GROWTH PERFORMANCE AND AMINO ACID DIGESTIBILITIES AFFECTED BY VARIOUS PLANT PROTEIN SOURCES IN GROWING-FINISHING PIGS

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Summary

This experiment was carried out to compare the effects of six different plant protein sources such as soybean meal, extruded full-fat soybean, canola meal, rapeseed meal, cottonseed meal and perilla meal as a sole protein source of diets on growth performance and amino acid bioavailabilities in growing-finishing pigs. A total of 54 pigs with average 25 kg of body weight were used as experimental subjects for a 65-d feeding trial. Digestion trial was carried out with seven ileal-cannulated pigs. The most rapid rate of weight gain was observed in pigs fed soybean meal and full-fat soybean, the moderate one in pigs fed canola meal and cottonseed meal and the least one in pigs fed rapeseed meal and perilla meal ($p < 0.05$). Feed efficiency was better for groups fed soybean meal and full-fat soybean than other protein meals ($p < 0.05$). The apparent ileal digestibilities of essential amino acids of soybean meal and full-fat soybean (82.5% and 81.6%) were significantly ($p < 0.05$) higher than those of other protein sources (61.2 to 69.4%). Regardless of protein sources, the apparent ileal digestibility of arginine was highest, whereas that of histidine was lowest among essential amino acids. Proline had the lowest digestibility among non-essential amino acids. True amino acid digestibilities tended to be higher than apparent amino acid digestibilities. The differences between true and apparent ileal digestibilities were greater in canola meal, rapeseed meal or cottonseed meal than other protein sources. The differences was greatest in proline except for cottonseed meal. The fecal digestibility appeared to be higher than the ileal digestibility. The differences between fecal and ileal digestibilities were greater in canola meal, rapeseed meal, cottonseed meal and perilla meal than in soybean meal and full-fat soybean. In general, proline was the most disappeared amino acid in the hind gut, while the net synthesis of lysine in the large intestine was observed in all protein sources except perilla meal. It is appropriate that swine feeds should be formulated based on true ileal amino acid digestibility of protein sources for pig's normal growth.

(Key Words: Plant Protein Sources, Pigs, Amino Acid Digestibility, Cannulation)

Introduction

It is necessary to provide animals with adequate amount of protein for their normal growth and muscle deposition. Nutritional and physiological functions of dietary protein depend on the quantity and quality of amino acids which can be digested and absorbed in the digestive tract of animals. Protein quality of individual feedstuff was determined by its amino acid composition, content, balance or digestibility because total amount of amino acids in feeds was not available to the animals (Engster, 1985).

Enzymatic method (Denton and Elvehjem, 1953), chemical method (Sanger, 1945), microbiological method (Ford, 1960), plasma amino acid (Denton and Elvehjem, 1954), growth assay (Gupta and Elvehjem, 1957), fecal analysis method (Kuiken and Lyman, 1948) and ileal analysis method (Zebrowska, 1973) have been introduced to measure amino acid digestibility. The widely used method among them is ileal analysis method to measure the amino acid patterns that had disappeared in the small intestine of the animals fitted with ileal cannulaes, with consideration of microbial activities in large intestine (Low, 1979; Tanksley et al., 1981; Tanksley and Knabe, 1984; Furuya et al., 1986).

In many circumstances the cost of pig diets can be reduced if soybean meal is substituted with alternative protein sources. However, the ability of these protein sources to supply nutrients for normal growth needs to be fully evaluated before they can be efficiently incorporated in diet for

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TABLE 1. FORMULA AND CHEMICAL COMPOSITION OF THE DIETS FOR FEEDING TRIAL

