Comparative Efficacy of Plant and Animal Protein Sources on the Growth Performance, Nutrient Digestibility, Morphology and Caecal Microbiology of Early-weaned Pigs

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ABSTRACT : The present study was conducted to evaluate and compare the effects of various animal and plant protein sources on piglet's performance, digestibility of amino acids and gut morphology in weaned pigs until 28 days after weaning. The plant protein sources used were soybean meal (SBM), fermented soy protein (FSP), rice protein concentrate (RPC); and animal protein sources tested were, whey protein concentrate (WPC) and fishmeal (FM). Iso-proteinous (21%) diets were formulated and lysine (1.55%) content was similar in all the diets. The level of each protein source added was 6% by replacing SBM to the same extent from the control diet containing 15% SBM. The ADG was higher ($p<0.05$) in the groups fed animal proteins as compared with plant proteins at all the levels of measurement, except during 15-28 days. The highest ADG was noted in WPC and FM fed diets and lowest in SBM fed diet. The feed intake was higher in animal protein fed groups than plant proteins at all phases, but the feed:gain ratio was not affected by protein sources except during overall (0 to 14 day) measurement which was improved ($p<0.05$) in animal protein fed diets compared to plant protein sources. The digestibilities of gross energy, dry matter and crude protein were higher in animal protein fed groups than for plant protein fed sources. The apparent ileal digestibilities of essential amino acids like Leu, Thr, and Met were significantly ($p<0.05$) higher in animal proteins fed animals as compared with plant protein fed animals. But the apparent fecal digestibilities of essential amino acids like Arg and Ile were significantly higher ($p<0.05$) in plant protein diets than animal protein sources. The villous structure studied by scanning electron microscope were prominent, straight finger-like, although shortened and densely located in FM fed group as compared with others. The lactic acid bacteria and *C. perfringens* counts were higher in caecal contents of pigs fed plant proteins than the animal proteins. Overall, it could be concluded that animal protein sources in the present study showed better effects on growth performance, nutrient digestibility and gut morphology than plant protein sources. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 9 : 1285-1293)***

Key Words : Plant, Animal, Pigs, Soybean Meal, Fishmeal, Whey Protein Concentrate

INTRODUCTION

The availability, cost and the risk factors associated with diseases from animal protein sources make the nutritionist to think on alternative plant protein sources in weaned pigs diet. Plant protein sources are generally cheaper per unit of nutrient as compared with the animal protein sources. In general, plant protein supplements are lower in some essential amino acids, energy and minerals such as phosphorus as compared with animal protein supplements. The cost of animal protein sources is generally higher than that of plant protein sources, but the inclusion rates for animal protein sources are lower.

Special diets and management schemes have been developed to overcome nutritional problems associated with weaning. Though soybean meal is a widely used protein source, but piglet's sensitivity to antigenic activity of SBM due to anti-nutritional factors causes reduced growth and digestive disorders (Lalles, 1993). Refined soy proteins sources like FSP, a specially designed protein source prepared by fermentation and enzymatic degradation of dehulled soybean meal has been reported to have a promising future in the diets of weaning piglets (Genebiotech, Korea, company brochure). The fermentation was carried out by using *Bacillus subtilis*. Rice protein concentrate (RPC) which contains 75% crude protein and 4,381 kcal/kg ME for pigs is somewhat cheaper than soy-protein concentrate (SPC) and can replace SPC up to 9% in piglets prestarter diet (Yun et al., 2005).

Diets containing milk proteins were developed because non-milk proteins caused digestive disorders (Cline, 1991). Attempts have been made to replace milk products with alternative protein sources due to their inconsistent availability and high cost for piglet production.

Fishmeal (FM) is widely used in the diets of young pigs as a relatively inexpensive source of readily digestible, high quality protein. The amino acid profile of the proteins in fishmeal is very close to that of the proteins in the sow's milk and of piglet body tissue (Fowler, 1997). Fishmeal is traditionally recognized as a very digestible protein with a high content of amino acids, vitamins and minerals (Kim and Easter, 2001).

There is a dearth of information with respect to the

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Table 1. Formula and chemical composition of experimental diets for feeding trials (0 to 2 wk)

