Standardized ileal digestibility of amino acids in cereal grains and co-products in growing pigs

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Objective: The objective was to determine standardized ileal digestibility (SID) of crude protein (CP) and amino acids (AA) in cereal grains and various co-products fed to growing pigs.

Methods: Ten feed ingredients tested were barley (9.3% CP), lupin kernels (31.1% CP), and wheat (11.3% CP) as cereal grains, and 2 sources of corn gluten feed produced in China (21.6% CP) and Korea (24.6% CP), corn gluten meal (65.3% CP), lupin hulls (11.6% CP), rice bran (14.5% CP), soybean meal (44.8% CP), and wheat bran (15.4% CP) as co-products. Ten experimental diets were formulated to contain each ingredient as a sole source of N and an N-free diet was used to correct basal endogenous losses of CP and AA. All diets also contained 0.5% Cr2O3 as an indigestible index. A replicated 11×6 incomplete Latin square design with 11 dietary treatments, 6 periods, and 22 animals was employed. Twenty-two barrows with an initial body weight of 64.6±4.9 kg were equipped with a T-cannula in the distal ileum. An experimental period consisted of a 4-d adaptation period and a 2-d collection period.

Results: The SID of CP in the barley, lupin kernels, wheat, 2 sources of corn gluten feed, corn gluten meal, lupin hulls, rice bran, soybean meal, and wheat bran were 84.7%, 90.5%, 90.4%, 77.4%, 74.6%, 89.5%, 90.4%, 74.4%, 86.9%, and 63.4% (standard error of the mean [SEM] = 5.3, p = 0.006), respectively. The respective SID values of Lys were 75.5%, 88.4%, 83.9%, 74.7%, 89.5%, 90.4%, 74.4%, 86.9%, and 63.4% (standard error of the mean [SEM] = 3.3, p<0.001), and the SID values of Met were 83.6%, 88.7%, 89.4%, 85.7%, 85.3%, 85.3%, 85.3%, 89.4%, 91.1%, and 77.0% (SEM = 2.4, p<0.001), respectively.

Conclusion: The ileal digestibility of protein and amino acids varies among the feed ingredients fed to pigs.

Keywords: Alternative Feed Ingredient; Cereal Grains; Co-products; Digestibility; Swine

INTRODUCTION

Amino acids (AA) are crucial nutrients for the metabolism of pigs. An adequate amount of AA in swine diets based on an accurately determined digestible AA in feed ingredients is important. Ileal digestibility of AA has been measured for an accurate determination of biological availability of AA, and a partial rather than a total collection method using an index has been widely used [1]. The use of standardized ileal digestibility (SID) values enables an accurate formulation due to the additivity [2,3] resulting in maximal N retention and reduced N excretion [4]. The use of SID of AA has been suggested by Stein et al [5] and the AA contents in feed ingredients and the requirement estimates are expressed based on the SID in swine diet formulation [6].

The prices of conventional feed ingredients including corn and soybean meal (SBM) show yearly fluctuation. For an economic advantage, alternative feed ingredients have been used to substitute the conventional feed ingredients [7,8]. Information on the SID of AA in the...
alternative feed ingredients is necessary to accurately formulate swine diets. However, data on the SID of AA in some feed ingredients including corn gluten feed, lupin hulls, and rice bran are limited in the literature [6]. Thus, the objective of the present study was to determine the SID of crude protein (CP) and AA in the various feed ingredients for pigs.

MATERIALS AND METHODS

Animal care
The experimental procedure was approved by the Institutional Animal Care and Use Committee at Konkuk University (KU12127).

Animals, experimental design, and diets
The ileal digestibility of AA in the feed ingredients was determined by employing a replicated 11×6 incomplete Latin square design with 11 dietary treatments, 6 periods, and 22 animals [9]. Twenty-two barrows with an initial body weight (BW) of 64.6±4.9 kg were equipped with a T-cannula in the distal ileum using the procedures adapted from Stein et al [10], and were individually housed.