	Soybean meal		Full-fat soybean		Canola meal		Rapeseed meal		Cottonseed meal		Perilla meal	
	Growing	Finishing	Growing	Finishing	Growing	Finishing	Growing	Finishing	Growing	Finishing	Growing	Finishing
Ingredients (%):												
Corn	76.10	81.44	72.96	79.54	69.13	76.07	65.00	73.00	70.70	77.30	68.12	75.36
Soybean meal	19.82	14.92	—	—	—	—	—	—	—	—	—	—
Full-fat soybean	—	—	24.50	18.36	—	—	—		—	—	—	—
Canola meal	—	—	—		24.40	18.50	—	—	—	—	—	
Rapeseed meal	—	—	—	—	—	—	25.92	19.64	—	—	—	—
Cottonseed meal	—	—	—	—		—			21.54	16.32	—	—
Perilla meal	—				—	—	—	—	—	—	23.38	17.72
Tallow	1.58	1.54	—	—	4.40	3.65	6.77	5.43	5.12	4.20	6.05	4.89
Lysine	—	—	0.04	—	0.05	—	0.21	0.12	0.24	0.14	0.39	0.25
Limestone	0.73	0.80	0.75	0.80	1.00	0.93	0.93	0.96	1.25	1.19	0.93	0.93
Dicalcium-phosphate	0.92	0.45	0.90	0.45	0.17	—	0.32	—	0.30	—	0.28	—
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
V-M mixture[1]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Antibiotics[2]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[3]												
ME (kcal/kg)	3,260.39	3,275.30	3,288.51	3,282.42	3,263.18	3,275.95	3,261.33	3,275.01	3,260.38	3,275.15	3,260.93	3,275.10
CP (%)	15.20	13.50	15.23	13.51	15.20	13.50	15.20	13.50	15.20	13.50	15.20	13.50
Lysine (%)	0.77	0.64	0.77	0.61	0.77	0.61	0.77	0.60	0.77	0.60	0.77	0.60
Methionine (%)	0.25	0.23	0.25	0.24	0.30	0.27	0.30	0.27	0.24	0.23	0.33	0.29
Ca (%)	0.61	0.50	0.62	0.50	0.61	0.50	0.61	0.50	0.61	0.50	0.61	0.50
P (%)	0.50	0.40	0.51	0.41	0.51	0.43	0.50	0.40	0.50	0.41	0.51	0.42

[1] Vit.-min. mixture contains as followings in 1 kg: Vitamin A, 2,000,000 IU; Vitamin D_3, 400,000 IU; Vitamin E, 250 IU; Vitamin K_3, 200 mg; Vitamin B_1, 20 mg; Vitamin B_6, 700 mg; Riboflavin, 10,000 mg; Pantothenic calcium, 3,000 mg; Choline chloride, 30,000 mg; Niacin, 8,000 mg; Folacin, 200 mg; Vitamin B_{12}, 13 mg; Mn, 12,000 mg; Zn, 15,000 mg; Co, 100 mg; Cu, 500 mg; Fe, 4,000 mg; Folic acid, 40 mg, BHT, 5,000 mg.

[2] Antibiotics: Virginiamycin 10 mg/kg

[3] Calculated value.

mulation. More comprehensive information on their compositional and nutritional characteristics would enable one to adjust dietary ingredients to any differences.

The objectives of these studies were (1) to compare alternative protein sources to soybean meal in terms of growth performance and amino acid digestibilities in growing-finishing pigs, and (2) to compare ileal vs. fecal and apparent vs. true amino acid digestibilities.

Materials and Methods

Diets

For the feeding trial, experimental diets were formulated to maintain 3,260 kcal/kg ME and 15.2% CP for growing period (1 to 6 weeks) and 3,275 kcal/kg ME and 13.5% CP for finishing period (7 to 9 weeks). Dietary protein was provided by each test protein source [soybean meal, extruded full-fat soybean, canola meal, rapeseed meal, cottonseed meal and perilla (*Perilla acimoides*, L.) meal] and the diets deficient in lysine were supplemented with synthetic L-lysine. The formula and chemical composition of the diets are given in table 1. All nutrients were formulated to meet or exceed the NRC nutrient requirements (NRC, 1988).

The cornstarch-based diets were used to estimate the protein and amino acid digestibility. Cr_2O_3 was included at 0.3% level in the diet and 0 to 5% of cellulose was used to control dietary energy level. A protein-free diet was used to estimate endogenous amino acid excretion. The formula and chemical composition of the diets for digestion trial are shown in table 2.