Treatments	SBM	FSP	RPC	WPC	FM
Ingredients (%)					
Corn-grain	28.88	29.79	29.92	30.82	31.01
Whey powder	20.00	20.00	20.00	20.00	20.00
FSP	-	6.00	-	-	-
RPC	-	-	6.00	-	-
WPC	-	-	-	6.00	-
FM	-	-	-	-	6.00
SBM (dehulled)	15.00	9.00	9.00	9.00	9.00
SDPP	6.00	6.00	6.00	6.00	6.00
Lactose	15.00	15.00	15.00	12.24	15.00
SPC	4.99	4.00	4.00	6.00	4.00
Biscuit byproduct	4.00	4.00	4.00	4.00	4.00
Animal fat	2.00	2.00	2.00	2.00	2.00
Limestone	1.30	1.39	1.36	1.27	0.81
MCP	0.57	0.53	0.56	0.48	0.46
ZnO	0.25	0.25	0.25	0.25	0.25
Vitamin premix[1]	0.30	0.30	0.30	0.30	0.30
Trace mineral premix[2]	0.20	0.20	0.20	0.20	0.20
Salt	0.20	0.20	0.20	0.20	0.20
Acidifier	0.20	0.20	0.20	0.20	0.20
Apramycin	0.15	0.15	0.15	0.15	0.15
L-lysine (78%)	0.31	0.33	0.39	0.17	0.28
DL-methionine (50%)	0.35	0.36	0.17	0.42	0.30
Choline chloride (25%)	0.10	0.10	0.10	0.10	0.10
Sulfathiazol	0.10	0.10	0.10	0.10	0.10
Mecadox-200	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Calculated composition					
ME (kcal/kg)	3,365	3,357	3,419	3,367	3,358
CP	21.00	21.06	21.83	21.00	21.19
Ca	0.80	0.82	0.82	0.80	0.82
Av-P	0.40	0.40	0.40	0.40	0.40
Lys	1.55	1.55	1.55	1.55	1.55
Met+Cys	0.85	0.85	0.85	0.86	0.85

[1] Supplied per kg diet: 9,600 IU vitamin A, 1,800 IU vitamin D_3, 24 mg vitamin E, 1.5 mg vitamin B_1, 12 mg vitamin B_2, 2.4 mg vitamin B6, 0.045 mg vitamin B_{12}, 1.5 mg vitamin K_3, 24 mg Pantothenic acid, 45 mg niacin, 0.09 mg biotin, 0.75 mg folic acid, 18 mg ethoxyquin.

[2] Supplied per kg diet: 162 mg Fe, 96 mg Cu, 72 mg Zn, 46.49 mg Mn, 0.9 mg I, 0.9 mg Co, 0.3 mg Se.

comparison of animal and protein sources in weaned pigs diet and its effect on intestinal morphology and nutrient digestibility. Hence, the present study was conducted to evaluate and compare the effects of various animal and plant protein sources on piglets performance, digestibility of amino acids and gut morphology in the weaned pigs fed until 14 days after weaning, and whether they further affect the growth performance fed a common diet for next 14 days.

MATERIALS AND METHODS

Two hundred seventy weaned pigs of 17±3 days of age (Landrace×Yorkshire×Duroc) were allotted to five treatments with 3 replicates in each, comprising 18 pigs of the same ancestry but mixed sex (male: female ratio same) in each replicate. The average body weight when weaned was 5.83±0.92 kg. The pigs were housed in partially slotted and concrete floor pens with a pen size of 3×2 m, with a self-feeder and nipple waterer to allow *ad libitum* access to feed and water. The main objective of the study was to compare the plant and animal protein sources in weaned pigs diet. Hence the plant protein sources used were soybean meal (SBM), fermented soy proteins (FSP), rice protein concentrate (RPC), and animal protein sources used were whey protein concentrate (WPC) and fishmeal (FM). Iso-proteinous (21% CP) diets were formulated and lysine content (1.55%) was similar in all the diets.

The level of each protein source added was 6% of diet by replacing SBM to the same extent from the control diet containing 15% SBM. In case of WPC, the substitution was 6% WPC and 2% soy-protein concentrate for part of SBM and lactose. So it could be considered as if, one vegetal and one animal source were evaluated especially for this group, since crude protein content in WPC is low. All the diets

Table 2. Crude protein and essential amino acid profiles of protein sources (as-fed basis)[1]

Protein sources	SBM	FSP	RPC	WPC	FM
Crude protein (%)	47.7	53.5	67.0	35.0	70.0
Essential amino acid[2] (%)					
Arginine	3.46	3.80	5.55	0.80	4.40
Histidine	1.18	1.62	1.75	0.70	1.43
Isoleucine	2.36	2.36	2.82	2.00	2.76
Leucine	3.46	4.17	5.92	3.60	5.06
Lysine	2.91	3.09	2.50	2.37	5.25
Phenylalanine	2.46	2.58	3.84	1.10	2.67
Threonine	1.81	2.07	2.64	2.27	2.83
Valine	2.46	2.37	3.66	2.00	3.48
Methionine	0.66	0.64	2.31	0.47	1.76
Total	20.76	22.7	30.99	15.31	29.64
TEAA[3]/CP	0.44	0.43	0.46	0.44	0.42

[1] SBM: Soybean meal; FSP: Fermented soybean protein; RPC: Rice protein concentrate; WPC: Whey protein concentrate; FM: Fishmeal.
[2] Tryptophan was not determined.
[3] Total essential amino acid.

meet or exceed the nutrient requirements as suggested by NRC (1998). These diets were fed for only 14 days (Phase I) in mash form, and then each group was fed the common commercial diet as crumbs during phase II (15-28 d). The composition of the starter diet (Phase-I, for 2 weeks) is presented in Table 1. The experiment was conducted for 4 weeks during which the body weights and feed intake were noted after each week of experimental feeding during phase I, and at the end of phase II.

