Ileal Amino Acid Digestibility in Different Cultivars of Chinese Rapeseed Meals for Growing-finishing Pigs**

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ABSTRACT : Studies were conducted with nine barrows, average initial body weight 44.5±2.1 kg, fitted with a T-cannula at the distal ileum, to determine the apparent ileal (and true) digestibility (AID and TID) of CP and AA in different cultivars of rapeseed meals and soybean meal. The barrows were fed either a casein diet or one of eight corn starch-based semipurified diets, formulated to contain 17.0% CP (DM basis) with one of seven different cultivars of rapeseed meal or soybean meal as the sole source of dietary protein, according to a six-period, nine-treatment, incomplete Latin Square. Chromic oxide (0.5%) was used as a digestibility marker. The pigs were fed of 4% of body weight twice daily, at 08:00 and 20:00 h. Ileal digesta were collected at 2 h intervals daily from 5 d to 7 d. The AID or TID values of CP and most AA (Cysteine excluded) were significantly lower in the rapeseed meals than in soybean meal ($p<0.05$). There were significant differences in the AID or TID values of CP and AA among the seven different cultivars rapeseed meals ($p<0.05$); the seven rapeseed meals were arranged according to the size of the AA digestibility values of the rapeseed meals from the greatest to the least, as Zayou 59, Youyan 7, Ganyou 16, Qingyou 2, Huaza 3, Ningza 1 and Lianglou 586; differences in CP, AA, NDF and ADF contents in the rapeseed meals were mainly responsible for the variation in the AID or TID values of AA among rapeseed meals. The AID value of CP can be used as an index of the AID or TID values of most AA in rapeseed meals. However, the AID value of CP was less appropriate as a direct indicator of the AID or TID values for cysteine, methionine, tryptophan, phenylalanine and proline. *(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 9 : 1326-1333)*

Key Words : Chinese Rapeseed Cultivars, Amino Acids, Ileal Digestibility, Pigs

INTRODUCTION

The CP content in rapeseed meal is abundant, about 32.0%-44.3%, and the profile of AA in the CP reflects a good balance, so rapeseed meal is a valuable alternative protein supplement to soybean meal in China (Li et al., 1995). However, the high levels of crude fiber (8.81%-13.20%) and glucosinolates (4.0%-6.0%) in rapeseed meal have negative effects on the digestibility and absorption of CP and AA by single stomach animals (Rundgren et al., 1985; Mitaru et al., 1984). Therefore, It is important to measure not only the total AA content in rapeseed meal, but also the corresponding AA digestibility values, in order to formulate a balance diet containing rapeseed meal (Green and Kiener, 1989). Determinations of the AID values in feedstuffs provide better estimates for AA availability in pigs than do fecal measurements (Sauer and Ozimek, 1986; Tanksley and Knabe, 1993). But ileal cannula methods are complex and expensive, so studies on the ileal digestibility of AA in rapeseed meals are none in China, except for the study determining AA ileal digestibility in Chinese rapeseed meal using the regression technique (Li et al., 2000).

The objectives of this study were to investigate differences among the AID and TID values of AA in seven cultivars rapeseed meals and to identify factors responsible for the differences.

MATERIALS AND METHODS

Animals and housing

Nine crossbred barrows (Duroc×Landrance), average initial body weight 44.5±2.1 kg, were surgically fitted with a simple T-cannula at the distal ileum according to procedures adapted from Gargallo and Zimmerman (1980). After surgery, the barrows were individually housed in cast iron metabolic cages (50×150 cm) at a temperature of 22-25°C. During a 10 d recovery period, the barrows were fed a piglet diet with 18.0% CP. A detailed description of pre- and post- operative care was previously presented by Zhu et al. (1998). Following recovery, the barrows were fed one of the nine experimental diets, i.e. seven rapeseed meal diets, one soybean meal diet and one casein diet. The experiment was designed as a six-period, nine-treatment, incomplete Latin Square. The barrows were fed 4% of body weight twice daily, equal amounts each meal, at 08:00 and 20:00 h. Water was freely available. Average final body weight of the barrows was 68.7±3.2 kg.