TABLE 2. FORMULA AND CHEMICAL COMPOSITION OF THE DIETS FOR DIGESTION TRIAL

	Soybean meal	Full fat soybean	Canola meal	Rapeseed meal	Cottonseed meal	Perilla meal	Protein free
Ingredients (%):							
Soybean meal	36.87	–	–	–	–	–	–
Full-fat soybean	–	44.20	–	–		–	–
Canola meal	–	–	42.70	–	–	–	–
Rapeseed meal	–	–	–	44.20	–	–	–
Cottonseed meal		–	–	–	38.80	–	–
Perilla meal	–	–	–		–	41.70	
Corn starch	55.20	47.90	55.15	50.00	52.50	51.90	88.95
Cellulose	5.00	5.00	–	–	2.95	1.25	5.00
Corn oil	–			3.50	3.00	3.00	2.00
Limestone	0.18	0.18	0.70	0.65	1.10	0.70	–
Dicalcium-phosphate	1.60	1.57	0.30	0.50	0.50	0.30	2.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
V-M mixture[1]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Antibiotics[2]	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Cr_2O_3	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[3]							
ME (kcal/kg)	3,417.29	3,537.41	3,380.96	3,326.12	3,332.84	3,326.82	3,740.58
CP (%)	16.22	16.22	16.23	16.18	16.18	16.18	0.00
Lysine (%)	1.07	0.99	0.97	0.69	0.66	0.40	0.00
Methionine (%)	0.19	0.20	0.29	0.30	0.19	0.35	0.00
Ca (%)	0.61	0.61	0.63	0.63	0.61	0.63	0.79
P (%)	0.51	0.54	0.55	0.53	0.54	0.54	0.50

[1,2] See the footnote of table 1.

[3] Calculated value.

Design

A total of 54 castrated two way-crossbred pigs (Landrace × Large White) with average of 25 kg of initial body weight were assigned in Completely Randomized Design for a feeding trial. Six treatments in the feeding trial had 3 replicates with 3 heads in each replicate. Seven boars weighing 25 to 30 kg and fitted with ileocecal simple T-cannula were assigned in the 7 × 4 Youden Square of Incomplete Latin Square Design for digestion trial. Cannulation was performed according to the procedure described by Walker et al. (1986). Each test period lasted seven days, and during this period equal amounts of diet mixed with water were given twice daily at the level of 5.3% body weight at 08:00 h and 20:00 h. Feces were collected for 24 hours on the 5th day after 4 days of adaptation period. On the 6th and 7th day postfeeding, ileal digesta was collected in soft plastic bags for 2-h intervals between 08:00 h and 20:00 h each day. On the second day of collection, the ileum collections were made in the alternative 2-h periods to those of the previous day. The entire feces and digesta samples were dried in an air-forced drying oven at 60℃ for 48 or 72 hours, respectively. All the samples prepared in this manner were ground with 1 mm mesh Wiley mill for chemical analyses.

Chemical analyses

Proximate nutrients of diets, intestinal digesta and feces were analyzed according to AOAC (1990) procedures. Cr was measured by atomic absorption spectrophotometer (Shimadzu, AA625). Amino acid contents were determined by automated amino acid analyzer (Model: 4150 alpha, LKB), following acid hydrolysis in 6N HCl at 110℃ for 16 hours (Mason, 1984).

Calculations

Nitrogen and amino acid (AA) digestibilites were calculated based on the levels of chromic oxide in feed, ileal digesta and feces according to the following equations.

$$\text{(1) AID (\%)} = \frac{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}} - \dfrac{\text{ileal AA content}}{\text{ileal Cr content}}}{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}}} \times 100$$

$$\text{(2) AFD (\%)} = \frac{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}} - \dfrac{\text{fecal AA content}}{\text{fecal Cr content}}}{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}}} \times 100$$

$$\text{(3) TID (\%)} = \frac{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}} - \left(\dfrac{\text{ileal AA content}}{\text{ileal Cr content}} - \dfrac{\text{EIAA}}{\text{ICr}}\right)}{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}}} \times 100$$

$$\text{(4) TFD (\%)} = \frac{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}} - \left(\dfrac{\text{fecal AA content}}{\text{fecal Cr content}} - \dfrac{\text{EFAA}}{\text{FCr}}\right)}{\dfrac{\text{dietary AA content}}{\text{dietary Cr content}}} \times 100$$

* AID : apparent ileal digestibility　　TID : true ileal digestibility

AFD : apparent fecal digestibility　　TFD : true fecal digestibility

EIAA : endogenous ileal AA content after feeding protein free diet

ICr : ileal Cr content after feeding protein free diet

EFAA : endogenous fecal AA content after feeding protein free diet

FCr : fecal Cr content after feeding protein free diet

Statistical Analyses

Treatment means were compared by Duncan's multiple range test (Duncan, 1955), using General Linear Model Procedure of SAS (1985) package program.

