Apparent Digestibility of Amino Acids, Energy and Proximate Nutrients in Dietary Protein Sources for Young Pigs

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ABSTRACT : This experiment was conducted to determine apparent ileal and fecal digestibilities of protein sources for young pigs (15.6 kg BW) which were fitted with simple ileal T-cannulas. Experimental diets included one of the followings as a sole protein source: spray-dried plasma protein (SDPP), spray-dried blood meal (SDBM), soybean meal (SBM), isolated soy protein (ISP), dried skim milk (DSM), and fish meal (FM). The digestibilities of dry matter (DM), gross energy (GE) and crude protein (CP) in DSM-based diet were the highest ($p<0.05$), and those of SDBM and SBM diets were the lowest at the terminal ileum. The average ileal digestibilities of essential amino acids (AAs) were 88.3, 84.7, 84.6, 83.4, 83.0 and 77.7% for pigs fed the DSM, ISP, SDBM, SBM, SDPP and FM diets, respectively. There were no significant differences in overall apparent ileal AAs digestibilities in DSM and ISP diets. Digestibilities of essential AAs in DSM, however, were significantly higher than those of ISP ($p<0.05$). Among the essential AAs, the digestibility of arginine was higher except for SDBM or DSM, than other AAs. The ileal digestibilities of lysine, methionine and threonine were higher ($p<0.05$) in pigs fed SDBM or DSM diet than in those fed SBM diet. Digestibilities for SDPP or ISP diet in these AAs were similar except for threonine which was higher ($p<0.05$) for SDPP diet. The apparent ileal digestibilities of lysine and methionine ranged from 79.6 (FM) to 92.5 (DSM) and 75.4 (SDPP) to 88.7 (DSM), respectively. The apparent fecal digestibilities of average essential AAs were 90.4, 89.1, 86.0, 84.4, 84.2 and 80.8% in pigs fed the DSM, ISP, SDBM, SDPP, SBM and FM diets, respectively. The fecal digestibilities of essential AAs were higher ($p<0.05$) in pigs fed the DSM and ISP. Lysine digestibility in pigs fed the DSM or ISP diet was higher ($p<0.05$) than that of pigs fed SBM diet. Apparent essential AAs digestibility was the highest ($p<0.05$) in pigs fed DSM diet, and was the lowest ($p<0.05$) in pigs fed FM diet. Digestibilities of essential AAs and nonessential AAs were higher when measured over the total digestive tract than at the end of the small intestine except for several AAs in SDPP, SDBM and SBM diets. In conclusion, whether it is fecal or ileal, the digestibilities of proximate nutrients and AAs in pigs fed DSM and ISP diet were the highest, and those of pigs fed FM was the lowest.

(**Key Words**: Young Pigs, Protein Sources, Apparent Ileal Digestibility, Cannulation, Apparent Fecal Digestibility)

INTRODUCTION

Knowledge on amino acid digestibilities of feedstuffs is particularly important in formulating pig diets since the minimum quantity of high-protein feedstuffs is included to meet the requirement for the first limiting amino acid. In order to provide adequate, but not excessive, levels of amino acids for swine, it is important to formulate diets based on digestible amino acids rather than total amino paid to amino acids likely to be limiting. The nutritive value of protein is determined not only by its amino acid composition but also by its ability to supply biologically available amino acids for protein synthesis.

During the last 2 decades, many attempts have been conducted to replace milk products with alternative protein sources due to their inconsistent availability and high cost for growing period. Refined soy proteins, but not soybean meal, provide equal or improved growth performance as compared with a milk-based diet (Dietz et al., 1988; Geurin et al., 1988; Li et al., 1991; Sohn et al., 1994). Several reports suggested that even though digestibilities of further processed soybean products were

This study was funded by Korean Science & Engineering Foundation (KOSEF) and Pusan Kyungnam Pig Farmers Co-operative.

