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Comparative Efficacy of Different Soy Protein Sources on Growth Performance, Nutrient Digestibility and Intestinal Morphology in Weaned Pigs

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ABSTRACT : To elucidate the efficacy of different soy protein sources on piglet's performance, a total of 280 weaned piglets (Duroc×Yorkshire×Landrace, 23±3 d of age, 5.86±0.45 kg initial BW) were allotted to 5 treatment diets comprising soybean meal (SBM), soy protein concentrate (SPC), Hamlet protein (HP300), fungal (*Aspergillus oryzae*) fermented soy protein (FSP-A), and fungal plus bacterial (*A. oryzae–Bacillus subtilis*) fermented soy protein (FSP-B), respectively. Experimental diets for feeding trial were formulated to contain each soy protein sources at 8% level to corn-whey powder basal diet. There were 14 pigs per pen and 4 pens per treatment. Experimental diets were fed from 0 to 14 d after weaning and then a common commercial diet was fed from 15 to 35 d. Also for ileal digestibility studies, 18 pigs were assigned to 6 dietary treatments as N-free, SBM, SPC, HP300, FSP-A and FSP-B with T-canulation at distal ileum for 6 days. At 14th d of experimental feeding, the ADG was significantly higher ($p<0.05$) in SPC fed diet as compared with others. Similar trend was noticed during the 15-35 d and overall study (0-35 d). All the processed soy protein sources tested in this experiment improved ($p<0.05$) growth than SBM during overall study. The nutrient digestibility of GE, DM, CP and Ca showed lower ($p<0.05$) values in SBM and FSP-A fed groups than SPC and FSP-B treatments. The apparent ileal digestibility of TEAA, non-TEAA and TAA showed lower ($p<0.05$) in SBM treatments compared with other soy protein sources. The true ileal digestibility of TEAA, non-TEAA and TAA were lower ($p<0.05$) in SBM fed group than SPC and HP300 treatments, and lower than FSP treatments though they didn't achieve significant difference ($p>0.05$). Villous height and crypt depth was not affected by dietary treatments. In conclusion, the growth and digestibility of nutrients in weaned pigs fed SPC was superior to others. Also FSP-A and FSP-B showed improved performance than those fed SBM. (**Key Words** : Piglets, Growth, Nutrient Digestibility, Intestine, Fermented Soy Protein)

INTRODUCTION

Soybean meal (SBM) is an essential component in the feed formulation used for farm animals throughout the world. However, because of antigenic activity and antinutritional factors, young animals such as calves and piglets are sensitive to SBM and poor growth and digestive disorders are common when it is fed (Lalles, 1993).

In fact, milk products such as dried skim milk, dried whey and other animal protein sources like spray-dried plasma proteins and dried porcine soluble are typical feed ingredients in young pigs due to their high palatability and digestibility, but these are somewhat expensive. Therefore, specially processed soy products such as soy protein concentrate (SPC), HP300 (Hamlet Protein A/S Company Denmark) and soy protein isolate (SPI) is used in the starter diets. SPC is prepared from soybeans by removing most of the fat and water-soluble, non-protein constituents, and SPI is prepared by removing the majority of water-soluble, non-protein components from dehulled SBM (Kolar et al., 1985; Cromwell, 2001). It was reported that SPC and SPI provide equal or improved growth performance as compared with milk-based diets (Sohn et al., 1994).

Refined soy proteins sources like fermented soy protein (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 *Aspergillus oryzae* and *Bacillus subtilis*. The methodology is based on principle that microorganisms utilize carbohydrates and thereby the proteins are concentrated and since microbes are also protein in nature.

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Table 1. Formula and chemical composition of experimental diets for feeding trials (day 0 to 14)

