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Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs[1,2]

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ABSTRACT: An experiment was conducted to determine the effect of feed intake (FI) on endogenous losses and the digestibility of CP and AA by growing pigs. Six growing barrows (initial BW = 70.3 kg) had a T-cannula installed in the distal ileum and were used in a 6 × 6 Latin square design. A soybean meal cornstarch-based diet and a N-free diet were formulated. Chromic oxide (0.25%; as-fed basis) was included in both diets as an inert marker. Each diet was provided at three different levels of FI. Feed intake level 1 was equal to the estimated energy requirement for maintenance of the pigs, whereas levels 2 and 3 were two or three times this amount, respectively. Each experimental period lasted 7 d. The initial 4 d of each period comprised an adaptation period to the experimental diets. On d 5, fecal samples were collected, while ileal digesta were collected during two 10-h periods on d 6 and 7. Between each experimental period, a corn-soybean meal-based diet (16% CP) was fed to all pigs for 7 d. The basal ileal endogenous losses (IAA_{end}) of CP and AA were measured for each level of FI from pigs fed the N-free diet. Likewise, the apparent (AID) and standardized (SID) ileal digestibility coefficients for CP and AA in soybean meal were calculated for each level of FI. The total-tract digestibility coefficient of energy in the soybean meal-based diet also was calculated. The AID for CP and all indispensable AA except Lys, Met, and Thr increased ($P \le 0.055$) as FI increased. The IAA_{end} of CP and all AA except Pro decreased linearly ($P < 0.05$) as FI increased when expressed as g/kg of DMI; however, the total daily IAA_{end} increased as FI increased (linear, $P \le 0.056$) for all AA, except for Phe, Thr, Trp, Val, Cys, Gly, and Ser. The AA composition (% of CP) of endogenous protein was not affected by the level of FI, except for Arg, Thr, Pro, and Ser. As FI increased, the SID decreased linearly ($P < 0.04$) for CP and all AA, except Arg, Trp, Asp, Pro, and Tyr. The total-tract digestibility of energy was not influenced by the FI level. These results demonstrate that the FI level significantly influenced AID, SID, and IAA_{end} for CP and AA. Therefore, pigs used to measure AA digestibility coefficients and IAA_{end} should be fed at a level that is close to what is used under commercial conditions.

Key Words: Amino Acid Digestibility, Endogenous Losses, Feed Intake, Pigs

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Introduction

The amount of feed consumed voluntarily by pigs is variable and is affected by many factors (Hyun et al., 1997). However, the level of feed intake (**FI**) has been shown to have only minimal or no effect on apparent ileal digestibility coefficients (**AID**) of CP and AA by growing pigs (Sauer et al., 1982; Haydon et al., 1984; Albin et al., 2001).

Standardized ileal digestibility coefficients (**SID**) yield more precise estimates of the amount of digestible AA in a mixed diet than do AID (Mosenthin et al., 2000; Jansman et al., 2002). To calculate SID, AID must be corrected for the basal ileal endogenous losses (**IAA_{end}**) of CP and AA (Stein et al., 2001). Endogenous losses of CP and AA are influenced by the FI level (Butts et al., 1993; Hess and Seve, 1999; Stein et al., 1999b). Therefore, the level of FI is expected to influence SID, but this hypothesis has not been investigated.

Previous experiments investigating the effect of FI on energy digestibility have yielded conflicting results. The DE of barley and of mixed diets has been shown not to vary with the level of FI (Dammers, 1964; Peers et al., 1976). However, Tollet et al. (1961) reported an improvement in DE as FI increased, whereas Morgan et al. (1975) found a significant decrease in DE with increasing level of FI.

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Table 1. Ingredient composition (%) of the experimental diets, as-fed basis

Ingredient, %	Soybean meal diet	N-free diet
Soybean meal, 44%	37.50	—
Corn starch	51.75	78.40
Soybean oil	3.00	3.00
Dextrose	5.00	10.00
Solka floc[a]	—	5.0
Limestone	0.50	—
Dicalcium phosphate	1.40	2.75
Chromic oxide	0.25	0.25
Salt	0.40	0.40
Vitamin premix[b]	0.10	0.10
Micromineral premix[c]	0.10	0.10

[a]Fiber Sales Corp., Urbana, OH.
[b]Provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 10,032 IU as vitamin A acetate; vitamin D_3, 992 IU as D-activated animal sterol; vitamin E, 88 IU as DL-α-tocopheryl acetate; vitamin K_3, 1.52 mg as menadione dimethylpyrimidinol bisulfite; thiamin, 1.5 mg as thiamine mononitrate; riboflavin, 10 mg; pyridoxine, 4.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.05 mg; D-pantothenic acid, 25 mg as calcium pantothenate; niacin, 60 mg; folic acid, 1.5 mg; and biotin, 0.4 mg.
[c]Provided the following quantities of minerals per kilogram of complete diet: Cu, 25 mg as copper sulfate; Fe, 120 mg as iron sulfate; I, 0.30 mg as potassium iodate; Mn, 25 mg as manganese sulfate; Se, 0.30 mg as sodium selenite; and Zn, 125 mg as zinc oxide.

