canola meal. Experiment 2

Diets*	1	2	3	4	5	6
Canola Supplementation (%)	0	0	50	50	100	100
Total lysine (calculated %)	0.74	0.84	0.74	0.84	0.74	0.84
Daily feed intake (g)	1279[1]	1372	1320	1297	1070	1257
	±97.6[1]	±99.2	±74.2	±88.4	±50.9	±93.8
Feed:gain	2.16	2.20	2.27	2.14	2.48	2.28
	±0.20	±0.08	±0.06	±0.06	±0.14	±0.14

1 Standard deviation of the mean

* Diets contain the following sources of supplemental protein (% of total diet)

1. 13.5% SBM 0.0% CM
2. 17.2% SBM 0.0% CM
3. 6.8% SBM 9.50% CM
4. 8.75% SBM 11.75% CM
5. 0.00% SBM 18.00% CM
6. 0.00% SBM 24.00% CM

** See Table 9a.

Table 10 The performance of pigs (14-32 kg) fed diets supplemented with soybean meal and canola meal. Experiment 3

Diets*	1	2	3
Canola Supplementation (%) **	0	50	100
Total lysine (calculated %)	0.74	0.74	0.74
Daily feed intake (g)	1267±63.6	1415±76.7	1120±57.4
Daily gain (g)	531±31.6[1a]	624±50.5[a]	501±24.0[a]
Feed:gain	2.36±0.16	2.27±0.11	2.22±0.10

[1] Standard error of the mean

a,b Means in the same row with the same superscript do not differ ($P<0.05$) (for daily gain only)

* Diets contain the following sources of supplemental protein (% of total diet)

1. 13.5% SBM 0.0% CM
2. 6.8% SBM 9.5% CM
3. 0.0% SBM 18.0% CM

** Refers to the % of supplemental protein provided by canola meal in the diet. SBM provided the remainder.

Feed to gain ratios were similar for all diets used in each experiment (Tables 8a, 9b and 10). The feed efficiencies obtained in these studies are in good agreement with the recent literature where canola meal was used in starter diets (McKinnon and Bowland, 1977; McIntosh and Aherne, 1981; McIntosh et al., 1986; Baidoo and Aherne, 1987a, b).

Feed consumption tended to decrease as the level of CM increased in the diets utilized in experiments 1, 2 and 3 (Tables 8b, 9b, 10). Up to a 28% reduction in feed intake was noted when CM was used as the sole protein supplement compared to the wheat-SBM control diets used in these experiments. McIntosh and Aherne (1981) reported that pigs in the weight range of 8 to 24 kg had lower feed intake (24%) and daily gain (9%) when CM was used as a partial replacement (50%) for SBM and included at 15% in barley-wheat based diets. The reduction in feed intake in the present studies are similar to those reported by McIntosh and Aherne (1981). Thus, reduced feed intakes of the CM-based diets may have contributed to the decreased gains noted for pigs fed those diets compared to pigs fed the wheat-SBM based diets.

The studies cited in the literature review which compared CM and SBM starter diets formulated them on an isocaloric and isolysinic basis by adding fat and synthetic lysine to the CM based diets as required (McKinnon and Bowland, 1977; McIntosh and Aherne; Baidoo and Aherne, 1987a, b). Sauer et al. (1982) reported CM had lower amino acid availabilities than SBM and suggested diets using CM should be formulated on available rather than total lysine content. Such formulations may overcome some of the inherent effects, i.e. poorer performance, when diets with lower availabilities (digestibilities) are fed, especially for the young pig (Walker et al., 1987a, b).

The prestarter diets used in experiment 4 were formulated to contain similar available lysine supplies (Table 6) and have a total lysine supply similar to what the most recent studies report as necessary for optimum growth, that is approximately 1.10 to 1.15% total lysine for pigs 5 to 20 kg (Campbell, 1978; Lewis et al., 1981; Aherne and Nielsen, 1983).

The prestarter diets for pigs fed from 6 to 14 kg containing CM supported similar (P>0.05) daily gains as the wheat-SBM control diet (Table 11). There was a slight nonsignificant decrease in feed intake as the level of CM in these diets increased however daily gains were not significantly (P>0.05) different. McIntosh et al. (1986) reported a decrease in feed intakes and daily gains of 4g and 2g respectively for every 1% increase in the level of CM in the diet of young pigs fed from 6 to 20 kg. The study reported here does not support this conclusion but this experiment (4) used pigs fed from 6 to 14 kg and had an upper level of SBM replacement of 82% by CM and synthetic lysine, whereas McIntosh et al. (1986) compared pigs fed from 6 to 20 kg and had diets with complete replacement of SBM by CM and synthetic lysine. Thus, the prestarter test period in experiment 4 may not have been conducted

Table 11 The performance of pigs (6-14 kg) fed diets formulated to contain equivalent availalbe lysine supplies and supplemented with soybean meal and canola meal. Experiment 4 (prestarter)

Diets*	1	2	3	4
Daily feed intake (g)	806±41.2[1]	772±86.5	731±14.5	778±14.8
Daily gain (g)	427±29.4	379±31.8	390±27.6	394±27.6
Feed:gain	1.91±0.04	2.11±0.13	1.87±0.03	1.99±0.23

[1] Standard error of the mean.

* Diets contain the following sources of supplemental protein (% of total diet)

1. 25.9% SBM 0.0% CM 0.00 Lysine HCl
2. 17.4% SBM 12.6% CM 0.00% Lysine HCl
3. 8.0% SBM 13.0% CM 0.38% Lysine HCl
4. 0.0% SBM 14.0% CM 0.50% Lysine HCl

over a long enough period of time to detect significant differences.