Ten feed ingredients were used including barley, lupin kernels, and wheat as cereal grains, 2 sources of corn gluten feed produced in China (corn gluten feed-C) and Republic of Korea (corn gluten feed-K), corn gluten meal, lupin hulls, rice bran, and wheat bran as co-products, and SBM as a reference ingredient for AA digestibility (Table 1). Eleven experimental diets were prepared (Tables 2, 3). In addition to the 10 diets containing a test feed ingredient as the sole source of AA, an N-free diet was also formulated based on cornstarch and sucrose to determine the basal endogenous losses (BEL) of CP and AA. In all diets, vitamin and mineral premix was also supplemented to meet or exceed the nutrient requirement estimates suggested by NRC [11]. All diets contained 0.5% Cr₂O₃ as an indigestible index [1].

Feeding and sample collection
The daily feed allowance per pig was 2.3 times the metabolizable energy (ME) requirement for maintenance (i.e., 2.3×106

Table 1. Analyzed nutrient composition in feed ingredients (as-fed basis)

| Item (%)                  | Cereal grains                  | Co-products                  |
|---------------------------|--------------------------------|-----------------------------|
|                           | Barley                        | Lupin kernels               | Wheat |
| Dry matter                | 91.18                         | 91.53                       | 92.75 |
| Crude protein             | 9.32                          | 31.13                       | 11.30 |
| Crude fiber               | 4.35                          | 6.46                        | 2.44  |
| Neutral detergent fiber   | 16.19                         | 11.54                       | 14.22 |
| Acid detergent fiber      | 6.63                          | 9.48                        | 3.57  |
| Lys:crude protein         | 4.40                          | 5.82                        | 3.36  |
| Arg                       | 0.51                          | 3.84                        | 0.60  |
| His                       | 0.22                          | 0.99                        | 0.29  |
| Ile                       | 0.31                          | 1.45                        | 0.42  |
| Leu                       | 0.66                          | 2.50                        | 0.81  |
| Lys                       | 0.41                          | 1.81                        | 0.38  |
| Met                       | 0.16                          | 0.21                        | 0.20  |
| Phe                       | 0.48                          | 1.44                        | 0.54  |
| Thr                       | 0.35                          | 1.37                        | 0.36  |
| Trp                       | 0.09                          | 0.25                        | 0.08  |
| Val                       | 0.46                          | 1.48                        | 0.53  |
| Ala                       | 0.42                          | 1.32                        | 0.46  |
| Asp                       | 0.63                          | 3.55                        | 0.63  |
| Cys                       | 0.27                          | 0.56                        | 0.35  |
| Glu                       | 2.03                          | 7.68                        | 3.25  |
| Gly                       | 0.41                          | 1.56                        | 0.49  |
| Pro                       | 0.79                          | 1.09                        | 0.93  |
| Ser                       | 0.41                          | 1.73                        | 0.51  |
| Tyr                       | 0.29                          | 1.20                        | 0.31  |

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Table 2. Ingredient composition of experimental diets (as-fed basis)

| Item (%) | Cereal grains | Co-products |
|----------|---------------|-------------|
|          | Barley        | Lupin kernels | Wheat | Corn gluten feed-China | Corn gluten feed-Korea | Corn gluten meal | Lupin hulls | Rice bran | Soybean meal | Wheat bran | N-free |
| Corn starch | 27.15 | 37.20 | 27.15 | 37.35 | 37.20 | 50.50 | 37.50 | 27.40 | 44.15 | 27.45 | 68.35 |
| Sucrose | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| Barley | 50.00 | - | - | - | - | - | - | - | - | - | - |
| Lupin kernels | - | 40.00 | - | - | - | - | - | - | - | - | - |
| Wheat | - | - | 50.00 | - | - | - | - | - | - | - | - |
| Corn gluten feed-China | - | - | - | - | - | - | 40.00 | - | - | - | - |
| Corn gluten feed-Korea | - | - | - | - | - | - | 40.00 | - | - | - | - |
| Corn gluten meal | - | - | - | - | - | - | - | 26.50 | - | - | - |
| Lupin hulls | - | - | - | - | - | - | - | 40.00 | - | - | - |
| Rice bran | - | - | - | - | - | - | - | 50.00 | - | - | - |
| Soybean meal | - | - | - | - | - | - | - | - | 33.00 | - | - |
| Wheat bran | - | - | - | - | - | - | - | - | 50.00 | - | - |
| Soybean oil | - | - | - | - | - | - | - | - | - | - | 4.00 |
| Cellulose | - | - | - | - | - | - | - | - | - | - | 4.00 |
| K₂CO₃ | - | - | - | - | - | - | - | - | - | - | 0.40 |
| MgO | - | - | - | - | - | - | - | - | - | - | 0.10 |
| Ground limestone | 0.75 | 0.80 | 0.85 | 0.70 | 1.00 | 0.90 | 0.10 | 1.20 | 1.00 | 1.15 | 0.75 |
| Dicalcium phosphate | 0.70 | 0.60 | 0.60 | 0.55 | 0.40 | 0.70 | 1.00 | - | 0.45 | - | 1.00 |
| Salt | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin-mineral premix² | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Cr₂O₃ | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |

¹Provided the following quantities per kg of a diet: vitamin A, 25,000 IU; vitamin D₃, 4,000 IU; vitamin E, 50 IU; vitamin K, 5 mg; thiamin, 4.9 mg; riboflavin, 10.0 mg; pyridoxine, 4.9 mg; vitamin B₁₂, 0.06 mg; pantothenic acid, 37.5 mg; folic acid, 1.00 mg; niacin, 62.0 mg; biotin, 0.06 mg; Cu, 25 mg as CuSO₄; Fe, 268 mg as FeSO₄; I, 5.0 mg as KIO₃; Mn, 125 mg as MnSO₄; Se, 0.38 mg as Na₂SeO₃; Zn, 313 mg as ZnO; butylated hydroxytoluene, 50 mg.

 kcal of ME/kg of BW⁰.⁷⁵ [11] based on a calculated ME of each diet and equally provided twice as meals at 0830 and 1630 h. Water was freely available at all times.

An experimental period consisted of a 4-d adaptation period and a 2-d collection period. The ileal digesta from pigs were collected from 0900 to 1630 h on the collection days by attaching a plastic bag with a wire to the cannula barrel of pigs. Sample bags were changed at least once every 30 min or whenever the bags were filled with digesta. The collected ileal digesta samples were immediately stored at −20°C to prevent bacterial degradation of the AA. At the end of experiment, the samples were freeze-dried and ground before the analyses.

Chemical analyses

Based on the methods illustrated in AOAC International [12], the feed ingredient, diet, ileal digesta samples were analyzed for dry matter (DM; method 930.15) and CP (method 990.03), and AA concentrations were also analyzed by hydrolyzing with 6 N HCl for 24 h at 110°C (method 994.12) except for sulfur-containing AA (method 985.28) and Trp (method 988.15). For Met and Cys, samples were analyzed as methionine sulfone and cysteic acid after cold perfomric acid oxidation before the acid hydrolysis. For analysis of Trp, samples were hydrolyzed using barium hydroxide. The experimental diets were analyzed for ether extract (method 920.39), crude fiber (method 978.10), ash (method 942.05), Ca (method 978.02), and P (method 946.06). Concentrations of Cr in the diets and ileal digesta samples were analyzed using UV/Vis spectrophotometer (Optizen 2120UV, Mecasys Inc., Deajeon, Korea). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) in the feed ingredient samples were also analyzed using Ankom Technology methods 12 and 13, respectively (Ankom 200 Fiber Analyzer, Ankom Technology, Macedon, NY, USA). Both ADF and NDF were expressed inclusive of residual ash and NDF was assayed with a heat stable amylase.

Calculations

The apparent ileal digestibility (AID) and SID of CP and AA were calculated based on CP, AA, and Cr concentrations in diets and ileal digesta. Because each feed ingredient was the sole source of N in the experimental diets, the AID or SID of
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A diet was considered as the AID or SID in each feed ingredient. The AID of CP and AA were calculated based on the following equation [1]:

$$AID(\%) = \left[ 1 - \left( \frac{Cr_{input}}{Cr_{output}} \right) \times \left( \frac{AA_{output}}{AA_{input}} \right) \right] \times 100$$

where $Cr_{input}$ and $Cr_{output}$ represented the Cr concentrations (g/kg) in the diets and ileal digesta from pigs, respectively; $AA_{input}$ and $AA_{output}$ represented the CP or AA concentrations (g/kg) in the diets and ileal digesta from the pigs, respectively.