Table 2. Analyzed nutrient composition of the experimental diets, as-fed basis

Item	Soybean meal diet	N-free diet
DM, %	93.85	92.98
CP, %	18.16	0.26
GE, kcal/kg	4,031	3,733
Ca, %[a]	0.60	0.60
P, %[a]	0.50	0.50
Ash, %	3.37	3.37
NDF, %	6.78	1.6
ADF, %	3.54	2.92
Indispensable AA		
Arginine, %	1.31	0.02
Histidine, %	0.48	—
Isoleucine, %	0.85	0.01
Leucine, %	1.40	0.02
Lysine, %	1.07	0.01
Methionine, %	0.30	0.01
Phenylalanine, %	0.95	0.01
Threonine, %	0.64	0.01
Tryptophan, %	0.20	—
Valine, %	0.87	0.01
Dispensable AA		
Alanine, %	0.81	0.02
Aspartate, %	2.15	0.03
Cysteine, %	0.22	—
Glutamic acid, %	3.21	0.04
Glycine, %	0.78	0.01
Proline, %	0.92	—
Serine, %	1.07	0.01
Tyrosine, %	0.67	0.01

[a]These values were calculated rather than analyzed (NRC, 1998).

The objective of the current experiment was to determine the effect of different levels of FI on IAA_{end} and on AID and SID of CP and AA in soybean meal by growing pigs. A second objective was to determine the influence of the level of FI on the total tract digestibility of energy in a soybean meal cornstarch-based diet.

Materials and Methods

Animals, Housing, and Experimental Design

Six growing barrows (average initial BW = 70.3 kg) were obtained from the South Dakota State University Swine Research Farm. A T-cannula was installed in the distal ileum of each pig using a procedure adapted from Stein et al. (1998). Following surgery, pigs were allowed to recuperate for 14 d. The pigs were housed individually in 1.2 × 1.8 m pens for the duration of the experiment in an environmentally controlled room. Room temperature was maintained at 20°C. A 6 × 6 Latin square design was used, with six periods and six animals representing the rows and the columns, respectively. The experimental protocol was reviewed and approved by the South Dakota State University Animal Care and Use Committee (No. 01-A023).

Diets, Feeding, and Sample Collection

Two diets were prepared. Diet 1 was a soybean meal-based diet, and Diet 2 was a N-free diet (Tables 1 and 2). Chromic oxide (0.25%; as-fed basis) was included in both diets as an inert marker. Vitamins and minerals were included at levels that met or exceeded the estimated requirements for growing pigs (NRC, 1998).

Each of the two diets was fed at three different FI levels. Because FI may be influenced by the ME concentration in the feed, the three FI levels were defined in relation to the intake of ME. The ME concentrations in the diets were calculated from the expected ME concentrations in the individual feed ingredients (NRC, 1998). Thus, FI level 1 was calculated to equal the energy requirement for maintenance (i.e., 106 kcal ME × $BWkg^{0.75}$; NRC, 1998), whereas levels 2 and 3 were equal to two or three times this amount, respectively. The daily allotment of feed was divided into two equal meals. Water was available at all times. The pigs were fed the experimental diets at their respective FI levels for 7 d. The initial 4 d were considered an adaptation period to the diets. On d 5, a fecal sample was collected from each of the three pigs fed the soybean meal-based diet because the energy digestibility was calculated only for the soybean meal-based diet and not for the N-free diet. Digesta were collected at the distal ileum from all pigs on d 6 and 7 as described previously (Stein et al., 1999a). At the conclusion of one period, all pigs were provided ad libitum access to a corn soybean meal-based diet (16% CP) for 7 d before the next experimental period was initiated. This procedure was adapted to avoid

Table 3. Apparent ileal digestibility coefficients (AID) for CP and AA (%) in soybean meal by growing pigs as affected by level of feed intake (FI)[a,b]

