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Standardized ileal protein and amino acid digestibility by growing pigs and sows[1,2]

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ABSTRACT: Experiments were conducted to determine the effect of the physiological condition of swine on standardized ileal digestibility coefficients (SID). The apparent ileal digestibility coefficients were determined for crude protein and amino acids in six feed ingredients (corn, barley, wheat, soybean meal, canola meal, and meat and bone meal) in growing pigs and in gestating and lactating sows. Growing pigs and lactating sows were given free access to their diets, whereas gestating sows were allowed to consume only 2 kg of feed daily. The nonspecific (basal) endogenous losses of protein and amino acids were determined under similar feeding regimens after feeding a protein-free diet. The SID for crude protein and amino acids were calculated by correcting the apparent ileal digestibility coefficients for the nonspecific endogenous losses of protein and amino acids. With a few exceptions, there were no differences ($P > 0.05$) in the SID for crude protein and amino acids between growing pigs and lactating sows. Overall, gestating sows had higher ($P < 0.05$) SID for crude protein and all amino acids, except for tryptophan and aspartate, compared with growing pigs. Likewise, the SID of most amino acids obtained by gestating sows were higher ($P < 0.05$) than those obtained by lactating sows. Interactions ($P < 0.05$) between animals and diets were observed for gestating sows compared with growing pigs as well as gestating sows compared with lactating sows. As a consequence, it is not possible to extrapolate data from one feed ingredient to another. On most occasions, the lowest SID among the indispensable amino acids was calculated for threonine, valine, and lysine. It is concluded that gestating sows fed 2 kg of feed per day have higher standardized digestibility coefficients than do growing pigs and lactating sows given free access to their diets. This difference may be due to differences in daily feed intake rather than to the physiological status of the animals.

Key Words: Amino Acids, Digestibility, Pigs, Sows

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Introduction

Inaccuracies may be associated with the use of values for apparent ileal amino acid digestibilities in practical feed formulation because values obtained for individual ingredients are not always additive when mixed together (Furuya and Kaji, 1991; Rademacher et al., 1999). Inaccuracies may occur because apparent ileal amino acid digestibility coefficients are dependent on the dietary level of that amino acid (Li et al., 1993; Fan et al., 1994; Rademacher et al., 1999). This is especially true when low-protein feed ingredients, such as cereal grains, are included in the feed mixture. This situation can be ameliorated by correcting the apparent ileal amino acid digestibility coefficients for the nonspecific (basal) endogenous losses of amino acids (Mariscal-Landin, 1992; Jondreville et al., 1995). Values obtained after this correction are described by the term *standardized ileal digestibility coefficients* (***SID***). By using SID rather than apparent ileal digestibility coefficients, digestibility coefficients that more correctly estimate the nutritional value of a feed mixture can be calculated (Jondreville et al., 1995; Rademacher et al., 1999).

Standardized ileal digestibility coefficients have been reported for a wide range of feed ingredients by Jondreville et al. (1995) and by Rademacher et al. (1999). However, all these digestibility coefficients were determined using growing pigs, and no data exist for gestating and lactating sows. Therefore, it is presently not known whether the results from growing pigs are also representative for gestating and lactating sows.

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Table 1. Analyzed composition (%) of the feed ingredients (as-fed basis)

Item	Corn	Barley	Wheat	SBM[a]	CM[b]	MBM[c]
Dry matter	83.30	86.50	84.50	87.40	89.10	95.50
Crude protein	7.50	8.50	10.80	43.30	31.40	60.10
Ash	1.02	1.54	1.99	6.10	6.40	20.70
Indispensable amino acids						
Arginine	0.40	0.45	0.57	3.55	2.19	4.22
Histidine	0.24	0.20	0.27	1.30	0.98	1.08
Isoleucine	0.29	0.29	0.37	2.13	1.32	1.67
Leucine	1.07	0.58	0.74	3.74	2.48	3.60
Lysine	0.24	0.35	0.35	3.05	2.05	3.45
Methionine	0.18	0.15	0.21	0.68	0.70	0.90
Phenylalanine	0.43	0.40	0.49	2.47	1.44	2.07
Threonine	0.30	0.29	0.33	1.91	1.55	1.99
Tryptophan	0.07	0.09	0.12	0.65	0.47	0.41
Valine	0.40	0.46	0.52	2.30	1.80	2.54
Dispensable amino acids						
Alanine	0.64	0.38	0.42	2.12	1.59	4.49
Aspartate	0.52	0.56	0.58	5.43	2.57	4.43
Cysteine	0.19	0.20	0.30	0.73	0.85	0.59
Glycine	0.33	0.39	0.49	2.04	1.82	8.21
Glutamate	1.57	1.72	2.92	8.66	5.82	7.25
Proline	0.72	0.81	1.04	2.55	2.14	5.19
Serine	0.39	0.32	0.44	2.36	1.52	2.47
Tyrosine	0.28	0.22	0.27	1.75	1.02	1.39

[a]SBM = soybean meal.
[b]CM = canola meal.
[c]MBM = meat and bone meal.

In the present work, SID for protein and amino acids in six common feed ingredients were estimated using growing pigs, and gestating and lactating sows. The objective was to compare the values obtained for each of the three animal groups to test the hypothesis that SID obtained in growing pigs are also representative for gestating and lactating sows.

