Effect of Particle Size of Brown Rice on Digestibility of Energy and Crude Protein in Growing-Finishing Pigs

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Introduction

Recently, considerable attention has been given to the use of brown rice as a feed ingredient for pigs in Japan, and a variety of rice cultivars for grain feed have been developed. At present, some reports are available on the digestibility of energy, crude protein (CP) and amino acids of pig feed (FURUYA and KAJI, 1987; LI et al., 2006; ISHIDA et al., 2014). However, the practical nutritional value of brown rice remains unclear.

It is well known that some types of feed processing, such as grinding or rolling ingredients, and/or some types of diets themselves increase nutrient digestibility and, consequently, improve pig performance (OWSLEY et al., 1981; WONDRA et al., 1995; NATIONAL RESEARCH COUNCIL (NRC), 2012). NRC (2012) suggests that grain refinement of corn or sorghum increases the apparent total tract energy digestibility by approximately 8.6% per 1 mm mean particle size reduction. However, to the best of our knowledge, any correlation between particle size and nutrient digestibility of brown rice is currently unknown.

As amino acids are absorbed only from the small intestine, ileal analysis is an adequate in-situ method for determining the CP and amino acid digestibilities of feedstuffs for pigs (SAUER and OZIMEK, 1986).

The objectives of this study was to evaluate the effect of reducing the particle size of brown rice on standardized ileal digestibility (SID; STEIN et al., 2007) of CP, and on energy digestibility in the terminal ileum and over the total digestive tract of growing-finishing pigs.

Materials and Methods

This experiment was approved by the Institutional Animal Care and Use Committee at Gifu University (Approval number 14005).

Diets

A brown rice cultivar for grain feed named Momi-Roman was processed to produce three groups with differing particle size: coarse (C), medium (M), and fine (F). The particles were ground in a Willey mill (WT-150; Miki; Tokyo) equipped with 8.0-, 5.0-, and 2.0-mm screens to obtain C, M and F, respectively.

The basal ingredient composition of brown rice-casein diets is shown in Table 1. Celite 545 was added as a source of acid insoluble ash (AIA) in order to determine the digestibilities of energy and CP. The analyzed composition of the experimental diet, brown rice and casein is shown in Table 2.

Animals and experimental design

Three gilts (Large White × Landrace) (approx. initial body weight (BW) 35 kg) were used. For each animal, a simple T-cannula (Kyoritu; Tokyo) was fitted at the terminal ileum, approximately 30 cm anterior to the ileocecal junction according to the procedures described by FURUYA et al. (1974). After the surgery, the pigs were allowed to convalesce for...
2 weeks in pens (1.2×1.8m²) with solid concrete flooring without bedding. This convalescence was followed by a 3-wk growing period prior to the onset of test protocol. The animals, which weighed approximately 56 kg at the beginning of the testing period, were subjected to a 3×3 Latin square design: three sets of particle sizes distributions of brown rice in diets vs. three periods (5 days/duration).

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

| Item                          | %   |
|-------------------------------|-----|
| Brown rice                    | 88.0|
| Casein                        | 6.0 |
| Limestone                     | 1.0 |
| Triphosphate carbonate        | 2.0 |
| Sodium chloride               | 0.4 |
| Vitamin premix 1              | 0.2 |
| Vitamin premix 2              | 0.2 |
| Mineral premix 3              | 0.2 |
| Cellite®545                   | 2.0 |

1 Provided the following quantities of vitamins per kilogram of complete diet: Vitamin A, 10,000,000 IU as vitamin A acetate; vitamin D₃, 20,000,000 IU as D-activated animal sterol; vitamin E, 10 g as dl-alpha tocopherol acetate. 2 Provided the following quantities of vitamins per kilogram of complete diet: Thiamin, 1000 mg as thiamin mononitrate; riboflavin, 7000 mg; pyridoxine, 500 mg as pyridoxine hydrochloride; D-pantothenic acid, 10,900 mg as calcium pantothenate; nicotinic acid, 6000 mg as nicotinic acid amide; choline, 576,000 mg as choline chloride. 3 Provided the following quantities of minerals per kilogram of complete diet: Cu, 10,000 mg as copper sulfate; Fe, 50,000 mg as iron sulfate; I, 1,000 mg as calcium iodate; Mn, 50,000 mg as manganese sulfate; Zn, 60,000 mg as zinc carbonate.

### Feeding and sample collection

Pigs were fed daily, with the amount of feed given based on 4% of their average initial BW (56 kg). Feedings were divided into 3 meals (700 g) dispensed every 8 h (09:00 h, 17:00 h, and 1:00 h). Throughout the experiment, pigs were given free access to water from a nipple drinker.