McIntosh and Aherne (1981) reported that pigs in the weight range of 8 to 24 kg had lower feed intakes (25%) and daily gains (9%) when CM was used as a partial replacement (50%) for SBM and included at 15% in barley-wheat based diets. Total lysine content of these diets were 1.04% for the diet with 16% CM and 1.09% for the SBM control diet. Available lysine was not reported, thus their results may be a reflection of lower available lysine supplies in the CM diet. In the present study (experiment 4), it can be concluded that by taking into account available lysine and using a higher dietary lysine content (1.09 to 1.13%) in the diets, up to 14% CM with 0.5% lysine HCL can replace up to 82% of the SBM, on an isonitrogenous basis, without significantly reducing performance.

In the starter test period of experiment 4, pigs over the weight range of 14 to 32 kg fed the starter diets formulated to contain 0.85% total lysine supplemented with 8.75, 12.0 or 25.6% CM had reduced feed intakes (up to 26%) and significantly ($P<0.05$) poorer daily gains (up to 27%) compared to the wheat-SBM control diet (Table 12). These data are in contrast to that recorded in experiments 1 and 2 where CM replaced SBM at the 50% level (isonitrogenous basis) in diets formulated to contain 0.84% lysine. However the daily gains observed for the pigs fed the wheat-SBM diet in experiment 4 are considerably higher than those

Table 12 The performance of pigs (14-32 kg) fed diets supplemented with soybean meal and canola meal. Experiment 4 (starter)

Diets*	1	2	3	4
Daily feed intake (g)	1762±83.0[1]	1256±140.0	1420±65.5	1309±22.4
Daily gain (g)	799±55.1[a]	677±31.9[b]	676±27.5[b]	587±27.6[b]
Feed:gain	2.12±0.07	1.86±0.08	2.25±0.12	2.19±0.08

[1] Standard error of the mean.

[a, b] Means with the same superscript in the same row do not differ (P<0.05) (for daily gains only)

* Diets contain the following sources of supplemental protein (% of total diet)

1. 16.80 SBM 0.0% CM
2. 11.25 SBM 8.75 CM
3. 8.75 SBM 12.0% CM
4. 0.0% SBM 25.6% CM

observed in experiments 1 and 2 and thus the differences noted between the pigs fed the control diet and those fed diets containing CM have been due in part to the high performance of the pigs fed the wheat-SBM diet rather than poorer performance of pigs fed diets containing CM. It is to be noted that the gains recorded in experiments 1 and 2 are quite similar to those of pigs in experiment 4 when comparing pigs fed diets which contained CM as a partial (50%) replacement for SBM. In addition, the data of McKinnon and Bowland (1977) using diets containing 0.82% lysine and 50% replacement of SBM (isonitrogenous basis) showed no adverse effects on performance.

The overall results of experiment 4 (Tables 13, 14) indicated that pigs fed from 6 to 32 kg with diets supplemented with increasing levels of CM had reduced feed intakes and consequently, significantly ($P<0.05$) lower daily gains compared to pigs fed wheat-SBM diets. Pigs fed prestarter diet 2 followed by starter diet 2 had reduced feed intakes and daily gains of 18% and 14% respectively compared to pigs fed the control diets in each test period (i.e. wheat-SBM diets). Similarly, pigs fed the prestarter-starter diet 3 sequence had decreased feed intakes and daily gains of 17% and 13% respectively. Impaired performance was greatest where pigs fed the prestarter-starter diet 4 sequence had decreased feed intakes and daily gains of 21% and 20% respectively.

These data are a reflection of similar performance for all treatments in the prestarter phase and a poorer performance when CM was used in the starter diets. This resulted in a significant (P<0.05) treatment by period interaction observed in experiment 4 (Appendix Table 4) which indicated the pigs fed the SBM diet had improved (P<0.05) daily gains in the starter phase relative to pigs fed the CM diets. Such a result was not totally unexpected since a previous report had indicated that grower pigs, 20 to 45 kg, fed CM supplemented diets after initially being fed CM based diets from 5 to 20 kg had lower gains than pigs fed SBM supplemented diets in the starter and grower stage (McKinnon and Bowland, 1977).

NRC (1979) suggested expected daily gains and feed efficiencies of 500 g and 2.00 respectively for pigs 10 to 20 kg and 600 g and 2.50 respectively for pigs 20 to 35 kg. In the present studies, average daily gains and feed efficiencies for pigs 6 to 14 kg were 398 g (range 379 to 427) and 1.97 (1.87 to 2.11), whereas for pigs 14 to 32 kg the average daily gains and feed efficiencies for pigs 6 to 14 kg were 398 g (range 379 to 427) and 1.97 (1.87 to 2.11), whereas for pigs 14 to 32 kg the average daily gains and feed efficiencies were as follows:

Experiment 1:	663g (629-681)	2.21 (2.02-2.34)
Experiment 2:	562g (487-607)	2.26 (2.16-2.48)
Experiment 3:	552 (501-624)	2.28 (2.22-2.36)
Experiment 4 (starter)	685 (587-799)	2.11 (1.86-2.25)

Table 13 Comparison of overall average daily gains of pigs (6-32 kg) fed diets supplemented with soybean meal and canola meal. Experiment 4

Main effect	diet sequence**	n	mean	SEM+
A. Diet*	1	7	613.0[a]	20.9
	2	6	528.2[b]	22.5
	3	8	532.9[b]	19.5
	4	8	490.2[b]	19.5
B. Period	Prestarter	29	397.3[b]	14.6
	Starter	29	684.9[a]	14.6

+ Standard error of the means.

a,b Means in the same row with the same superscript do not differ ($P<0.05$)

* For sources of supplemental protein (% of total diet) see Tables 11 and 12.