In order to study the effect of different protein sources on nutrient digestibility, a digestibility trial was conducted using chromic oxide (0.25%) as an indicator. The pigs were fed diets mixed with chromic oxide on day 7 and fecal samples were collected from day 11 to 14 during Phase I and pooled. The fecal samples were dried in a forced-air drying oven at 60°C for 72 h and ground with a 1mm mesh Wiley mill for chemical analysis. The apparent fecal amino acid digestibilities were also studied in the collected samples. Proximate analyses of the experimental diets were carried out following the AOAC (1990) methods. Gross energy and chromium were measured by a bomb calorimeter (Model 1261, Parr Instrument Co., Molin, IL) and an automated spectrophotometer (Shimadzu, Japan), respectively. Following acid hydrolysis in 6 N HCL at 105°C for 24 h, amino acid concentrations were analyzed by using a HPLC (Waters 486, USA). Sulfur containing amino acids was analyzed after cold performic acid oxidation (Moore, 1963) overnight with subsequent hydrolysis.

To study the effect of diets on apparent ileal amino acid digestibilities, gut morphology, villi height and caecal micro-biota, representative pigs from each group (2 per replicate) reflecting average body weights were selected and killed by electrocution at 14 days of age. Immediately after slaughter the small intestine was excised. The ileal contents (chyme) were collected in sterilized plastic bottle in icebox and then brought to laboratory and frozen-dried until analysis for apparent ileal amino acid digestibility. The small intestine was then immersed in 10% buffered formaline and then brought to laboratory for further studies. The caecal contents were also collected and used for the microbiological assay by the procedure suggested by Torrallardona et al. (2003).

The small intestinal segment was rinsed with 0.4 M KCL and then cut in 2 mm^2 small segments and submerged in a fixative solution (0.1 M collidine buffer, pH 7.3) containing 3% glutaraldehyde, 2% paraformaldehyde and 1.5% acrolein. Cross-sectional small intestine samples from the formalin preserved segments were fixed by standard paraffin embedding. Samples were sectioned at 6 µm and stained with azur A and eosine. Villous height and crypt depth were measured on the stained sections under microscope at 40× magnification equipped with an ocular micrometer. A minimum of 10 well-oriented intact villi was measured in duplicate specimens for each pig. Villous height was measured from the crypt base to the villous tip and all measurements (villous height and crypt depth) were made in 10-micrometer increments as mentioned by Cera et al. (1988).

Scanning electron microscopy was performed on the 2 mm^2 specimens. Samples were dehydrated in an ethanol-freon series as described by Liepens and DeHaven (1978). Following platinum coating, specimens were viewed with an ISI scanning electron microscope (International Scientific Instruments, Inc. Milpitas, CA) and were photographed.

Data collected was subjected to statistical analysis using contrast procedure of SAS (1985) by using statistical software package using completely randomized design to compare between the plant and animal protein sources. For this, the plant protein sources used were only FSP and RPC and both the animal protein sources were considered. Also, comparison was made between the SBM and other protein sources. The treatments were the main effects. When significant differences were noted, the means were compared using LSD's multiple range test. The level of significance was accepted at $p<0.05$, unless otherwise noted.

RESULTS AND DISCUSSION

Chemical composition of protein sources

The crude protein and essential amino acid (EAA) profile is presented in Table 2. The TEAA/CP ratio almost remained same in all the protein sources tested. The tryptophan was not determined in any of the protein source. The CP content was higher in FM (70.0%) and the lowest in WPC (35.0%). The analyzed amino acid composition for EAA is nearly similar to Mackerel fishmeal dried at 85°C used by Kim and Easter (2001) in their studies comparing

Table 3. Effect of different protein sources on growth performance in early-weaned pigs

Period	SBM	Plant		Animal		SEM[1]	Contrast[2], p<	
		FSP	RPC	WPC	FM		S vs. O	P vs. A
0-7 d								
ADG (g)	187^{c}	207^{b}	201^{b}	236^{a}	225^{a}	4.90	***	***[3]
ADFI (g)	265^{b}	279^{b}	276^{b}	315^{a}	305^{a}	5.52	**	***
F/G	1.42^{a}	1.35^{c}	1.38^{b}	1.34^{c}	1.36^{bc}	0.01	***	NS[4]
8-14 d								
ADG (g)	271^{c}	307^{ab}	296^{b}	326^{a}	322^{a}	5.73	***	**
ADFI (g)	417^{d}	452^{bc}	430^{cd}	470^{ab}	474^{a}	6.49	***	**
F/G	1.54^{a}	1.47^{b}	1.45^{b}	1.45^{b}	1.47^{b}	0.01	***	NS
0-14 d								
ADG (g)	229^{c}	257^{b}	248^{b}	281^{a}	273^{a}	5.17	***	***
ADFI (g)	339^{c}	370^{b}	357^{bc}	397^{a}	389^{a}	5.83	***	***
F/G	1.49^{a}	1.44^{b}	1.44^{b}	1.42^{c}	1.42^{bc}	0.01	***	**
15-28 d								
ADG (g)	337^{b}	376^{ab}	367^{ab}	400^{a}	390^{a}	8.40	*	NS
ADFI (g)	509^{d}	523^{cd}	529^{c}	584^{a}	553^{b}	7.38	***	***
F/G	1.51^{a}	1.40^{c}	1.46^{b}	1.46^{b}	1.42^{bc}	0.01	**	NS
0-28 d								
ADG (g)	283^{c}	316^{ab}	307^{bc}	340^{a}	332^{ab}	6.19	**	*
ADFI (g)	425^{d}	447^{c}	443^{c}	491^{a}	471^{ab}	6.22	***	***
F/G	1.50^{a}	1.42^{b}	1.45^{b}	1.44^{b}	1.42^{b}	0.01	**	NS