Item	DMI, kg/d:	Level 1[c] 0.78	Level 2[c] 1.57	Level 3[c] 2.46	SEM —	*P*-value Linear effect —	Quadratic effect —
CP		66.6	73.7	71.9	0.66	0.004	0.007
Indispensable AA							
Arginine		86.1	88.5	88.9	0.52	0.014	0.219
Histidine		82.2	86.0	83.8	0.78	0.194	0.048
Isoleucine		73.6	78.4	76.9	0.82	0.039	0.045
Leucine		75.6	80.1	78.4	0.72	0.042	0.035
Lysine		78.5	82.0	79.8	1.13	0.424	0.139
Methionine		78.9	79.6	78.4	1.45	0.805	0.642
Phenylalanine		77.6	81.4	79.8	0.73	0.085	0.055
Threonine		66.5	73.0	71.2	1.58	0.081	0.125
Tryptophan		70.9	76.8	75.8	0.81	0.010	0.035
Valine		69.5	75.5	73.5	0.86	0.019	0.023
Mean, indispensable AA		76.7	80.9	79.4	0.75	0.047	0.049
Dispensable AA							
Alanine		63.1	70.4	67.6	0.97	0.023	0.018
Aspartic acid		79.1	79.9	79.4	1.34	0.846	0.732
Cysteine		64.2	70.5	70.2	0.93	0.008	0.056
Glutamic acid		80.8	82.7	80.7	0.97	0.975	0.206
Glycine		49.9	62.9	61.4	1.06	0.001	0.007
Proline		52.5	54.7	58.2	4.06	0.341	0.919
Serine		73.3	78.4	77.1	0.97	0.040	0.069
Tyrosine		76.4	81.2	79.0	1.00	0.115	0.060
Mean, dispensable AA		72.4	76.1	74.9	0.52	0.018	0.027
Mean, all AA		74.3	78.2	77.0	0.54	0.018	0.023

[a]{100 − [(CP or AA in digesta/CP or AA in feed) × (Cr in feed/Cr in digesta)]} × 100%.
[b]n = 6.
[c]Level 1 = BW, kg$^{0.75}$ × 106 kcal ME; Level 2 = BW, kg$^{0.75}$ × 106 kcal ME × 2; Level 3 = BW, kg$^{0.75}$ × 106 kcal ME × 3.

feeding the animals energy and protein below their requirements for extended periods of time.

Chemical Analyses

At the conclusion of the experiment, digesta and fecal samples were thawed, mixed within animal and diet, and a subsample was taken for chemical analyses. All digesta samples were lyophilized and finely ground prior to chemical analysis. Fecal samples were oven dried at 60°C. Dry matter was determined in diets, digesta, and fecal samples (AOAC, 2000). The concentrations of Kjeldahl N and AA were determined in diets and digesta samples (AOAC, 2000). Amino acids were analyzed on a Chrom-tech HPLC AA analyzer (Thermo Quest, Inc., San Jose, CA), using ninhydrin for post derivitization and nor-leucine as the internal standard (AOAC, 2000). Samples were hydrolyzed with 6 *N* HCL for 24 h at 110°C. Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight prior to hydrolysis (AOAC, 2000). Tryptophan was determined after samples had been flushed with nitrogen and hydrolyzed with 6 *N* NaOH for 22 h at 110°C (AOAC, 2000). The Cr concentration of diets, digesta, and fecal samples were determined by spectrophotometry (Fenton and Fenton, 1979). The soybean meal-based diet and fecal samples were analyzed for GE according to AOAC (2000) using a bomb calorimeter (PARR 1563, Moline, IL).

Calculations and Statistical Analyses

Apparent ileal digestibility coefficients for AA were calculated as follows (Stein et al., 1999a):

$$AID = (100 - [(AAd/AAf) \times (Crf/Crd)]) \times 100 \quad [1]$$

where AID is the apparent ileal digestibility coefficient of an AA (%), AAd is the AA concentration in the ileal digesta DM (g/kg), AAf is the AA concentration in feed DM (g/kg), Crf is the chromium concentration in the feed DM (g/kg), and Crd is the chromium concentration in the ileal digesta DM (g/kg). The AID of CP and the total tract digestibility of energy were also calculated using Eq. [1].

The IAA_{end} of each AA was determined based on the flow obtained after feeding the N-free diet as follows (Stein et al., 1999b):

$$IAA_{end} = [AAd \times (Crf/Crd)] \quad [2]$$

Table 4. Flow to the distal ileum (g/kg DMI) of endogenous CP and AA by growing pigs fed a N-free diet as affected by level of feed intake (FI)[a,b]