Results and Discussion

Growth performance

Table 3 shows daily weight gain, daily feed intake and feed efficiency of pigs fed six protein meal diets for 65-d postfeeding. Overall means of final body weights ranged from 52 to 82 kg. The most rapid body weight gain was observed in pigs fed soybean meal and full-fat soybean, the moderate one was in pigs fed canola meal and cottonseed meal, the least one was in pigs fed rapeseed meal and perilla meal ($p < 0.05$). Feed intake was highest for pigs fed full-fat soybean and pigs fed soybean meal, canola meal and cottonseed meal showed moderate feed intake. Pigs fed rapeseed meal and perilla meal showed the lowest feed intake. Feed efficiency was better for groups fed soybean meal and full-fat soybean than other protein meals ($p < 0.05$).

The performance of pigs fed cottonseed meal diet was low probably due to low lysine digestibility of cottonseed meal as described by Knabe et al. (1979). Furthermore, they indicated that growth performance of pigs fed cottonseed meal diets never equaled that of pigs fed soybean meal diet even if synthetic lysine was supplemented up to a total dietary lysine content of 0.8%. It was suggested that the growth depressing effect by rapeseed meal was due to the poor palatability, toxic effects of residual glucosinolate and the low digestibility of most of its amino acids (Cho and Bayley, 1972; Han et al., 1975). We couldn't explain about what caused to limit feed intake when fed perilla meal

TABLE 3. EFFECT OF PLANT PROTEIN SOURCES ON THE DAILY BODY WEIGHT GAIN, FEED INTAKE AND FEED EFFICIENCY OF PIGS

	Initial body weight (kg)	Final body weight (kg)	Daily weight gain (kg/d)	Daily feed intake (kg/d)	Feed efficiency
Soybean meal	25.0	79.6[a]	0.84[a]	2.38[ab]	2.84[b]
Full-fat soybean	25.2	82.0[a]	0.87[a]	2.56[a]	2.94[b]
Canola meal	25.6	70.0[b]	0.68[b]	2.35[ab]	3.43[a]
Rapeseed meal	25.5	62.5[c]	0.57[c]	2.10[b]	3.71[a]
Cottonseed meal	25.9	70.1[b]	0.68[b]	2.39[ab]	3.52[a]
Perilla meal	24.8	52.5[d]	0.43[d]	1.55[c]	3.65[a]
SE[1]	0.14	2.58	0.04	0.09	0.10

[abcd] Values with different superscripts within the same column are significantly different ($p < 0.05$).

[1] Pooled standard error, n = 3.

Unprocessed full-fat soybeans did not improve pig performances due to its antinutritional factors or inefficient energy and protein utilization (Rackis, 1972; Cook et al., 1988; Cera et al., 1990). But extruded full-fat soybeans markedly improved animal performance in this study as indicated by Rackis (1972), Vandergrift et al. (1983) and Knabe et al. (1989). They reported that heating or extruding soybeans improved nitrogen, amino acid and energy digestibility, nitrogen retention and pig performance. Performance, feed intake, or palatability of pigs fed other protein meals did not exceed those of pigs fed either soybean meal or full-fat soybean as demonstrated by many workers (Han et al., 1975; Sauer et al., 1982; Kim, 1988; Mckinnon and Bowland, 1977; Cho and Bayley, 1972; Dyer et al., 1951; Hale and Lyman, 1961; Larson and Bell, 1967).

Amino acid digestibility

1) Apparent and true ileal digestibility

Table 4 presents the mean values of apparent and true ileal amino acid or crude protein digestibilities of six protein sources. Apparent ileal digestibilities of total essential amino acids were in the order of soybean meal, full-fat soybean, canola meal, cottonseed meal, rapeseed meal and perilla meal, respectively, from the highest to the lowest. No significant differences were observed between soybean meal and full-fat soybean ($p > 0.05$). Apparent ileal digestibilities of most essential amino acids of soybean meal and full-fat soybean were remarkably higher than those of other protein sources. There were no significant differences in apparent ileal protein digestibilities among soybean meal, full-fat soybean and cottonseed meal ($p > 0.05$). Those digestibilities, however, were significantly higher than those of rapeseed meal or perilla meal ($p < 0.05$).

Apparent ileal digestibility of lysine was 87.1 % for soybean meal, which was similar to the values estimated by Sauer et al. (1982), Green et al. (1988), Tanksley et al. (1981), Knabe et al. (1989), Tanksley and Knabe (1984) and Green and Kiener (1989). For soybean meal, apparent ileal digestibility of methionine (71.9%) was lower than the previous values (83.0-89.1%) whereas that of threonine (82.6%) was higher than those (73.6-76.0 %) reported by Sauer et al. (1982), Tanksley and Knabe (1984) and Green and Kiener (1989).