[a-d] Values with different superscripts in the same row differ significantly (p<0.05).
[1] Pooled standard error of means. [2] Contrast: Soybean meal vs. others.
Plant proteins (FSP and RPC) vs. animal proteins (WPC and FM).
[3] * p<0.05; ** p<0.01; *** p<0.001. [4] Not significant (p>0.05).

the nutritional value of fishmeals in the diet of young pigs. The amino acid profile of RPC are excellent when compared with FSP or SBM, even the CP content is very high. As reported by Hoseney, (1994) lysine is the first limiting amino acid in RPC. RPC have better sulfur amino acids than the FM (3.62 vs. 2.38%). The essential amino acid profile in WPC is inferior as compared with other protein sources.

Growth performance

The ADG, ADFI and feed:gain ratios are presented in Table 3. The ADG was higher (p<0.001) in the groups fed diet with animal proteins as compared with plant proteins after one week. The highest ADG was noted in WPC and FM fed diets and lowest in SBM fed animals. Similar trend was noticed at 14th day of measurement. The higher ADG noted at all phases of measurement, except during 15-28 d, in animal protein fed animals is the effect of increased feed intake in these groups as compared with plant protein fed diets. The ADG between WPC and FM were comparable at all levels of measurement. Even the ADG in plant protein sources FSP and RPC were comparable at all levels; but significantly higher than SBM fed group. Several studies have reported greater ADG and improved feed efficiency in weaned pigs fed diets based on milk products compared to those fed isolated soy products (Maner et al., 1961; Wilson and Leibholz, 1982; Walker et al., 1986b) or soybean meal (Leibholz, 1981; Wilson and Leibholz, 1981a; Sohn et al., 1994). The reason for lower ADG was poor palatability; one of the distinct problems with SBM-based diets as was mentioned by Sohn et al. (1994). Though the palatability problem was not prominently observed during 0-7 d study, but it was lower in SBM based diet during 8-14, 0-14 and 0-28 d study as compared with FSP and even with RPC at 0-7, 8-14, and 0-14 d measurement. Similar response of lower feed intake and ADG in SBM fed diet when compared with dried skim milk (DSM), ISP (isolated soy proteins), SDPP and wheat gluten fed diets were also noted by Chae et al. (1999). There are few studies, where refined soybean proteins could serve as an alternative protein source to DSM in early-weaned pigs (Dietz et al., 1988; Geurin et al., 1988; Sohn et al., 1994). RPC when compared with animal proteins showed better ADG and FCR in spray-dried porcine plasma (SDPP) fed diet during phase I (0-14 days), but pigs fed dried porcine soluble during phase II (14-35 d) showed lower ADG than RPC; and in overall study (0-35 d) there were no differences in ADG, ADFI and FCR among treatments (Yun et al., 2005) in our earlier reports. RPC is a good protein source and also the amino acid profile is very high as shown in Table 2. The feed intake was higher in animal protein fed diets than plant protein at all phases in the present study. But the feed:gain ratio was not affected by protein sources except during 0-14 d measurement, which was improved (p<0.05) in animal protein fed diets as to plants protein sources. The feed:gain ratio was poor in SBM fed animals at all times. Grinstead et al. (2000)

Table 4. Effect of different protein sources on nutrient digestibility (%)

Item	SBM	Plant		Animal		SEM[1]	Contrast[2], p<	
		FSP	RPC	WPC	FM		S vs. O	P vs. A
DM	84.19[c]	86.43[b]	86.41[b]	87.56[a]	86.99[ab]	0.31	*	***[3]
GE	83.66[d]	85.74[c]	85.98[bc]	87.37[a]	86.43[b]	0.33	*	***
CP	71.09[c]	77.87[b]	77.22[b]	80.27[a]	79.37[a]	0.87	**	***
EE	53.05[b]	61.30[a]	62.08[a]	62.79[a]	64.43[a]	1.28	NS	NS[4]
Ca	54.34[b]	61.30[a]	59.75[a]	60.63[a]	57.72[a]	0.88	**	NS
P	50.89[c]	58.18[ab]	56.40[b]	60.21[a]	57.72[ab]	0.92	NS	NS

[a-d] Values with different superscripts in the same row differ significantly (p<0.05).
[1] Pooled standard error of means. [2] Contrast: Soybean meal vs. others.
Plant protein (FSP and RPC) vs. Animal protein (WPC and FM).
[3] * p<0.05; ** p<0.01; *** p<0.001. [4] Not significant (p>0.05).