Item	DMI, kg/d:	Level 1[c] 0.74	Level 2[c] 1.46	Level 3[c] 2.18	SEM —	*P*-value Linear effect —	Quadratic effect —
CP		48.60	32.45	24.92	2.27	<0.001	0.182
Indispensable AA							
Arginine		1.53	0.87	0.77	0.12	0.006	0.120
Histidine		0.53	0.34	0.26	0.03	0.002	0.238
Isoleucine		1.20	0.83	0.60	0.08	0.003	0.495
Leucine		1.72	1.19	0.85	0.13	0.005	0.551
Lysine		1.39	0.96	0.71	0.10	0.006	0.502
Methionine		0.41	0.28	0.21	0.03	0.003	0.445
Phenylalanine		1.05	0.74	0.51	0.08	0.006	0.670
Threonine		1.53	0.92	0.68	0.09	0.001	0.178
Tryptophan		0.36	0.23	0.16	0.04	0.011	0.605
Valine		1.48	0.99	0.70	0.10	0.003	0.460
Mean, indispensable AA		1.14	0.74	0.55	0.08	0.003	0.314
Dispensable AA							
Alanine		2.05	1.4	1.03	0.13	0.002	0.382
Aspartic acid		2.57	1.87	1.35	0.24	0.015	0.770
Cysteine		0.53	0.34	0.24	0.03	0.002	0.319
Glutamic acid		3.31	2.38	1.67	0.23	0.004	0.709
Glycine		4.30	2.54	1.97	0.28	0.002	0.140
Proline		10.54	7.36	6.88	1.09	0.064	0.354
Serine		2.05	1.21	0.91	0.12	0.001	0.125
Tyrosine		0.92	0.66	0.46	0.07	0.005	0.695
Mean, dispensable AA		3.29	2.22	1.81	0.22	0.006	0.279
Mean, all AA		2.09	1.39	1.11	0.13	0.003	0.245

[a][(CP or AA in digesta) × (Cr in diet/Cr in digesta)].
[b]n = 6.
[c]Level 1 = BW, $kg^{0.75}$ × 106 kcal ME; Level 2 = BW, $kg^{0.75}$ × 106 kcal ME × 2; Level 3 = BW, $kg^{0.75}$ × 106 kcal ME × 3.

where IAA_{end} is the basal endogenous loss of an AA (g/kg DMI).

The daily flow (g/d) of endogenous CP and AA was calculated by multiplying the IAA_{end} per kilogram of DMI for CP and each AA by the daily DMI.

By correcting the AID for the endogenous losses of each AA, the SID were calculated for each level of FI as follows (Stein et al., 2001):

$$SID = AID + [(IAA_{end}/AAf) \times 100] \quad [3]$$

where SID is the standardized ileal digestibility coefficient (%). In this calculation, the IAA_{end} used to correct the AID were obtained at FI levels that were identical to those used to determine the AID.

The AA composition of endogenous protein was calculated for each level of FI by expressing each AA as a percentage of total endogenous protein.

The GLM procedure of SAS (SAS Inst., Inc., Cary, NC) was used to evaluate the effect of the level of FI on IAA_{end}, AID, SID, and DE. An analysis of variance was conducted with FI, pig, and period as the main effects. Linear and quadratic effects of FI on IAA_{end}, AID, SID, and DE were determined using GLM with contrast statements.

Results

Apparent Ileal Digestibility Coefficients

The AID for CP, the mean of the indispensable AA, and for all indispensable AA except Arg, Lys, Met, and Thr, increased (quadratic, $P \leq 0.055$) as FI increased (Table 3). For CP, Ile, Leu, Trp, and Val and for the mean of the indispensable AA, a linear effect ($P < 0.05$) was observed in addition to the quadratic effect. For Arg, only a linear response was observed ($P < 0.02$), whereas there was no effect of FI on the AID for Lys, Met, and Thr.

The AID for Ser increased linearly as FI increased ($P = 0.04$). Both linear and quadratic responses were observed for Ala, Cys, and Gly, and the mean of the dispensable AA ($P \leq 0.056$), but the AID for the remaining dispensable AA were not influenced by FI. The AID for the mean of all AA showed a linear and a quadratic ($P \leq 0.023$) response to increased levels of FI.

Endogenous Losses of CP and AA

The IAA_{end} measured in grams per kilogram of DMI for CP and all AA except Pro decreased linearly ($P <$

Table 5. Daily flow to the distal ileum (g) of endogenous CP and AA by growing pigs fed a N-free diet as affected by level of feed intake (FI)[a,b]