Materials and Methods

Apparent ileal digestibility coefficients for protein and amino acids in corn, barley, wheat, soybean meal, canola meal, and meat and bone meal were previously estimated by the direct method for growing pigs and gestating and lactating sows (Stein et al., 1999a). The amino acid composition of the six feed ingredients is shown in Table 1. Diet composition and procedures for animal handling, digesta collections, and sample processing have been described in detail (Stein et al., 1999a). In short, 12 growing pigs and 12 gestating sows were equipped with T-cannulas in the distal ileum for digesta collection using the method described by Stein et al. (1998). Six diets containing one of each of the feed ingredients were formulated. Six sows and six growing pigs were arranged in a repeated 3 × 3 Latin square design and fed the three diets containing the corn, the wheat, and the barley, respectively. The remaining six sows and six growing pigs were used in a similar arrangement and fed the three diets containing the soybean meal, the canola meal, and the meat and bone meal, respectively. Chromium oxide (0.25%) was included in all diets as an inert marker. Growing pigs and lactating sows were allowed ad libitum access to their diets, whereas gestating sows were restricted to 2 kg of feed per day. Apparent ileal amino acid digestibility coefficients were calculated using the following equation (Fan et al., 1995):

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

where AID is the apparent ileal digestibility coefficient of an amino acid (%), AAd is the amino acid content in ileal digesta (mg/kg DM), AAf is the amino acid content in feed (mg/kg DM), and Crf and Crd are the chromium content in the feed DM and in the ileal digesta DM, respectively. Apparent ileal digestibility of protein was calculated in a similar way.

The nonspecific endogenous losses of protein and amino acids were previously estimated for growing pigs and gestating and lactating sows (Stein et al., 1999b). Ten growing pigs and five sows were fed a nitrogen-free diet, and digesta were collected at the distal ileum. Also in that diet, chromium oxide was included at a level of 0.25%. The sows were fed the experimental diet during lactation as well as during gestation. Growing pigs and lactating sows were allowed ad libitum access to the diet, whereas gestating sows were restricted to 2 kg of feed per day. Details on diet formulation have been described previously (Stein et al., 1999b). All experimental procedures in this experiment were identical to those in Exp. 1. The nonspecific losses of amino acids were calculated using the following equation (Moughan et al., 1992):

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

where EAL is the endogenous loss of an amino acid (mg/kg DMI), AAd is the concentration of that amino acid in digesta (mg/kg DM), Crf is the chromium content in feed DM, and Crd is the chromium content in digesta DM. The endogenous loss of protein was calculated using the same equation.

To calculate SID, values for apparent ileal digestibilities and the nonspecific endogenous losses were added according to the following equation (Jondreville et al., 1995):

$$\text{SID} = \text{AID} + (\text{EAL}/\text{AAf}) \times 100\% \quad [3]$$

where SID represents the standardized ileal digestibility coefficient (%) of an amino acid, AID is the apparent ileal digestibility coefficient (%) calculated using Eq. [1], EAL is the nonspecific endogenous loss of that amino acid measured at the distal ileum (mg/kg DMI) after feeding the protein-free diet and calculated according to Eq. [2], and AAf is the dietary content of the amino acid (mg/kg diet DM). The same equation was used to calculate the SID for protein.

Results were statistically analyzed using the Proc Mixed procedure of SAS, SAS Institute, Cary, NC. Values for SID obtained for gestating sows and lactating sows were compared using a repeated measures analysis. Values obtained for growing pigs were compared with those obtained in gestating sows and lactating sows, using a model that included the physiological status of the animal, the diet, and the interaction between the physiological status and the diet as the main effects. Treatment means were separated using a least significant difference test.

The experiments reported here were approved by the University of Illinois Laboratory Animal Care Committee (protocol no. A3S-164).

Results

The calculated SID for the six feed ingredients are presented in Tables 2 to 7. The SID for tryptophan in corn and wheat were higher ($P < 0.05$) in lactating sows than in growing pigs. For arginine, the SID for corn in lactating sows was lower ($P < 0.05$) than in growing pigs, but for all other indispensable amino acids and for crude protein, no differences ($P > 0.05$) between growing pigs and lactating sows were observed for any of the feed ingredients evaluated. The SID for proline in corn, barley, soybean meal, and canola meal were lower ($P < 0.05$) in lactating sows than in growing pigs. The same was true for the SID of glutamate for corn, but for all other dispensable amino acids, no differences ($P > 0.05$) between growing pigs and lactating sows were observed in any of the feed ingredients.