**
1. prestarter 1 - starter 1
2. prestarter 2 - starter 2
3. prestarter 3 - starter 3
4. prestarter 4 - starter 4

Table 14 Comparisons of overall feed consumption and feed efficiency for pigs fed diets supplemented with soybean meal and canola meal. Experiment 4

Diets*	P1-S1	P2-S2	P3-S3	P4-S4
Daily feed intake (g)	1326±107.8[1]	1082±70.2	1105±78.1	1045±61.3
Feed:gain	2.02±0.04	2.04±0.04	1.99±0.07	2.04±0.05

+ Standard deviation of the mean

* Diets refer to the following combinations of diets from prestarter and starter feeding periods:

  P1-S1: prestarter 1 - starter 1
  P2-S2: prestarter 2 - starter 2
  P3-S3: prestarter 3 - starter 3
  P4-S4: prestarter 4 - starter 4

These values compare favorably with NRC (1979) values.

The postweaning lag cited in the literature (Owley et al., 1986a) was not observed for the very young pigs (6 to 14 kg) fed the prestarter diets in experiment 4. These pigs had access to a commercial dry prestarter diet for approximately a week before being placed on test, thus were accustomed to a typical dry, plant-protein diet by commencement of the test. Since all test diets contained semi-dwarf wheat as the basal energy source, the above high performance data indicated adequate nutritive quality of this relatively new energy supply source.

B. Digestibility Data

The digestibility studies conducted in experiment 3 indicated that as the level of CM increased in diets for pigs fed from 14 to 32 kg apparent dry matter and nitrogen digestibilities significantly ($P<0.05$) decreased in value (Table 15). The values obtained in this study were 84.5, 79.9 and 76.7% for dry mater digestibilities of each diet containing increased amounts of CM (0, 9.5 or 18.0% respectively) and 83.2, 80.7 and 77.8% for nitrogen digestibilities (Table 15). McKinnon and Bowland (1977) reported nitrogen digestibilities of 80.4, 77.6 and 75.8% for diets supplemented with 0, 11.9 or 25.3% CM fed to pigs approximately 16 kg in size. The values obtained in the present study (experiment 3) compare favourably with those of McKinnon and Bowland (1977). There was no noticeable trend toward increasing

Table 15 Comparison of apparent fecal digestibility coefficients of dry matter and nitrogen digestibilities in diets supplemented with soybean meal and canola meal. Experiment 3

Main effects	DM digestbilities level	n	mean	N digestibilities level	n	mean
A. Canola meal**	0	6	84.5[a]	0	6	83.2[a]
	50	6	79.9[b]	50	6	80.7[b]
	100	6	76.7[c]	100	6	77.8[c]
	SEM*		3.9	SEM*		2.63
	Day					
B. Time period	12	9	80.1	12	9	80.7
	26	9	80.6	26	9	80.4
	SEM*		0.60	SEM*		0.54

* Standard error of the mean

a,b,c Means in the same column with the same superscript do not differ ($P<0.05$)

** Canola meal refers to the % of supplemental protein provided by canola meal in the diet. SBM provides the remainder.

digestibilities over time (P>0.05). Dry matter digestibility increased by 0.5% (80.1 vs. 80.6%) whereas nitrogen digestibility decreased by 0.3% (80.7 vs. 80.4) between the day 12 and day 26 collection periods (Table 15).

The digestibility study conducted during the starter test period of experiment 4 indicated that th wheat-soybean control diet had significantly (P<0.05) higher apparent dry matter and nitrogen digestibility coefficients than did the diets containing 8.75, 12.0 or 25.6% CM (Table 16). The values obtained in this study were 85.0, 80.3, 79.4 and 79.1% for apparent dry matter digestibilities and 84.9, 81.0, 80.3 and 80.7% for apparent nitrogen digestibilities in order of increasing levels of CM. The differences among the CM-containing diets were not significant (P>0.05). Thus increasing the CM content of the diet did not always decrease digestibility coefficients. The apparent nitrogen digestibilities of the present study (experiment 4) are higher than those of McKinnon and Bowland (1977) and McIntosh et al. (1986) who reported dry matter digestibilities of 70.6 to 76.0% and nitrogen digestibilities of 67.4 to 73.4% for starter pigs fed diets containing up to 36% CM.

While there were reductions in digestibility of DM and N noted when comparing the CM-based diets to the SBM-based diets, there was not always a noticeable increase in digestibility as the level of CM in the diet decreased. Thus, it could be concluded that the reductions in daily gain noted for pigs fed diets

Table 16 Comparison of apparent fecal digestibility coefficients of dry matter (DM) and nitrogen (N) of diets supplemented with soybean meal and canola meal. Experiment 4 (starter)

Diets*	1	2	3	4	SEM[+]
Digestibilities (%)					
DM	85.0[a]	80.3[b]	79.4[b]	79.1[b]	0.76
N	84.9[a]	81.0[b]	80.3[b]	80.7[b]	0.91

[1] Standard error of the mean.

[a,b] Means with the same superscript in the same row do not differ (P<0.05)

* Diets contain the following sources of supplemental protein (% of total diet)

1. 16.80 SBM 0.0% CM
2. 11.25 SBM 8.75 CM
3. 8.75 SBM 12.0% CM
4. 0.0% SBM 25.6% CM

containing increasing levels of CM were not always due to the reduction in digestibility coefficients of DM and N.