Apparent ileal digestibility of essential amino acids was 81.6% for full fat soybean, which was in good agreement with the value in autoclaved soyflake reported by Ozimek et al. (1985). Apparent ileal digestibilities of lysine and threonine in full-fat soybean were 89.3% and 83.6%, respectively, in the present study. These values were higher than 82.0-78.0% and 70.0-67.0%, respectively, obtained from the studies by Knabe et al. (1989) and Rudolph et al. (1983).

Canola meal had slightly higher digestibilities than rapeseed meal without significant differences ($p > 0.05$). Apparent digestibilities of lysine (70.4 %) and threonine (65.6%) of canola meal measured at the end of small intestine were in good agreement with the values of 72.8-75.4% and 62.1-67.2%, respectively, reported by Sauer et al. (1982), Sauer and Ozimek (1986), Knabe et al. (1989) and Imbeah and Sauer (1991). For canola meal, methionine was the most digestible (89.3%) essential amino acid through the small intestine.

Apparent ileal digestibility of methionine in rapeseed meal (81.5%) agreed well with 82.0-84.3 % estimated by Sauer et al. (1982) and Green and Kiener (1989). Lysine and threonine digestibilities in rapeseed meal in this trial, 63.2% and 49.4%, respectively, were lower than the values of 69.0-73.5% and 64.0-68.0%, respectively, reported by Green and Kiener (1989) and Sauer et al. (1982).

Marked reduction in ileal and fecal lysine digestibilities of cottonseed meal was also noticed in this study as indicated by Tanksley et al. (1981) and Furuya et al. (1986), which evidently led to poor performances. Therefore, it was suggested to add lysine to the diets composed of large proportion of cottonseed meal (Tanksley and Knabe, 1984). Apparent ileal digestibility of lysine in cottonseed meal was estimated to be 56.0%, which was close to the 53.0% reported by Sauer and Ozimek (1986), but lower than 67.0% estimated by Furuya and Kaji (1989). Methionine and threonine digestibilities of cottonseed meal at the end of small intestine were 56.0% and 52.5%, respectively, in the present study, while the values ranged from 67.7% to 78.0% and 62.0% to 69.0%, respectively, in the studies by Tanksley and Knabe (1984) and Furuya and Kaji (1989).

Apparent ileal digestibility of lysine (66.6%) in perilla meal was in good agreement with 69.7% estimated by Kim (1988), while those of methionine and threonine, 58.1% and 46.6%, respectively, in the present study were relatively lower than the values of 92.3% and 79.0%, respectively, reported by Kim (1988).

Fecal or ileal amino acid digestibilities of soybean meal or full-fat soybean were reported to be relatively higher than those of canola meal, sunflower meal, perilla meal, cottonseed meal, peanut meal, feather meal, rapeseed meal, or meat and bone meal (Knabe et al., 1989; Cho and Bayley, 1972; Kim, 1988).

These results support those responses obtained from the feeding trial in which pigs fed either soybean meal or full-fat soybean grew more rapidly, ate more feed, and showed better feed efficiency than those pigs fed other protein sources.

Regardless of the dietary protein source, the apparent ileal digestibility of arginine was highest among other amino acids, which was in good agreement with the results of Knabe et al. (1989), Furuya et al. (1986), Tanksley et al. (1981) and Rudolph et al. (1983), whereas that of histidine was lowest. Among the dispensable amino acids, proline had the least digestibility, which appeared to be due to its high concentration in the endogenous protein as described by Holmes et al. (1974) and Green et al. (1987).

Similar to apparent ileal amino acid digestibi-

TABLE 4. APPARENT AND TRUE ILEAL DIGESTIBILITIES OF CRUDE PROTEIN AND AMINO ACIDS OF PLANT PROTEIN SOURCES FED TO PIGS (%)