Table 2. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for corn by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 5), mean ± SE[b]	Gestating sows (n = 5), Mean ± SE[c]	Lactating sows (n = 6), Mean ± SE[d]
Crude protein	75.0 ± 2.6[e]	87.3 ± 2.5[f]	69.5 ± 2.3[e]
Indispensable amino acids			
Arginine	85.2 ± 1.5[e]	91.9 ± 1.5[f]	79.5 ± 1.4[g]
Histidine	81.0 ± 1.6[e]	89.8 ± 1.6[f]	82.4 ± 1.5[e]
Isoleucine	80.5 ± 1.9[e]	88.4 ± 1.8[f]	78.5 ± 1.8[e]
Leucine	81.0 ± 1.7[e]	91.1 ± 1.9[f]	84.4 ± 1.6[e]
Lysine	77.3 ± 2.0[e]	84.9 ± 1.9[f]	72.8 ± 1.8[e]
Methionine	82.5 ± 1.5[e]	90.2 ± 1.4[f]	84.1 ± 1.4[e]
Phenylalanine	81.2 ± 1.5[e]	90.0 ± 1.5[f]	83.3 ± 1.4[e]
Threonine	76.1 ± 2.7[e]	84.7 ± 2.3[f]	77.1 ± 2.5[e]
Tryptophan	83.1 ± 2.5[e]	90.9 ± 2.1[f]	95.4 ± 2.3[f]
Valine	79.2 ± 2.0[e]	86.9 ± 1.8[f]	79.1 ± 1.9[e]
Mean	80.7 ± 1.7[e]	88.9 ± 1.6[f]	81.7 ± 1.5[e]
Dispensable amino acids			
Alanine	80.2 ± 2.5[e]	88.4 ± 2.4[f]	80.2 ± 2.3[e]
Aspartate	79.1 ± 2.8[ef]	85.9 ± 2.5[f]	75.8 ± 2.5[e]
Cysteine	74.9 ± 3.0[e]	86.1 ± 2.3[f]	76.6 ± 2.8[e]
Glutamate	80.8 ± 1.9[e]	89.4 ± 2.0[f]	73.9 ± 2.0[g]
Glycine	73.2 ± 3.7[e]	89.6 ± 4.5[f]	65.5 ± 3.3[e]
Proline	93.2 ± 5.0[e]	119.0 ± 9.6[e]	60.5 ± 7.8[f]
Serine	79.6 ± 2.1[e]	87.1 ± 1.8[f]	81.7 ± 1.9[ef]
Tyrosine	77.2 ± 1.8[e]	88.1 ± 1.8[f]	79.5 ± 1.7[e]
Mean	78.9 ± 2.1[e]	91.8 ± 2.7[f]	74.4 ± 3.3[e]

[a] [Apparent digestibility + (endogenous loss/intake)] × 100%.
[b] Standard error for growing pigs vs lactating sows.
[c] Standard error for growing pigs vs gestating sows.
[d] Standard error for growing pigs vs lactating sows.
[e,f,g] Means within a row lacking a common superscript differ ($P < 0.05$).

Table 3. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for barley by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 5), mean ± SE[b]	Gestating sows (n = 5), mean ± SE[c]	Lactating sows (n = 6), mean ± SE[d]
Crude protein	75.2 ± 2.6[e]	82.8 ± 2.5[f]	70.9 ± 2.3[e]
Indispensable amino acids			
Arginine	85.2 ± 1.5[ef]	88.9 ± 1.5[f]	83.7 ± 1.4[e]
Histidine	84.2 ± 1.6	86.9 ± 1.6	84.3 ± 1.5
Isoleucine	84.6 ± 1.9	83.3 ± 1.8	81.1 ± 1.8
Leucine	83.3 ± 1.7	83.7 ± 1.9	81.9 ± 1.6
Lysine	83.4 ± 2.0	83.0 ± 1.9	80.4 ± 1.8
Methionine	85.5 ± 1.5	85.2 ± 1.4	83.4 ± 1.4
Phenylalanine	82.9 ± 1.5	85.1 ± 1.5	83.7 ± 1.4
Threonine	78.8 ± 2.7	78.3 ± 2.3	75.5 ± 2.5
Tryptophan	89.2 ± 2.5	87.1 ± 2.1	90.9 ± 2.3
Valine	83.0 ± 2.0	83.8 ± 1.8	82.4 ± 1.8
Mean	84.0 ± 1.7	84.6 ± 1.6	82.7 ± 1.5
Dispensable amino acids			
Alanine	77.4 ± 2.5	76.2 ± 2.4	72.7 ± 2.3
Aspartate	81.5 ± 2.8	80.2 ± 2.5	75.8 ± 2.5
Cysteine	81.2 ± 3.0	82.5 ± 2.3	81.7 ± 2.8
Glutamate	87.0 ± 2.0	88.3 ± 2.0	86.3 ± 1.8
Glycine	77.3 ± 3.7[e]	93.8 ± 4.50[f]	82.9 ± 3.3[ef]
Proline	101.3 ± 5.0[e]	130.5 ± 9.6[g]	77.1 ± 5.0[f]
Serine	80.6 ± 2.1	81.0 ± 1.8	78.4 ± 1.9
Tyrosine	82.7 ± 1.8	82.1 ± 1.8	80.7 ± 1.7
Mean	83.6 ± 2.1[ef]	89.5 ± 2.7[f]	81.2 ± 2.1[e]

[a][Apparent digestibility + (endogenous loss/intake)] × 100%.
[b]Standard error for growing pigs vs lactating sows.
[c]Standard error for growing pigs vs gestating sows.
[d]Standard error for growing pigs vs lactating sows.
[e,f,g]Means within a row lacking a common superscript differ ($P < 0.05$).

Table 4. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for wheat by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 6), mean ± SE[b]	Gestating sows (n = 6), mean ± SE[c]	Lactating sows (n = 6), mean ± SE[d]
Crude protein	88.3 ± 2.3	90.7 ± 2.3	88.6 ± 2.3
Indispensable amino acids			
Arginine	91.1 ± 1.4	94.1 ± 1.4	90.7 ± 1.4
Histidine	89.9 ± 1.5	90.6 ± 1.4	93.0 ± 1.5
Isoleucine	90.3 ± 1.8	89.5 ± 1.6	89.3 ± 1.8
Leucine	89.4 ± 1.6	86.2 ± 1.8	90.5 ± 1.6
Lysine	85.5 ± 1.8	89.4 ± 1.8	87.2 ± 1.8
Methionine	90.9 ± 1.4	91.1 ± 1.3	91.0 ± 1.4
Phenylalanine	90.5 ± 1.4	89.6 ± 1.4	91.2 ± 1.4
Threonine	85.3 ± 2.5	84.3 ± 2.1	89.5 ± 2.5
Tryptophan	87.8 ± 2.3[e]	90.6 ± 1.9[ef]	96.3 ± 2.3[f]
Valine	87.5 ± 1.8	88.0 ± 1.7	89.1 ± 1.9
Mean	88.8 ± 1.5	89.3 ± 1.4	90.8 ± 1.5
Dispensable amino acids			
Alanine	83.6 ± 2.3	81.1 ± 2.2	84.0 ± 2.3
Aspartate	89.1 ± 2.5	85.7 ± 2.3	85.4 ± 2.5
Cysteine	89.1 ± 2.8	89.1 ± 2.1	91.0 ± 2.8
Glutamate	94.9 ± 1.8	94.2 ± 1.8	94.6 ± 1.8
Glycine	86.7 ± 3.3	93.9 ± 4.2	94.2 ± 3.3
Proline	107.7 ± 4.6[ef]	130.2 ± 8.8[e]	96.1 ± 4.6[f]
Serine	89.5 ± 1.9	88.5 ± 1.7	91.9 ± 1.9
Tyrosine	87.8 ± 1.7	86.3 ± 1.7	89.0 ± 1.7
Mean	91.0 ± 1.9	93.6 ± 2.5	90.8 ± 1.9