Item	DMI, kg/d:	Level 1[c] 0.74	Level 2[c] 1.46	Level 3[c] 2.18	SEM —	*P*-value Linear effect —	Quadratic effect —
CP		34.73	45.55	49.28	2.45	0.008	0.289
Indispensable AA							
Arginine		1.10	1.24	1.50	0.11	0.056	0.642
Histidine		0.38	0.49	0.52	0.04	0.050	0.515
Isoleucine		0.85	1.19	1.20	0.08	0.027	0.178
Leucine		1.21	1.67	1.69	0.13	0.043	0.204
Lysine		0.98	1.36	1.42	0.11	0.037	0.301
Methionine		0.29	0.41	0.41	0.02	0.012	0.113
Phenylalanine		0.74	1.04	1.03	0.09	0.068	0.212
Threonine		1.10	1.32	1.37	0.11	0.155	0.566
Tryptophan		0.26	0.33	0.31	0.04	0.400	0.444
Valine		1.05	1.40	1.40	0.11	0.065	0.221
Mean, indispensable AA		0.81	1.04	1.09	0.08	0.054	0.365
Dispensable AA							
Alanine		1.45	1.95	2.02	0.12	0.022	0.266
Aspartic acid		1.77	2.64	2.72	0.24	0.039	0.238
Cysteine		0.37	0.49	0.48	0.04	0.129	0.278
Glutamic acid		2.34	3.35	3.34	0.23	0.028	0.131
Glycine		3.18	3.52	3.93	0.27	0.101	0.915
Proline		7.83	10.12	13.41	0.95	0.009	0.689
Serine		1.47	1.72	1.83	0.14	0.121	0.716
Tyrosine		0.66	0.93	0.94	0.07	0.039	0.173
Mean, dispensable AA		2.38	3.09	3.58	0.22	0.011	0.704
Mean, all AA		1.51	1.95	2.20	0.13	0.015	0.566

[a]Calculated by multiplying the loss in g/kg DMI by the daily DMI of the animals.
[b]n = 6.
[c]Level 1 = BW, $kg^{0.75}$ × 106 kcal ME; Level 2 = BW, $kg^{0.75}$ × 106 kcal ME × 2; Level 3 = BW, $kg^{0.75}$ × 106 kcal ME × 3.

0.02) as the FI increased (Table 4). For Pro, there was a tendency for a linear decrease ($P = 0.064$) in IAA_{end} as FI increased. For CP and all AA except Phe, Thr, Trp, Val, Cys, Gly and Ser, the daily flow to the distal ileum increased (linear, $P < 0.008$ to 0.056) as FI increased (Table 5). In contrast, except for minor changes in the concentration of Arg, Thr, Pro, and Ser, the AA composition of IAA_{end} was not affected by FI (Table 6).

Standardized Ileal Digestibility Coefficients

Except for Arg and Trp, the SID (Table 7) for CP and all indispensable AA and for the mean of the indispensable AA decreased linearly with increasing level of FI ($P = 0.003$ to 0.035). The SID for the mean of the dispensable AA and for all dispensable AA except Asp, Pro, and Tyr also decreased linearly ($P = 0.002$ to 0.034) with increasing level of FI, as did the SID for the mean of all AA ($P = 0.006$).

Energy Digestibility Coefficients

The digestibility coefficients for energy in the soybean meal-based diet were 84.8, 87.2, and 86.9% for FI levels 1, 2, and 3, respectively. These values were not significantly different.

Discussion

Apparent Ileal Digestibility

The AID obtained in the current experiment for pigs fed the highest level of FI are close to values reported for soybean meal by Green and Keener (1989) and by Fan et al. (1995a). However, the numbers are lower than the AID reported for dehulled soybean meal by Traylor et al. (2001) and by Dilger et al. (2004).

Previous experiments have shown limited or no effects of FI on AID (Sauer et al., 1982; Haydon et al., 1984; Albin et al., 2001). The results of the current experiment disagree with those reports; however, the lowest level of FI used in the above studies was higher than the lowest level used in the present experiment. This may explain why a different response was obtained in the current experiment because the increases in AID are mainly found between low levels of FI.

The reason why AID increase for most AA as FI is increased from a low to a medium level is that IAA_{end} contribute more to the total output of AA at lower levels of FI than at higher levels. Because the ileal output consists of both IAA_{end} and undigested dietary AA, a higher proportion of IAA_{end} will lead to a lower calculated AID. However, the relative influence of IAA_{end}

Table 6. Amino acid composition (% of CP) of endogenous protein in pigs fed a N-free diet at different levels of feed intake (FI)[a,b]