Ileal digesta samples were manually obtained between 13:00 and 17:00 h on d 3, 4, and 5, as modified from a previous paper (FURUYA et al., 1986): the only difference was that ileal digesta were obtained between 13:00 and 17:00 h instead of 13:00 and 14:00 h as described by FURUYA et al. (1986). The samplings were performed by attaching a 200 mL plastic bag to the cannula and detaching it when the bag was filled with approximately 200 g of digesta. Bags were stored at 4°C until subsequent use. For every 3-day period, each pig’s collected samples were combined on an individual basis and stored at −20°C. The frozen samples were lyophilized (SSD; Labconco; Hannover) and then ground and sieved with a 1-mm screen for chemical analysis.

On d 5, fecal samples were collected by grab-sampling to be stored at 0°C and then dried at 60°C in a forced air dry oven (DKN812; Yamato; Tokyo). Samples were then ground and sieved with a 1-mm screen (WT-150; Miki; Tokyo) for chemical analysis.

### Analytical methods

Gross energy was measured using a bomb calorimeter (Ca-4PJ; Shimadzu; Kyoto). Dry matter and nitrogen were assayed according to the procedures of the Association Of Official Analytical Chemists (1990): dry matter was determined by drying at 110°C and nitrogen was analyzed using the KJELDAHL method. AIA was analyzed according to the method described by FURUYA et al. (2001).

### Table 2. Analyzed composition of experimental diet, brown rice, and casein, as dry basis

| Item                        | Experimental | Brown rice | Casein |
|-----------------------------|--------------|------------|--------|
| Protein (N×6.25), %         | 12.9         | 8.3        | 93.6   |
| Gross energy, kcal/g        | 4.13         | 4.30       | 5.80   |
| Moisture¹, %                | 11.7         | 11.7       | 11.2   |

¹ Moisture is expressed as fed basis.
Particle size distribution and geometric mean particle size of the brown rice samples were determined as follows. Duplicate 100 g samples of the milled brown rice were placed on the top screen of a sieve shaker (AS200; Retsch; Hann). Nine sizes of sieve screens (screen openings of 3,350, 2,800, 2,360, 2,000, 1,700, 1,000, 600, 300, and 150 μm) were used. Each sample was sieved for 1 min. Any remaining material on each screen was weighed to calculate geometric mean particle size, with the assumption that the particle size of the brown rice remaining on each mesh showed the median of the ambilateral neighbored sieve opening sizes. The obtained geometric mean particle sizes for C, M and F were 1.94, 1.48 and 0.80 mm, respectively (Table 3).

Calculations
The apparent ileal digestibility (AID) of CP in diets containing brown rice was calculated according to Eq. (1).

\[ \text{AID} (\%) = \left( 1 - \frac{\text{CPd}}{\text{CPF}} \right) \times \left( \frac{\text{AIAf}}{\text{AIAd}} \right) \times 100. \]  

where \( \text{CPd} \) is the concentration of CP in the ileal digesta (%), \( \text{CPF} \) is the concentration of CP in the diets (%), \( \text{AIAf} \) is the AIA concentration in the diet (%), and \( \text{AIAd} \) is the AIA in the ileal digesta (%).

The SID of CP in the diets was calculated using the following equation proposed by Furuya and Kaji (1989).

\[ \text{SID} (\%) = \text{AID} + \left( \frac{\text{basal CP}_{\text{end}}}{\text{CP}_{\text{diet}}} \right) \times 100. \]  

where \( \text{basal CP}_{\text{end}} \) is the basal ileal endogenous loss of CP (g/kg in DM intake) and \( \text{CP}_{\text{diet}} \) is the concentration of CP in the diet (g/kg in DM). In this study, SID was calculated by using a value referred to by Furuya and Kaji (1992): basal ileal endogenous loss of CP, which they reported as 13.8 g/kg DM intake.

Energy digestibility in the terminal ileum and over the total tract in the diets was calculated using an equation similar to that used in the case of CP (Eq. (1)).

Energy digestibility and SID of CP in brown rice alone were calculated by assuming that the digestibility of casein was 100% both in the ileum and over the total digestive tract (Furuya et al., 1986), and that the small contribution of energy from vitamin premixes was negligible.

Data were analyzed statistically using the proc GLM procedure of SAS9.4 (SAS Inst. Inc., Cary, NC). The SID of CP and energy digestibility in both the terminal ileum and the total tract were compared using a one way ANOVA with Tukey test.

