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Apparent and Standardized Ileal Digestibility of Essential Amino Acids of Paddy Rice, Broken rice and Rice Bran Fed to Growing Pigs

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Abstract | The study aimed at determining the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of essential amino acids (EAAs) in paddy rice, broken rice and rice bran fed to growing pigs. A total sixteen barrows of 35 kg were randomly allocated into one of 4 dietary treatments namely NFD (animals fed nitrogen-free diet), and paddy rice, broken rice and rice bran, used chromic oxide as an indicator. Pigs were fed for 14 days and on day 14th, all animal were killed to collect the ileal digesta for chemical and amino acid analyses. Results show that total basal ileal endogenous loss of EAAs is 1.22 g/kg dry matter intake; the average AID and SID values of EAAs in broken rice are highest (81.72% and 83.57%, respectively), and lowest in paddy rice (72.69% and 74.85%, respectively). The values of AID and SID of most essential amino acids are higher in broken rice than in paddy rice and rice bran. In conclusion, the broken rice, rice bran and paddy rice contained readily digestible essential amino acid and SID values are very high.

Keywords | Basal endogenous loss, Energy-rich feeds, Ileal digestibility

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INTRODUCTION

An accurate formulation of a pig's diet meeting amino acid requirements, particularly essential amino acids (EAAs) is important to improve pig's production as well as to minimize the excretion of nitrogen (N) to environment. It is essential to estimate N and EAAs utilization. Among estimates for the digestibility of these nutrients, ileal digestibility rather than total tract digestibility has been known to be more reliable to represent EAAs digestibility (Sauer and Ozimek, 1986; McDonald *et al*., 2010). To attain ileal digestible EAAs contents in a diet or a feed ingredient, apparent ileal digestibility (AID) has been used. The AID was estimated by the difference between the ingested and recovered quantity of amino acids from the ileum digesta without considering the endogenous amino acid losses which was derived from animal body, and consequently, was underestimated especially when feeding pigs, a low-protein diet (Mosenthin *et al*., 2000; McDonald *et al*., 2010). To overcome this inaccuracy of AID value, the standardized ileal digestibility (SID) has been introduced. The SID value was corrected for the AID value and the ba-

sal endogenous amino acid losses. The use of SID value of amino acids to formulate diet could reduce excessive amino acids in manure and urine since SID was more accurate estimated than AID (Just *et al*., 1985; Jondreville *et al*., 1995; McDonald *et al*., 2010).

In Vietnam recent years, pig diets contain amounts of cereal grains and their byproducts such as corn, wheat and brans. However, corn, wheat and brans were depended very much on importation. In 2023, a total 16.8 million tons of raw materials were imported, accounting for about 84% of total commercial feed production, including 7 million tons of corn, 1.4 million tons wheat and oat and 474 thousand tons of brans (Ha Ngan, 2023). Thus, finding local available energy-rich feedstuff is needed. Many alternative feed ingredients that may be cost effective and useful in pig diets are produced locally such as paddy rice, broken and by-products which didn't properly apply in pig diets. Meanwhile Vietnam is one of the world's richest agricultural regions and is the second-largest (after Thailand) exporter worldwide and the world's seventh-largest consumer of rice. According to GSO (2024), during 2021-2023, rice production ranged 42.7 - 43.8 million tons, in which 6.2 - 8.3 million tons for exportation. Rice bran production was estimated approximately 10.7-11 million tons/year. Chemical compositions of paddy rice, broken rice and rice bran were varied and depended on rice variety, cultivating technology and rice processing. According Thong *et al.* (2012), rice bran contained 84.7 – 89.8% DM, 11.8- 13.9% CP, 4.4 – 8.7% CF, 6.1 – 18.7% EE and 6.03 – 14.9% total ash. Meanwhile, Kinh (2003) reported that paddy rice contained 87.8 – 89.5% DM, 6.9-8.6% CP, 1.5-1.7% EE, 10.6-12% CF and 3.7-4.6% total ash. In addition, cereal grains usually contribute the majority of fiber content to the diet, but high fiber content causes negative effect on energy and nutrient utilization (Lenis *et al*., 1996; Souffrant, 2001).

However, there is a paucity of information on their ileal digestibility of amino acids for pigs. To our knowledge, few articles have reported AID and SID values for EAAs of paddy rice, broken rice and rice bran fed to pigs (Dadalt *et al*., 2016; Feng *et al*., 2024). Therefore, this study aimed to evaluate the apparent and standardized ileal digestibility of essential amino acids of above-mentioned feed ingredients in growing pigs.