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Received March 20, 1997; Accepted September 3, 1997

improved over that of soybean meal, digestibilities of the alternative protein sources were still poorer than those obtained in pigs fed milk protein (Walker et al., 1986b). Sohn (1992a,b) suggested that ISP (isolated soy protein), SPC (soy protein concentrate), SDPP (spray dried plasma protein) and SDBM (spray dried blood meal) could be effectively used as an alternatives to milk protein in early-weaned pigs. However, there is not much information on the ileal digestibility of those alternative protein sources except Sohn et al. (1994) and Chae (1996). Chae (1996) reported that nutrient digestibilities in several protein sources were generally higher in conventionally-weaned (CW) pigs (21 day-old and 6.26 kg average BW) than in early-weaned (EW) pigs (10 day old and 3.13 kg average BW) and that the crude protein and average essential amino acid digestibilities of SBM- and SDPP-based diets were lower than digestibility of DSM-based diet in early-weaned pigs.

Therefore, this study was designed to determine the ileal and fecal digestibilities of nutrients of the six different protein sources in young pigs and provide a basic information for formulating young pigs diet.

MATERIALS AND METHODS

Thirty six castrated crossbred pigs (Landrace × Large White, 15.6 kg of BW) were housed individually on metabolism cage on the basis of body weight. The six dietary treatments were spray dried plasma protein (SDPP), spray dried blood meal (SDBM), isolated soy protein (ISP), soybean meal (SBM), dried skim milk (DSM) and fish meal (FM). Cr_2O_3 was added to each diet to provide an indigestible marker. Compositions of experimental diets and amino acid profiles of protein sources are shown in table 1 and 2. Diets were formulated to 20% crude protein and supplemented with

Table 1. Composition of experimental diets for digestibility trial (%)

	SDPP	SDBM	SBM	DSM	ISP	FM
Ingredients:						
SDPP	26.66	–	–	–	–	–
SDBM	–	23.25	–	–	–	–
SBM	–	–	45.46	–	–	–
DSM	–	–	–	60.07	–	–
ISP	–	–	–	–	22.22	–
FM	–	–	–	–	–	30.77
Corn starch	32.78	36.42	15.04	32.58	36.73	32.63
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00
Lactose	30.00	30.00	30.00	0.00	30.00	30.00
Limestone	0.01	0.00	0.10	0.00	0.00	0.00
DCP (18%)	4.80	4.58	3.35	1.60	5.00	0.85
Salt	0.00	0.00	0.30	0.00	0.30	0.00
Vit.-min. mix.[1]	2.50	2.50	2.50	2.50	2.50	2.50
Antibiotics[2]	1.00	1.00	1.00	1.00	1.00	1.00
Chromic oxide	0.25	0.25	0.25	0.25	0.25	0.25
Limestone	0.01	0.00	0.10	0.00	0.00	0.00
ME (kcal/kg)	3,637.31	3,259.69	3,318.03	3,606.31	3,463.75	3,326.72
CP (%)	20.00	20.00	20.00	20.00	20.00	20.00
Lysine (%)	1.63	1.73	1.32	1.53	1.38	1.54
Methionine (%)	0.14	0.24	0.24	0.54	0.33	0.61

Abbreviations; SDPP=spray-dried plasma protein; SDBM=spray-dried blood meal; SBM=soybean meal; ISP=isolated soy protein; DSM=dried skim milk; FM=fish meal.

[1] Supplied per kilogram of diet: 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_2, 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; sucrose to make 1 kg vit.-min. mixture.

[2] Supplied per kilogram of diet: Chlortetracycline, 110 mg; Sulfathiazole, 110 mg; penicillin, 55 mg.

vitamins and minerals over the estimated NRC (1988) requirement. Metabolic energy of diets ranged from 3,637 (SDPP) to 3,260 (SDBM) kcal/kg. Lactose was added to all diets except for dried skim milk for an equal amount of lactose provided by DSM. Lysine and threonine contents were greater for SDPP and SDBM sources than any other protein sources whereas methionine content of SDPP and SBM sources was lower than that of any other protein sources (table 2).