Soy protein sources[1]	SBM	SPC	HP300	FSP-A	FSP-B
Ingredient (%)					
Whey powder	38.00	38.00	38.00	38.00	38.00
Corn	36.64	37.05	36.89	36.92	36.97
Soy bean meal (SBM, 48%)	8.00	-	-	-	-
Soy protein concentration (SPC)	-	8.00	-	-	-
HP300	-	-	8.00	-	-
FSP-A, B	-	-	-	8.00	8.00
Spray dried plasma protein (SDPP)	7.80	7.80	7.80	7.80	7.80
Fish meal	5.00	5.00	5.00	5.00	5.00
Soy oil	2.00	1.80	1.80	1.80	1.80
L-lysine HCl (78%)	0.15	0.02	0.13	0.12	0.08
DL-methionine (50%)	0.14	0.06	0.11	0.09	0.08
Limestone	0.60	0.60	0.60	0.60	0.60
Salt	0.20	0.20	0.20	0.20	0.20
Zinc oxide	0.34	0.34	0.34	0.34	0.34
Vitamin premix[2]	0.28	0.28	0.28	0.28	0.28
Mineral premix[3]	0.20	0.20	0.20	0.20	0.20
Acidifier	0.20	0.20	0.20	0.20	0.20
Apramycin (10%)	0.15	0.15	0.15	0.15	0.15
Choline chloride (25%)	0.10	0.10	0.10	0.10	0.10
Sulfathizol (10%)	0.10	0.10	0.10	0.10	0.10
Mecadox (5%)	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Analyzed chemical composition (as-fed basis)					
Crude protein (CP, %)	20.72	22.04	21.73	21.55	22.39
Ether extract (EE, %)	4.63	4.19	4.53	4.47	4.19
Ash (%)	7.20	7.28	7.51	7.39	7.52
Calcium (Ca, %)	0.71	0.71	0.71	0.72	0.72
Phosphorus (P, %)	0.62	0.61	0.62	0.66	0.62
ME (kcal/kg, calculated)	3,300	3,300	3,300	3,300	3,300

[1] SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300; FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae–B. subtilis*.

[2] Supplied per kg diet: 9,600 IU vitamin A, 1,800 IU vitamin D3, 24 mg vitamin E, 1.5 mg vitamin B1, 12 mg vitamin B2, 2.4 mg vitamin B6, 0.045 mg vitamin B12, 1.5 mg vitamin K3, 24 mg pantothenic acid, 45 mg niacin, 0.09 mg biotin, 0.75 mg folic acid, 18 mg ethoxyquin.

[3] 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.

ultimately increases the protein content of the product after fermentation. Fermented soybean meals were shown to contain proteins with high proportion of small peptides due to enzymatic degradation during fermentation process (Hong et al., 2004). Recently, Min et al. (2004) reported that feeding processed soy protein to weanling pigs that has high proportion of small peptides increased growth performance, nutrient digestibility and apparent ileal digestibilities of dry matter, nitrogen and most amino acids.

A. oryzae and *B. subtilis* were isolated from fermented soy (Meju) and the amylase activity was improved by mutation. The processing method contains soaking, increasing surface area, injection of microbes, fermentation at higher temperature and then drying. This increases the crude protein (CP) content to 53-57%. The trypsin inhibitor, oligosaccharides like raffinose and stachyose in soybean meal was removed during fungal and bacterial fermentation by protease and glucoamylase causing hydrolysis and the processed soy protein was developed (Kim, 2005).

Another processed soy product, HP300 is a soya-bean protein product that is obtained by purifying and defattening soya bean via a proprietary microbial process that decreased the level of trypsin inhibitors and other anti-nutritional factors in soya bean (Zhang et al., 2005).

There is a dearth of information with respect to the comparison of different soy proteins sources in weaned pigs diet and its effect on performance, intestinal morphology, and nutrient digestibility. Hence, the present study was conducted to evaluate and compare the effects of various soy protein sources on piglets performance, digestibility of amino acids and gut morphology in the weaned pigs fed till 14 days after weaning, and whether they further affect the growth performance fed a common diet for next 21 days.

MATERIALS AND METHODS

Two hundred eighty weaned pigs of 23±3 days of age (Landrace×Yorkshire×Duroc) were allotted to five

Table 2. Formula and chemical composition of experimental diets for ileal digestibility trial