Comparison of apparent fecal digestibilities (availabilities) for selected amino acids in experiment 3 indicated the diet containing CM as the sole protein source had significantly ($P<0.05$) lower digestibilities than either of the diets containing 0 or 50% CM as a replacement for SBM (Table 17). Lysine and threonine apparent digestibilities were the lowest among the selected amino acids. The apparent digestibilities were 75.1, 72.2 and 66.7% for lysine and 79.9, 77.6 and 73.8% for threonine for diets with increasing CM levels (Table 17). The dat from experiment 3 indicated that there were lower ($P<0.05$) amino acid digestibilities in the diet that contained CM as the sole protein source. This fact may help account for the reduced performance of pigs fed this diet compared to the other test groups.

Comparison of apparent fecal digestibilities for selected amino acids (Table 18) in starter diets fed to pigs 14 to 32 kg in experiment 4 indicated the wheat-SBM diets had the highest digestibility values, however the values were not always significantly ($P>0.05$) higher than the CM supplemented diets, neither was there a consistent trend toward decreasing digestibilities as the level of CM in the diets increased. As in experiment 3, the apparent digestibilities of lysine and threonine were the lowest among the selected amino acids. The apparent digestibilities for lysine were 78.7, 72.6, 72.3 and 71.6% for

Table 17 Comparison of apparent fecal amino acid digestibility coefficients for selected amino acids in diets supplemented with soybean meal and canola meal. Experiment 3

Main effects	level	n	Ile means	Lys means	Met + Cys means	Thr means	Val means
A.							
Canola Meal**	0	6	86.32[a]	75.06[a]	81.91[a]	79.94[a]	86.40[a]
	50	6	83.48[a]	72.21[a]	80.15[a]	77.97[a]	85.00[a]
	100	6	76.76[b]	66.68[b]	77.07[b]	73.78[b]	80.20[b]
	SEM*		10.34	9.56	2.94	6.43	6.08
B.	Day						
Time period	12	9	80.35[b]	69.76[a]	79.79[a]	75.89[a]	82.62[a]
	26	9	84.03[a]	72.87[a]	79.62[a]	78.30[a]	85.11[a]
	SEM*		8.64	6.31	1.95	4.82	5.54

* Standard error of the means

a,b Means in the same column with the same superscript do not differ ($P<0.05$)

** Canola meal refers to the % of the supplemental protein provided by canola meal in the diet, SBM provides the remainder.

Table 18 Comparison of apparent fecal amino acid digestibility coefficients for selected amino acids in diets supplemented with soybean meal and canola meal. Experiment 4 (starter)

Diets*	1	2	3	4	SEM+
Amino acids:					
Ile	87.97[a]	82.14[b]	76.51[c]	81.09[bc]	1.58
Lys	78.73[a]	72.59[b]	72.31[b]	71.55[b]	1.76
Met + Cys	82.30[a]	80.66[a]	81.64[a]	80.82[a]	0.71
Thr	81.31[a]	74.17[b]	76.34[ab]	75.07[b]	1.61
Val	86.66[a]	80.53[b]	79.93[b]	79.32[b]	1.49

+ Standard error of the means.

a,b,c Means in the same row with the same superscript do not differ ($P<0.05$)

* Diets contain the following sources of supplemental protein (% of total diet):

1. 16.80% SBM 0.0% CM
2. 11.25% SBM 8.75% CM
3. 8.75% SBM 12.0% CM
4. 0.0%% SBM 25.6% CM

lysine and 81.3, 74.2, 76.3 and 75.1% for threonine for diets with increasing CM levels (Table 18). McKinnon and Bowland (1977) reported apparent digestibilities of 80.3, 79.9 and 75.9% for lysine and 81.7, 81.1 and 77.6% for threonine in starter diets containing 0, 11.9 or 15.3% CM and approximately 0.82% lysine. The present studies which used diets containing 0, 9.5 or 18.0% CM and 0.74% lysine in experiment 3 and 0, 8.75, 12.0 and 25.6% CM and 0.85% lysine in experiment 4 had similar amino acid digestibilities to those reported by McKinnon and Bowland (1977).

The digestibility studies that compared diets for pigs from14 to 32 kg (experiments 3 and 4) indicated a trend toward lower digestibility coefficients as the level of CM in the diet increased, however the results were not always consistent. Similarly,McIntosh et al. (1986) reported that DM and N digestibility coefficients did not follow a consistent trend of reduced digestibility with an increase of CM in the diets and concluded that digestibility coefficients did not explain the poorer performance observed for pigs fed CM supplemented diets.

The apparent dry matter and nitrogen digestibilities of the prestarter diets fed to pigs 6 to 14 kg in experiment 4 indicated DM and N digestibilities were highest for the wheat-SBM diet however they were not always significantly (P>0.05) higher than the CM supplemented diets (Table 19). Apparent DM digestibilities were 80.3, 78.0, 75.6 and 75.8% for diets supplemented with 0, 12.6, 13 or 14% CM whereas N digestibilities were 81.3, 81.2, 77.9

and 78.3% respectively. The apparent DM and N digestibility coefficients of the prestarter diets (experiment 4) are higher than those reported by McIntosh et al. (1986) who reported DM digestibilities of 69.2 to 74.9% and N digestibilities of 63.4 to 70.1% for pigs fed from 7 to 15 kg.