Rapeseed meals and diets

Seven different cultivars rapeseeds were collected from the main provinces in China, where rapeseed is cultivated, including Ganyou 16 (Jiangxi province), Ningza 1 (Jiangshu province), Liangyou 586 (Jiangxi province),

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Huaza 3 (Hubei province), Youyan 7 (Hunan province), Qingyou 2 (Jiangshu province) and Zayou 59 (Hebei province). These rapeseeds were manufactured into meals in local oilseed processing plants using a prepress-extraction processing method (Tables 1 and 2). Corn starch-based semipurified diets were formulated to contain 17.0% CP (DM basis) with the specific rapeseed meals or one soybean meal as the sole source of dietary protein (Tables 3 and 4). A low-protein casein diet was formulated to contain 5% casein and was used to estimate endogenous losses of amino acids (Tables 3 and 4). Sucrose was included at a level of 20% in the diets to improve palatability. Soybean oil was included at a level of 3% to reduce dustiness of the diets. Vitamins and minerals were supplemented according to NRC (1998) standard. Chromic oxide (0.5%) was included in the diets as the digestibility marker.

Experimental procedure

Each experimental period comprised of 7 d, including 4 d for adaptation to the dietary treatments and 3 d for collecting digesta, according to the recommendation by Mitaru et al. (1984). Ileal digesta were collected every other 2 h from 08:00 to 20:00 h daily during days 5, 6 and 7. Sample collection was accomplished using a foam rubber bag fastened to the cannula with a rubber band. The bag was removed and replaced as soon as it was partially filled with digesta. Then digesta were immediately frozen at -20°C following collection. At the end of collection period, the three daily digesta collections for individual pigs in each period were stirred and subsampled. Digesta samples were freeze-dried at 30°C shelf temperature, then ground through a 0.8 mm mesh screen in a sample mill (Tecator 1093, America) and stored in plastic bottles at -20°C until required for analyse of DM, CP, AA and chromium. Samples of ingredients and diets were ground similarly.

Chemical analyses

Analyses for DM, CP, ash, ether extract, calcium and total phosphorus were assayed according to the methods of the AOAC (1990). NDF and ADF were analyzed according to the principles outlined by Goering and Van Soest (1970) using ANKOM[220] Fiber Analyzer (ANKOM Technology Corp. America). Chromic oxide was determined according to the procedures of Fenton and Fenton (1979) using Atomic Absorption Spectrometer (Hitachi Z-5000, Japan). For AA analyses, with the exception of the sulfur-containing AA and tryptophan, the samples were hydrolyzed with 6 N HCL at 110°C for 24 h. The AA was analyzed using an Automatic Amino Acid Analyzer (Hitachi L-8800, Japan). Methionine and cysteine were determined as methionine sulfone and cysteine acid after oxidation with performic acid (1 ml hydrogen peroxide plus 9 ml formic acid). The oxidation process was carried out according to AOAC (1990) method. The oxidized samples were then hydrolyzed and analyzed in the same manner as acid hydrolysis. Tryptophan analysis was determined after hydrolysis with 4 N NaOH at 110°C for 24 h, according to GB/T18246-2000 (2000) method using High Performance Liquid Chromatography (Shimadzu LC-10A, Japan). Glucosinolate was determined by the palladium chloride method (Yu, 1992). Erucic acid was assayed according to the procedure outlined by Pritam and Palmquist (1988) using Gas Chromatography (HP 6890, America). Protein solubility was determined by the method (Yang, 1993) using 0.2% potassium hydroxide.

Calculations and statistical analyses

The apparent ileal digestibility values of DM, CP and AA in the rapeseed meals and soybean meal were calculated with the indicator technique (Fan and Sauer, 1996a). Endogenous amino acids losses (g/kg DM intake) were determined using the low-protein casein diet that was

Table 1. Chemical composition of rapeseed meal and soybean meal samples (DM basis)

Items (%)	Rapeseed meals							Soybean meal	Casein
	Ganyou 16	Ningza 1	Liangyou 586	Huaza 3	Youyan 7	Qingyou 2	Zayou 59		
Dry matter	89.9	89.3	90.9	90.3	90.3	89.6	91.5	92.6	90.5
Organic matter	92.2	91.8	91.8	91.6	91.7	91.4	91.0	93.5	-
Crude protein	40.3	37.8	40.2	36.7	38.9	40.8	39.9	48.0	91.9
Ether extract	2.0	2.4	1.7	3.4	3.2	1.8	2.7	3.4	-
Acid detergent fiber	26.7	26.8	28.6	26.0	25.9	21.0	23.2	7.8	-
Neutral detergent fiber	38.4	38.8	40.9	39.3	36.8	32.0	34.7	12.8	-
Ash	7.8	8.2	8.2	8.4	8.3	8.6	8.9	6.5	-
Total phosphorus	1.2	1.1	1.1	1.1	1.2	1.2	1.1	0.2	-
Calcium	0.8	1.0	0.7	0.8	0.8	0.7	0.7	0.4	-
Gross energy (MJ/kg)	19.4	19.3	19.1	19.5	19.5	19.0	18.9	18.2	17.1
Protein solubility	50.9	60.5	55.7	49.8	55.8	59.4	54.4	-	-
Erucic acid	0.7	0.3	0.7	0.9	0.7	0.4	0.7	-	-
Glucosinolate (mg/g)	18.4	17.3	15.5	16.4	18.8	15.2	17.3	-	-