MATERIALS AND METHODS

Animal Ethic Statement

The experimental design and animal ethic approved by the Scientific Committee of the Department of Science Technology and Environment, Ministry of Agriculture and Rural Development of Viet Nam (MARD). This procedure also follows the world procedure as respecting principle of replacement, reduction and refinement which minimize animal suffering and improve welfare. The experiment was carried out at the Institute of Animal Sciences (IAS) for Southern Viet Nam.

Feedstuff

Paddy rice (PR), broken rice (BR) and rice bran (RB) were locally collected, had good quality as used in animal production in Vietnam and their chemical composition and amino acid profile present in Table 1.

Table 1: Chemical composition and content of essential amino acids (%)*.

Chemical composition	Paddy rice	Broken rice	Rice bran	Amino acid	Paddy rice	Broken rice	Rice bran
Dry matter	88.0	89.0	89.6	Lysine	0.28	0.30	0.65
Crude protein	6.65	8.55	13.25	Methionine	0.18	0.18	0.31
Crude fiber	9.60	0.10	8.03	Leucine	0.58	0.67	1.00
Ether extract	2.20	1.30	16.50	Isoleucine	0.33	0.34	0.73
Total ash	4.19	1.02	8.04	Tryptophan	0.13	0.10	0.23
Ca	0.26	0.18	0.27	Arginine	0.58	0.52	1.09
P	0.30	0.21	1.20	Threonine	0.27	0.26	0.54
				Valine	0.43	0.49	0.80
				Histidine	0.17	0.18	0.38
				Phenylalanine	0.38	0.39	0.67

*analyzed.

Experimental Design

Sixteen barrows with average initial body WEIGHT of 35 kg were assigned in a completely randomized design with 4 dietary treatments and 4 replicates. Animals were received one of 4 diets, including nitrogen-free diet (NFD), and diets composed from paddy rice (PRD), broken rice (BRD) and rice bran (RBD). All diets were added 0.4% Cr_2O_3 as an indicator since many studies found that digestion coefficients derived from the chromium oxide concentrations of the feed and feces were in close agreement with those determined in total collection trials (Clawson et al., 1955).

The ingredient proportion of the NFD and testing diets presents in Table 2. The NFD was a reference diet to collect basal endogenous nitrogen losses, and used to calculate AID of amino acids in individual feed ingredients such as paddy rice in the PRD, broken rice in the BRD and rice bran in the RBD. Diet of rice bran need to use more corn starch to make the diet balanced in energy. Casein had been

used to provide protein sources for not affecting the digestibility of experimental materials. Pigs were fed experimental diets twice daily during 14 days followed the protocol of Donkoh *et al*. (1994) and Nyachoti *et al*. (1997), and water was provided *ad lib*. At the end of the experiment, all pigs were slaughtered to collect the ileal contents followed the protocol of Donkoh *et al*. (1994) and Nyachoti *et al*. (1997).

Table 2: Ingredient proportions and nutritive value of the nitrogen-free diet and test diets.

	Diets*			
	NFD	PRD	BRD	RBD
Ingredient proportion (g/100 g air DM)				
Paddy rice	-	60	-	-
Broken rice	-	-	60	-
Rice bran	-	-	-	36
Casein	-	13.5	13.5	14
Corn starch	79.1	5.6	5.6	29.1
Dextrose	10	10	10	10
Soybean oil	3	3	3	3
Cellulose	4	4	4	4
Limestone	0.5	0.5	0.5	0.5
Monocalcium phosphate	1.9	1.9	1.9	1.9
Chromic oxide	0.4	0.4	0.4	0.4
Salt	0.4	0.4	0.4	0.4
Vitamin premix	0.05	0.05	0.05	0.05
Mineral premix	0.15	0.15	0.15	0.15
Potassium carbonate	0.4	0.4	0.4	0.4
Magnesium oxide	0.1	0.1	0.1	0.1
Total	100	100	100	100
Nutritive value and amino acid composition (g/kg)**				
Dry matter		861	882	886
Crude protein		152.4	163.6	162.1
Crude fiber		57.6	6.2	28.9
Lysine (Lys)		6.87	9.94	11.85
Methionine (Met)		2.24	3.10	3.37
Met + Cysteine		4.05	5.44	6.23
Threonine (Thr)		5.84	9.65	11.16
Tryptophan (Trp)		4.04	4.80	5.46
Arginine (Arg)		8.27	6.11	7.89
Leucine (Leu)		5.71	13.69	15.48
Isoleucine (Isl)		5.25	7.78	8.88
Valine (Val)		6.72	8.50	10.25
Histidine (His)		3.07	2.93	3.07
Phenylalanine (Phe)		5.33	5.13	5.98

*NFD: nitrogen-free diet; PRD, BRD and RBD are diets containing paddy rice, broken rice and rice bran, respectively; ** Analyzed.