Apparent amino acid digestibility coefficients for selected amino acids in the prestarter diets did not indicate a trend toward significantly ($P>0.05$) decreased digestibilities as the level of CM in the diets increased (Table 20). Combinations of CM and synthetic lysine were used to replace 0, 35, 69 and 82% of the SBM on an isonitrogenous basis. Such combination of CM and synthetic lysine were used so that all the diets contained similar available lysine supplies. As well, the higher availability of synthetic lysine would influence the digestibility coefficients and help explain why diet 4 had the highest lysine digestibility coefficient. Lysine and threonine had the lowest digestibilities. The values were 76.9, 76.3, 74.6 and 79.2% for lysine and 77.8, 77.7, 68.7 and 70.6% for threonine for each diet with increasing levels of CM (Table 20). It is interesting to note that the digestibility coefficients for threonine in diets3 and 4 decreased significantly ($P\leq0.05$) when compared to diets 1 and 2. In contrast with this the lysine digestibility coefficients were not significantly different between treatments. In the prestarter diets used, lysine would be considered the first limiting amino acid but formulating the diets based on available lysine resulted

Table 19 Comparison of apparent fecal digestibility coefficients of dry matter (DM) and nitrogen (N) in diets supplemented with soybean meal and canola meal. Experiment 4 (prestarter)

Diets*	1	2	3	4	SEM+
Digestibilities (%)					
DM	80.3[a]	78.0[ab]	75.6[b]	75.8[b]	0.68
N	81.3[a]	81.2[a]	77.9[a]	78.3[a]	1.00

\+ Standard error of the means.

a, b Means in the same row with the same superscript do not differ ($P<0.05$)

* Diets contain the following sources of suplemental protein (% of total diet):

1. 25.9% SBM 0.0% CM 0.00% Lysine HCl
2. 17.4% SBM 12.6% CM 0.00% Lysine HCl
3. 8.0% SBM 13.0% CM 0.38% Lysine HCl
4. 0.0% SBM 14.0% CM 0.50% Lysine HCl

Table 20 Comparison of apparent fecal digestibility coefficients for selected amino acids in diets supplemented with soybean meal and canola meal. Experiment (prestarter)

Diets*	1	2	3	4	SEM+
Amino acids:					
Ile	79.23	79.38	71.46	79.43	19.44
Lys	76.93	76.30	74.60	79.17	5.17
Met + Cys	80.85	80.57	77.73	77.81	1.25
Thr	77.83[a]	77.67[a]	68.66[b]	70.58[b]	6.06
Val	81.11	81.64	72.76	76.65	14.01

+ Standard error of the means.

* Diets contain the following sources of suplemental protein (% of total diet):

1. 25.9% SBM	0.0% CM	0.00% Lysine HCl
2. 17.4% SBM	12.6% CM	0.00% Lysine HCl
3. 8.0% SBM	13.0% CM	0.38% Lysine HCl
4. 4.0% SBM	14.0% CM	0.50% Lysine HCl

in no significant differences in performance or lysine digestibility coefficients. This supports the concept of Sauer et al. (1982) that amino acid availability be given consideration in diet formulation.

The results of McIntosh et al. (1986) showed a trend toward increased DM and N digestibilities with increasing size of the pig. Comparing DM and N digestibilities in the prestarter and starter diets (experiment 4) indicated increased DM (81.0 vs. 77.4%) and N (81.7 vs. 79.7%) digestibilities in the starter versus prestarter diets which lends support to the results of McIntosh et al. (1986). In addition, in experiment 4, the amino acid digestibilities are higher for the starter than the prestarter diet lending support to the DM and N digestibility data.

More research data are required on amino acid digestibilities for the newly weaned pig as it adapts to a new type of diet. Studies on the replacement of standard protein sources by new (other) sources and synthetic amino acids should have a high priority.

SUMMARY

The experiments of the present study indicate that 100% replacement of SBM by CM on an isonitrogenous isocaloric basis in diets of pigs fed from 14 to 32 kg caused a reduction in feed intake and consequently reduced daily gains. Partial replacement by CM (50% on an isonitrogenous basis) in diets for pigs 14 to 32 kg did not cause significant reductions in performance in 3 out of 4 studies. CM was included at up to 12% in these diets, therefore the 12% inclusion rate of CM in starter diets for pigs 14 to 32 kg could be considered as the optimum replacement level.

Diets formulated to contain similar available lysine supplies for young pigs fed from 6 to 14 kg resulted in similar performance among all diets. The total lysine levels used in these diets ranged from 1.09 to 1.13% which are similar to those currently recommended in the literature (Campbell, 1978; Aherne and Nielsen, 1983). By formulating diets based on available rather than total lysine, up to 82% of the SBM supplement may be replaced on an isonitrogenous basis by including up to 14% CM and 0.5% lysine HCl in the diets of pigs fed from 6 to 14 kg.

Significant differences were observed for DM, N and amino acid digestibility coefficients. However, there was not a consistent trend to lower digestibility with increasing levels of CM even though it appeared that complete replacement by CM caused

a significant reduction in digestibility compared to the wheat-SBM control diets.

Feed efficiencies were similar for all diets used in each experiment, with one minor exception. Since all diets were formulated on an isocaloric basis this was to be expected. Thus it appears digestibility coefficients and feed to gain ratios do not help explain the poorer performance of pigs fed diets supplemented with CM. The same conclusion was suggested by McIntosh et al. (1986). Lower digestibilities of the CM-supplemented diets may be related to the higher fiber levels of the CM-supplemented diets (Tables 3 to 7).

The reduced feed intakes observed for the CM supplemented diets caused reduced growth rates and may be related to the higher fiber levels in the CM supplemented diets (Castell, 1977; McKinnon and Bowland, 1977), hydrolitic products of glucosinolates (Ochetim et al., 1980; Bell, 1984) and/or lower palatability of the CM diets (Chubb, 1982; McIntosh et al., 1986).

The CM based diets used in these experiments had higher fiber levels than those of the wheat-SBM diets. Since all diets were formulated to be isocaloric the situation where higher dietary fiber results in increased feed intake was not observed as pigs eat enough feed to meet their energy requirements (Pond and Maner 1984). It is possible that the hydrolitic products of glucosinolates caused the CM-based diets to have lower palatabilities therefore the pigs consumed less of these diets and the reduced feed intakes caused the decreased daily gains noted in these experiments.