The BEL of CP and AA (g/kg of DM intake) were based on the following equation [1]:

$$BEL of CP and AA (g/kg of DM intake) = \frac{(Cr_{input} / Cr_{output}) \times AA_{output}}{AA_{input}}$$

where $Cr_{input}$ and $Cr_{output}$ represented the Cr concentrations (g/kg of DM) in an N-free diet and ileal digesta from pigs fed the N-free diet, respectively; $AA_{input}$ represented the CP or AA concentrations (g/kg of DM) in the ileal digesta from pigs fed the N-free diet.

The SID of CP and AA were calculated based on the following equation [1]:

$$SID(\%) = AID(\%) + \left[ 100 \times \left( \frac{BEL}{AA_{input}} \right) \right]$$

Statistical analysis

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA). An initial model included diet as a fixed effect and replication, period nested within replication, and animal nested within replication as random effects. The random variables were not significant and consequently were excluded from the final model. Least squares mean separation in the AID and SID of CP and AA among the feed ingredients was performed using the PDIFF option with Tukey’s adjustment. The pig was the experimental unit, and significance was determined at p-values less than 0.05.

Table 3. Analyzed nutrient composition of experimental diets (as-fed basis)

|            | Cereal grains   | Co-products       | N-free          |
|------------|-----------------|-------------------|-----------------|
|            | Barley          | Lupin kernels     | Corn gluten     | Corn gluten meal | Lupin hulls | Rice bran | Soybean meal | Wheat bran |
|            |                 |                   | feed-China      | feed-Korea      |             |           |              |           |
| Dry matter | 91.35           | 91.67             | 92.48           | 91.23           | 91.48       | 91.41     | 91.51        | 91.03      | 91.10     | 90.62     | 91.99     |
| Crude protein | 5.22           | 12.17             | 5.97            | 8.66            | 10.83       | 19.89     | 3.94         | 8.19       | 15.49     | 7.96      | 0.48      |
| Ether extract | 0.79           | 2.05              | 0.73            | 0.58            | 1.45        | 0.15      | 0.65         | 9.09       | 0.50      | 1.56      | 2.74      |
| Crude fiber | 2.47            | 3.71              | 1.52            | 3.98            | 2.83        | 0.80      | 14.6         | 3.09       | 2.94      | 4.35      | 2.03      |
| Ash        | 3.68            | 3.65              | 3.53            | 4.55            | 5.84        | 3.06      | 3.35         | 6.60       | 4.80      | 4.69      | 3.53      |
| Ca         | 0.51            | 0.61              | 0.51            | 0.47            | 0.66        | 0.58      | 0.50         | 0.59       | 0.76      | 0.53      | 0.60      |
| P          | 0.25            | 0.29              | 0.26            | 0.35            | 0.45        | 0.21      | 0.27         | 0.90       | 0.33      | 0.45      | 0.20      |

| Item (%) | Diet            | Co-products       | N-free          |
|----------|-----------------|-------------------|-----------------|
|          | Barley          | Lupin kernels     | Corn gluten     | Corn gluten meal | Lupin hulls | Rice bran | Soybean meal | Wheat bran |
| Dry matter | 91.35           | 91.67             | 92.48           | 91.23           | 91.48       | 91.41     | 91.51        | 91.03      | 91.10     | 90.62     | 91.99     |
| Crude protein | 5.22           | 12.17             | 5.97            | 8.66            | 10.83       | 19.89     | 3.94         | 8.19       | 15.49     | 7.96      | 0.48      |
| Ether extract | 0.79           | 2.05              | 0.73            | 0.58            | 1.45        | 0.15      | 0.65         | 9.09       | 0.50      | 1.56      | 2.74      |
| Crude fiber | 2.47            | 3.71              | 1.52            | 3.98            | 2.83        | 0.80      | 14.6         | 3.09       | 2.94      | 4.35      | 2.03      |
| Ash        | 3.68            | 3.65              | 3.53            | 4.55            | 5.84        | 3.06      | 3.35         | 6.60       | 4.80      | 4.69      | 3.53      |
| Ca         | 0.51            | 0.61              | 0.51            | 0.47            | 0.66        | 0.58      | 0.50         | 0.59       | 0.76      | 0.53      | 0.60      |
| P          | 0.25            | 0.29              | 0.26            | 0.35            | 0.45        | 0.21      | 0.27         | 0.90       | 0.33      | 0.45      | 0.20      |