[a][Apparent digestibility + (endogenous loss/intake)] × 100%.
[b]Standard error for growing pigs vs lactating sows.
[c]Standard error for growing pigs vs gestating sows.
[d]Standard error for growing pigs vs lactating sows.
[e,f]Means within a row lacking a common superscript differ ($P < 0.05$).

Table 5. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for soybean meal by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 6), mean ± SE[b]	Gestating sows (n = 6), mean ± SE[c]	Lactating sows (n = 5), mean ± SE[d]
Crude protein	84.8 ± 2.3[e]	95.1 ± 2.3[f]	81.7 ± 2.6[e]
Indispensable amino acids			
Arginine	92.4 ± 1.4[e]	97.0 ± 1.4[f]	92.2 ± 1.5[e]
Histidine	91.1 ± 1.5[e]	95.6 ± 1.4[f]	90.1 ± 1.6[e]
Isoleucine	88.8 ± 1.8[e]	93.5 ± 1.6[f]	88.1 ± 1.9[e]
Leucine	87.4 ± 1.6[e]	92.9 ± 1.8[f]	87.6 ± 1.7[e]
Lysine	91.4 ± 1.8[e]	97.2 ± 1.8[f]	90.0 ± 2.0[e]
Methionine	89.7 ± 1.4[e]	95.1 ± 1.3[f]	87.8 ± 1.5[e]
Phenylalanine	88.5 ± 1.4[e]	93.1 ± 1.4[f]	88.7 ± 1.5[e]
Threonine	85.4 ± 2.5[e]	92.5 ± 2.1[f]	87.2 ± 2.7[ef]
Tryptophan	90.1 ± 2.3	94.3 ± 1.9	95.5 ± 2.5
Valine	86.0 ± 1.8[e]	91.8 ± 1.7[f]	85.7 ± 2.0[e]
Mean	89.1 ± 1.5[e]	94.3 ± 1.5[f]	89.3 ± 1.7[e]
Dispensable amino acids			
Alanine	83.2 ± 2.3[e]	91.7 ± 2.2[f]	80.9 ± 2.5[e]
Aspartate	87.5 ± 2.5[ef]	93.2 ± 2.3[f]	84.2 ± 2.8[e]
Cysteine	82.9 ± 2.8[e]	91.4 ± 2.1[f]	82.9 ± 3.1[e]
Glutamate	87.4 ± 1.8[e]	94.5 ± 1.8[f]	85.2 ± 2.0[e]
Glycine	79.5 ± 3.3[e]	98.7 ± 4.2[f]	84.5 ± 4.1[e]
Proline	102.2 ± 5.0[e]	132.4 ± 8.8[f]	56.5 ± 7.9[g]
Serine	88.8 ± 1.9[e]	93.5 ± 1.7[f]	88.8 ± 2.1[ef]
Tyrosine	89.8 ± 1.7[e]	95.2 ± 1.7[f]	90.6 ± 1.8[ef]
Mean	87.2 ± 2.1[e]	98.8 ± 2.5[f]	85.9 ± 3.3[e]

[a][Apparent digestibility + (endogenous loss/intake)] × 100%.
[b]Standard error for growing pigs vs lactating sows.
[c]Standard error for growing pigs vs gestating sows.
[d]Standard error for growing pigs vs lactating sows.
[e,f,g]Means within a row lacking a common superscript differ ($P < 0.05$).