Table 5. Effect of different protein sources on apparent ileal amino acid digestibility (%) in early-weaned pigs (at 14 d)

Item	SBM	Plant		Animal		SEM[1]	Contrast[2], p<	
		FSP	RPC	WPC	FM		S vs. O	P vs. A
Essential amino acids								
Arg	77.01	79.53	80.46	77.42	79.05	0.57	NS	NS[3]
His	69.71[b]	74.64[a]	71.72[ab]	74.13[ab]	71.29[ab]	0.75	NS	NS
Ile	69.71[c]	76.67[a]	76.65[a]	73.40[b]	73.45[b]	0.75	***	**[4]
Leu	72.42[c]	76.41[b]	76.45[b]	79.20[a]	78.26[ab]	0.67	***	**
Lys	71.62[c]	79.00[a]	76.20[ab]	78.15[ab]	76.13[b]	0.75	***	NS
Met	73.82[c]	78.38[ab]	76.85[bc]	81.41[a]	79.12[ab]	0.77	**	*
Phe	73.16[c]	79.77[a]	76.54[b]	79.46[a]	75.88[b]	0.72	***	NS
Thr	68.10[d]	73.21[bc]	72.38[c]	75.35[ab]	76.36[a]	0.83	***	**
Val	68.87[b]	74.49[a]	73.03[a]	74.42[a]	74.62[a]	0.67	***	NS
Sub-mean	71.60[b]	76.90[a]	75.59[a]	76.99[a]	76.02[a]	0.59	***	NS
Non-essential amino acids								
Ala	72.81[c]	76.75[b]	75.57[b]	79.28[a]	75.20[b]	0.59	***	NS
Asp	75.19[c]	79.73[ab]	76.84[bc]	80.75[a]	80.68[a]	0.71	**	*
Cys	61.67[c]	65.40[ab]	63.19[bc]	67.16[a]	62.32[bc]	0.67	*	NS
Glu	75.87[d]	80.07[ab]	78.49[bc]	81.62[a]	75.97[cd]	0.67	**	NS
Gly	62.82[b]	68.29[a]	68.70[a]	70.90[a]	67.99[a]	0.85	**	NS
Pro	71.78[b]	75.05[a]	77.31[a]	75.33[a]	75.72[a]	0.61	**	NS
Ser	73.14[c]	78.39[a]	74.91[c]	77.75[ab]	75.68[bc]	0.59	**	NS
Tyr	69.47[b]	71.42[ab]	72.13[ab]	73.42[a]	70.04[b]	0.52	NS	NS
Sub-mean	70.34[c]	74.39[ab]	73.39[b]	75.78[a]	72.95[b]	0.55	***	NS
Total	70.97[b]	75.64[a]	74.49[a]	76.39[a]	74.48[a]	0.56	***	NS

[a-d] Values with different superscripts in the same row differ significantly (p<0.05).
[1] Pooled standard error of means. [2] Contrast: Soybean meal vs. others
Plant proteins (FSP and RPC) vs. animal proteins (WPC and FM).
[3] Not significant (p>0.05). [4] * p<0.05; ** p<0.01; *** p<0.001.

recorded that the pigs fed increasing whey protein product (5.4% of diet) had greater ADG than pigs fed the control diet (no whey protein), and there was no increase in feed intake, and this was a result of improved feed efficiency. Mackerel fishmeal dried at 70°C can replace SDPP without compromising the growth response of young pigs was also reported by Kim and Easter (2001).

Nutrient digestibility

The nutrient digestibility conducted after 14 days of experimental feeding is presented in Table 4. The digestibility of gross energy, dry matter and crude protein was higher (p<0.05) in animal protein fed diets than to plant protein fed sources. The higher nutrient digestibility in these groups had culminated into increased weight gains in these animals. But the ether extract, calcium and phosphorus digestibility remained unaffected due to experimental treatments. Though it is reported that the phosphorus content is normally higher in animal protein sources than plant proteins but the digestibility remained comparable in our study. When compared among the individual groups, the SBM fed animals have lower nutrient digestibilities than all other groups, which possibly resulted in lowest ADG in this group. It is commonly noticed that when the feed intake is low, the nutrient digestibility is high but we could not find such effect. Even the ether extract, calcium and phosphorus digestibilities were lower in SBM fed animals and the other groups were comparable. The

Table 6. Effect of different protein sources on apparent fecal amino acid digestibility (%) in early-weaned pigs