| Item (%) | Diet            | Co-products       | N-free          |
|----------|-----------------|-------------------|-----------------|
|          | Barley          | Lupin kernels     | Corn gluten     | Corn gluten meal | Lupin hulls | Rice bran | Soybean meal | Wheat bran |
| Dry matter | 91.35           | 91.67             | 92.48           | 91.23           | 91.48       | 91.41     | 91.51        | 91.03      | 91.10     | 90.62     | 91.99     |
| Crude protein | 5.22           | 12.17             | 5.97            | 8.66            | 10.83       | 19.89     | 3.94         | 8.19       | 15.49     | 7.96      | 0.48      |
| Ether extract | 0.79           | 2.05              | 0.73            | 0.58            | 1.45        | 0.15      | 0.65         | 9.09       | 0.50      | 1.56      | 2.74      |
| Crude fiber | 2.47            | 3.71              | 1.52            | 3.98            | 2.83        | 0.80      | 14.6         | 3.09       | 2.94      | 4.35      | 2.03      |
| Ash        | 3.68            | 3.65              | 3.53            | 4.55            | 5.84        | 3.06      | 3.35         | 6.60       | 4.80      | 4.69      | 3.53      |
| Ca         | 0.51            | 0.61              | 0.51            | 0.47            | 0.66        | 0.58      | 0.50         | 0.59       | 0.76      | 0.53      | 0.60      |
| P          | 0.25            | 0.29              | 0.26            | 0.35            | 0.45        | 0.21      | 0.27         | 0.90       | 0.33      | 0.45      | 0.20      |
RESULTS

Nutrient composition
The CP concentration in the feed ingredients used in the present study ranged from 9.3% to 65.3% (Table 1). Lysine:CP ratios that generally represent the quality of proteins in wheat and corn co-products were less than those in other feed ingredients. Analyzed CP and AA concentrations in the experimental diets except the lupin hull-containing diet agreed with the calculated values (Table 3).

Apparent ileal digestibility of crude protein and amino acids
The AID of CP and AA in the 10 feed ingredients differed from each other (p<0.05; Table 4). The AID of CP and indispensable AA in lupin kernels were greater (p<0.05) than those in barley and wheat except Arg, Lys, Met, and Trp. The AID of CP and AA in corn gluten meal and SBM did not differ from each other. The AID of Arg, Lys, and Trp in the 2 sources of corn gluten feeds were less (p<0.05) compared with the values in SBM, and the AID of Ile, Leu, Phe, Thr, and Val in rice bran were also less (p<0.05) than the values in SBM. The AID values for CP and most AA in lupin hulls and wheat bran were less (p<0.05) than those in SBM.

Standardized ileal digestibility of crude protein and amino acids
The SID of CP and AA in the 11 feed ingredients differed from each other (p<0.05; Table 5) except for Arg and Gly. The SID of CP and most AA in corn gluten feed-C, corn gluten meal, lupin hulls did not differ. The SID of Ile, Leu, Phe, and Val in rice bran were less (p<0.05) than other co-products except for wheat bran. The SID values of most indispensable AA in wheat bran were less than the values in the SBM (p<0.05).

DISCUSSION

The CP and most indispensable AA in barley, lupin kernels, corn gluten feed-C, SBM, and wheat bran agreed with the previous values [6,13,14]. The CP and most AA concentrations of wheat and rice bran used in the present study were less than those reported previously [6,14,15], but similar to those in Sauvant et al [13]. The CP and AA concentrations in corn gluten feed-K and corn gluten meal were greater than the values presented by the literature [6,13,14]. The AA concentrations in lupin hulls used in this study were about twice

Table 4. Apparent ileal digestibility of crude protein and amino acids in feed ingredients