Table 6. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for canola meal by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 6), mean ± SE[b]	Gestating sows (n = 6), mean ± SE[c]	Lactating sows (n = 5), mean ± SE[d]
Crude protein	76.1 ± 2.3	77.4 ± 2.3	74.7 ± 2.6
Indispensable amino acids			
Arginine	86.9 ± 1.4	85.6 ± 1.4	86.2 ± 1.5
Histidine	87.3 ± 1.5	88.8 ± 1.4	89.7 ± 1.6
Isoleucine	81.3 ± 1.8	83.3 ± 1.6	84.5 ± 2.0
Leucine	82.3 ± 1.6	84.5 ± 1.8	86.7 ± 1.7
Lysine	83.6 ± 1.8	88.1 ± 1.8	86.2 ± 2.0
Methionine	86.7 ± 1.4	88.7 ± 1.3	89.9 ± 1.6
Phenylalanine	82.6 ± 1.4	84.6 ± 1.4	86.8 ± 1.5
Threonine	78.5 ± 2.5	80.5 ± 2.1	83.4 ± 2.7
Tryptophan	88.7 ± 2.3[ef]	86.8 ± 1.9[e]	94.7 ± 2.5[f]
Valine	79.4 ± 1.9	80.8 ± 1.7	83.5 ± 2.1
Mean	83.7 ± 1.5	85.2 ± 1.5	87.2 ± 1.7
Dispensable amino acids			
Alanine	80.0 ± 2.3	82.4 ± 2.2	82.8 ± 2.5
Aspartate	81.0 ± 2.5	81.0 ± 2.3	82.4 ± 2.8
Cysteine	81.5 ± 2.8	84.1 ± 2.1	84.9 ± 3.1
Glutamate	82.7 ± 1.8	81.3 ± 1.8	85.1 ± 2.0
Glycine	77.5 ± 3.3	77.3 ± 4.2	81.6 ± 3.7
Proline	97.7 ± 5.0[e]	85.2 ± 10.7[ef]	66.3 ± 6.4[f]
Serine	81.1 ± 1.9	79.7 ± 1.7	82.8 ± 2.1
Tyrosine	81.9 ± 1.7	84.8 ± 1.7	84.8 ± 1.8
Mean	83.2 ± 2.1	82.6 ± 3.0	82.8 ± 2.7

[a][Apparent digestibility + (endogenous loss/intake)] × 100%.
[b]Standard error for growing pigs vs lactating sows.
[c]Standard error for growing pigs vs gestating sows.
[d]Standard error for growing pigs vs lactating sows.
[e,f]Means within a row lacking a common superscript differ ($P < 0.05$).

Table 7. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for meat and bone meal by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 6), mean ± SE[b]	Gestating sows (n = 5), mean ± SE[c]	Lactating sows (n = 5), mean ± SE[d]
Crude protein	81.3 ± 2.3	87.0 ± 2.5	81.6 ± 2.6
Indispensable amino acids			
Arginine	88.5 ± 1.4[e]	92.0 ± 1.5[f]	89.5 ± 1.5[ef]
Histidine	84.8 ± 1.5	88.5 ± 1.6	85.9 ± 1.6
Isoleucine	83.5 ± 1.8[ef]	87.6 ± 1.8[f]	81.0 ± 1.9[e]
Leucine	83.4 ± 1.6	87.8 ± 1.9	83.1 ± 1.7
Lysine	82.4 ± 1.8	87.3 ± 1.9	85.3 ± 2.0
Methionine	83.9 ± 1.4[e]	88.2 ± 1.4[f]	85.8 ± 1.5[ef]
Phenylalanine	84.0 ± 1.4[e]	88.2 ± 1.5[f]	83.8 ± 1.5[e]
Threonine	81.3 ± 2.5	86.1 ± 2.3	83.1 ± 2.7
Tryptophan	87.2 ± 2.3	87.6 ± 2.1	91.0 ± 2.5
Valine	82.2 ± 1.9	85.7 ± 1.8	81.8 ± 2.0
Mean	84.1 ± 1.5	87.9 ± 1.6	85.0 ± 1.7
Dispensable amino acids			
Alanine	84.0 ± 2.3	87.9 ± 2.4	87.2 ± 2.5
Aspartate	70.6 ± 2.5	72.9 ± 2.5	69.9 ± 2.8
Cysteine	59.5 ± 2.8[e]	69.5 ± 2.3[f]	58.5 ± 3.0[e]
Glutamate	82.9 ± 1.8	86.7 ± 2.0	82.6 ± 2.0
Glycine	82.9 ± 3.3	87.3 ± 4.5	88.6 ± 3.7
Proline	85.6 ± 4.6[ef]	110.1 ± 9.6[e]	79.9 ± 5.0[f]
Serine	82.2 ± 1.9	85.1 ± 1.8	81.4 ± 2.1
Tyrosine	84.9 ± 1.7	88.9 ± 1.8	84.9 ± 1.8
Mean	79.1 ± 1.9	85.8 ± 2.7	79.1 ± 2.1

[a][Apparent digestibility + (endogenous loss/intake)] × 100%.
[b]Standard error for growing pigs vs lactating sows.
[c]Standard error for growing pigs vs gestating sows.
[d]Standard error for growing pigs vs lactating sows.
[e,f]Means within a row lacking a common superscript differ ($P < 0.05$).

Gestating sows had higher ($P < 0.05$) SID than growing pigs in corn for crude protein and all amino acids except proline and aspartate. Likewise, in soybean meal gestating sows had higher ($P < 0.05$) SID than growing pigs for crude protein and all amino acids except tryptophan and aspartate. For meat and bone meal, gestating sows had higher ($P < 0.05$) SID than growing pigs only for arginine, methionine, phenylalanine, and cysteine. In the case of barley, the SID for crude protein, glycine, and proline were higher ($P < 0.05$) in gestating sows than in growing pigs, whereas those for the remaining amino acids were not different ($P > 0.05$) between these two groups. In wheat and canola meal, the SID for protein and amino acids in gestating sows were not different ($P > 0.05$) from those in growing pigs.

The SID of crude protein and all amino acids except tryptophan and serine in corn and threonine, tryptophan, serine, and tyrosine in soybean meal were higher ($P < 0.05$) for gestating sows than for lactating sows. In meat and bone meal, the coefficients for isoleucine, phenylalanine, cysteine, and proline in gestating sows were higher ($P < 0.05$) than in lactating sows, whereas for the remaining amino acids and for crude protein they were not different ($P > 0.05$). For the remaining feed ingredients, SID obtained in gestating sows were, with a few exceptions, not different ($P > 0.05$) from those obtained in lactating sows.