CONCLUSIONS

1. Partial replacement of SBM by CM at 50% on an isonitrogenous basis, did not significantly (P>0.05) reduce daily gains of pigs fed from 14 to 32 kg. These data suggest that CM could be included at up to 12% in starter diets.
2. Starter diets with complete replacement of SBM by CM caused significantly (P<0.05) reduced feed intakes and daily gains for pigs fed from 14 to 32 kg when their performance was compared to pigs fed a wheat-SBM control diet.
3. Pigs fed from 14 to 32 kg with diets formulated to contain 0.84% total lysine had higher daily gains than those fed diets formulated to 0.74% total lysine which indicated the current NRC (1979) recommended lysine level (0.70%) for pigs 20 to 35 kg may be underestimated.
4. Isocaloric prestarter diets formulated with a consideration for equivalent available lysine, resulted in nonsignificant (P>0.05) reductions in daily gains for pigs 6 to 14 kg. Thus, it appeared that up to 82% of the SBM could be replaced, on an isonitrogenous basis, by up to 14% CM and 0.5% synthetic lysine in the prestarter diets.

5. Differences (P>0.05) were detected among the apparent fecal digestibility coefficients for dry matter, nitrogen and selected amino acids, however a consistent trend was not always observed. Therefore decreased digestibility coefficients in the CM supplemented diets did not account for the reduced pig performance noticed as the level of CM in the diets increased.
6. Digestibility coefficients for DM, N and amino acids were higher for heavier pigs (14-32 kg) than lighter pigs (6-14 kg).

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APPENDICES

Appendix Table 1 Analysis of variance of average daily gain Experiment 1

Source	df	Mean square	F-value	PR>F	Sig
canola (C)	2	0.012212	0.59	0.5613	NS
lysine (L)	1	0.0264	1.27	0.2674	NS
C x L	2	0.009406	0.45	0.6399	NS
error	36	0.020806			

Appendix Table 2 Analysis of variance of average daily gain Experiment 2

Source	df	Mean square	F-value	PR>F	Sig
canola (C)	2	0.059672	5.73	0.0069	*
lysine (L)	1	0.034172	3.28	0.0785	NS
C x L	2	0.008136	0.78	0.4656	NS
error	36	0.01042			

* $P<0.05$

Appendix Table 3 Analysis of variance of average daily gain Experiment 3

Source	df	Mean square	F-value	PR>F	Sig
canola (C)	2	0.032874	2.99	0.0722	NS
error	21	0.01006			
corrected total	23	0.296866			

Appendix Table 4 Analysis of variance of average daily gain Experiment 4

Source	df	Mean square	F-value	PR>F	Sig
trt	3	0.038996	3.91	0.0203	*
indiv (trt)	25	0.009968	1.16	0.1125	NS
period	1	1.183314	194.29	0.0001	**
trt x period	3	0.02053	3.37	0.0342	*
error	25	0.00609			

* P<0.05
** P<0.001

Appendix Table 5 Analysis of variance for apparent fecal dry matter and nitrogen digestibility coefficients. Experiment 3

		DM digestibility			N digestibility		
Source	df	MS	PR>F	Sig	MS	PR>F	Sig
canola (c)	2	91.933	0.0001	*	43.309	0.0004	*
time (t)	2	1.037	0.5794	NS	0.299	0.7416	NS
C x t	2	8.892	0.1016	NS	9.787	0.0551	NS
error	12	3.194			2.6261		

*P<0.001

Table 6 Analysis of variance for apparent fecal amino acid digestibility coefficients for selected amino acids. Experiment 3

		Ile			Lys			Met & Cys			Thr			Val		
Source	df	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig
canola (C)	2	144.699	0.0007	**	135.926	0.0017	*	35.963	0.0013	*	57.845	0.0041	*	63.506	0.0024	*
time (t)	1	60.855	0.0320	**	43.666	0.0538	NS	0.132	0.8359	NS	26.174	0.0665	NS	27.907	0.0533	NS
C x t	2	53.494	0.0240	**	45.821	0.0295	**	20.789	0.0094	*	20.0801	0.0808	NS	21.413	0.0626	NS
error	12	10.342			9.556			2.942			6.4261			6.078		

* P<0.01
** P<0.05

Appendix Table 7 Analysis of variance for apparent fecal dry matter and nitrogen digestibility coefficients. Experiment 4 (prestarter)

		DM digestibility			N digestibility		
Source	df	MS	PR>F	Sig	MS	PR>F	Sig
canola	3	9.632	0.0232	*	7.023	0.1287	NS
error	4	0.924			2.006		

* P<0.05

Table 8 Analysis of variance for apparent fecal amino acid digestibility coefficients for selected amino acids. Experiment 4 (prestarter)

		Ile			Lys			Met & Cys			Thr			Val		
Source	df	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig
canola	3	31.082	0.3228	NS	7.151	0.3691	NS	5.820	0.0855	NS	45.278	0.0407	*	11.574	2.48	NS
error	4	19.444			5.169			1.248	6.056			14.009				

* P<0.05

Appendix Table 9 Analysis of variance for apparent fecal dry matter and nitrogen digestibility coefficients. Experiment 4 (starter)

		DM digestibility			N digestibility		
Source	df	MS	PR>F	Sig	MS	PR>F	Sig
canola (C)	3	19.776	0.0024	**	11.044	0.0064	*
time (T)	1	0.018	0.9140	NS	0.04	0.8555	NS
C x T	2	2.806	0.2062	NS	1.294	0.3657	NS
error	7	1.406			1.111		

* P<0.01
** P<0.005

Table 10 Analysis of variance for apparent fecal amino acid digestibility coefficients for selected amino acids. Experiment 4 (starter)