Item	Soybean meal		Full-fat soybean		Canola meal		Rapeseed meal		Cottonseed meal		Perilla meal		SE[1]	
	Apparent	True	Apparent	True	Apparent	True	Apparent	True	Apparent	True	Apparent	True	Apparent	True
Crude protein	75.3[a]	79.2[A]	81.7[a]	84.9[A]	62.9[b]	68.2[B]	52.7[c]	59.1[C]	71.9[ab]	77.3[A]	42.5[d]	48.8[D]	3.04	2.79
Essential amino acids														
ARG	94.0[a]	94.6[AB]	94.9[a]	96.3[A]	90.5[a]	90.9[B]	90.7[a]	91.3[AB]	92.8[a]	93.4[AB]	80.4[b]	80.7[C]	1.31	1.59
HIS	64.5[a]	69.9[A]	60.4[a]	66.3[A]	43.5[bc]	44.5[AB]	43.8[bc]	44.6[AB]	51.6[ab]	57.5[AB]	35.0[c]	40.6[B]	2.76	3.67
ILE	86.5[a]	87.1[A]	82.6[a]	83.5[A]	69.9[b]	71.7[B]	55.8[c]	57.5[C]	63.1[bc]	64.6[BC]	66.4[b]	66.5[BC]	2.65	2.40
LEU	86.0[a]	87.4[A]	86.7[a]	88.2[A]	72.3[b]	74.8[B]	62.2[c]	55.3[CD]	68.1[bc]	71.2[BC]	63.4[c]	63.8[D]	2.43	2.27
LYS	87.1[a]	88.5[A]	89.3[a]	90.9[A]	70.4[b]	71.0[B]	63.2[bc]	63.5[B]	56.0[c]	66.9[B]	66.6[b]	66.7[B]	2.96	3.42
MET	71.9[b]	79.3[BC]	75.2[b]	82.5[ABC]	89.3[a]	90.4[A]	81.5[ab]	83.2[AB]	56.0[c]	73.5[C]	58.1[c]	59.0[D]	2.88	2.41
PHE	87.8[a]	88.4[A]	81.3[ab]	81.7[AB]	50.8[c]	51.1[C]	73.6[b]	74.8[B]	84.0[ab]	84.9[A]	72.4[b]	72.5[B]	2.91	2.79
THR	82.6[a]	85.0[A]	83.6[a]	85.7[A]	65.6[b]	69.1[B]	49.4[c]	52.1[D]	52.5[c]	59.1[C]	46.6[c]	47.6[D]	3.57	3.32
VAL	81.7[a]	84.0[A]	80.8[a]	83.9[A]	71.9[b]	75.0[B]	53.1[d]	57.8[D]	63.5[c]	67.5[C]	61.6[cd]	63.3[CD]	2.58	2.22
Submean	82.5[a]	84.9[A]	81.6[a]	84.4[A]	69.4[b]	70.9[B]	63.7[bc]	65.6[C]	65.3[bc]	71.0[B]	61.2[c]	62.3[C]	2.02	2.04
Non-essential amino acids														
ALA	76.9[a]	80.3[A]	76.3[a]	80.3[A]	64.7[b]	70.3[B]	51.9[c]	58.8[C]	58.6[bc]	65.1[BC]	52.3[c]	57.4[C]	2.64	2.18
ASP	85.4[a]	87.5[A]	90.1[a]	91.8[A]	68.6[b]	73.0[B]	70.3[b]	75.1[B]	71.7[b]	76.3[B]	47.9[c]	51.0[C]	3.15	2.88
GLU	86.2[ab]	87.5[AB]	91.3[a]	92.1[A]	76.2[c]	78.2[C]	76.1[c]	78.3[C]	79.0[bc]	81.1[BC]	53.2[d]	54.5[D]	2.73	2.63
GLY	78.2[a]	81.8[A]	77.6[a]	80.7[A]	68.4[ab]	76.2[A]	59.7[b]	64.2[B]	58.8[b]	64.6[B]	39.5[c]	44.2[C]	3.14	2.95
PRO	70.1[a]	79.5[A]	74.8[a]	80.9[A]	55.1[b]	82.2[A]	26.8[c]	85.9[A]	56.2[b]	56.5[B]	37.5[c]	44.7[B]	4.11	4.36
SER	85.5[a]	87.4[A]	86.0[a]	87.5[A]	65.6[b]	68.9[B]	61.8[bc]	65.6[B]	64.6[b]	68.3[B]	53.2[c]	55.4[C]	2.88	2.61
TYR	88.2[a]	89.2[A]	81.9[a]	82.5[A]	62.1[b]	62.3[C]	70.4[b]	71.0[B]	81.1[a]	82.7[A]	70.1[b]	71.5[B]	2.22	2.16
Submean	81.5[a]	84.8[A]	82.6[a]	85.1[A]	65.8[b]	73.0[B]	59.6[b]	71.3[B]	67.1[b]	70.6[B]	50.5[d]	54.2[C]	2.64	2.32
Mean	82.0[a]	84.8[A]	82.0[a]	84.7[A]	67.8[b]	71.9[B]	61.9[bc]	68.1[B]	66.1[b]	70.8[B]	56.5[c]	58.8[C]	2.26	2.09

a,b,c,d Values with different superscripts within the same row are significantly different ($p < 0.05$).