Table 2. Amino acid profiles of protein sources (as fed-basis)

	SDPP	SDBM	SBM	DSM	ISP	FM
CP (%)	74.75	90.42	43.03	35.34	86.27	56.79
EAA (%)						
THR	4.29	4.63	1.61	1.43	3.01	2.59
VAL	4.31	6.97	1.59	1.95	4.05	3.23
MET	0.64	1.57	0.51	0.92	1.06	3.13
ILU	2.28	0.67	1.68	1.51	3.19	2.52
LEU	5.66	9.09	3.30	2.75	6.55	4.41
PHE	3.38	4.20	1.96	1.38	4.52	2.39
HIS	2.52	5.17	1.10	1.13	2.03	1.62
LYS	6.17	8.30	2.45	2.66	5.25	4.14
ARG	4.24	3.86	3.21	1.51	6.00	3.53
Sub-total	33.49	44.46	17.41	15.24	35.66	27.56
NEAA (%)						
ASP	7.09	9.35	5.01	2.56	9.72	4.35
SER	4.12	4.78	2.20	1.82	4.82	2.08
GLU	10.25	7.98	8.53	6.93	16.54	5.93
PRO	3.82	3.77	1.51	2.97	5.25	3.01
GLY	2.44	3.52	2.04	0.61	3.78	4.99
ALA	3.57	6.76	2.12	1.05	3.51	3.45
TYR	3.10	2.25	1.67	1.40	3.17	1.35
Sub-total	34.39	38.41	23.08	17.34	46.79	25.16
Total (%)	67.88	82.87	40.49	32.58	82.45	52.72

Abbreviations: see table 1.

Each pig was fitted with a simple T-cannula located at the distal ileum approximately 7 cm from the ileocecal junction. After one day fasting, hipnodil and stresnil (Janssen Co. Belgium) anesthesia were administered via intravenous injection. The cannula and surgical procedure used in this study were made according to the method suggested by Walker et al. (1986a). Following surgery, procain penicillin (2 ml) was administered before closing the incision site and injected daily for consecutive 5 d at a dose of 20,000 IU/kg body weight. Immediately following surgery, the pigs were transferred to individual metabolism crates (90-cm × 60-cm × 50-cm). Crates were equipped with woven plastic floor and automatic watering system. The room temperature was maintained at 32℃ for the first five days after surgery and 30℃ (± 2) for the rest of the experiment. Pigs were fed on a *ad libitum* basis until they fully recuperated from the surgery. Then each pig was fed a restricted amount of feed (about 5% of the BW/day) twice daily at 08:00 and 20:00 hour and had *ad libitum* access to water throughout the trial.

Ileal samples were collected continuously in vinyl bags between 08:00 h and 24:00 h at 2-h intervals on collection days. Collected samples were immediately frozen and stored at −20℃, freeze dried (Ilsin Eng. Co, Korea), ground with a 1 mm mesh Wiley mill, and used for analysis. A fresh fecal sample was collected for 24 hours in pans placed under individual metabolic crate on the seventh and eighth day after five to six days of

adaptation periods. Chemical analyses of the experimental diets, intestinal digesta, feces were carried out according to the AOAC (1990) methods and Cr was measured by atomic absorption spectrophotometer (Shimadzu, AA625, Japan). Amino acid contents were determined following acid hydrolysis in 6N HCl at 110℃ for 16 hours (Mason, 1984), using an amino acid analyzer (LKB 4150 alpha, Pharmacia Instrument Co, England). Statistical analysis was carried out by comparing means according to Duncan's multiple range test (Duncan, 1955), using General Linear Model (GLM) Procedure of SAS (1985) package program.