| Item (%) | Cereal grains | Co-products | SEM | p-value |
|----------|---------------|-------------|-----|---------|
|          | Barley | Lupin kernels | Wheat | Corn gluten feed-China | Corn gluten feed-Korea | Corn gluten meal | Lupin hulls | Rice bran | Soybean meal | Wheat bran |
| Observation (n) | 9 | 11 | 8 | 9 | 7 | 8 | 8 | 5 | 9 | 8 | - | - |
| CP | 51.5 | 75.9 | 49.9 | 55.3 | 59.3 | 80.5 | 49.9 | 59.9 | 74.5 | 43.4 | - | 4.3 | <0.001 |
| Indispensable AA | | | | | | | | | | | | |
| Arg | 60.4 | 92.7 | 79.1 | 71.9 | 70.0 | 79.9 | 71.1 | 83.4 | 89.6 | 81.8 | - | 3.3 | <0.001 |
| His | 68.3 | 86.8 | 66.4 | 78.2 | 76.2 | 84.4 | 64.6 | 76.9 | 84.6 | 78.3 | - | 2.3 | <0.001 |
| Ile | 53.6 | 83.2 | 59.6 | 67.6 | 69.5 | 82.3 | 59.6 | 45.4 | 81.0 | 60.2 | - | 3.8 | <0.001 |
| Leu | 64.9 | 85.3 | 65.7 | 82.0 | 79.1 | 87.8 | 65.7 | 58.6 | 82.9 | 66.7 | - | 2.5 | <0.001 |
| Lys | 59.3 | 83.7 | 71.0 | 64.1 | 53.7 | 71.2 | 71.0 | 73.2 | 84.7 | 64.0 | - | 3.5 | <0.001 |
| Met | 74.0 | 82.4 | 77.0 | 79.5 | 73.3 | 87.1 | 77.0 | 82.1 | 87.5 | 72.2 | - | 2.7 | <0.001 |
| Phe | 70.8 | 84.1 | 64.6 | 77.9 | 73.7 | 86.1 | 64.6 | 60.3 | 83.1 | 69.0 | - | 2.4 | <0.001 |
| Thr | 45.3 | 77.5 | 47.4 | 59.3 | 52.4 | 77.8 | 47.4 | 74.7 | 76.4 | 47.0 | - | 4.1 | <0.001 |
| Trp | 56.4 | 84.7 | 24.3 | 43.5 | 6.0 | 75.4 | 24.3 | 63.4 | 83.2 | 39.5 | - | 8.2 | <0.001 |
| Val | 52.0 | 75.7 | 52.7 | 69.5 | 61.4 | 79.8 | 52.7 | 51.5 | 77.2 | 54.8 | - | 3.3 | <0.001 |
| Dispensable AA | | | | | | | | | | | | |
| Ala | 43.9 | 72.3 | 47.7 | 75.8 | 69.6 | 84.2 | 47.7 | 58.0 | 74.1 | 48.5 | - | 4.1 | <0.001 |
| Asp | 50.5 | 83.0 | 61.7 | 60.4 | 56.3 | 79.2 | 61.7 | 63.6 | 82.6 | 57.4 | - | 3.4 | <0.001 |
| Cys | 60.3 | 82.9 | 70.5 | 62.0 | 54.8 | 77.1 | 70.5 | 65.7 | 74.6 | 62.8 | - | 3.6 | <0.001 |
| Glu | 79.0 | 89.5 | 75.4 | 77.7 | 75.4 | 86.7 | 75.4 | 74.4 | 86.4 | 81.1 | - | 1.8 | <0.001 |
| Gly | 8.0 | 74.1 | 11.5 | 32.3 | 32.6 | 58.1 | 11.5 | 40.8 | 60.7 | 46.5 | - | 8.7 | <0.001 |
| Pro | -78.8 | -59.1 | -177 | -23.5 | 7.8 | 55.9 | -177 | -124 | 0.14 | -28.7 | - | 44.7 | 0.032 |
| Ser | 53.9 | 81.8 | 57.8 | 65.5 | 63.6 | 83.0 | 57.8 | 55.9 | 81.6 | 62.2 | - | 2.9 | <0.001 |
| Tyr | 58.6 | 85.3 | 66.0 | 68.1 | 67.4 | 82.5 | 66.0 | 61.7 | 80.7 | 64.7 | - | 3.1 | <0.001 |

SEM, standard error of the mean; CP, crude protein; AA, amino acids.
**Within a row, means without a common superscript differ (p<0.05).
greater compared to the data reported by Fernández and Batterham [16]. The reason for these discrepancies in the nutrient compositions of co-products among studies may be explained by several factors including different variety, growing environment, and processing methods and conditions [14]. Information on the AA compositions or digestibility of lupin hulls was not available to be compared.