		Iile			Lys			Met & Cys			Thr			Val		
Source	df	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig	MS	PR>F	Sig
canola (C)	3	51.666	0.0059	**	30.549	0.0374	*	1.794	0.2351	NS	23.331	0.0464	*	35.408	0.0116	*
time (t)	1	57.696	0.0116	*	4.117	0.4406	NS	2.701	0.1439	NS	14.906	0.1338	NS	34.442	0.0270	*
C x t	2	28.163	0.0352	*	10.524	0.2488	NS	3.932	0.0714	NS	14.428	0.1291	NS	10.108	0.1726	NS
Error	7	5.022			6.162			0.998			5.187			4.430		

* P<0.05
** P<0.01

Appendix Table 11 Amino acid composition of diets, as-fed basis. Experiment 1

Diets	1	2	3	4	5	6
Amino acids:						
Indispensable						
Arginine	1.19	1.16	1.05	1.12	0.96	1.10
Histidine	0.46	0.46	0.44	0.47	0.42	0.47
Isoleucine	0.62	0.55	0.53	0.52	0.44	0.52
Leucine	1.30	1.29	1.23	1.26	1.11	1.23
Lysine	0.72	0.79	0.68	0.74	0.64	0.75
Methionine + cystine	0.68	0.72	0.69	0.72	0.77	0.77
Phenylaline	1.02	1.07	0.94	1.02	0.89	0.93
Threonine	0.66	0.68	0.65	0.68	0.63	0.71
Valine	0.79	0.74	0.72	0.73	0.68	0.75
Dispensable						
Alanine	0.78	0.83	0.76	0.82	0.75	0.84
Aspartic acid	1.43	1.56	1.33	1.43	1.14	1.28
Glutamic acid	5.87	5.76	5.64	5.74	5.28	5.35
Glycine	5.78	0.94	0.90	0.96	0.90	0.98
Proline	1.09	1.14	1.05	1.10	0.98	1.03
Serine	1.09	1.14	1.05	1.10	0.98	1.03
Tyrosine	0.55	0.58	0.52	0.57	0.50	0.53

Appendix Table 12 Amino acid composition of diets, as-fed basis. Experiment 2

Diets	1	2	3	4	5	6
Amino acids:						
Indispensable						
Arginine	1.10	1.20	1.06	1.16	0.99	1.10
Histidine	0.44	0.48	0.43	0.47	0.44	0.46
Isoleucine	0.50	0.53	0.52	0.58	0.52	0.54
Leucine	1.22	1.31	1.17	1.28	1.16	1.21
Lysine	0.70	0.80	0.65	0.75	0.65	0.73
Methionine + cystine	0.70	0.73	0.69	0.72	0.74	0.79
Phenylaline	1.01	1.10	0.91	1.01	0.89	0.92
Threonine	0.63	0.67	0.63	0.69	0.64	0.71
Valine	0.70	0.71	0.71	0.77	0.75	0.74
Dispensable						
Alanine	0.77	0.83	0.74	0.80	0.76	0.80
Aspartic acid	1.44	5.82	5.45	5.67	5.22	5.37
Glutamic acid	5.78	5.82	5.45	5.67	5.22	5.37
Glycine	0.89	0.93	0.88	0.94	0.91	0.96
Proline	1.86	2.00	1.67	1.83	1.67	1.87
Serine	1.08	1.16	1.00	1.06	0.94	1.02
Tyrosine	0.54	0.59	0.51	0.54	0.49	0.51

Appendix Table 13 Amino acid composition of diets, as-fed basis. Experiment 3

Diets	1	2	3
Amino acids:			
Indispensable			
Arginine	1.08	1.09	1.00
Histidine	0.45	0.45	0.43
Isoleucine	0.61	0.59	0.49
Leucine	1.26	1.24	1.15
Lysine	0.71	0.71	0.66
Methionine + cystine	0.69	0.67	0.65
Phenylaline	0.99	0.95	0.89
Threonine	0.63	0.65	0.64
Valine	0.76	0.81	0.72
Dispensable			
Alanine	0.75	0.78	0.76
Aspartic acid	1.38	1.30	1.15
Glutamic acid	5.73	5.58	5.27
Glycine	0.86	0.89	0.90
Proline	1.85	1.92	1.86
Serine	1.05	1.03	0.96
Tyrosine	0.52	0.52	0.49

Appendix Table 14 Amino acid composition of diets, as-fed basis. Experiment 4 (prestarter)

Diets	1	2	3	4
Amino acids:				
Indispensable				
Arginine	1.44	1.38	1.12	1.08
Histidine	0.54	0.54	0.45	0.44
Isoleucine	0.70	0.62	0.53	0.62
Leucine	1.48	1.46	1.20	1.29
Lysine	1.02	1.02	1.13	1.18
Methionine + cystine	0.70	0.75	0.70	0.68
Phenylaline	1.13	1.16	0.94	1.08
Threonine	0.78	0.80	0.65	0.63
Valine	0.89	0.83	0.67	0.68
Dispensable				
Alanine	0.92	0.95	0.81	0.80
Aspartic acid	1.89	1.89	1.39	1.26
Glutamic acid	5.85	5.89	5.22	5.12
Glycine	0.98	1.05	0.91	0.89
Proline	2.06	2.02	1.73	1.80
Serine	1.22	1.24	1.00	0.98
Tyrosine	0.63	0.64	0.50	0.65

Appendix Table 15 Amino acid composition of diets, as-fed basis. Experiment 4 (starter)