Ileal Digesta Collection

Collection of the ileal digesta followed the procedure of Donkoh *et al*. (1994) and Nyachoti *et al*. (1997). On day 14th of the experiment, the diets were given to pigs every two hours during 10 hours. The pigs were shocked by electricity and killed at 10 a.m., then after killing, ileal digesta were collected at the terminal ileum of pigs (20 cm from ileocecal valve). Ileal digesta was washed by 10-ml distilled water then frozen immediately at -20^{0}C. The ileal digesta were dried at 60^{0}C in 48 hours and ground prior to chemical and amino acid analyses.

Chemical Analysis

The proximate composition in feed ingredients was determined by AOAC (1990). Amino acid contents in feed ingredients and the digesta were determined by using ion-exchange chromatography with post column derivatization with ninhydrin. Tryptophan was analyzed by high performance liquid chromatography-fluorescence method (extinction 280 nm, emission 356 nm). Lysine contents were determined according to. Chromium was analyzed, after the samples were ashed at 600˚C for 12 hours in a muffle furnace, using an inductively coupled plasma mass spectrometry (ICP-AES Vista; Varian, Palo Alto, CA) according to the method of AOAC (2005).

Digestibility Calculation

The **AID** of EAA was calculated using the equation developed by Fan and Sauer (1995):

$$\text{AID (\%)} = 100 \times \{100\left(\frac{AA_d}{AA_f} \times \frac{Cr_f}{Cr_d}\right)\}$$

In where, AA_d and AA_f are the content of EAA in ileal digesta and feed (g/kg, DMI), respectively; Cr_f and Cr_d content of chromic oxide in feed and digesta (g/kg, DMI), respectively.

The basal endogenous losses of EAA (BELA), induced by the nitrogen-free diet, were followed by the equation (Moughan *et al*., 1992):

$$BELA\ (g/kg, DMI) = AA_d \times \frac{Cr_f}{Cr_d}$$

The SID of EAA was calculated based on the AID and BELA values according to the equation developed by Jondreville *et al*. (1995):

$$SID\ (\%) = AID + \frac{BEA}{AA_f} \times 100$$

The AID and SID of amino acids in testing feed ingredient such as PR, BR and RB were calculated by the difference method.

Statistical Analysis

Data were presented in the form of the mean (M), standard error of the mean (SEM). The data were statistically processed by analysis of variance (ANOVA) by General Linear Model in Minitab v. 16.2 (2010). The difference between the mean values was determined by the Tukey method at a confidence level of 95%. Statistical model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

Where: μ is the average value; T_i is the effect of feed ingredient; e_{ij} is the experimental error.

RESULTS AND DISCUSSION

Basal Endogenous Losses of Amino Acids

The concentrations of EAAs in the ileal digesta and the basal endogenous losses of amino acid (BELA) value present in the Table 3. The total EAAs concentration in the ileal digesta is 3.34 g/kg DMI (ranges 0.11-0.6 g/kg DMI) and the total BELA value is 1.22 g/kg DMI (range 0.04-0.22 g/kg DMI). The BELA of Arginine (0.2 g/kg DMI) and Isoleucine (0.22 g/kg DMI) are highest.

Table 3: Amino acid concentrations in the ileal digesta and endogenous losses in the nitrogen-free diet (g/kg) (M±SEM).

Amino acids	Ileal digesta	Endogenous amino acid
Lysine	0.34±0.081	0.12±0.011
Methionine	0.11±0.041	0.04±0.017
Threonine	0.39±0.071	0.14±0.025
Tryptophan	0.21±0.022	0.08±0.077
Arginine	0.52±0.311	0.20±0.125
Leucine	0.36±0.082	0.13±0.08
Isoleucine	0.60±0.361	0.22±0.111
Valine	0.28±0.032	0.10±0.075
Histidine	0.17±0.052	0.06±0.027
Phenylalanine	0.20±0.044	0.07±0.035
Total	3.34±1.017	1.22±1.001

Ileal apparent and standardized ileal digestibility

Data in Table 4 indicate that, the average AID value of EAAs in the broken rice (81.72%) is highest and in the paddy rice is lowest (72.69%) at p<0.05. For individual EAAs, the AID values of all most EAAs are lower in the paddy rice than in the broken rice and rice bran (p<0.05). The AID values of lysine and tryptophan in the broken rice is higher than in the paddy rice and rice bran (p<0.05), however, these values of threonine, leucine, isoleucine and histidine are lower in the paddy rice than in the broken rice and rice bran (p<0.05). The SEM of most of AID of the amino acids of paddy rice, broken rice and rice bran were small means that the average value of these parameters of amino acids were very high.

Table 4: Apparent ileal digestibility of essential amino acids in testing ingredients (%) (n=4).