Table 3. Percentage of brown rice retained on sieves with different-sized openings and geometric mean, as fed basis

| Criterion | Coarse | Medium | Fine |
|-----------|--------|--------|------|
| Size of sieve opening, μm | — | — | — |
| 4,000 | — | — | — |
| 3,350 | 0.2 | — | — |
| 2,800 | 1.5 | 0.4 | — |
| 2,360 | 41.0 | 13.3 | — |
| 2,000 | 21.3 | 20.2 | — |
| 1,700 | 14.0 | 21.0 | — |
| 1,000 | 15.5 | 28.3 | 35.8 |
| 1,600 | 3.7 | 9.4 | 38.0 |
| 1,300 | 2.8 | 7.3 | 20.4 |
| 1,150 | — | — | 5.7 |
| Residual | — | — | 0.1 |
| Geometric mean, mm | 1.94 | 1.48 | 0.80 |

*Values are the percentages of each 100-g sample retained on the top sieves after 1 min of shaking.
level of 0.05 was used to assess significance among means.

**Results and Discussion**

The energy digestibility in the terminal ileum and in the total tract, and the SID of CP in each particle size of brown rice are presented in Table 4. Brown rice had higher energy digestibility in the terminal ileum in groups F and M than in group C (P < 0.05). The digestibility of energy over the total digestive tract was higher in group F than in groups M and C (P < 0.05). Overall, energy digestibility was higher across the total digestive tract than in the terminal ileum (P < 0.05). Conversely, the net disappearance of energy in the large intestine calculated by subtracting digestibility in the ileum from digestibility in the total tract, was relatively low (3.3–5.7%), indicating that the overall contribution of the large intestine to energy absorption is not significant regardless of the particle sizes of feed ingredients.

In the present study, DE (digestible energy) in the DM of F, M and C brown rice was calculated from the gross energy of brown rice, 4.30 kcal/g DM, and accordingly, the DE in the total tract was 3.92, 3.79, and 3.53 kcal/g, respectively. The DE of brown rice (dehulled rice) according to the National Agriculture and Food Research Organization (NARO, 2009) is 4.24 kcal, which is higher than that obtained in the present study and in the study by Li et al. (2006), i.e., 3.99 kcal/g. DE values of feedstuffs shown in NARO (2009) were calculated from total digestible nutrient (TDN) value by assuming that 1 g TDN contains 4410 digestible calories. However, this calculation method using TDN system has been criticized, because it gives protein the same weightage as carbohydrates, although carbohydrates provide only 3.7 (glucose) to 4.2 (starch) kcal/g, whereas protein provides 5.6 kcal/g (Ewan, 2001; NARO, 2013). Therefore, the DE in feedstuffs with low protein content such as grains might be overestimated, while the DE in feedstuffs with high protein content might be underestimated.

As shown in Table 4, SID of CP for F, 79.3%, was significantly higher than that of C, 64.4% (P < 0.05). It is thus possible to postulate that the correlation between particle size and digestibility is valid not only for energy absorption, but also for protein absorption. Although the SID of amino acids was not analyzed in this study, it may also improve as particle size decreases. This assumption is based on a study by Furuya et al. (1986) which showed that the average SID of amino acids corresponds to the SID of CP for various protein ingredients. For example, the SID of CP in soya-bean meal, casein, fish meal and cotton-seed meal was 82, 99, 93 and 78, respectively, whereas the average SID of amino acids was 83, 99, 96, and 81, respectively. Therefore, it was quite reasonable that the average SID of amino acids in the brown rice (Momi-Roman), 76.3%, reported by Ishida et al. (2014) was similar to the SID of CP for

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**Table 4. Effect of particle size on digestibilities of energy and crude protein in brown rice**

| Item                        | Fine (F)       | Medium (M)    | Coarse (C)     |
|-----------------------------|----------------|---------------|----------------|
| Gross energy Terminal ileum, % | 86.7±2.21<sup>a</sup> | 82.4±2.78<sup>b</sup> | 78.7±1.81<sup>b</sup> |
| Total tract, %              | 91.1±1.29<sup>a</sup> | 88.1±0.90<sup>b</sup> | 82.0±2.31<sup>b</sup> |
| Difference, %               | 4.4±4.1        | 5.7±2.6       | 3.3±1.3        |
| CP SID, %                   | 79.3±2.68<sup>a</sup> | 72.4±7.31<sup>ab</sup> | 64.4±2.01<sup>b</sup> |

Values are the means of 3 observations±standard deviations. <sup>a-b</sup>Means in the same row with different superscript differ (P<0.05). <sup>c</sup>Difference : Total tract digestibility minus ileal digestibility. CP, Crude protein ; SID, standard ileal digestibility.
the brown rice (Momi-Roman) F and M, 79.3 and 72.4 %, respectively, in the present study. NRC (2012) suggests that for each 1 mm reduction in mean particle size of corn or sorghum, the apparent energy digestibility along the total tract increases by approximately 8.6%. The relationship between particle size of brown rice and digestibility of energy and CP is shown in Fig. 1. The slope of the line shows a proportional increase in digestibility with a reduction in mean particle size of brown rice as follows: for energy digestibility in the terminal ileum (7.0%/mm), for energy digestibility over the total tract (7.7%/mm), and for SID of CP (12.9%/mm).