Item DMI, kg/d:	Level 1[c] 0.74	Level 2[c] 1.46	Level 3[c] 2.18	SEM —
CP	100	100	100	—
Indispensable AA				
Arginine	3.09[x]	2.69[y]	3.03[xy]	0.10
Histidine	1.10	1.08	1.05	0.04
Isoleucine	2.51	2.62	2.43	0.07
Leucine	3.55	3.69	3.44	0.15
Lysine	2.86	3.00	2.86	0.12
Methionine	0.85	0.89	0.84	0.03
Phenylalanine	2.17	2.29	2.09	0.11
Threonine	3.20[x]	2.92[xy]	2.74[y]	0.10
Tryptophan	0.75	0.72	0.64	0.06
Valine	3.05	3.11	2.82	0.11
Total, indispensable AA	23.1	23.0	21.9	0.75
Dispensable AA				
Alanine	4.17	4.28	4.15	0.11
Aspartic acid	5.11	5.75	5.46	0.38
Cysteine	1.08	1.08	0.99	0.06
Glutamic acid	6.85	7.31	6.71	0.24
Glycine	9.01	7.70	7.87	0.39
Proline	21.34[x]	21.80[x]	27.03[y]	1.47
Serine	4.25[x]	3.79[xy]	3.70[y]	0.13
Tyrosine	1.92	2.06	1.88	0.07
Total, dispensable AA	53.73	53.77	57.80	1.38
Total all AA	76.84	76.77	79.72	1.40

[a]The endogenous loss of each AA was calculated as the percentage of the loss of CP.
[b]n = 6.
[c]Level 1 = BW, $kg^{0.75} \times 106$ kcal ME; Level 2 = BW, $kg^{0.75} \times 106$ kcal ME × 2; Level 3 = BW, $kg^{0.75} \times 106$ kcal ME × 3.
[x,y]Means that do not have a common superscript letter are different, $P < 0.05$.

decreases as FI is increased, which partly explains why no significant differences in AID are observed at higher FI levels.

Endogenous Losses

The linear decreases in IAA_{end} measured in grams per kilogram of DMI for CP and AA that were found in the present experiment confirm previous findings (Butts et al., 1993; Hess and Seve, 1999; Stein et al., 1999b). In contrast, the daily flow of IAA_{end} increased as FI increased. This is in agreement with James et al. (2002), who observed an increase in the daily loss of all AA with increasing DMI in rats. Similar results were also reported by Butts et al. (1993) and Hess and Seve (1999). Thus, as FI is increased, the IAA_{end} decrease when expressed relative to the DMI of the animals, but they increase when expressed as the daily flow. The reason for this is that one fraction of the basal daily endogenous flow of CP and AA is secreted in response to the DMI of the animals, whereas another fraction is a daily loss secreted regardless of the DMI of the animal (Furuya and Kaji, 1991).

Standardized Ileal Digestibility

The SID were calculated in the current experiment using the principles previously described for correcting AID for the basal IAA_{end} of CP and AA (Stein et al., 2001; Jansman et al., 2002). The limitation to the use of AID is the assumed lack of additivity of digestibility coefficients for individual feed ingredients in mixed diets (Jansman et al., 2002). The most likely reason for this lack of additivity is that the digesta collected at the distal ileum contains IAA_{end} along with undigested dietary protein which may lead to an underestimation of the AID in feed ingredients with relatively low concentrations of AA (i.e., cereal grains). As the dietary AA levels increase, the contribution of IAA_{end} as a percentage of total ileal output will decrease, which leads to an increase in AID (Fan et al., 1995b). Therefore, calculated AID will change with the dietary concentration of CP and AA. In contrast, SID are independent of the AA concentration in the assay diet because SID are corrected for IAA_{end}. Thus, by using SID, it has been suggested that diets can be formulated with greater accuracy (Jansman et al., 2002). Nonetheless, the results from the current experiment demonstrate that SID are influenced by the FI level of the animals. To our knowledge, such a finding has not been previously reported.

Because of the design of this experiment, the intake of CP and AA in the soybean meal-based diets increased as the DMI increased. The increased DMI leads to a decrease in basal endogenous losses as illustrated in

Table 7. Standardized ileal digestibility coefficients (SID) for CP and AA (%) in soybean meal by growing pigs as affected by level of feed intake (FI)[a,b]

Item	DMI, kg/d:	Level 1[c] 0.78	Level 2[c] 1.57	Level 3[c] 2.46	SEM —	*P*-value Linear effect —	Quadratic effect —
CP		91.7	89.1	84.7	1.31	0.003	0.611
Indispensable AA							
Arginine		97.0	94.5	94.3	1.37	0.189	0.533
Histidine		92.5	91.8	88.9	1.10	0.035	0.427
Isoleucine		86.8	86.6	83.5	0.69	0.006	0.125
Leucine		87.1	86.7	84.1	0.60	0.004	0.162
Lysine		90.6	89.6	86.0	1.20	0.017	0.388
Methionine		91.8	88.1	85.0	1.17	0.002	0.871
Phenylalanine		88.0	87.7	84.9	0.60	0.004	0.125
Threonine		88.7	85.8	81.1	2.06	0.019	0.738
Tryptophan		87.0	87.3	82.8	1.78	0.107	0.310
Valine		85.1	84.6	81.0	0.86	0.005	0.176
Mean, indispensable AA		89.9	88.5	85.7	0.85	0.004	0.524
Dispensable AA							
Alanine		86.7	84.1	79.5	1.34	0.002	0.580
Aspartic acid		90.2	88.1	85.3	2.73	0.216	0.939
Cysteine		87.2	84.1	80.7	1.90	0.034	0.953
Glutamic acid		90.4	88.3	85.6	1.28	0.018	0.839
Glycine		101.6	92.2	85.0	3.39	0.004	0.799
Proline		159.2	132.5	127.9	15.05	0.158	0.580
Serine		91.3	88.6	85.2	1.54	0.013	0.850
Tyrosine		89.2	90.0	85.5	1.34	0.071	0.151
Mean, dispensable AA		97.4	92.4	88.8	1.95	0.010	0.800
Mean, all AA		94.0	90.7	87.4	1.42	0.006	0.980