Table 2. Amino acid composition of rapeseed meal and soybean meal samples (DM basis)

Amino acids (%)	Ganyou 16	Ningza 1	Liangyou 586	Huaza 3	Youyan 7	Qingyou 2	Zayou 59	Soybean meal	Casein
Arginine	2.40	2.12	2.50	2.04	2.39	2.50	1.90	3.43	3.37
Cysteine	0.88	0.77	0.79	0.79	0.86	0.83	0.92	0.58	0.80
Histidine	1.59	1.46	1.65	1.40	1.64	1.60	1.33	1.47	2.93
Isoleucine	1.65	1.40	1.74	1.36	1.63	1.70	1.37	2.08	4.80
Leucine	3.05	2.73	3.11	2.67	2.96	3.12	2.63	3.78	8.49
Lysine	2.30	2.35	2.35	2.06	2.38	2.59	2.08	3.14	7.78
Methionine	0.44	0.52	0.44	0.51	0.55	0.52	0.59	0.55	2.01
Phenylalanine	1.68	1.44	1.72	1.48	1.63	1.70	1.36	2.31	4.46
Threonine	1.94	1.72	2.03	1.66	1.87	1.95	1.66	2.06	4.09
Tryptophan	0.33	0.33	0.54	0.26	0.37	0.62	0.51	0.55	3.49
Valine	2.02	1.76	2.17	1.69	1.99	2.04	1.63	1.97	5.33

assumed to be 100% digestibility (Van Kempen et al., 2002). This method was chosen because protein-free diets were considered physiologically abnormal (Low, 1980), and protein-free diet led to considerable underestimation of the physiologically nitrogen normal level of endogenous excretion (De lange et al., 1990). Casein has a high digestibility, as the sole source of protein is an improved method that supplies amino acids necessary for protein synthesis in the gastrointestinal tract (Alpers, 1972). The total endogenous outputs of CP and AA in the ileal digesta are calculated from Eq.1. (Fan and Sauer, 1996a).

$$A_o = A_I \times (I_D / I_I) \quad (1)$$

Where A_o is ileal endogenous outputs of CP and AA (g/kg DM intake). A_I is the concentration of CP and AA in ileal digesta (g/kg DM ileal digesta), I_D is marker concentration in the casein diet (g/kg DM diet) and I_I is marker concentration in ileal digesta (g/kg DM ileal digesta)

The true ileal digestibility values of CP and AA were calculated according to Eq.2. (Fan and Sauer, 1996a).

$$D_T = D_D + (A_E / A_D) \times 100 \quad (2)$$

Where D_T is the true ileal digestibility values of CP and AA in the assay diets (%). D_D is the apparent ileal digestibility values of CP and AA in the assay diets (%), A_E is the mounts of endogenous CP and AA in ileal digesta (g/kg DM intake). A_D is the concentrations of CP and AA in the assay diets (g/kg DM diet).

Statistical analysis was performed by SPSS 6.0 software (SPSS Inc., America). The digestibility values of DM, CP and AA were subjected to analysis of variance (ANOVA) of SPSS software. When ANOVA indicated a significant p value, means were separated using Duncan's multiple range test of SPSS software. Pearson partial correlation analyses were conducted to determine the relationships between the apparent (or true) ileal digestibility (AID or TID) of CP or AA and the contents of CP, AA, NDF and ADF in the assay diets by using SPSS 6.0 software. Pearson partial correlation analysis was conducted between the AID value of CP and the AID or TID values of AA, then the Linear Regression Analyses of SPSS 6.0 software were carried out to establish the regressive equation between the AID of CP value and AID or TID values of AA. The AID values of AA in rapeseed meal were compared with the TID values of the corresponding AA by using Pair-Sample T Test of SPSS 6.0 software.

RESULTS

The AID or TID values of CP and AA in different cultivars rapeseed meals and soybean meal

The AID or TID values of CP and most AA (cysteine excluded) were higher in soybean meal than seven rapeseed meals ($p<0.05$, see Tables 5 and 6). The AID or TID values of lysine, methionine, threonine and trytophan in rapeseed meals were 63.6% or 65.5%, 88.1% or 90.1%, 68.3% or 70.2%, 75.3% or 78.8% of the AID or TID values of the corresponding AA in soybean meal.