Soy protein sources[1]	N-free	SBM	SPC	HP300	FSP-A	FSP-B
Ingredient (%)						
Soy bean meal (SBM, 48%)	-	45.66	-	-	-	-
Soy protein concentration (SPC)	-	-	31.20	-	-	-
HP300	-	-	-	37.00	-	-
FSP-A, B	-	-	-	-	37.58	35.36
Corn starch	31.15	6.95	25.37	18.01	17.12	19.67
Cellulose	3.00	-	-	-	-	-
Lactose	30.00	20.00	20.00	20.00	20.00	20.00
Glucose	20.00	10.00	10.00	10.00	10.00	10.00
Sucrose	9.00	9.00	9.00	9.00	9.00	9.00
Corn oil	2.60	4.70	0.60	2.20	2.40	2.00
Limestone	0.80	1.44	1.40	1.63	1.46	1.48
Dicalcium phosphate	2.55	1.00	1.20	0.95	1.10	1.05
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Mineral premix[3]	0.20	0.20	0.20	0.20	0.20	0.20
L-lysine HCl (78%)	-	0.21	0.19	0.22	0.22	0.30
DL-methionine (50%)	-	0.14	0.14	0.09	0.22	0.24
Choline chloride (25%)	0.10	0.10	0.10	0.10	0.10	0.10
Chromic oxide	0.25	0.25	0.25	0.25	0.25	0.25
Mecadox (5%)	0.10	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition (calculated)						
ME (kcal/kg)	3,470	3,464	3,494	3,464	3,465	3,459
CP (%)	20.24	20.39	20.39	20.39	20.39	20.39
Ca (%)	0.90	0.90	0.90	0.90	0.90	0.90
P (%)	0.48	0.48	0.48	0.48	0.48	0.48
Lys (%)	0.00	1.50	1.50	1.50	1.50	1.50
Met (%)	0.00	0.35	0.35	0.35	0.35	0.35

[1] SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300; FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae+B. subtilis*.

[2] 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 B_6, 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.

[3] 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.

treatments with 4 replicates in each, comprising 14 pigs of the same ancestry but mixed sex (male:female ratio same) in each replicate. Five diets were prepared by mixing with different soy protein sources. They were soybean meal (SBM), soy protein concentrate (SPC), Hamlet protein (HP300), fungal fermented soy protein (FSP-A; *A. oryzae*), and fungal+bacterial fermented soy protein (FSP-B; *A. oryzae+B. subtilis*). The average body weight when weaned was 5.86±0.45 kg. The pigs were housed in partially slotted and concrete floor pens with a pen size of 1.9×2.54 m, with a self-feeder and nipple waterer to allow *ad libitum* access to feed and water.

In this experiment the high quality soy proteins were produced by fungal and bacterial fermentation. The product developed by this method had low antinutritional factors and it contained small peptides (data not shown). The microbial protease increases their crude protein to 53-57% and small peptides were produced (Kim, 2005).

The level of each soy protein source added was 8% of diet. All the diets 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 crumble during phase II (15-35 d). The composition of the starter diet (Phase-I, for 2 weeks) is presented in Table 1. The experiment was conducted for 5 weeks during which the body weights and feed intake were noted at the end of each phase of experimental feeding.

In order to study the effect of different levels of fermented soy protein source on apparent total tract nutrient digestibility, all pigs in all pens were fed their originally assigned diets mixed with chromic oxide (0.25%) from d 7 to 14 of phase I and fecal samples were collected from d 11 to 14 and pooled. The fecal samples were freshly collected from 5-6 pigs randomly from each pen each day to ensure no microbial modification of the nutrient contents. 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.

Also, an ileal digestibility trial was conducted to compare the ileal digestibility of amino acids in the tested protein sources: SBM, SPC, HP300, FSP-A and FSP-B. A

Table 3. Crude protein (CP) and essential amino acid profiles of protein sources (as-fed basis)[1]

Soy protein sources[2]	SBM	FSP-A	SPC	HP300	FSP-B
Crude protein (CP, %)	45.2	53.0	64.0	55.0	57.0
Essential amino acid (%)					
Arginine	3.27	3.97	5.79	-	3.83
Histidine	1.34	1.44	1.80	-	1.68
Isoleucine	1.85	2.47	3.30	4.80	2.42
Leucine	4.69	4.12	5.30	7.80	5.28
Lysine	2.87	3.32	4.20	6.20	3.02
Phenylalanine	2.00	2.73	5.90[3]	5.00[3]	2.79
Threonine	1.73	2.09	2.80	4.00	2.06
Valine	1.86	2.57	3.40	5.20	2.48
Methionine	0.48	0.75	1.90[4]	3.00[4]	0.80
Total	20.09	23.46	34.39	36.00	24.36
TEAA[5]/CP	0.44	0.44	0.54	0.65	0.43

[1] Tryptophan was not determined.
[2] SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300.
FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae+B. subtilis*.
[3] Phenylalanine+tyrosine. [4] Methionine+cysteine. [5] Total essential amino acid.