RESULTS AND DISCUSSION

Apparent ileal and fecal digestibilities of dry matter (DM), gross energy (GE) and crude protein (CP) from various protein sources are presented in table 3. DM, GE and CP digestibilities for the total digestive tract were higher than estimates obtained at the ileum. DSM, SDPP and FM had the highest DM digestibilities measured at both the end of the small intestine and over the total digestive tract, SBM had the lowest ($p < 0.05$) DM digestibilities. The higher fecal DM digestibility for DSM than for SBM in this experiment agrees with the report by Sohn et al. (1994). DM digestibility for SBM at the end of small intestine was lower than the values reported previously (81.7-84.1%), whereas digestibility over the total digestive tract was similar to the values (83.0-84.7 %) reported by de Lange et al. (1990), Herkelman et al. (1992), Sohn et al. (1994) and Sauer et al. (1974). The ileal DM digestibilities for the DSM and ISP diets reported in this study were similar to the values of 82.6 and 82.5% for pigs fed milk and ISP diets, respectively, reported by Wilson and Liebholz (1981a). DSM, ISP, FM and SDPP had higher GE digestibilities than SDBM and SBM at the terminal ileum (table 3). Apparent GE digestibilities of DSM measured at the end of ileum and

Table 3. Apparent ileal and fecal digestibilities of proximate nuritents in protein

	SDPP	SDBM	SBM	DSM	ISP	FM	SE
Dry matter;							
Terminal ileum	85.74^{a}	78.01^{b}	77.79^{b}	86.65^{a}	80.81^{b}	86.09^{a}	0.92
Total tract	86.48^{ab}	84.14^{ab}	84.99^{b}	87.89^{a}	86.86^{ab}	87.36^{ab}	0.36
Difference	0.7	9.1	7.2	1.2	6.1	1.3	
Gross energy;							
Terminal ileum	85.35^{a}	80.57^{b}	79.43^{b}	89.10^{a}	86.04^{a}	86.30^{a}	0.98
Total tract	85.60^{b}	87.01^{ab}	86.57^{ab}	90.45^{a}	87.34^{ab}	86.90^{ab}	0.59
Difference	0.3	6.4	7.1	1.4	1.3	0.6	
Crude protein;							
Terminal ileum	85.54^{ab}	82.70^{b}	82.55^{b}	87.32^{a}	85.11^{ab}	75.91^{c}	0.84
Total tract	87.89^{a}	87.89^{a}	83.01^{b}	87.62^{a}	87.98^{a}	79.96^{b}	0.92
Difference	2.4	5.2	0.5	0.3	2.9	4.7	
Among protein sources							
Dry matter	86.11^{ab}	82.58^{c}	81.39^{c}	87.27^{a}	83.83^{bc}	86.72^{a}	0.57
Gross energy	87.98^{a}	83.79^{bc}	83.00^{c}	89.78^{a}	86.69^{ab}	86.60^{ab}	0.59
Crude protein	84.72^{a}	85.30^{a}	81.28^{b}	87.47^{a}	86.54^{a}	77.94^{c}	0.62

Between region	Drymatter	Gross energy	Crude protein
Terminal ileum	82.46^{b}	85.09^{b}	83.04
Total tract	86.79^{a}	87.37^{a}	84.46
Probability (P):			
Sources	0.0001	0.0003	0.0001
Region	0.0001	0.0267	0.1072
Sources × Region	0.0016	0.0047	0.0473

Abbreviations: see table 1.