A,B,C,D Values with different superscripts within the same row are significantly different ($p < 0.05$)

[1] Pooled standard error, n = 4.

TABLE 5. APPARENT AND TRUE FECAL DIGESTIBILITIES OF CRUDE PROTEIN AND AMINO ACIDS OF PLANT PROTEIN SOURCES FED TO PIGS (%)

Item	Soybean meal		Full-fat soybean		Canola meal		Rapeseed meal		Cottonseed meal		Perilla meal		SE[1]	
	Apparent	True	Apparent	True	Apparent	True	Apparent	True	Apparent	True	Apparent	True	Apparent	True
Crude protein	81.2[a]	95.0[A]	82.2[a]	93.4[AB]	69.8[b]	88.7[B]	66.3[b]	88.3[B]	70.8[b]	93.0[AB]	52.9[c]	73.4[C]	2.39	1.63
Essential amino acids														
ARG	96.3[a]	97.3[A]	93.8[ab]	94.9[AB]	89.3[bc]	90.5[BC]	95.1[a]	96.0[AB]	93.3[ab]	94.3[AB]	86.6[c]	87.9[C]	0.94	0.93
HIS	64.6[a]	71.1[A]	65.5[a]	68.4[AB]	48.9[bc]	58.5[BC]	44.1[c]	56.3[BC]	57.8[ab]	72.2[A]	46.9[c]	49.3[C]	2.15	2.25
ILE	89.7[a]	91.7[A]	85.3[ab]	87.8[AB]	78.5[bc]	82.0[BC]	72.4[c]	77.9[C]	77.9[bc]	83.9[BC]	76.4[c]	79.9[C]	1.51	1.32
LEU	87.3[a]	89.6[A]	85.3[a]	87.7[AB]	76.3[b]	80.0[BC]	73.7[b]	79.1[BC]	76.6[b]	82.7[ABC]	72.9[b]	76.9[C]	1.57	1.42
LYS	84.6[a]	87.4[A]	85.9[a]	88.2[A]	56.8[c]	65.2[C]	46.6[d]	56.2[D]	52.0[cd]	63.1[CD]	68.0[b]	77.1[B]	3.39	2.78
MET	77.2[bc]	80.5[BC]	81.0[ab]	82.8[BC]	90.0[a]	92.0[A]	35.1[ab]	88.8[AB]	68.1[c]	78.1[C]	73.0[bc]	77.1[C]	2.10	1.65
PHE	84.9[a]	87.0[A]	87.4[a]	89.5[A]	81.2[ab]	84.7[A]	85.7[a]	88.8[A]	85.6[a]	89.0[A]	76.4[b]	77.3[B]	1.18	1.16
THR	87.5[a]	90.5[A]	84.1[a]	87.0[AB]	75.9[b]	79.9[BCD]	70.0[bc]	76.3[CD]	75.9[b]	82.9[ABC]	65.5[c]	72.1[D]	1.82	1.59
VAL	88.5[a]	91.0[A]	86.0[a]	88.6[A]	79.1[ab]	82.4[AB]	72.6[b]	77.9[B]	81.1[ab]	86.5[AB]	73.9[b]	77.6[B]	2.68	1.57
Submean	84.5[a]	87.3[A]	83.8[a]	86.1[AB]	75.1[b]	79.5[BC]	71.7[b]	77.5[C]	74.2[b]	81.4[ABC]	71.1[b]	75.0[C]	1.41	1.22
Non-essential amino acids														
ALA	74.6[a]	78.4[AB]	63.3[b]	68.2[B]	71.1[ab]	72.7[AB]	66.4[ab]	73.9[AB]	72.8[ab]	81.2[A]	70.9[ab]	75.7[AB]	1.41	1.58
ASP	90.8[a]	93.1[A]	89.7[a]	91.6[AB]	74.5[c]	80.2[D]	79.6[b]	84.7[CD]	82.1[b]	87.8[BC]	66.9[d]	72.3[E]	1.80	1.55
GLU	90.7[a]	92.4[A]	89.5[a]	90.9[AB]	82.9[b]	85.9[B]	86.2[ab]	89.1[AB]	87.9[ab]	91.1[AB]	72.7[c]	75.1[C]	1.34	1.31
GLY	79.1[a]	82.5[A]	75.3[a]	78.6[AB]	76.2[a]	80.2[A]	75.7[a]	80.7[A]	78.2[a]	84.6[A]	68.0[b]	72.4[B]	1.10	1.14
PRO	87.0[a]	87.5[A]	86.1[a]	86.6[A]	75.1[b]	78.8[AB]	66.9[c]	73.4[B]	75.7[b]	83.3[A]	45.2[d]	48.7[C]	2.94	2.56
SER	89.2[a]	91.7[A]	88.0[a]	90.2[AB]	75.0[b]	79.4[D]	77.8[b]	82.7[CD]	79.5[b]	85.2[BC]	63.3[c]	71.0[E]	1.86	1.54
TYR	84.3[ab]	85.9[AB]	82.8[abc]	85.9[AB]	78.2[abc]	82.4[AB]	74.6[c]	79.4[B]	85.3[a]	89.4[A]	75.5[bc]	79.1[B]	1.35	1.23
Submean	85.1[a]	87.4[A]	82.1[ab]	84.6[A]	76.1[bc]	80.0[A]	75.3[c]	80.6[A]	80.7[abc]	86.1[A]	66.1[d]	70.6[B]	1.41	1.31
Mean	84.8[a]	87.4[A]	83.0[a]	85.4[AB]	75.6[b]	79.7[BC]	73.3[bc]	78.8[BC]	76.9[b]	83.4[AB]	68.9[c]	73.1[C]	1.35	1.12