total of 18 castrated piglets (L×Y×D, 22±2 d of age, initial BW 5.48±0.39 kg) were used in a completely randomized design and housed in individual cages. Of the pigs, three were assigned to collect ileal digesta for endogenous amino acid excretions. After one day of fasting, pigs were fitted with a T-cannula in the terminal ileum according to the method suggested by Walker et al. (1986a). Semi-purified diets were formulated with each protein sources to be tested (Table 2), a N-free diet was also prepared, and each pig was fed a restricted amount of feed (5% of the body weight/day) three times daily. From the sixth day post-surgery, digesta was collected for 4 days. The collected samples were immediately frozen at -80°C, freeze dried (Samwon Inc., Korea), ground in a 1 mm-mesh Wiley Mill, and stored in a refrigerator until analysis.

Proximate analyses of the experimental diets were carried out following the AOAC (1990) methods. Gross energy was measured by a bomb calorimeter (Model 1261, Parr Instrument Co., Molin, IL) and chromium with an automated spectrophotometer (Shimadzu, Japan) according to the procedure of Fenton and Fenton (1979), 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 gut morphology, villi height and crypt depth, representative pigs from each group (2 per replicate) reflecting average body weights were selected and killed by electrocution at 14 days of experiment. Immediately after slaughter the small intestine was excised. The small intestine was then immersed in 10% buffered formaline and then brought to laboratory for further studies. The small intestinal segment especially at ileum 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).

Data collected were subjected to statistical analysis using GLM procedure of SAS (1985) by using statistical software package using completely randomized design to compare between the soy protein sources. The treatments were the main effects. The pens were the experimental units for all analysis but for ileal digestibility each pig was the experimental unit. 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

Chemical composition of protein sources

The CP and essential amino acid (EAA) profile of each soy protein source is presented in Table 3. The TEAA/CP ratio almost remained similar for FSP-A, FSP-B and SBM. But the ratio was higher in SPC and HP300. The tryptophan was not determined in any of the protein source. The CP content was higher in SPC (64.0%) and the lowest in SBM (45.2%).

Table 4. Effects of different soy protein source on growth performance in weaned pigs

Soy protein sources[1]	SBM	SPC	HP300	FSP-A	FSP-B	SEM[2]
Day 0-14						
ADG (g)	267^{c}	291^{a}	282^{b}	280^{b}	281^{b}	2.21
ADFI (g)	430^{c}	446^{ab}	449^{a}	431^{bc}	443^{abc}	2.79
F/G	1.60^{ab}	1.53^{c}	1.57^{b}	1.60^{a}	1.61^{a}	0.01
Day 15-35						
ADG (g)	430^{c}	477^{a}	461^{ab}	453^{b}	469^{ab}	4.69
ADFI (g)	684^{b}	711^{a}	700^{ab}	685^{b}	704^{a}	3.56
F/G	1.56^{a}	1.49^{b}	1.52^{ab}	1.51^{ab}	1.53^{ab}	0.01
Overall (day 0-35)						
ADG (g)	369^{c}	403^{a}	391^{b}	389^{b}	390^{b}	3.02
ADFI (g)	582^{b}	605^{a}	599^{a}	584^{b}	599^{a}	2.71
F/G	1.58^{a}	1.50^{c}	1.53^{bc}	1.54^{bc}	1.55^{ab}	0.01

a, b, c Values with different superscripts in the same row significantly differ ($p<0.05$).

1 SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300.
FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae–B. subtilis*.

2 Standard error of means.

Table 5. Effects of different soy protein source on fecal digestibility of nutrients in weaned pigs (at day 14)

Soy protein sources[1]	SBM	SPC	HP300	FSP-A	FSP-B	SEM[2]
GE	79.10^{c}	82.57^{a}	80.79^{b}	78.90^{c}	82.52^{a}	0.46
DM	79.85^{b}	82.80^{a}	80.47^{b}	80.34^{b}	82.66^{a}	0.36
CP	66.72^{b}	73.85^{a}	71.49^{a}	68.20^{b}	73.49^{a}	0.84
EE	51.65^{ab}	58.58^{ab}	40.92^{b}	49.09^{ab}	62.24^{a}	2.98
Ash	50.10^{ab}	57.07^{a}	48.87^{b}	55.54^{ab}	56.35^{a}	1.25
Ca	43.44^{b}	50.21^{a}	45.91^{b}	45.50^{b}	52.41^{a}	0.95
P	44.01^{bc}	48.50^{ab}	40.84^{c}	51.61^{a}	47.87^{ab}	1.20

a, b, c Values with different superscripts in the same row significantly differ ($p<0.05$).