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

over the total digestive tract were in good agreement with the values of 85% and 95%, respectively, reported by Just et al. (1985). For CP, apprent ileal and fecal digestibilities of DSM, SDPP and ISP were the highest ($p < 0.05$), those of SBM and FM were the lowest ($p < 0.05$). Sohn et al. (1994) reported the fecal CP digestibility of ISP to be 92.3%, which was similar to the value (88.0%) reported in this experiment. The low CP digestibility in pigs fed the SBM diet may be due to the presence of indigestible carbohydrate complex (Walker et al., 1986a). The presence of indigestible proteins such as glycinin and β-conglycinin (Li et al., 1991) or the presence of proteolyic enzyme inhibitor (Bowman, 1994) have also been associated with lower digestibility (Sohn et al., 1994). Apparent ileal digestibility of CP was similar to the values (83.1-83.8%) estimated by Herkelman et al. (1992) and de Lange et al. (1990) whereas higher than those (72-75%) obtained by Furuya and Kaji (1991), Moon et al. (1994) and Chae (1996). The ileal digestibility of CP of pigs fed the ISP diets in this study was similar to or lower than values reported by other workers for pigs of this age (Ducuypere et al., 1988; Wilson and Leibholz, 1981b), who reported values ranging from 88.4 to 95.7%. The ileal digestibility of CP for pigs fed the DSM diet is similar to the values (86%) reported by Wilson and Leibholz (1981b). Digestibilities of DM and CP in DSM and ISP in this experiment were similar to the report by Sohn et al. (1994). Regardless of the region when the digestibility was measured, SDPP and DSM was the best protein sources in terms of the digestibility. FM was the worst in terms of crude protein digestibility. Dry matter and gross energy digestibility was affected by the region where the digestibility was measured, while crude protein digestibility was not affected by the region. Interaction between protein sources and region (terminal ileum and total digestive tract) was found in all parameters measured. Thus it is possible to under- or over-estimate the values of protein sources depending on the region where the digestibility was measured.

Table 4 presents mean values of apparent ileal amino acid digestibilities of various protein sources given to

Table 4. Apparent ileal digestibilities of amino acids in protein sources (%)

	SDPP	SDBM	SBM	DSM	ISP	FM	SE
Essential amino acids							
THR	80.92^{a}	85.25^{a}	81.26^{b}	87.03^{a}	77.90^{bc}	75.41^{c}	1.03
VAL	81.54^{b}	90.46^{a}	82.33^{c}	86.77^{b}	85.58^{b}	78.36^{d}	0.90
MET	75.43^{b}	83.46^{ab}	78.19^{b}	88.67^{a}	82.13^{ab}	78.18^{ab}	1.85
ILE	87.06^{a}	61.70^{c}	87.29^{a}	84.31^{a}	87.06^{a}	74.69^{b}	2.09
LEU	83.79^{bc}	91.91^{ab}	84.09^{d}	92.80^{a}	88.31^{c}	78.17^{e}	1.12
PHE	77.57^{c}	88.97^{a}	78.16^{bc}	88.29^{a}	80.77^{b}	81.29^{b}	1.35
HIS	82.92^{ab}	85.28^{ab}	81.47^{ab}	85.86^{a}	76.41^{bc}	70.53^{c}	1.51
LYS	85.60^{a}	92.28^{a}	85.67^{b}	92.48^{a}	90.98^{a}	79.61^{c}	1.03
ARG	92.43^{ab}	82.26^{c}	92.23^{ab}	88.64^{b}	93.28^{a}	83.23^{c}	1.00
Sub-mean	83.03^{b}	84.62^{b}	83.41^{b}	88.31^{a}	84.71^{b}	77.72^{c}	0.77
Non-essential amino acids							
ASP	86.61^{a}	88.00^{a}	86.78^{a}	87.53^{a}	89.38^{a}	66.38^{b}	1.74
SER	84.35^{a}	87.25^{a}	84.41^{a}	76.73^{b}	87.93^{a}	76.35^{b}	1.09
GLU	87.64^{b}	85.23^{c}	87.83^{bc}	87.72^{bc}	92.24^{a}	77.67^{d}	0.97
PRO	91.04^{bc}	69.34^{c}	91.08^{ab}	93.85^{a}	93.35^{a}	66.15^{c}	2.80
GLY	78.38^{ab}	74.81^{bc}	78.91^{ab}	70.89^{c}	81.56^{ab}	83.84^{a}	1.31
ALA	81.91^{ab}	90.06^{a}	82.20^{c}	82.29^{c}	84.10^{bc}	82.20^{c}	0.76
TYR	44.18^{c}	76.61^{ab}	44.95^{d}	82.51^{a}	70.11^{abc}	67.95^{bc}	2.94
Sub-mean	79.16^{bc}	81.61^{bc}	79.45^{c}	83.07^{ab}	85.52^{a}	74.36^{d}	0.81
Mean	82.60^{bc}	83.30^{abc}	81.34^{c}	86.02^{a}	85.07^{ab}	76.25^{d}	0.74

Abbreviations: see table 1.