The combined results for the six feed ingredients are presented in Table 8. For crude protein and all amino acids, except tryptophan and aspartate, gestating sows had higher ($P < 0.05$) SID than had growing pigs. Likewise, coefficients for crude protein and all amino acids, except leucine, threonine, tryptophan, and serine, were higher ($P < 0.05$) in gestating sows than in lactating sows. The coefficients for crude protein and all amino acids, except tryptophan and proline, in growing pigs were not different ($P > 0.05$) from those in lactating sows.

Except for proline, there were no interactions ($P > 0.05$) between the values in growing pigs and those in lactating sows (Table 9). However, interactions ($P < 0.05$) for the SID in growing pigs compared with gestating sows were observed for crude protein and all amino acids except lysine, aspartate, and proline. Comparing lactating sows and gestating sows, interactions ($P < 0.05$) were observed for crude protein and all amino acids except for threonine, tryptophan, cysteine, proline, and serine.

Discussion

The endogenous losses of protein and amino acids in pigs can be divided into the nonspecific (or basal) losses and the diet-specific losses (Jondreville et al., 1995; Boisen, 1998). The nonspecific losses represent the amino acid losses that are related only to the DMI of the animal and are not influenced by the type of diet or the feed ingredient itself. However, most feed ingredients also induce additional diet-specific endogenous losses because of their content of fiber (Schulze et al., 1994, 1995b; Leterme et al., 1996) or antinutritional factors (le Guen et al., 1995; Schulze et al., 1995a). The nonspecific endogenous losses of amino acids can be measured after feeding a protein-free diet, a casein-based diet, or a diet based on hydrolyzed casein. The values for nonspecific endogenous losses are used to calculate SID. Because SID are not corrected for the diet-specific endogenous losses induced by the feed ingredient itself, they should not be referred to as true digestibility coefficients (Nyachoti et al., 1997). The SID are not related to the dietary level of crude protein and amino acids, and they are likely to be more additive in a mixed diet than values for apparent ileal digestibility coefficients (Jondreville et al., 1995; Boisen and Moughan, 1996; Rademacher et al., 1999).

The SID for growing pigs in the present experiment were close to values previously reported (Jondreville et al., 1995; Rademacher et al., 1999) for wheat, barley, and soybean meal. Our values for corn are lower, and the values for canola meal and for meat and bone meal are higher than the values presented by Jondreville et al. (1995) and Rademacher et al. (1999). The differences between our results and those previously reported may be due to differences in experimental methodologies, varieties, soil conditions, and fertilizer levels, which have been shown to influence digestibility coefficients for canola meal (Fan et al., 1996). Likewise, for meat and bone meal, digestibility coefficients are influenced by the source of raw materials and processing procedures (Bellaver et al., 1997). The lowest SID for the indispensable amino acids were usually obtained for threonine, valine, and lysine, regardless of the physiological condition of the animals. Previously, the lowest SID for corn, wheat, and barley in growing pigs were reported for lysine and threonine (Green et al., 1987).

The fact that lactating sows and growing pigs had similar SID for most amino acids in all feed ingredients is in contrast to our previous calculations based on apparent ileal digestibility coefficients that showed digestibility coefficients for lactating sows being higher than digestibility coefficients for growing pigs (Stein et al., 1999a). The reason for this apparent discrepancy is that lactating sows have lower nonspecific endogenous losses of most amino acids compared with growing pigs (Stein et al., 1999b). Thus, the previously reported differences in apparent ileal digestibility coefficients between growing pigs and lactating sows are not caused by a difference in the digestibility of dietary

Table 8. Standardized ileal digestibility coefficients (%) of crude protein and amino acids for corn, barley, wheat, soybean meal, canola meal, and meat and bone meal by growing pigs, and gestating and lactating sows[a]

Item	Growing pigs (n = 34), mean ± SE[b]	Gestating sows (n = 34), mean ± SE[c]	Lactating sows (n = 33), mean ± SE[d]
Crude protein	80.1 ± 1.0[e]	86.7 ± 1.3[f]	77.8 ± 1.0[e]
Indispensable amino acids			
Arginine	88.2 ± 0.7[e]	91.6 ± 0.9[f]	87.0 ± 0.7[e]
Histidine	86.4 ± 0.7[e]	90.0 ± 0.8[f]	87.6 ± 0.7[e]
Isoleucine	84.8 ± 0.8[e]	87.6 ± 0.7[f]	83.7 ± 0.9[e]
Leucine	84.5 ± 0.7[e]	87.7 ± 0.7[f]	85.7 ± 0.7[ef]
Lysine	83.9 ± 1.0[e]	88.3 ± 0.9[f]	83.6 ± 1.0[e]
Methionine	86.5 ± 0.7[e]	89.7 ± 0.6[f]	87.0 ± 0.7[e]
Phenylalanine	84.9 ± 0.7[e]	88.5 ± 0.7[f]	86.2 ± 0.7[e]
Threonine	80.9 ± 1.1[e]	84.4 ± 0.9[f]	82.6 ± 1.2[ef]
Tryptophan	87.7 ± 1.0[e]	89.5 ± 1.0[e]	94.0 ± 1.0[f]
Valine	82.6 ± 0.8[e]	86.2 ± 0.9[f]	83.6 ± 0.9[e]
Mean	85.1 ± 0.7[e]	88.4 ± 0.7[f]	86.1 ± 0.7[e]
Dispensable amino acids			
Alanine	81.4 ± 1.0[e]	84.6 ± 1.0[f]	81.3 ± 1.0[e]
Aspartate	81.5 ± 1.2[ef]	83.2 ± 1.0[f]	78.9 ± 1.2[e]
Cysteine	78.2 ± 1.3[e]	83.8 ± 0.9[f]	79.3 ± 1.3[e]
Glutamate	84.9 ± 0.9[e]	89.1 ± 0.8[f]	85.8 ± 0.9[e]
Glycine	79.5 ± 1.6[e]	90.1 ± 2.7[f]	82.9 ± 1.6[e]
Proline	98.0 ± 2.2[e]	117.9 ± 4.7[f]	72.7 ± 2.7[g]
Serine	83.6 ± 0.9[e]	85.8 ± 0.7[f]	84.2 ± 0.9[ef]
Tyrosine	84.0 ± 0.7[e]	87.6 ± 0.7[f]	84.9 ± 0.8[e]
Mean	83.8 ± 0.9[e]	90.3 ± 1.2[f]	82.4 ± 1.1[e]