[a]Apparent ileal digestibility + (endogenous loss/intake) × 100%.
[b]n = 6.
[c]Level 1 = BW, $kg^{0.75}$ × 106 kcal ME; Level 2 = BW, $kg^{0.75}$ × 106 kcal ME × 2; Level 3 = BW, $kg^{0.75}$ × 106 kcal ME × 3.

Table 4. Thus, the DMI per se will affect AA digestibility. This effect is responsible for the observed increase in AID at low DMI levels (Table 3) because the endogenous losses influence AID. If the entire effect of FI on AA digestibility could be explained by the increase in DMI and the resulting decrease in endogenous losses, then the SID should have been constant regardless of the FI of the animals because IAA_{end} are excluded from the calculations when SID are estimated. However, the SID for CP and all AA except Arg, Trp, Asp, and Pro decreased linearly as FI was increased, as illustrated in Table 7. This observation demonstrates that the digestibility of dietary AA decreases as FI increases. This effect is caused by the increased AA intake of the animals and is unrelated to the increased DMI. It follows from the above that the increase in DMI and the increase in CP and AA intake independently affect the AA digestibility in a feed ingredient. This combined effect is included in the calculation of AID, whereas the effects on SID are caused only by the increase in CP and AA intake. The reason why AID tends to plateau at higher FI levels (i.e., greater than two times the energy required for maintenance) is that the decreased IAA_{end} seem to be offset by the reduced digestibility of dietary AA. A consequence of this observation is that SID are only accurately predicting the digestibility of a diet if the animals that consume this diet have a FI similar to the FI of the animals used to measure the SID. Because many of the SID in the literature were obtained from animals that were restricted in their FI, these values may not be representative of animals that are allowed ad libitum access to feed.

Energy Digestibility

In the current experiment, the total-tract digestibility of energy was not affected by FI. This result agrees with previous reports (Zivkovic and Bowland, 1963; Peers et al., 1976; Haydon et al., 1984). These results indicate that growing pigs are capable of digesting the energy of a diet with the same efficiency at high levels of FI as at low levels. Thus, substrate availability seems not to influence energy digestibility. Another implication of this finding is that there seems to be no net loss of energy caused by the endogenous loss of CP and AA.

Implications

The level of feed intake influenced basal ileal endogenous losses of crude protein and amino acids and apparent and standardized ileal digestibility coefficients. Although apparent ileal digestibility coefficients were influenced mainly if feed intake were low, there was a linear effect of feed intake on standardized ileal digestibility coefficients. As a consequence, feeding the animals close to the voluntary feed intake during digestibility trials will lead to decreased basal ileal endogenous losses per kilogram of dry matter intake and increases the accuracy of the results. Therefore, growing pigs and lactating sows used in studies aimed at determining apparent and standardized ileal digestibility coefficients should be fed close to their voluntary feed intake; however, in gestating sows, restricted feeding is recommended to reflect commercial conditions.

Literature Cited

Albin, D. M., J. E. Wubben, M. R. Smiricky, and V. M. Gabert. 2001. The effect of feed intake on ileal rate of passage and apparent amino acid digestibility determined with or without correction factor in pigs. J. Anim. Sci. 79:1250–1258.

AOAC. 2000. Official Methods of Analysis. 17th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Butts, C. A., P. J. Moughan, W. C. Smith, G. W. Reynolds, and D. J. Garrick. 1993. The effect of food dry matter intake on the endogenous ileal amino acid extraction determined under peptide alimentation in the 50 kg live weight pig. J. Sci. Food Agric. 62:235–243.

Dammers, J. 1964. Verteringsstudies bij het varken. Ph.D. Diss., Univ. of Louvain, The Netherlands.

Dilger, R. N., J. S. Sands, D. Ragland, and O. Adeola. 2004. Digestibility of nitrogen and amino acids in soybean meal with added soyhulls. J. Anim. Sci. 82:715–724.