Item	SBM	Plant		Animal		SEM[1]	Contrast[2], p<	
		FSP	RPC	WPC	FM		S vs. O	P vs. A
Essential amino acids								
Arg	75.91[bc]	78.37[a]	78.89[a]	74.73[c]	77.18[ab]	0.49	NS	**[3]
His	67.13[d]	73.36[a]	70.95[bc]	72.49[ab]	69.72[c]	0.61	***	NS[4]
Ile	66.00[c]	74.94[a]	72.02[ab]	70.52[b]	69.92[b]	0.89	**	*
Leu	70.05[c]	72.98[bc]	75.08[ab]	77.69[a]	76.65[ab]	0.87	**	*
Lys	69.68[b]	74.79[a]	75.04[a]	74.60[a]	73.86[a]	0.65	**	NS
Met	70.40[b]	73.93[a]	74.93[a]	74.83[a]	73.89[a]	0.49	***	NS
Phe	71.22[c]	76.76[a]	72.38[bc]	74.37[ab]	72.82[bc]	0.59	**	NS
Thr	63.40[b]	70.66[a]	70.93[a]	70.54[a]	69.95[a]	0.83	***	NS
Val	62.17[d]	69.90[bc]	67.45[c]	73.04[a]	72.22[ab]	1.09	***	***
Sub-mean	68.44[b]	73.97[a]	73.07[a]	73.65[a]	72.91[a]	0.61	***	NS
Non-essential amino acids								
Ala	64.90[b]	72.35[a]	71.67[a]	73.27[a]	70.67[a]	1.01	**	NS
Asp	72.24[c]	75.33[b]	74.45[bc]	78.61[a]	73.73[bc]	0.66	**	NS
Cys	59.91[b]	63.69[a]	62.97[a]	64.50[a]	63.44[a]	0.52	**	NS
Glu	73.84[c]	77.04[b]	77.03[b]	79.14[a]	71.89[c]	0.73	**	*
Gly	60.09[b]	63.42[ab]	66.58[a]	67.69[a]	64.92[a]	0.88	**	NS
Pro	66.83[ab]	69.58[ab]	69.87[a]	68.43[ab]	66.29[b]	0.57	NS	NS
Ser	71.17[b]	74.57[a]	73.56[ab]	72.68[ab]	72.28[ab]	0.50	NS	NS
Tyr	64.01[b]	67.71[ab]	68.32[ab]	69.16[a]	65.43[ab]	0.77	NS	NS
Sub-mean	66.62[c]	70.46[ab]	70.56[ab]	71.69[a]	68.58[bc]	0.60	**	NS
Total	67.53[b]	72.21[a]	71.82[a]	72.67[a]	70.75[a]	0.59	**	NS

[a-d] Values with different superscripts in the same row differ significantly ($p<0.05$).
[1] Pooled standard error of means. [2] Contrast: Soybean meal vs. others.
Plant proteins (FSP and RPC) Vs. Animal proteins (WPC and FM).
[3] * $p<0.05$; ** $p<0.01$; *** $p<0.001$. [4] Not significant ($p>0.05$).

lower nutrient digestibility in SBM than that of milk products based diets is consistent with previous studies (Walker et al., 1986b; Sohn et al., 1994). The poor digestibility of nutrients in pigs fed the SBM diet may be due to the presence of indigestible carbohydrate complexes (Walker et al., 1986b), indigestible proteins such as glycinin and B-conglycinin (Li et al., 1991), and (or) anti-nutritional factors, in addition to the incomplete development of digestive system in pigs (14 days old). The lower digestibility of nutrients lowered the ADG in this group.

Apparent ileal and fecal amino acid digestibilities

The apparent ileal digestibility of essential amino acids like Leu, Met and Thr was significantly ($p<0.05$) higher in animal proteins fed groups as compared with plant protein fed animals (Table 5). But the digestibilities of Arg, His, Lys, Phe and Val were comparable. The digestibilities of all essential amino acids were comparable between the animal protein sources except Phe. The Ile, Leu, Lys, Phe, Thr and Val apparent ileal digestibilities were lower in SBM fed groups when compared with other groups. The non-essential amino acid Asp digestibility was only higher in animal protein fed animals than plant protein fed groups; and all other amino acids remained comparable. Ala, Gly and Pro apparent ileal digestibilities were significantly lower in SBM fed groups than its counterparts. Higher digestibility of some of the essential and non-essential amino acids were also noted in SDPP fed diets than SPC or RPC during Phase I in recent studies in our lab (Yun et al., 2005). The sub-mean digestibility of EAA was lowest in SBM and highest in WPC based diet. Similar trend was noticed when sub-mean digestibility of non-EAA was studied in present research. The sub- mean digestibility of essential amino acids in an isolated soy protein based diet was not greater than that of mean digestibility of essential amino acid in a SBM based diet was reported by Chae et al. (1999) which contradicts to our study, but the ileal digestibilities of amino acids in refined soybean proteins such as ISP and soybean protein concentrate were improved over that of soybean meal due to reduction in anti-nutritional factors was reported by Walker et al. (1986) and Sohn et al. (1994) that supports our findings. The mean digestibility of EAA and non-EAA were comparable between FSP and RPC and also among WPC and FM. Pigs fed fish meals from mackerel dried at 70°C had greater ileal digestibility of amino acids and growth performance than pigs fed menhaden fish meal (Kim and Easter, 2001) and it was mentioned that the digestibility depends on the species of fish used and the drying temperature.