[a][Apparent digestibility + (endogenous loss/intake)] × 100%.
[b]Standard error for growing pigs vs lactating sows.
[c]Standard error for growing pigs vs gestating sows.
[d]Standard error for growing pigs vs lactating sows.
[e,f,g]Means within a row lacking a common superscript differ ($P < 0.05$).

Table 9. Interactions between the physiological status of the animals and the digestibility coefficients of diets

	Comparison[a]		
Item	Growing pigs vs lactating sows	Growing pigs vs gestating sows	Lactating sows vs gestating sows
Number of observations	34	34	33
Crude protein	NS	*	***
Indispensable amino acids			
Arginine	NS	*	*
Histidine	NS	*	*
Isoleucine	NS	*	*
Leucine	NS	*	*
Lysine	NS	NS	**
Methionine	NS	*	**
Phenylalanine	NS	*	*
Threonine	NS	*	NS
Tryptophan	NS	*	NS
Valine	NS	*	*
Mean	NS	*	*
Dispensable amino acids			
Alanine	NS	*	*
Aspartate	NS	NS	*
Cysteine	NS	*	NS
Glutamate	NS	***	***
Glycine	NS	*	***
Proline	***	NS	NS
Serine	NS	*	NS
Tyrosine	NS	**	*
Mean	NS	*	*

[a]NS = Non significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.005$.

amino acids per se, but rather by differences in the nonspecific endogenous losses of amino acids. It has been reported that the nonspecific losses of protein and amino acids, expressed as grams per kilogram of DMI, decrease with increasing DMI (Furuya and Kaji, 1992; Butts et al., 1993; Stein et al., 1999b). The lactating sows had a higher daily feed intake of the tested feed ingredients as well as of the protein-free diet used to measure the nonspecific endogenous losses (Stein et al., 1999a,b). Therefore, the differences in the nonspecific endogenous losses may have been caused by differences in daily feed intake.

Gestating sows had the highest ($P < 0.05$) SID for crude protein and most amino acids compared with growing pigs and lactating sows. Previously, it was reported that apparent ileal digestibility coefficients for gestating sows are lower than those determined for lactating sows, but usually not different ($P > 0.05$) from those obtained for growing pigs (Stein et al., 1999a). However, it was also reported (Stein et al., 1999b) that the nonspecific endogenous losses of crude protein and all amino acids for gestating sows restricted in their feed intake were higher ($P < 0.05$) than for lactating sows and growing pigs given ad libitum access to the diet. In addition, endogenous losses per kilogram of DMI for gestating sows fed only 2 kg of feed per day were also higher ($P < 0.05$) than for gestating sows given free access to their diet. Because SID are corrected for the nonspecific endogenous losses, the differences in endogenous losses between the three groups of animals are the reason why the results of this experiment are different from those on apparent ileal digestibilities previously reported. Consequently, the differences in SID between gestating sows and growing pigs and lactating sows in the present experiment may have been caused by differences in feed intake rather than by the physiological condition of the animal. Nonetheless, the feeding levels used in this experiment for all three groups of animals are close to what is usually used under practical feeding conditions. Therefore, it is likely that the results of this experiment reflect the situation under practical conditions. The results also highlight that if the nonspecific endogenous losses of amino acids measured at the distal ileum are expressed as grams per kilogram of DMI, the daily feed intake influences these losses.

If it is accepted that the reason for the higher SID for gestating sows as compared with growing pigs and lactating sows is the lower daily feed intake, it indicates that the coefficients will decrease as DMI increases. In other words, the digestibility and absorption of amino acids decrease as daily feed intake increases. In contrast, the apparent ileal digestibility coefficients of amino acids have been reported not to be influenced by the feeding level of the animal (Sauer et al., 1982; Haydon et al., 1984). This difference between apparent and standardized ileal amino acid digestibility coefficients can be explained by the fact that the nonspecific endogenous losses are reduced as DMI increases. Because apparent ileal digestibility coefficients are not corrected for the endogenous losses, the decreasing endogenous losses of amino acids with increasing DMI offsets the decreasing digestibility and absorption of amino acids, resulting in constant digestibility coefficients regardless of DMI. In contrast, when calculating SID, the nonspecific endogenous losses are excluded from the calculation, and, therefore, the decreasing digestibility and absorption of amino acids with increasing DMI cannot be offset, resulting in decreasing SID with increasing DMI.

The fact that there were significant interactions between animals and diets when gestating sows were compared with either lactating sows or growing pigs indicates that the differences in SID between these animal groups are not of the same magnitude for all feed ingredients. Therefore, it is not possible to extrapolate data from one feed ingredient to another.