Fan, M. Z., W. C. Sauer, and C. F. M. de Lange. 1995a. Amino acid digestibility of soybean meal, extruded soybean and full-fat canola for early weaned pigs. Anim. Feed Sci. Technol. 52:189–203.

Fan, M. Z., W. C. Sauer, and M. I. McBurney. 1995b. Estimation by regression analysis of endogenous amino acid levels by digesta collected from the distal ileum of pigs. J. Anim. Sci. 73:2319–2328.

Fenton, T. W., and M. Fenton. 1979. An improved procedure for determination of chromic oxide in feed and feces. Can. J. Anim. Sci. 59:631.

Furuya, S., and Y. Kaji. 1991. The effects of feed intake and purified cellulose on the endogenous ileal amino acid flow in growing pigs. Br. J. Nutr. 68:463–472.

Green, S., and T. Keener. 1989. Digestibilities of nitrogen and amino acids in soya-bean, sunflower, meat and rapeseed meals measured with pigs and poultry. Anim. Prod. 48:157–179.

Haydon, K. D., D. A. Knabe, and T. D. Tanksley, Jr. 1984. Effects of level of feed intake on nitrogen, amino acid and energy digestibilities measured at the end of the small intestine and over the total digestive tract of growing pigs. J. Anim. Sci. 59:717–724.

Hess, V., and B. Seve. 1999. Effect of body weight and feed intake level on basal ileal endogenous losses in growing pigs. J. Anim. Sci. 77:3281–3288.

Hyun, Y., M. Ellis, F. K. McKeith, and E. R. Wilson. 1997. Feed intake pattern of group-housed growing-finishing pigs monitored using a computerized feed intake recording system. J. Anim. Sci. 75:1443–1451.

James, K. A. C., C. A. Butts, J. P. Koolaard, H. E. Donaldson, M. F. Scott, and P. J. Moughan. 2002. The effect of food dry matter intake on the flow of amino acids at the terminal ileum for rats fed an enzyme-hydrolysed casein-based diet. J. Sci. Food Agric. 82:1128–1135.

Jansman, A. J. M., W. Smink, P. van Leeuwen, and M. Rademacher. 2002. Evaluation through literature data of the amount and amino acid composition of basal endogenous crude protein at the terminal ileum of pigs. Anim. Feed. Sci. Tech. 98:49–60.

Morgan, D. J., D. J. A. Cole, and D. Lewis. 1975. Energy values in pig nutrition. J. Agric. Sci. Camb. 64:59–65.

Mosenthin, R., W. C. Sauer, R. Blank, J. Huisman, and M. Z. Fan. 2000. The concept of digestible amino acids in diet formulation for pigs. Livest. Prod. Sci. 64:265–280.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Peers, D. G., A. G. Taylor, and C. T. Whittemore. 1976. The influence of feeding level and level of dietary inclusion on the digestibility of barley meal in the pig. Anim. Feed Sci. Technol. 2:41–47.

Sauer, W. C., A. Just, and H. Jørgensen. 1982. The influence of daily feed intake on the apparent digestibility of crude protein, amino acids, calcium, and phosphorous at the terminal ileum and overall in pigs. Z. Tierphysiol. Tierernaehr. Futtermittelkd. 48:177–182.

Stein, H. H., S. Aref, and R. A. Easter. 1999a. Comparative protein and amino acid digestibilities in growing pigs and sows. J. Anim. Sci. 77:1169–1179.

Stein, H. H., S. W. Kim, T. T. Nielsen, and R. A. Easter. 2001. Standardized amino acid digestibilities in growing pigs and sows. J. Anim. Sci. 79:2113–2122.

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436.

Stein, H. H., N. L. Trottier, C. Bellaver, and R. A. Easter. 1999b. The effects of feeding level and physiological status on total flow and amino acid composition of endogenous protein at the distal ileum in swine. J. Anim. Sci. 77:1180–1187.

Tollet, J. T., A. H. Jensen, and D. E. Baker. 1961. Influence of age of pig and level of feed intake on the metabolizable energy value of the diet. J. Anim. Sci. 20:953. (Abstr)

Traylor, S. L., G. L. Cromwell, M. D. Lindemann, and D. A. Knabe. 2001. Effects of supplemental phytase on ileal digestibility of amino acids, calcium, and phosphorus in dehulled soybean meal for growing pigs. J. Anim. Sci. 79:2634–2642.

Zivkovic, S., and J. P. Bowland. 1963. Nutrient digestibilities and composition of measures of feed energy for gilts fed rations varying in energy and protein level during growth, gestation and lactation. Can. J. Anim. Sci. 43:86–97.