The apparent fecal digestibilities of essential amino acids like Arg and Ile, were significantly higher ($p<0.05$) in plant protein sources than animal proteins (Table 6) and

Table 7. Effect of different protein sources on villous height and crypt depth of the intestinal region in early-weaned pigs

	SBM	Plant		Animal		SEM[1]	Contrast[2], p<	
		FSP	RPC	WPC	FM		S vs. O	P vs. A
Villous height (μm)								
Duodenum	319^{b}	327^{b}	343^{ab}	363^{a}	358^{a}	5.43	**[3]	**
Jejunum	310^{c}	322^{bc}	330^{abc}	351^{a}	345^{ab}	5.00	NS[4]	*
Ileum	301^{c}	312^{bc}	318^{bc}	344^{a}	327^{ab}	4.65	*	*
Crypt depth (μm)								
Duodenum	218^{ab}	222^{a}	214^{ab}	203^{b}	207^{ab}	2.91	*	*
Jejunum	218	219	212	213	216	2.04	NS	NS
Ileum	211	212	205	206	210	1.93	*	NS
Villous height:crypt depth								
Duodenum	1.47^{b}	1.48^{b}	1.61^{ab}	1.79^{a}	1.73^{a}	0.04	**	**
Jejunum	1.43^{c}	1.48^{bc}	1.56^{abc}	1.65^{a}	1.60^{ab}	0.03	NS	*
Ileum	1.42^{b}	1.47^{b}	1.55^{ab}	1.67^{a}	1.56^{ab}	0.03	*	*

[a-c] Values with different superscripts in the same row differ significantly (p<0.05).
[1] Pooled standard error of means. [2] Contrast: Soybean meal vs. others.
Plant proteins (FSP and RPC) vs. animal proteins (WPC and FM).
[3] *p<0.05; ** p<0.01; *** p<0.001. [4] Not significant (p>0.05).

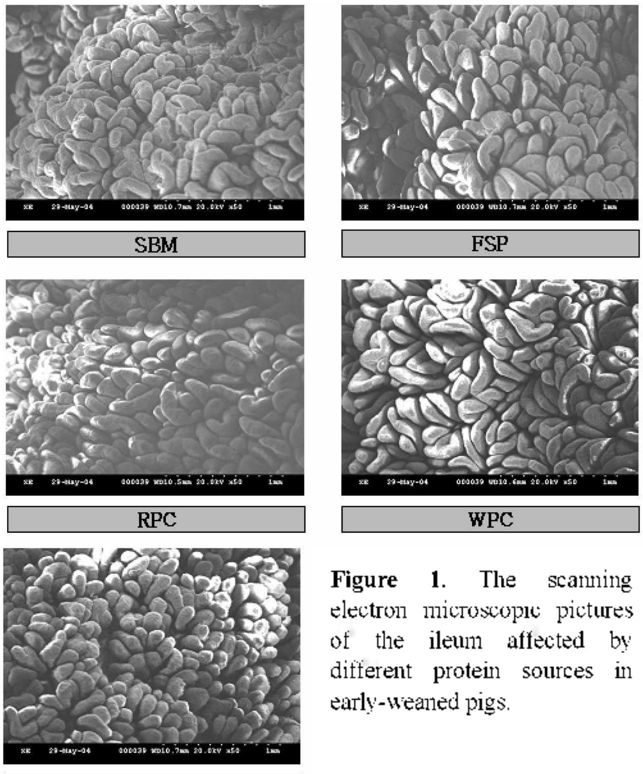


Figure 1. The scanning electron microscopic pictures of the ileum affected by different protein sources in early-weaned pigs.

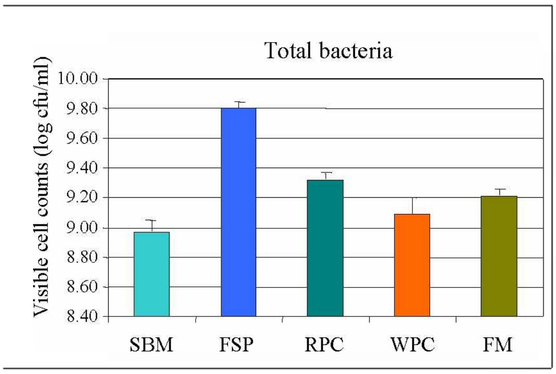
reverse was noticed when Leu and Val digestibilities were studied. The digestibilities of His, Lys, Met, Phe and Thr were not influenced due to dietary treatments and it remained comparable. When non-essential amino acids fecal digestibility were compared, only Glu digestibility was higher (p = 0.0431) in plant protein fed groups than animal protein fed animals. The apparent ileal amino acid digestibilities showed higher values than fecal amino acid digestibilities. The sub-mean of apparent fecal EAA and non-EAA digestibilities were not affected by the dietary treatments when compared between plant and animal protein sources.