There were significant differences among the AID or TID values of all AA in seven different cultivars rapeseed meals ($p<0.05$, see Tables 5 and 6). Of the seven different cultivars of rapeseed meal, Zayou 59 had the greatest AID and TID values of AA. Ningza 1 and Liangyou 586 had the least AID and TID values of AA. The AID and TID values of AA in other four cultivars rapeseed meals were between those of AA in Zayou 59 and Ningza 1. Seven rapeseed meals were arranged according to the size of AID and TID values of AA in the rapeseed meals from the greatest to the least, as Zayou 59, Youyan 7, Ganyou 16, Qingyou 2, Huaza 3, Ningza 1, Liangyou 586.

Comparing the AID of CP and AA with the TID of CP and the corresponding AA by using Pair-Sample T Test, the result indicated that the TID values were significantly higher than the AID values ($p<0.05$). The differences between the TID and AID values of AA were as follows.

Table 3. Ingredients and chemical composition of the experimental diets (DM basis)

Ingredients (%)	Ganyou 16	Ningza 1	Liangyou 586	Huaza 3	Youyan 7	Qingyou 2	Zayou 59	Soybean meal	Casein
Soybean meal	-	-	-	-	-	-	-	36.00	-
Rapeseed meal	43.80	47.00	43.40	47.90	45.20	43.40	43.50	-	-
Corn starch[1]	29.93	26.80	30.16	26.02	28.55	30.19	30.05	38.60	63.60
Casein[2]	-	-	-	-	-	-	-	-	5.00
Cellulose acetate[3]	-	-	-	-	-	-	-	-	5.00
Soybean oil[4]	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	2.00
Sucrose[5]	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Limestone	0.54	0.40	0.60	0.56	0.64	0.70	0.60	0.30	1.00
Dicalcium phosphate	0.93	1.00	1.04	0.72	0.81	0.91	1.05	2.30	1.60
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Premix[6]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chromium oxide	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Chemical composition (%)									
Dry matter	93.20	93.34	93.71	93.91	93.39	93.42	93.54	92.90	92.01
Organic matter	93.57	93.24	93.51	92.52	93.30	93.06	92.74	93.60	95.80
Crude protein	17.2	17.0	17.1	16.8	17.5	17.9	17.9	17.9	4.25
Acid detergent fiber	11.56	12.68	12.43	12.47	11.71	10.10	10.08	3.39	12.19
Neutral detergent fiber	16.81	18.25	18.48	18.36	16.63	14.91	15.09	4.61	27.96
Calcium	0.78	0.84	0.79	0.80	0.79	0.80	0.81	0.80	0.87
Total phosphorus	0.69	0.72	0.68	0.70	0.72	0.73	0.71	0.72	0.71
Gross energy (MJ/kg)	17.72	17.47	17.68	18.27	17.85	17.60	17.97	16.85	16.84
Erucic acid	0.32	0.15	0.30	0.43	0.33	0.18	0.30	-	-
Glucosinolate (mg/g)	8.07	8.13	6.72	7.87	8.51	6.59	7.54	-	-

[1] Purchased from Beijing Redstar Starch Company with GE 14.84 MJ/kg, DM 87.30%, CP 0.40%, Calcium 0.074%, total phosphorus 0.0073%.
[2] Purchased from Gansu Casein Company.
[3] Purchased from China Medicine and Reagent Company.
[4] Purchased from market with GE 7.54 MJ/kg.
[5] Purchased from market with DM 99.999%, GE 15.84 MJ/kg.
[6] The premix supplied per kilogram of feed: Vitamin A, 5.512 IU; Vitamin D_3, 2.200 IU; Vitamin E, 66.1 IU; Riboflavin, 5.5 mg; D-panthothenic acid, 13.8 mg; Niacin, 30.3 mg; Choline, 551 mg; Vitamin B_{12}, 27.6 μg; Mn, 100 mg; Fe, 100 mg; Cu, 250 mg; Zn, 100 mg; I_2, 0.3 mg; Se, 0.3 mg; Co, 1.0 mg.