Diets	1	2	3	4
Amino acids:				
Indispensable				
Arginine	1.24	1.34	1.20	1.14
Histidine	0.47	0.56	0.54	0.46
Isoleucine	0.72	0.71	0.73	0.62
Leucine	1.39	1.35	1.39	1.29
Lysine	0.82	0.84	0.85	0.81
Methionine + cystine	0.65	0.72	0.74	0.80
Phenylaline	1.05	1.14	1.12	0.94
Threonine	0.67	0.69	0.75	0.69
Valine	0.81	0.81	0.86	0.73
Dispensable				
Alanine	0.91	0.87	0.92	0.85
Aspartic acid	1.58	1.52	1.66	1.28
Glutamic acid	5.37	5.61	5.85	5.15
Glycine	0.92	0.96	1.02	0.97
Proline	1.91	1.68	1.90	1.93
Serine	1.04	1.05	1.14	0.99
Tyrosine	0.59	0.61	0.62	0.53

Appendix Table 16 Apparent fecal amino acid digestibility coefficients of diets supplemented with soybean meal and canola meal. Experiment 3

Diets	1		2		3	
Collection day	12	26	12	26	12	26
Amino acids:						
Indispensable						
Arginine	89.18	87.84	86.36	87.72	82.33	85.14
Histidine	89.86	88.23	86.77	88.38	83.57	86.88
Isoleucine	86.05	86.58	83.52	83.46	71.47	82.04
Leucine	87.12	86.08	83.88	85.63	78.72	83.56
Lysine	76.61	73.51	69.72	74.70	62.94	70.42
Methionine + cystine	83.83	79.98	78.39	81.90	76.64	77.49
Phenylaline	88.67	84.32	85.34	87.41	80.50	84.90
Threonine	80.66	79.21	76.14	79.00	70.87	76.70
Valine	86.05	86.74	85.03	84.98	76.78	83.61
Dispensable						
Alanine	77.09	73.55	71.10	75.74	67.25	71.19
Aspartic acid	81.32	77.22	73.47	78.17	67.83	72.08
Glutamic acid	94.65	93.64	92.90	93.67	91.00	92.64
Glycine	84.57	82.18	80.06	82.65	76.76	79.71
Proline	93.94	92.50	90.80	92.70	88.36	89.38
Serine	87.71	85.45	83.14	85.73	79.35	82.27
Tyrosine	83.47	81.96	78.89	82.93	73.60	78.12

Appendix Table 17 Apparent fecal amino acid digestibility coefficients of diets supplemented with soybean meal and canola meal. Experiment 4 (prestarter)

Diets	1	2	3	4
Amino acids:				
Indispensable				
Arginine	87.84	86.78	81.97	83.68
Histidine	87.52	86.90	82.31	83.58
Isoleucine	79.23	79.38	71.46	79.43
Leucine	82.91	82.97	76.72	81.32
Lysine	76.93	76.30	74.60	79.17
Methionine + cystine	80.85	80.57	77.73	77.81
Phenylaline	81.61	82.60	73.59	84.77
Threonine	77.83	77.67	68.66	70.58
Valine	81.12	81.64	72.78	76.65
Dispensable				
Alanine	73.79	73.98	64.17	68.78
Aspartic acid	80.41	79.68	68.37	70.08
Glutamic acid	92.13	92.01	89.92	91.28
Glycine	80.24	80.73	75.70	76.70
Proline	92.10	91.21	89.02	89.55
Serine	85.20	83.97	78.47	79.71
Tyrosine	81.08	80.08	72.69	80.30

Appendix Table 18 Apparent fecal amino acid digestibility coefficients of diets supplemented with soybean meal and canola meal. Experiment 4 (starter)

Diets	1		2		3		4	
Collection day	14	21	14	21	14	21	14	21
Amino acids:								
Indispensable								
Arginine	90.43	--*	87.17	89.95	86.03	84.91	85.45	84.93
Histidine	89.86	--	87.65	90.49	89.24	84.16	85.33	85.49
Isoleucine	87.97	--	82.14	88.24	76.51	85.14	81.09	79.53
Leucine	87.89	--	82.95	86.52	82.51	83.20	83.22	81.51
Lysine	78.73	--	72.59	76.97	72.31	70.21	71.55	72.78
Methionine + cystine	82.30	--	80.66	79.99	81.64	78.58	80.82	81.70
Phenylaline	90.24	--	86.12	88.46	85.49	81.07	83.27	82.10
Threonine	81.31	--	74.17	80.75	76.34	76.86	75.07	74.66
Valine	86.66	--	80.53	87.34	79.93	82.75	79.32	79.86
Dispensable								
Alanine	79.77	--	71.41	77.70	72.17	74.68	73.26	71.82
Aspartic acid	83.71	--	75.15	80.69	76.16	78.83	73.53	70.91
Glutamic acid	94.32	--	92.04	93.30	92.26	92.00	91.92	91.38
Glycine	84.79	--	79.64	83.75	80.96	80.67	80.84	79.42
Proline	93.09	--	90.15	91.56	90.56	91.65	93.33	89.04
Serine	87.79	--	82.14	83.18	84.12	83.37	83.76	80.35
Tyrosine	87.06	--	83.58	80.24	79.55	82.30	80.17	75.67

* Fecal samples were extremely low in Cr_2O_3 for some unknown reason therefore values have been omitted

Appendix Table 19 Apparent fecal digestibility coefficients of dry matter (DM) and nitrogen (N) in diets Experiment 4 (starter)

Diets	1	2	3	4
Day 14 (DM)	84.96	80.33	79.43	79.13
Day 14 (N)	84.85	81.02	80.31	80.66
Day 21 (DM)	---*	81.93	78.10	79.75
Day 21 (N)	---	82.10	79.13	80.42

* Fecal samples were extremely low in Cr_2O_3 for some unknown reason therefore values have been omitted