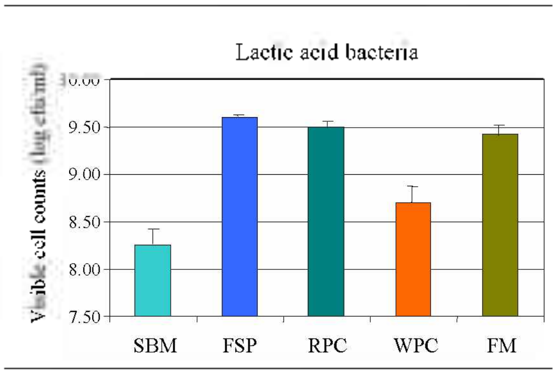
Effect on villous height and crypt depth

The dietary protein sources had a significant (p<0.05) impact on villous height at the duodenum, jejunum and ileum with maximum height in pigs fed animal protein sources than the plant protein sources (Table 7). The villous height was maximal in WPC fed group at duodenal, jejunal and ileal regions as compared with SBM. The crypt depth was lowest in WPC fed group at duodenal region as compared with FSP. The villous height to crypt depth ratios was higher (p<0.05) in animal protein sources than the plant proteins at all sites. The villi of the small intestine change with age and with weaning from a long and fine-finger like shape to a short and thick tongue like shape (Cera et al., 1988). Hypersensitivity to antigens in diet may be responsible for these changes as was also suggested by Li et al. (1990). High levels of plant proteins that may contan strong antigens greatly affect villous height and gut morphology (Li et al., 1991b). Kelly et al. (1991) and Vente-Spreeuwenberg et al. (2004) reported that villous height and crypt depth were positively related to feed intake. Furthermore, Kelly et al. (1991) and Pluske et al. (1996) reported that pigs fed less feed showed villous atrophy and increased crypt depth at all sites along the small intestine compared with pigs fed a higher quantity feed. The findings in our study can be better explained on this possibility since we have also noted a reduced feed intake in plant protein fed groups as compared with animal protein sources at all times of measurement.

Effect on gut morphology

The photographs taken by scanning electron microscope (Figure 1) clearly depicted the effect of protein sources on the gut morphology. In our study, the villi structures by SEM were prominent, straight, finger- like, though shortened and densely located in FM fed group as compared





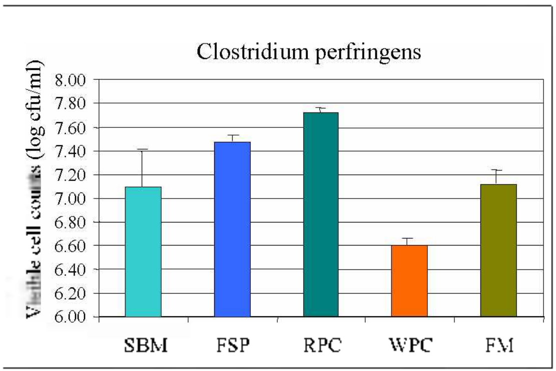


Figure 2. Bacterial cell counts (log cfu/ml) of intestinal contents in early-weaned pigs fed different protein sources.

with other. The luminal surfaces of the villi in each group were smoother and these were in close association. The photographs showed shortened villi, but the villous tips were neither eroded in any of the groups nor showed any effects of atrophy. The villi in other groups looked flattened with a broad diameter. But Cera et al. (1988) found lengthened villi clearly evident at 14 d post-weaning in their studies; where they compared the villi with suckling animals of same age having long, narrow finger like morphological structures and longitudinally flattened tongue like villi in post-weaning pigs, that we also observed. The lower feed intake that commonly observed after weaning is a contributing factor to the villous morphology. Gall and Chung (1982) also mentioned that food intake is more important rather than chronological age for the maturation of small intestine.

Effect on microbial population

The total bacterial counts in the caeca were higher ($p<0.05$) in plant protein sources than in animal proteins. The highest total bacterial count (TBC) was observed in FSP and the lowest in SBM fed groups (Figure 2). The lactic acid bacteria (LAB) counts were higher ($p<0.05$) in pigs fed plant protein than the animal proteins. The lowest LAB count was recorded for SBM fed animals. The inclusion of WPC resulted in an increase of LAB counts by 0.46 cfu/ml than SBM and in other diets it was increased to 1.18 to 1.32 cfu/ml. The *C. perfringens* was higher ($p<0.05$) in caeca of pigs fed diets containing plant proteins than to animal proteins and the lowest count was found in WPC fed group than its counterparts. We like to note here that, not a single animal was affected due to diarrhea or any other disease condition throughout the study. To the best of our knowledge, this is the first report where the effects of plant and animal protein sources on the cecal bacterial counts were studied. Hence before drawing any firm conclusion we suggest to conduct further studies in this area.

Overall, it could be concluded that animal protein sources in the present study showed better performance, nutrient digestibility and gut morphology than plant protein sources. The best effect was noted in FM and the lowest in SBM as compared with other sources.

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