Table 4. Amino acid composition of the experimental diets (DM basis)

Amino acids (%)	Ganyou 16	Ningza 1	Liangyou 586	Huaza 3	Youyan 7	Qingyou 2	Zayou 59	Soybean meal	Casein
Arginine	0.95	0.87	0.81	0.82	0.90	0.95	0.90	1.17	0.16.
Cysteine	0.42	0.39	0.42	0.33	0.36	0.34	0.32	0.22	0.00
Histidine	0.60	0.53	0.49	0.52	0.56	0.60	0.64	0.53	0.16
Isoleucine	0.64	0.54	0.59	0.58	0.64	0.61	0.64	0.76	0.25
Leucine	1.14	1.13	1.10	1.08	1.16	1.15	1.24	1.38	0.51
Lysine	0.86	0.98	0.80	0.83	0.88	0.95	0.98	1.15	0.41
Methionine	0.28	0.25	0.26	0.27	0.25.	0.22.	0.25.	0.17	0.11
Phenylalanine	0.59	0.54	0.60	0.60	0.63	0.60	0.63	0.84	0.26
Threonine	0.76	0.68	0.70	0.72	0.77	0.75	0.79	0.75	0.23
Tryptophan	0.27	0.26	0.29	0.27	0.32	0.28	0.26	0.31	0.21
Valine	0.79	0.71	0.70	0.71	0.80	0.75	0.77	0.72	0.27

for rapeseed meals, values for CP, all indispensable AA, all dispensable AA, sum AA were 6.14%, 4.51%, 8.62% and 6.14%, respectively. The differences in indispensable AA were greater than those in dispensable AA.

Relationships between the AID or TID of CP and AA and the concentration of CP, AA, NDF and ADF in diets

There was a poor correlation between the AID or TID values of CP and the dietary CP concentrations (r=0.42 or 0.39, Table 7). However, the AID or TID values of most AA (methionine and cysteine excluded) were positively

Table 5. The AID values of DM, CP and AA in rapeseed meal and soybean meal for pigs (DM basis)

Items (%)	Ganyou 16	Ningza 1	Liangyou 586	Huaza 3	Youyan 7	Qingyou 2	Zayou 59	Soybean meal	SEM	P value
Dry matter	60.7^{c}	46.7^{a}	53.0^{ab}	53.6^{b}	57.5^{bc}	56.5^{bc}	60.1^{c}	74.3^{d}	2.09	0.00
Crude protein	61.7^{cd}	51.2^{a}	53.4^{ab}	54.6^{abc}	58.1^{abc}	59.5^{bc}	67.9^{d}	81.3^{e}	2.52	0.00
Arginine	77.7^{bc}	66.8^{a}	66.4^{a}	72.4^{b}	76.6^{bc}	75.5^{bc}	79.3^{c}	90.1^{d}	1.76	0.00
Cysteine	65.3^{abc}	59.9^{abc}	55.8^{ab}	53.5^{a}	60.2^{abc}	54.8^{a}	69.2^{c}	68.0^{bc}	3.92	0.04
Histidine	71.7^{bc}	66.3^{b}	60.0^{a}	70.4^{bc}	68.2^{b}	70.7^{bc}	76.7^{c}	87.1^{d}	2.15	0.00
Isoleucine	66.4^{cd}	51.0^{a}	51.5^{a}	59.9^{b}	68.2^{d}	61.8^{bc}	70.8^{d}	87.2^{e}	2.05	0.00
Leucine	71.3^{b}	61.3^{a}	58.5^{a}	68.0^{b}	73.5^{bc}	68.6^{b}	76.9^{c}	87.2^{d}	1.83	0.00
Lysine	57.6^{c}	54.1^{bc}	44.0^{a}	48.3^{ab}	58.5^{c}	60.3^{c}	67.9^{d}	87.7^{e}	2.25	0.00
Methionine	81.7^{c}	76.1^{ab}	73.5^{a}	79.3^{bc}	79.1^{bc}	77.5^{abc}	81.4^{c}	89.0^{d}	1.53	0.00
Phenylalanine	70.3^{bc}	62.0^{a}	59.53^{a}	69.3^{b}	74.2^{bc}	68.7^{b}	76.1^{c}	87.8^{d}	2.02	0.00
Threonine	59.9^{de}	46.0^{ab}	42.1^{a}	50.7^{bc}	57.5^{de}	54.1^{cd}	64.1^{e}	78.4^{f}	2.22	0.00
Tryptophan	61.3^{c}	44.3^{a}	57.9^{c}	53.0^{b}	66.8^{d}	58.7^{c}	57.9^{bc}	75.9^{e}	1.60	0.00
Valine	60.9^{cd}	43.5^{a}	41.9^{a}	50.9^{b}	61.2^{cd}	54.9^{bc}	64.1^{d}	77.6^{e}	2.24	0.00

* SEM means standard error of the mean (n=6).