In conclusion, the finer the grind-level of brown rice in rations for growing-finishing pigs, the further improved are the SID of CP and the energy digestibility in the ileum, as well as in the total digestive tract. However, excessive grain refining might be associated with risks such as diminished palatability, which can cause bridging in self-feeders and induce gastric ulcers. Moreover, finer grinding requires additional electrical energy consumption. Although the suggested optimal particle size of feed for growing pigs is approximately 0.70 mm (NRC, 2012), the optimal particle size of brown rice should be defined by considering the various above-mentioned factors.

References

ASSOCIATION of OFFICIAL ANALYTICAL CHEMISTS : 1990, Official Methods of Analysis, 15th edn. Association of Official Analytical Chemists, Washington, DC.

EWAN, R.C. : 2001, Energy utilization in swine nutrition, In Swine Nutrition. (ed.) Levis, A.J. and L.L. Southern, 2nd ed., 85–86, CRCPress.

FURUYA, S. and Y. KAJI : 1987, Ileal digestibilities of amino acids in corn, rice, barley, naked barley and wheat for growing pigs. Jpn. J. Zootech. Sci. 58, 228–235.

FURUYA, S. and Y. KAJI : 1989, Estimation of the true ileal digestibility of amino acids and nitrogen from their apparent values for growing pigs. Anim. Feed Sci. Technol., 26, 271–285.

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

FURUYA, S., R. NAGANO and Y. KAJI : 1986, True ileal digestibility of crude protein and amino acids in protein sources as determined by a regression method for growing pigs. Jpn. J. Zootech. Sci., 57, 859–870.

FURUYA, S., S. TAKAHASHI and S. OMORI : 1974, The establishment of T-piece cannula fistulas into the small intestine of the pig. Jpn. J. Zootech. Sci., 45, 42–44.

FURUYA, S., A. YAMAMOTO, M. ITOH and Y. AOKI : 2001, Use of acid-insoluble ash added with celite as a marker for determining digestibility in pigs. Jpn. J. Swine Sci., 8, 171–176.

ISHIDA, A., A. ASHIHARA, H. KOBAYASHI and M. KATSU-MATA : 2014, The ileal amino acid digestibility of brown rice for forage in growing pigs. Jpn. J. Swine Sci., 51, 159–167.

LI, X.L., S.L. YUAN, X.S. PIAO, C.H. LAI, J.J. ZANG, Y.H. DING, L.J. HAN and IN K. HAN : 2006, The nutritional value of brown rice and maize for growing pigs. Asian-Aust. J. Anim. Sci., 19, 892–897.

NATIONAL AGRICULTURE AND FOOD RESEARCH ORGANIZATION : 2009, Standard tables of feed composition in Japan (2009), Japan Livestock Industry Association, Tokyo.

NATIONAL AGRICULTURE AND FOOD RESEARCH ORGANIZATION : 2013, Japanese feeding standard for swine (2013), 4, Japan Livestock Industry Association,
Tokyo.

NATIONAL RESEARCH COUNCIL : 2012. Nutrient requirements of swine, 11th edn. National Academy Press, Washington, DC.

OWSLEY, W.F., D.A. KNABE, T.D. TANKSLEY, Jr. : 1981. Effect of sorghum particle size on digestibility of nutrients at the terminal ileum and over the total digestive tract of growing-finishing pigs. J. Anim. Sci., 52, 557–565.

SAUER, W.C. and L. OZIMEK : 1986, Digestibility of amino acids in swine : Results and their practical applications. A review. Livest. Prod. Sci., 15, 367–388.

STEIN, H.H., B. SÈVE, M.F. FULLER, P.J. MOUGHAN and C.F.M. DE LANGE : 2007, Invited review : Amino acid bioavailability and digestibility in pig feed ingredients : Terminology and application. J. Anim. Sci., 85, 172–180.

WONDRA, K.J., J.D. HANCOCK, K.C. BEHNKE, R.H. HINES and C.R. STARK : 1995, Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci., 73, 757–763.