1 SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300.
FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae–B. subtilis*.

2 Standard error of means.

Growth performance

The average daily gain (ADG) was higher ($p<0.0001$) in the pigs fed SPC as compared with other protein sources at 0-14 d measurement (Table 4). A similar trend followed during overall (0-35 d) study. The ADG was higher in FSP-A and FSP-B than the SBM fed group at all phases. The ADG, ADFI and F/G were not different among FSP-A and FSP-B diets. Even the F/G in FSP-B diet remained similar to SBM diet. The ADG of piglets fed HP300 was higher than SBM fed animals but similar with FSP-A and FSP-B fed group at all measurements.

Nutrient digestibility

The apparent total tract nutrient digestibility conducted after 14 days of experimental feeding is presented in Table 5. The digestibility of gross energy, dry matter, CP and calcium was higher ($p<0.05$) in SPC fed diets than to SBM and FSP-A. The higher nutrient digestibility in SPC group had culminated into increased weight gains in these animals. There were no differences between the SPC and FSP-B diets with respect to nutrients digestibility. When compared between the SBM and FSP-A fed animals, except for phosphorus, there were no differences in these two groups. The digestibility of DM, EE, ash and calcium was lower in HP300 than FSP-B, however similar to FSP-A.

Apparent and true ileal amino acid digestibilities

The sub-mean apparent ileal digestibility of essential amino acids was higher ($p<0.05$) in FSP-B diet compared with SBM and HP300, but there was no significant difference among FSP-B, SPC and FSP-A diet (Table 6). The apparent ileal digestibility of His, Ile, Thr, Val and Met was higher in FSP-B diet than that of SBM ($p<0.05$).

The sub-mean of true ileal digestibility of essential and non-essential amino acids in SBM were not different to that of FSP-A and FSP-B fed animals, but lower than SPC and HP300 (Table 7). Similar trend was observed for the total true ileal amino acid digestibility. The Met, Asp, Cys and Tyr digestibility remained comparable among the treatments.

Effect on villous height and crypt depth

The dietary protein sources did not show any impact on villous height at the ileum (Table 8). The crypt depth and the villous height to crypt depth ratio were also not affected by dietary treatments.

DISCUSSION

The analyzed amino acid composition of fermented soy proteins for EAA was nearly similar to SBM but the CP content was higher in FSP-A and FSP-B than SBM. The

Table 6. Effects of different soy protein source on apparent ileal digestibility of amino acids in weaned pigs

Soy protein sources[1]	SBM	SPC	HP300	FSP-A	FSP-B	SEM[2]
Essential amino acids						
Arg	79.01[b]	82.92[ab]	85.62[a]	87.15[a]	84.40[ab]	1.01
His	75.27[b]	83.53[a]	75.28[b]	81.43[ab]	82.74[a]	1.26
Ile	70.99[b]	81.62[a]	79.96[a]	79.97[a]	79.33[a]	1.12
Leu	77.59	85.95	83.87	82.16	83.14	1.26
Lys	78.91	85.87	77.28	82.57	84.10	1.34
Met	80.40[ac]	83.56[ab]	85.99[a]	82.34[bc]	82.48[bc]	0.60
Phe	65.41[b]	75.22[a]	78.36[a]	74.24[a]	78.45[a]	1.42
Thr	72.05[b]	75.37[b]	79.88[a]	79.39[a]	81.41[a]	1.01
Val	75.06[b]	77.64[b]	75.26[b]	76.92[b]	83.49[a]	2.80
Sub-mean	74.96[c]	81.30[ab]	77.72[bc]	80.68[ab]	82.17[a]	0.88
Non-essential amino acids						
Ala	72.80[b]	77.33[a]	81.05[a]	78.86[a]	82.60[a]	1.60
Asp	85.36	87.58	85.70	86.98	85.74	0.76
Cys	77.22	82.56	80.35	80.67	83.64	1.05
Glu	84.08[b]	90.68[a]	86.14[ab]	89.42[a]	83.59[b]	0.98
Gly	60.22[c]	69.93[bc]	77.02[ab]	77.39[ab]	80.19[a]	2.26
Pro	73.75[b]	78.17[ab]	86.61[a]	86.43[a]	74.19[b]	1.93
Ser	79.01	82.89	84.24	81.67	80.56	0.85
Tyr	74.43	78.85	78.00	78.58	80.91	1.03
Sub-mean	75.36[b]	81.00[a]	82.39[a]	82.50[a]	81.43[a]	0.98
Total	75.16[b]	81.15[a]	80.05[a]	81.59[a]	81.80[a]	0.88

[a, b, c] Values with different superscripts in the same row significantly differ ($p<0.05$).