** Means within the same row followed with different letters differ ($p<0.05$). The following tables are same.

Table 6. The TID values of CP and AA in rapeseed meal and soybean meal for pig (DM basis)

Items (%)	Ganyou 16	Ningza 1	Liangyou 586	Huaza 3	Youyan 7	Qingyou 2	Zayou 59	Soybean meal	SEM	P value
Crude protein	67.8^{cd}	57.5^{a}	59.7^{ab}	61.1^{abc}	63.9^{abc}	65.5^{bc}	73.9^{d}	87.3^{d}	2.52	0.00
Arginine	81.5^{bc}	71.1^{a}	70.8^{a}	76.7^{b}	80.6^{bc}	79.7^{bc}	83.2^{c}	93.2^{d}	1.76	0.00
Cysteine	70.6^{ab}	65.2^{ab}	61.0^{a}	60.0^{a}	66.2^{ab}	61.4^{a}	76.0^{b}	68.0^{ab}	3.92	0.09
Histidine	74.9^{bc}	69.8^{ab}	64.0^{a}	74.0^{bc}	71.7^{b}	73.9^{bc}	79.7^{c}	90.9^{d}	2.16	0.00
Isoleucine	70.8^{bc}	56.2^{a}	56.3^{a}	64.8^{b}	72.6^{c}	66.5^{b}	75.3^{c}	91.0^{d}	2.05	0.00
Leucine	74.4^{bc}	64.5^{a}	61.7^{a}	71.3^{b}	76.5^{bc}	71.7^{b}	79.8^{c}	89.9^{d}	1.83	0.00
Lysine	61.1^{c}	57.4^{bc}	47.7^{a}	51.8^{ab}	61.9^{c}	63.5^{c}	70.9^{d}	90.3^{e}	2.25	0.00
Methionine	83.4^{c}	77.8^{ab}	75.3^{a}	81.0^{bc}	80.9^{bc}	79.6^{abc}	83.2^{c}	89.0^{d}	1.53	0.01
Phenylalanine	73.4^{bc}	65.2^{a}	62.6^{a}	72.3^{b}	77.1^{bc}	71.7^{b}	79.0^{c}	90.0^{d}	1.90	0.00
Threonine	64.9^{de}	51.2^{ab}	47.4^{a}	55.9^{bc}	62.4^{cde}	59.1^{cd}	68.9^{e}	83.4^{f}	2.22	0.00
Tryptophan	70.8^{cd}	54.1^{a}	66.6^{bc}	62.4^{b}	74.7^{d}	67.7^{c}	67.7^{c}	84.1^{e}	1.60	0.00
Valine	66.3^{cd}	49.6^{a}	47.9^{a}	56.8^{b}	66.5^{cd}	60.6^{bc}	69.6^{d}	83.5^{e}	2.24	0.00

correlated with the corresponding AA contents in the diets (r=0.54-0.79, Table 7). The AID or TID values of CP and most AA (methionine, cystionine and tryptophan excluded) were negatively correlated with the dietary NDF content (r=-0.69~-0.95, Table 7). The AID or TID values of CP and lysine were negatively correlated with the dietary ADF concentrations (r=-0.81~-0.84, Table 7).

The result of Pair-Sample T Test indicated that there were correlations between the AID values of CP and the AID or TID values of most AA in rapeseed meals (r=0.77-0.85). Table 8 illustrates the linear relationships between the AID value of CP and the AID or TID values of all AA in rapeseed meals. With the exception of methionine, cysteine, phenylalanine, tryptophan, proline and tyrosine, regressive equations were established between the AID values of CP and the AID or TID values of the other AA in rapeseed meals (r^2=0.59-0.72). Therefore, these linear regression equations can be applied to estimate the AID or TID values of most AA in rapeseed meals, excluding methionine, cysteine, phenylalanine, tryptophan, proline and tyrosine.

DISCUSSION

In our studies, the AID or TID values of CP and most AA were lower in rapeseed meals than soybean meal ($p<0.05$). This result was in agreement with the reports by Rowan and Lawrence (1986), Partidge et al. (1987) and Green and Kiener (1989). The lower digestibility of canola meal may be attributed to its higher fiber content, as a result of a larger proportion of hulls and protein associated with hulls which are of low digestibility (Sauer et al., 1982). In our studies, the contents of NDF and ADF in rapeseed meals were more than three times of those in soybean meal (Table 1).