In conclusion, the results from the present experiment suggest that SID obtained for growing pigs are also representative for lactating sows, if both groups of animals are consuming their diets on an ad libitum basis. However, coefficients obtained for growing pigs given free access to the diet are not representative for gestating sows restricted to 2 kg of feed per day. In general, SID seem to be influenced by the feeding level of the animal.

Implications

Results of the present experiment suggest that, in practical feed formulation, similar standardized ileal digestibility coefficients can be used for growing pigs and lactating sows provided that both groups are given free access to their diet. However, there are real differences in the digestion and absorption of amino acids between growing pigs given free access to their feed and gestating sows restricted to 2 kg of feed per day. Therefore, standardized ileal digestibility coefficients obtained by growing pigs are not representative for standardized ileal digestibility coefficients by gestating sows.

Literature Cited

Bellaver, C., R. A. Easter, C. M. Parson, and A. L. Guidoni. 1997. Prediction equations for protein and amino acid digestibility in meat and bone meals. In: J. P. Laplace, C. Fevrier, and A. Barbeau (ed.) Digestive Physiology in Pigs. EAAP Publ. No 88. p 426–429. St. Malo, France.

Boisen, S. 1998. A new protein evaluation system for pig feeds and its practical application. Acta Agric. Scand. Sect. A. Anim. Sci. 48:1–11.

Boisen, S. and P. J. Moughan. 1996. Different expressions of dietary protein and amino acid digestibility in pig feeds and their application in protein evaluation: A theoretical approach. Acta Agric. Scand. Sect. A. Anim. Sci. 46:165–172.

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 liveweight pig. J. Sci. Food Agric. 62:235–243.

Fan, M. Z., W. C. Sauer, and V. M. Gabert. 1996. Variability of apparent ileal amino acid digestibility in canola meal for growing-finishing pigs. Can. J. Anim. Sci. 76:563–569.

Fan, M. Z., W. C. Sauer, R. T. Hardin, and K. A. Lien. 1994. Determination of apparent ileal amino acid digestibility in pigs: Effect of dietary amino acid level. J. Anim. Sci. 72:2851–2859.

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

Furuya, S., and Y. Kaji. 1991. Additivity of the apparent and ileal digestible amino acid supply in barley, maize, wheat or soybean meal based diets for growing pigs. Anim. Feed Sci. Technol. 32:321–331.

Furuya, S., and Y. Kaji. 1992. The effect of feed intake and purified cellulose on the endogenous ileal amino acid flow in growing pigs. Br. J. Nutr. 68:463–472.

Green, S., S. L. Bertrand, M. J. C. Duron, and R. A. Maillard. 1987. Digestibility of amino acids in maize, wheat and barley meal, measured in pigs with ileo-rectal anastomosis and isolation of the large intestine. J. Sci. Food Agric. 41:29–43.

Haydon, K. D., D. A. Knabe, and T. D. Tanksley. 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.

Jondreville, C., J. Van den Broecke, F. Gatel, and S. Van Cauwenberghe. 1995. Ileal digestibility of amino acids in feedstuffs for pigs. Eurolysine/ITFC publication, Paris, France.

le Guen, M. P., J. Huismann, J. Gueguen, G. Beelen, and M.W.A. Verstegen. 1995. Effects of a concentrate of pea antinutritional factors on pea protein digestibility in piglets. Livest. Prod. Sci. 44:157–167.

Leterme, P., A. Thewis, P. van Leeuwen, T. Monmart, and J. Huismann. 1996. Chemical composition of pea fibre isolates and their effect on the endogenous amino acid flow at the ileum of the pig. J. Sci. Food Agric. 72:127–134.

Li, S., W. C. Sauer, and M. Z. Fan. 1993. The effect of dietary crude protein level on amino acid digestibility in early-weaned pigs. J. Anim. Physiol. Anim. Nutr. 70:26–37.

Mariscal-Landin, G. 1992. Facteurs de variation de l'utilisation digestive dés acides aminés chez le porc. Ph.D. thesis. Rennes University. Rennes, France.

Moughan, P. J., G. Schuttert, and M. Leenaars. 1992. Endogenous amino acid flow in the stomach and small intestine of the young growing pig. J. Sci. Food Agric. 62:437–442.

Nyachoti, C. M., C. F. M. de Lange, B. W. McBride, and H. Schulze. 1997. Significance of endogenous gut nitrogen losses in the nutrition of growing pigs: A review. Can. J. Anim. Sci. 77:149–163.

Rademacher, M., W. C. Sauer, and A. J. M. Jansman. 1999. Standardized ileal digestibility of amino acids in pigs. Degusa-Hülls AG publication, Frankfurt, Germany.

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

Schulze, H., H. S. Saini, J. Huisman, M. Hessing, J. W. O. van den Berg, and M. W. A. Verstegen. 1995a. Increased nitrogen secretion by inclusion of Soya pectin in the diets of pigs. J. Sci. Food Agric. 69:501–510.

Schulze, H., P. van Leeuwen, M. W. A. Verstegen, J. Huisman, W. B. Souffrant, and F. Ahrens. 1994. Effect of level of dietary neutral detergent fiber on ileal apparent digestibility and ileal nitrogen losses in pigs. J. Anim. Sci. 72:2362–2368.

Schulze, H., P. van Leeuwen, M. W. A. Verstegen, and J. W. O. van den Berg.

1995b. Dietary level and source of neutral detergent fiber and ileal endogenous nitrogen flow in pigs. J. Anim. Sci. 73:441–448.

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., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula in 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 effect 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.