[1] SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300.

FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae–B. subtilis*.

[2] Standard error of means.

higher CP content in FSP could be because of increased microbial content after fermentation. The essential amino acid profile in HP300 was superior as compared with other soy protein sources. Highest CP content was observed in SPC, followed by FSP-B, HP300, FSP-A, and lowest in SBM.

The highest ADG in SPC fed animals could be the effect of higher ($p<0.05$) average daily feed intake (ADFI), and even the F/G was significantly improved in this group. As previously mentioned, the CP concentration of SPC was highest, and probably the piglets on this diet received higher ADFI and thereby received more CP and faster growth rate. The findings in the present study again confirmed that FSP could significantly improve the ADG than SBM fed group that we reported earlier (Yun et al., 2005). There was a linear increase in ADFI because of feeding processed soy proteins was also reported by Min et al. (2004). The F/G was inferior in SBM fed animals at all times in the present study. The animal performance was superior with SPC diet than others, which could also be attributed to its higher apparent total tract nutrient digestibilities than others. HP300 showed similar ADG to SPC only during 15-35 d. 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, 1981a; Walker et al., 1986b) or soybean meal (Leibholz, 1981; Wilson and Leibholz, 1981b; 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). Although the palatability problem was not more prominently observed in the present research, but similar response of lower feed intake and ADG in SBM fed diet when compared with dried skim milk (DSM), ISP (isolated soy proteins), and wheat gluten fed diets were also noted by Chae et al. (1999). In our present study, during all periods we found no difference in HP300, FSP-A and FSP-B with respect to ADG.

The digestibility of GE, CP, calcium and phosphorus digestibilities were lower in SBM fed animals as compared with other plant protein sources in our earlier studies (Yun et al., 2005; Kim et al., 2007). Similar results of lower GE, CP and Ca digestibilities in SBM fed animals than SPC and FSP-B was observed in present study, however, it was not different than FSP-A. 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), trypsin inhibitors and indigestible proteins such as glycinin and B-conglycinin (Li et al., 1991a), and anti-nutritional factors, in addition to the incomplete development of digestive system in pigs. The lower digestibility of nutrients lowered the ADG in this group. Higher DM and N digestibilities were also reported in pigs fed processed soy protein diet than to negative control (only SBM, without

Table 7. Effects of different soy protein source on true ileal digestibility of amino acids in weaned pigs

Soy protein sources[1]	SBM	SPC	HP300	FSP-A	FSP-B	SEM[2]
Essential amino acids						
Arg	85.61[b]	88.91[ab]	90.48[a]	90.88[a]	87.91[ab]	0.75
His	81.14[b]	88.59[a]	82.33[b]	83.84[b]	84.57[ab]	0.87
Ile	75.61[c]	84.76[a]	82.81[ab]	81.36[ab]	80.23[b]	0.97
Leu	81.40[b]	85.31[a]	84.15[ab]	85.65[a]	84.18[ab]	0.60
Lys	83.42[b]	88.48[a]	84.96[ab]	86.13[ab]	85.27[ab]	0.71
Met	83.48	88.37	86.52	84.04	86.81	0.89
Phe	80.11[b]	82.57[ab]	86.62[a]	79.61[b]	81.41[b]	0.78
Thr	80.30[c]	86.43[a]	84.28[ab]	80.15[c]	82.03[bc]	0.85
Val	79.79[b]	82.62[ab]	86.20[a]	84.27[ab]	84.55[ab]	0.97
Sub-mean	81.21[b]	86.23[a]	85.37[a]	83.99[ab]	84.11[ab]	0.59
Non-essential amino acids						
Ala	76.56[b]	83.19[ab]	85.76[a]	82.17[ab]	85.60[a]	1.27
Asp	87.37	89.19	86.95	87.30	86.07	0.71
Cys	82.03	86.55	84.82	82.34	84.67	1.12
Glu	86.79[bc]	92.77[a]	88.12[ab]	90.51[ab]	84.55[b]	0.95
Gly	78.05[b]	86.95[a]	91.24[a]	88.72[a]	90.23[a]	1.65
Pro	81.11[b]	84.56[ab]	91.19[a]	90.29[a]	79.37[b]	1.66
Ser	87.82[ab]	91.82[a]	91.71[a]	88.30[ab]	86.03[b]	0.84
Tyr	81.32	85.85	84.34	83.02	84.00	0.74
Sub-mean	82.63[b]	87.61[a]	88.02[a]	86.58[ab]	85.07[ab]	0.77
Total	81.92[b]	86.92[a]	86.69[a]	85.29[ab]	84.59[ab]	0.64