The BEL of CP and AA determined from the pigs fed the N-free diet agreed with the previous studies [7,17] and the predicted BEL using an equation suggested by Park et al [18]. The AID of Pro in some feed ingredients showed negative values if an experimental diet contained low Pro concentration, which may be associated with low Pro digestibility, resulting in a larger contribution from the BEL of Pro that originated from mostly mucin and enzyme secretions to the ileal digesta [19,20]. The observation that the BEL of Pro was the greatest among other AA resulted also in large difference within a row, means without a common superscript differ (p < 0.05).

The SID of most AA and CP in feed ingredients tested in this study were within a range of data in the literature [6,13,14]. The SID of CP and AA in SBM used in the present study were similar to the values presented in the reviews of the literature [6,13,14] and the recent publications [21,22]. The SID of most AA and CP in barley [23,24] and wheat [25,26] were within a range of data in recent publications. Almeida et al [27] reported the SID values of AA in the co-products of corn fed to pigs, and the SID values were similar compared to the values in the corn gluten feed-C and-K in the present study. The SID of CP and AA in corn gluten meal used in the present study were within a range of data in the literature [27,28]. While corn gluten feed and corn gluten meal were the co-products from corn, the SID values were variable between the sources, which may be explained by different concentrations of corn fractions [29]. The SID of CP and AA in lupin hulls was similar to that in SBM. To our knowledge, there have been no data on the SID of AA in lupin hulls reported previously. For rice bran, the SID of CP and AA observed in the present study was less than the values reported by Casas et al [15], but greater than the values by Huang et al [30]. There were variations in the CP and AA contents in the full fat rice bran used among the experiments, but the SID values are not affected by the total contents of CP and AA [5].

| Item (%) | Barley | Lupin kernels | Wheat | Co-products | SE | p-value |
|----------|--------|---------------|-------|-------------|----|---------|
| CP       |        |               |       |             | 5.3| 0.006   |
| Arg      | 86.9   | 97.2          | 99.8  |             |    |         |
| His      | 83.0   | 91.0          | 83.5  |             |    |         |
| Ile      | 77.0   | 89.8          | 86.3  |             |    |         |
| Leu      | 80.0   | 90.2          | 85.1  |             |    |         |
| Lys      | 75.5   | 84.4          | 83.9  |             |    |         |
| Met      | 83.6   | 88.4          | 89.4  |             |    |         |
| Phe      | 83.2   | 89.6          | 83.8  |             |    |         |
| Thr      | 76.3   | 87.7          | 81.7  |             |    |         |
| Trp      | 80.8   | 91.5          | 92.8  |             |    |         |
| Val      | 77.4   | 86.5          | 82.7  |             |    |         |
| SEM      |        |               |       |             |    |         |
| p-value  |        |               |       |             |    |         |

SEM, standard error of the mean; CP, crude protein; AA, amino acids; SID, standardized ileal digestibility.

1 Each SID of CP and AA was calculated by correcting apparent ileal digestibility of CP and AA for basal endogenous losses. Basal endogenous losses (g/kg dry matter intake) were determined based on the Cr, CP, and AA concentrations in the N-free diet and the ileal digesta from pigs fed the N-free diet as: CP, 22.8; Arg, 0.87; His, 0.19; Ile, 0.38; Leu, 0.51; Lys, 0.38; Met, 0.09; Phe, 0.31; Thr, 0.55; Trp, 0.09; Val, 0.64; Ala, 0.76; Asp, 0.83; Cys, 0.25; Glu, 1.01; Gly, 1.96; Pro, 9.68; Ser, 0.63; Tyr, 0.26.

Within a row, means without a common superscript differ (p < 0.05).
fat contents in rice bran may increase the greater AA digestibility in pigs [31,32], but the crude fat concentrations in the rice bran were similar among the sources used in the present study and the previous studies. The difference in fiber contents may also affect the AA digestibility in rice bran. It is possible that dietary NDF can decrease the digestibility of CP [33], and the NDF contents in rice bran were 21.4% DM in the present study (Table 1) whereas the NDF in rice bran was 23.8% DM [30] and 5.1% DM [15], respectively. The SID in wheat bran used in this study was in agreement with the values reported by Eklund et al [25].

CONCLUSION

The values for the protein and AA digestibility in various feed ingredients in this study will be useful for the accurate formulation of swine diets. The ileal digestibility of protein and AAs varies among the feed ingredients fed to pigs.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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