^{a,b,c,d,e} Figures with different superscripts within the same row are significantly different ($p < 0.05$).

young pigs. DSM and ISP had the highest total average amino acid, essential amino acids and non-essential amino acids digestibilities, FM and SBM had the lowest ($p < 0.05$). Apparent ileal digestibilities of total amino acids for SBM was similar to the values (77-86%) reported by Furuya and Kaji (1991), Chae (1996), Moon et al. (1994) and Herkelman (1992). Digestibilities of essential amino acid in DSM were significantly higher than those of ISP ($p < 0.05$). Absolute differences of essential amino acids digestibilities among experimental diets ranged from 11.0 percentage unit for arginine to 25.6 percentage unit for isoleucine. For SBM, apparent average ileal digestibility of essential amino acid was similar to the values of 78%, 79% and 83%, respectively, reported by Furuya and Kaji (1991), Chae (1996) and Moon et al. (1994). Among the essential amino acids, the digestibility of arginine was higher except for SDBM or DSM, than any other amino acids. The ileal digestibilities of threonine, methionine and lysine of DSM and SDBM, in general, were higher ($p < 0.05$) than those of other sources. Digestibilities of SDPP or ISP diet in these amino acids were similar except for threonine which was higher ($p < 0.05$) in SDPP diet. In terms of nutrient digestibility, the quality of SDPP was inferior to that of DSM in ileal digestibilities. The ileal digestibility of lysine for DSM was similar to the value (94%) reported by Just et al. (1985). Apparent ileal digestibility of lysine in SDBM was in good agreement with 93% estimated by Knabe et al. (1989). Apparent ileal digestibility of lysine in SBM was in good agreement with values (84-87%) estimated by Chae (1996), Knabe et al. (1989), Herkelman et al. (1992). and de Lange et al. (1990). Sauer and Ozimek (1986) also reported the ileal lysine digestibility of SBM averaged from 85.0 to 89.2%. Apparent ileal digestibility of methionine in SBM was similar to the value (71.9%) estimated by Moon et al. (1994), and that of threonine in the present study also was in good agreement with the value (81.0%) reported by Herkelman (1992). But threonine digestibility in this experiment was higher than those (69-75%) reported by Furuya and Kaji (1991), Chae (1996), Knabe et al. (1989) and de Lange (1990). The ileal digestibility of methionine (78.2%) in FM was similar to the result (79.7-85%) of Sauer and Ozimek (1986). The ileal digestibility of threonine in FM was

Table 5. Apparent fecal digestibilities of amino acids in protein sources (%)