In our studies, there were significant differences among

Table 7. Correlation coefficients between the AID or TID values of CP and AA and the concentrations of CP, AA, NDF and ADF in the experimental diets

	Correlation coefficients between AID of CP and AA and the dietary CP, AA, NDF and ADF contents						Correlation coefficients between TID of CP and AA and the dietary CP, AA, NDF and ADF contents					
	CP or AA		NDF		ADF		CP or AA		NDF		ADF	
	r^x	P	r^x	P	r^x	P	r^x	P	r^x	P	r^x	P
Crude protein	0.42	**	-0.83	*	-0.84	*	0.39	**	-0.82	*	-0.83	*
Arginine	0.61	**	-0.80	*	-0.72	NS	0.59	**	-0.79	*	-0.71	NS
Cysteine	0.02	NS	-0.44	NS	-0.41	NS	0.05	NS	-0.51	NS	-0.48	NS
Histidine	0.59	**	-0.71	NS	-0.70	NS	0.56	**	-0.70	NS	-0.69	NS
Isoleucine	0.75	**	-0.73	NS	-0.64	NS	0.74	**	-0.73	NS	-0.63	NS
Leucine	0.62	**	-0.73	NS	-0.64	NS	0.61	**	-0.72	NS	-0.63	NS
Lysine	0.72	**	-0.89	**	-0.81	*	0.71	**	-0.89	**	-0.81	*
Methionine	0.09	NS	-0.51	NS	-0.45	NS	0.06	NS	-0.55	NS	-0.49	NS
Phenylalanine	0.57	**	-0.69	NS	-0.58	NS	0.56	**	-0.69	NS	-0.59	NS
Threonine	0.78	**	-0.76	*	-0.69	NS	0.77	**	-0.76	*	-0.69	NS
Tryptophan	0.62	**	-0.46	NS	-0.35	NS	0.56	**	-0.50	NS	-0.40	NS
Valine	0.77	**	-0.75	*	-0.65	NS	0.76	**	-0.75	*	-0.65	NS

r^x: Pearson partial correlation coefficients; P: Probability of significance.

Table 8. Results of regression analysis of the AID or TID values of AA (Y_1 or Y_2) on the AID value of CP (X) as: Y=a×X+b

	Y_1 (AID of AA)=a_1×X (AID of CP)+b_1			Y_2 (TID of AA) = a_2 × X (AID of CP)+b_2		
	a_1	b_1	R_1^2	a_2	b_2	R_2^2
Arginine	0.64	36.21	0.65	0.63	41.11	0.65
Cysteine	0.94	5.00	0.51	0.97	9.26	0.52
Histidine	0.67	30.10	0.59	0.65	34.60	0.59
Isoleucine	0.84	12.51	0.59	0.82	18.25	0.59
Leucine	0.71	26.91	0.59	0.70	30.57	0.58
Lysine	0.92	2.61	0.65	0.91	6.61	0.66
Methionine	0.38	56.52	0.44	0.38	58.13	0.45
Phenylalanine	0.63	32.29	0.49	0.62	35.58	0.49
Threonine	0.94	-0.86	0.70	0.92	4.95	0.70
Tryptophan	0.52	27.02	0.30	0.53	35.64	0.35
Valine	0.99	-3.62	0.66	0.97	3.11	0.66

Note: For all values, $p<0.01$; a_1, a_2: Slope; b_1, b_2: Intercept.

the AID or TID values of AA in the seven cultivars of rapeseed meal ($p<0.05$). In general, processing methods and cultivars of rapeseed were responsible for the variability of the AID or TID of AA values. Seven rapeseed meals were manufactured using prepress-extraction processing methods with similar conditions. Moreover, protein solubility in seven rapeseed meals ranged from 49.8% to 60.5% (Table 1), indicating that processing factors have less effect on the AA ileal digestibility of the rapeseed meals. Therefore, the cultivars of rapeseed meal might be responsible for the variability of their AID and TID of AA, which was proved by the correlation coefficients between the AID or TID values of CP and AA and the contents of CP, AA, NDF and ADF in diets (Table 7). The AID or TID values of CP and most AA in rapeseed meals were positively correlated with the dietary CP and corresponding AA contents (r=0.56-0.78), but negatively correlated with the dietary NDF and ADF contents (r=-0.69~-0.95 or -0.81~-0.84). Our findings agreed with the results reported by Grala et al. (1998) and Fan et al. (1996), indicating that the dietary AA, NDF and ADF contents were responsible for the variability of AID or TID of CP and most AA in rapeseed meals. The high fiber content in rapeseed meal comes mainly from a hull content of about 25%-30%. Rapeseed hulls contain about 60% NDF, of which lignin and cellulose constitutes almost 50% and 24.1% (Grala et al., 1998; Siddiqui and Wood, 1977). The fiber of rapeseed hulls decreased the ileal digestibilities of all nutrients in pigs (Mitaru et al., 1984). Particularly, the lignin present in rapeseed hulls may have contributed to this negative effect (Blair and Reichert, 1984; Bjergegaard et al., 1991). Of the carbohydrates present in the hulls, pectin, cellulose, hemicellulose and β-glucans are the most important from the viewpoint of their nutritional value for nonruminant animals, because the carbohydrates are not digested by intestinal enzymes (Bell and Shires, 1982). As a consequence, the above-mentioned constituents may decrease the apparent and true ileal digestibility values of CP (Mosenthin et al., 1994; Bjergegaard et al., 1991). As was discussed by De Lange et al. (1989) and Schulze et al. (1995), the dietary inclusion of water-insoluble fiber increased the levels of endogenous CP and AA at the distal ileum, therefore reducing the AID values. However, the increases in recovery of endogenous AA become quantitatively important only when a threshold level of water-insoluble fiber is exceeded (Li et al., 1994). Pectin is a water-soluble fiber. The inclusion of dietary pectin decreased the AID values of AA (Mosenthin et al., 1994). Anderson et al. (1990) showed that the gelling and viscosity properties of water-soluble fiber decreased the digestion and absorption of nutrients by reducing the mixing of intestinal contents, blocking enzyme-substrate interaction and by forming an unstirred water layer, thereby creating a physical barrier to nutrient absorption. Furthermore, this variation of the AID values of AA may be related to differences in the content of hulls in canola meal (Fan et al., 1996), since differences in the content of hulls in different cultivars of canola meal have been reported (Bell and Shires, 1982).