a,b,c,d Values with different superscripts within the same row are significantly different ($p < 0.05$).

A,B,C,D,E Values with different superscripts within the same row are significantly different ($p < 0.05$).

[1] Pooled standard error, n = 4.

lities, overall tendencies in the true ileal amino acid digestibilities almost unchanged. The true digestibility values, however, tended to be higher than the apparent digestibility values by 2.3-6.2 percentage units because endogenous amino acids were subtracted from the total amount of amino acids in ileal digesta. That is to say, the apparent digestibility may underestimate the real availability of nitrogen and amino acids in swine.

2) Apparent and true fecal digestibility

Apparent and true fecal digestibilities of crude protein and amino acids of six protein sources are presented in table 5. Soybean meal and full-fat soybean had more digestible essential and non-essential amino acids in the total digestive tract than other protein sources.

In general, apparent fecal digestibilities followed the same pattern as the apparent ileal digestibility, but the values tended to be higher when measured over the total digestive tract due to the disappearance of nitrogen in the hind gut. So, the digestibility measured over the total digestive tract may overestimate the real availability of amino acids since all amino acids would be deaminated by microorganisms to yield ammonia and various amines of no nutritional value in the large intestine as described by Fauconneau and Michel (1970), Michel (1966) and Zebrowska (1973). When ileal digestibility values are subtracted from fecal ones, a positive value indicates the amount of disappearance or extent of digestion in the large intestine (in percentage units), while a negative value indicates a synthesis of that amino acid in the large intestine. In most instances, amino acids disappeared from the large intestine. Greater disappearance in the large intestine occurred, in general, for amino acids with the lower digestibilities at the end of the small intestine, which were, for example, phenylalanine in canola meal, threonine in rapeseed meal and cottonseed meal and glycine in perilla meal. These were in good agreement with the results of Tanksley et al. (1984). The amount of amino acids disappeared in the large intestine was greater in canola meal, rapeseed meal, cottonseed meal and perilla meal than in soybean meal and full-fat soybean. For individual amino acids, proline, in general, was the most disappeared amino acid in the hind gut, while the net synthesis of lysine in the large intestine was observed in all protein sources except perilla meal. Net synthesis of some amino acids including lysine, arginine, methionine, cystine and tyrosine has been previously reported by other workers (Holmes et al., 1974; Tanksley et al., 1981; Tanksley and Knabe, 1984; Sauer and Ozimek, 1986).

True fecal digestibilities of essential and non-essential amino acid of each protein source tended to increase slightly more than the corresponding apparent fecal digestibilities since the contribution of endogenous amino acids was eliminated.

From these results, ileal or true digestibility seemed to be more accurate in determining digestible amino acid contents of pig diets rather than fecal or apparent digestibility. Therefore, swine feeds should be formulated based on true ileal amino acid digestibility for normal growth of pigs.

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