	SDPP	SDBM	SBM	DSM	ISP	FM	SE
Essential amino acids							
THR	90.44^{a}	89.52^{a}	81.67^{b}	91.08^{a}	87.68^{a}	79.91^{b}	1.03
VAL	89.29^{a}	91.66^{a}	82.11^{b}	89.80^{a}	89.55^{a}	81.45^{b}	0.94
MET	74.49^{cd}	79.97^{bc}	71.13^{d}	90.29^{a}	85.13^{ab}	79.84^{bc}	1.50
ILE	82.77^{bc}	62.67^{d}	87.54^{ab}	86.25^{b}	91.74^{a}	80.50^{c}	1.86
LEU	88.12^{bc}	92.72^{a}	87.12^{c}	92.97^{a}	91.28^{ab}	81.39^{d}	0.91
PHE	75.15^{e}	91.83^{a}	87.38^{bc}	88.82^{ab}	84.46^{cd}	82.60^{d}	1.09
HIS	78.66^{cd}	90.47^{a}	82.55^{bc}	91.94^{a}	84.23^{b}	74.61^{d}	1.37
LYS	91.91^{a}	93.33^{a}	85.31^{b}	94.53^{a}	93.05^{a}	82.60^{b}	1.00
ARG	89.08^{bc}	81.81^{d}	93.34^{ab}	88.04^{c}	94.51^{a}	84.49^{cd}	1.02
Sub-mean	84.43^{cd}	86.00^{bc}	84.24^{cd}	90.41^{a}	89.07^{ab}	80.82^{d}	0.78
Non-essential amino acids							
ASP	87.61^{b}	89.76^{b}	88.50^{b}	89.28^{b}	93.72^{a}	79.69^{c}	0.96
SER	91.11^{a}	90.65^{a}	86.26^{b}	82.13^{b}	92.54^{a}	81.96^{b}	0.97
GLU	90.39^{bc}	86.57^{cd}	91.52^{b}	90.99^{b}	95.62^{a}	83.06^{d}	0.91
PRO	84.47^{ab}	75.82^{b}	91.98^{a}	93.95^{a}	94.06^{a}	84.86^{ab}	1.72
GLY	82.30^{c}	86.41^{b}	81.65^{c}	81.21^{c}	88.96^{ab}	90.30^{a}	0.84
ALA	85.44^{b}	91.79^{a}	76.40^{c}	83.68^{b}	87.34^{b}	86.09^{b}	1.02
TYR	71.70^{c}	88.54^{a}	76.07^{bc}	87.90^{a}	83.01^{ab}	75.10^{bc}	1.63
Sub-mean	84.72^{b}	87.08^{ab}	84.62^{b}	87.02^{ab}	90.75^{a}	83.00^{b}	0.66
Mean	84.56^{bc}	86.47^{ab}	84.41^{bc}	88.93^{a}	89.81^{a}	81.78^{c}	0.70

Abbreviations: see table 1.

^{a,b,c,d,e} Figures with different superscripts within the same row are significantly different ($p < 0.05$).

close to the 74.2-77.3%, reported by Sauer and Ozimek (1986) and 81% estimated by Knabe et al. (1989). The ileal digestibility of non-essential amino acids in SBM was equal to the values of 75% (Furuya and Kaji, 1991), 76.6% (Chae, 1996) and 81.5% (Moon et al., 1994). The digestibility of apparent average essential amino acid in ISP diet was similar to the that of SBM diet. The results of this experiment are not consistent with previous reports by Walker et al. (1986b) and Sohn et al. (1994). They reported that the ileal digestibilities of refined soy proteins such as ISP and SPC were higher than that of soybean meal due to reduction in anti-nutritional factors. The difference in age of experimental animal could be a possible reason for the different digestibility, since in this study pigs weighing 15 kg were used, they already fully adapted to SBM diets thereby digested SBM much better than 28 days old piglets used in the study by Walker et al. (1986b) and Sohn et al. (1994).

Apparent fecal digestibilities of amino acids of various protein sources offered to young pigs are presented in table 5. 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. The average fecal digestibilities of total amino acids, essential amino acids and non-essential amino acids digestibilities in SBM were in agreement with values estimated by Moon et al. (1994). Apparent average fecal essential amino acid digestibility of DSM and ISP in the present study were slightly higher but similar to the values of 87.1% and 86.7%, respectively, reported by Sohn et al. (1994). The average fecal digestibilities of essential amino acids were higher ($p < 0.05$) for pigs fed the DSM and ISP than in those fed any other protein diets. Measured over the total digestive tract, FM in all essential amino acids had lower digestibility than DSM and ISP diet. Lysine digestibilities in pigs fed the DSM and ISP diet were higher ($p < 0.05$) than that in pigs fed SBM diet. Apparent fecal digestibility of lysine for SBM was in good agreement with values (82.5-88.6%) estimated by Sauer et al. (1974), Sohn et al. (1994) and Moon et al. (1994). The fecal digestibility of lysine in DSM, 92% and 96%, respectively, reported by Sohn et al. (1994) and Just et al. (1985) were similar to the value of 94.5% in this study. The fecal digestibility of lysine in