Within each rapeseed meal sample, of the indispensable AA, the AID or TID values of methionine, arginine and histidine were greatest, while the AID or TID values of valine, threonine and lysine were least (Tables 5 and 6); Of the dispensable AA, the AID or TID values of glutamic acid was greatest, but the AID or TID values of proline, glycine and serine were least. Our experimental results agreed with the results reported by Green and Kiener (1989), Fan et al. (1996), Sauer et al. (1982) and Knabe et al. (1989). The relatively high digestibility of arginine may result from enzyme specificity, an important determinant in protein digestion; data considered below on the absorption of free amino acids mixtures from isolated intestinal loops indicated that the amino acids appearing first after enzymic hydrolysis (based on the known specificity of the proteases and peptidases involved) was arginine (Low, 1980). Glutamic acid in canola meal was contained mainly in storage proteins having relatively high digestibility, which explains the high ileal digestibility of glumatic acid (Fan et al., 1996). The relatively low ileal digestibility values of glycine, threonine, serine and proline in rapeseed meals may result from their relatively high concentration in endogenous secretions. Holmes et al. (1974) and Sauer et al. (1977) showed relatively high contents of threonine, glycine and proline in digesta from the distal ileaum of growing pigs fed a protein-free diet. Cetta et al. (1972) reported that, compared with all other AA, threonine had the lowest AID value in the rapeseed meal diet and the low AID of threonine could result from an increased passage of mucus glycoproteins, which contain a large amount of threonine. The relatively low digestibility of tryptophan in canola meal may largely result from the fact that a large proportion of tryptophan in canola meal is located in the hull fraction, which is high in fiber and of low digestibility (Fan et al., 1996).

There was a linear relationship between the AID value of CP and the AID or TID values of most AA in rapeseed meals (Table 8). For all the rapeseed meals, digestion by the pigs of CP was fairly similar to those of most AA. Regression equations were established between the AID value of CP and the AID or TID values of most AA (methionine, cysteine, phenylalanine, typtophan and proline excluded). So the AID value of CP can be used to estimate the AID or TID values of most AA in rapeseed meals. This avoids the need for expensive AA analysis of digesta. However, the AID value of CP was less appropriate when applied to estimate the AID or TID values of methionine, cysteine, phenylalanine, tryptophan and proline.

IMPLICATIONS

The AID or TID values of CP and most AA were significantly lower in rapeseed meals than soybean meal. There were significant differences in the AID or TID values of CP and AA among seven cultivars of rapeseed meals; the seven rapeseed meals were arranged according to the size of the AA digestibility values from the greatest to the lowest, as Zayou 59, Youyan 7, Ganyou 16, Qingyou 2, Huaza 3, Ningza 1 and Lianglou 586; the differences in CP, AA, NDF and ADF of rapeseed meals were mainly responsible for the variation of the AID or TID values of AA among rapeseed meals. The AID value of CP may be used as an index of the AID or TID values of AA in rapeseed meals. However, the AID value of CP was less appropriate as a direct indicator of the AID or TID values for cysteine, methionine, tryptophan, phenylalanine and proline.

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