[a, b, c] Values with different superscripts in the same row significantly differ ($p<0.05$).

[1] SBM: soybean meal; SPC: soy protein concentrate; HP300. Hamlet protein 300.

FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae–B. subtilis*.

[2] Standard error of means.

Table 8. Effects of different soy protein source on ileal villous height, crypt depth and villous height: crypt depth ratio in weaned pigs

Soy protein sources[1]	SBM	SPC	HP300	FSP-A	FSP-B	SEM[2]
Villous height (μm)	310	312	314	311	315	4.32
Crypt depth (μm)	221	222	215	215	217	2.45
Villous height: crypt depth	1.41	1.40	1.46	1.44	1.45	0.02

[1] SBM: soybean meal; SPC: soy protein concentrate; HP300, Hamlet protein 300.

FSP-A, fermented soy protein by *A. oryzae*; FSP-B, fermented soy protein by *A. oryzae–B. subtilis*.

[2] Standard error of means.

processed soy protein) by Min et al. (2004). In our trial, except CP the digestibility of all the measured nutrients were lower ($p<0.05$) in HP300 than SPC and FSP-B.

Leu and Lys apparent ileal digestibility was not affected by dietary treatments. But the apparent ileal digestibility of some of the essential amino acids along with Leu and Lys was lower in SBM group than other plant protein sources like FSP and rice protein concentrate was reported earlier (Yun et al., 2005). The mean value of apparent ileal digestibility of non-essential amino acids was also lower in SBM as compared with other processed sources. The total amino acid digestibility also revealed the similar trend. The sub-mean value of apparent ileal digestibility of EAA was not different among FSP-B, FSP-A and SPC; but it was higher than HP300 and SBM. The non-essential amino acid like Asp, Cys, Ser and Tyr was not affected by dietary treatments. The mean apparent digestibility of non-EAA was comparable between FSP-A and FSP-B and also between SPC. Feeding processed soy protein to weanling pigs had increased apparent ileal digestibilities of most amino acids than to SBM diets were earlier reported (Min et al., 2004). As mentioned before, removal of one or the other anti-nutritional factors in processed soy protein sources as compared to SBM, improved the apparent amino acid digestibilities in processed soy sources. The trypsin inhibitor, oligosaccharides like raffinose and stachyose in soybean meal was removed during fungal and bacterial fermentation by protease and glucoamylase causing hydrolysis (Kim, 2005). The improvement in performance by FSP feeding could be the reduction in anti-nutritional factors, increase in CP content and these processed soy products contained small peptides that could be easily hydrolyzed by digestive proteases.

The sub-mean value of true ileal 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 present study, but the ileal digestibilities of amino acids in refined soybean proteins such as ISP and soy protein concentrate were improved over that of soybean meal due to reduction in anti-nutritional factors was reported by Walker et al. (1986b) and Sohn et al. (1994) that supports our findings. The sub-mean and total value of true ileal digestibility of EAA and non-EAA were comparable between SBM, FSP-A and FSP-B and also between SPC and HP300. However, HP300 and SPC showed improved true ileal digestibilities of EAA and non-EAA than SBM.

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 the morphological changes in intestine were suggested by Li et al. (1990), but the present study failed to show any such changes. High levels of plant proteins that may contain 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. Although the differences in feed intake in the present study were significant, it failed to contribute for significant changes in the villous structures. 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 are contradictory to the reports mentioned above and possibly this could be because of not much numerical differences in feed intake among treatments, although it is significant. Conclusively, the findings of the present study showed that the fermented soy proteins could be used as a replacement to soybean meal and may be an alternative for costly processed soy protein sources like HP300. Among different soy protein sources, soy protein concentrate gave superior results.

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