Table 6. Differences between apparent fecal and ileal digestibilities of amino acids in protein sources (fecal digestibility-ileal digestibility)

	SDPP	SDBM	SBM	DSM	ISP	FM
Essential amono acids						
THR	9.5	4.3	0.4	4.0	9.8	4.5
VAL	7.8	1.2	−0.2	3.0	4.0	3.1
MET	−0.9	−3.5	−7.1	1.6	3.0	1.7
ILU	−4.3	1.0	0.3	1.9	4.7	5.8
LEU	4.3	0.8	3.0	0.2	3.0	3.2
PHE	−2.4	2.9	9.2	0.5	3.7	1.3
HIS	−4.3	5.2	1.1	6.1	7.8	4.1
LYS	6.3	1.0	−0.4	2.0	2.1	3.0
ARG	−3.4	−0.5	1.1	−0.6	1.2	1.3
Sub-mean	1.4	1.4	0.8	2.1	4.4	3.1
Non-essential amino acids						
ASP	1.0	1.8	1.7	1.8	4.3	13.3
SER	6.8	3.4	1.9	5.4	4.6	5.6
GLU	2.8	1.3	3.7	3.3	3.4	5.4
PRO	−6.6	6.5	0.9	0.1	0.7	18.7
GLY	3.9	11.6	2.7	10.3	7.4	6.5
ALA	3.5	1.7	−5.8	1.4	3.2	3.9
TYR	27.5	11.9	31.1	5.4	12.9	7.1
Sub-mean	5.6	5.5	5.2	4.0	5.2	8.6
Mean	3.2	3.2	2.7	2.9	4.7	5.5

Abbreviations: see table 1.

ISP in the present study was slightly higher than the value (88.7%) by Sohn et al. (1994). Again different age of experimental animal could explain the difference. The fecal digestibility of threonine in DSM, ISP and SBM in the present study agree with 82.0-93% in DSM by Sohn et al. (1994) and Just et al. (1985), 83.4% in ISP by Sohn et al. (1994) and 75.5-88% in SBM by Sohn et al. (1994), Sauer et al. (1974) and Moon et al. (1994). Average digestibility of all non-essential amino acids (NEAA) evaluated was lower ($p < .05$) in pigs fed SDPP, SBM and FM than in pigs fed the ISP diet.

Table 6 shows the differences between small intestine and total digestive tract digestibilities, and the numbers were calculated by substracting ileal digestibility values from fecal digestibility values. Digestibilities of essential amino acids and non-essential amino acids were higher when measured over the total digestive tract than at the end of the small intestine except for several amino acids in SDPP, SDBM and SBM diets. In several studies, net synthesis of methionine and lysine has been roported in the large intestine (Zebrowska, 1978; Low, 1980; Sauer et al., 1982). Therefore, depending on the amino acid digestibilities obtained by the fecal analysis method may overestimate (which is usually the case) or underestimate the nutritive values of the ingredients. Higher digestibilities over the total digestive tract than digestibilities at the end of the small intestine have been reported for crude protein and most amino acids in soybean meal (Holmes et al., 1974; Sauer et al., 1982).

In conclusion, whether measured at the end of the small intestine or over the total digestive tract, the digestibilities of proximate nutrients and amino acids in pigs fed DSM and ISP diet were the highest, and those of pigs fed FM, were the lowest. Thus we assumed that the favorable effects of SDPP and SDBM on the performance in early-weaned piglets is not likely due to the high digestibility of the nutrients. Ermer et al. (1994) concluded that palatability rather than novelty was responsible for the increased feed intake observed in nursery pigs fed diets containing dried plasma proteins. Makkink et al. (1994) also investigated the effects of various protein sources on feed intake, intestinal tract morphology, gastric pH and proteolytic enzyme activities of postweaning pigs and concluded that feed intake had more dramatic effects on enzymatic activities.

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