Amino acids	Paddy rice	Broken rice	Rice bran	SEM	p-value
Lysine	73.03^{b}	82.67^{a}	75.97^{b}	1.323	0.002
Methionine	73.90^{b}	82.66^{a}	77.44^{ab}	1.412	0.006
Threonine	73.80^{b}	81.60^{a}	79.77^{a}	0.937	0.001
Tryptophan	73.77^{b}	81.63^{a}	76.36^{b}	0.822	<.001
Arginine	73.30^{b}	81.26^{a}	78.72^{ab}	1.797	0.033
Leucine	69.89^{b}	83.21^{a}	80.22^{a}	0.955	<.001
Isoleucine	71.16^{b}	81.14^{a}	76.99^{a}	1.104	<.001
Valine	74.79^{b}	81.63^{a}	79.41^{ab}	1.353	0.017
Histidine	70.68^{b}	81.45^{a}	80.17^{a}	1.419	0.001
Phenylalanine	72.56^{b}	79.91^{a}	74.78^{ab}	1.756	0.042
Average	72.69^{c}	81.72^{a}	77.98^{b}	0.903	<.001

^{a,b}: Means at the same row with different superscripts differ significantly at p<0.05.

Table 5: Standardized ileal digestibility of essential amino acids in testing ingredients (%) (n=4).

Amino acid	Paddy rice	Broken rice	Rice bran	SEM	p-value
Lysine	74.78^{b}	84.08^{a}	77.18^{b}	1.389	0.003
Methionine	75.66^{b}	83.89^{a}	78.53^{b}	1.305	0.005
Threonine	76.21^{b}	83.21^{a}	81.11^{a}	0.913	0.001
Tryptophan	75.66^{b}	83.29^{a}	77.77^{b}	1.346	0.003
Arginine	75.69^{b}	84.54^{a}	81.42^{ab}	1.476	0.007
Leucine	72.21^{b}	84.36^{a}	81.24^{a}	0.877	<.001
Isoleucine	75.36^{b}	84.21^{a}	79.74^{ab}	1.179	0.002
Valine	76.28^{b}	82.90^{a}	80.46^{ab}	1.364	0.022
Histidine	72.72^{b}	83.79^{a}	82.33^{a}	1.323	<.001
Phenylalanine	73.89^{b}	81.37^{a}	76.14^{ab}	1.771	0.040
Average	74.85^{c}	83.57^{a}	79.59^{b}	0.857	<.001

^{a,b}: Means at the same row with different superscripts differ significantly at p <0.05.

Similar AID values, the average SID value of EAAs in the paddy rice (74.85%) is lowest and in the broken rice (83.57%) is highest. Regarding individual EAAs, the SID values of the most essential amino acids are higher in the broken rice than in the paddy rice and rice bran (p<0.05). The SID values of lysine, methionine and tryptophan in the broken rice is higher than in the paddy rice and rice bran (p<0.05), however, these values of threonine, leucine and histidine are lower in the paddy rice than in the broken rice and rice bran (p<0.05). Looking at the data in Tables 4 and 5, it is easy to recognize that all of data in Table 5

is higher than that in Table 4. That means SID values are always higher than respectively AID, e.g., SID of lysine in paddy rice is 74.78% meanwhile AID of paddy rice is 73.03%. In general, the SID values are 2-3% higher than the AID values. This also implies that the diet using SID value could bring more benefit than the diet using AID since it saves 2-3% more feed.

The SID values for EAAs are important reference indices for diet formulations to meet the nutritional needs of pigs. The approach requires the accurate determination of ileal BELA in pigs, with N-free diets traditionally used to calculate SID values (Zhou *et al*., 2022). The ileal BELA values are considered inevitable losses.

In this study, the NFD based on corn starch-dextrose, and the BELA value is 1.22 g/kg DMI, and the highest loss of arginine (0.2 g/kg DMI) and isoleucine (0.22 g/kg DMI). This finding is lower than previous reports by many authors, who reported that the BELA values ranged 3.02 – 3.9 g/kg DMI and the loss of lysine ranged 0.43 - 0.49 g/kg DMI in growing pigs with 47.1 – 92.1 kg (Stein *et al*., 2005; Zhai and Adeola, 2011). In addition, the highest endogenous amino acid losses are arginine, threonine and leucine in growing pigs in our study. Stein *et al*. (2005) reported that the endogenous loss of leucine and threonine was highest in growing pigs of 92.1 kg, and Zhai and Adeola (2011) found the highest endogenous losses were arginine and leucine in growing pigs 47.1 kg and 61.3 kg. This difference may be due to differences in tested pigs and different ingredient composition in N-free diets (Zhou *et al*., 2022). Moreover, Soomro *et al*. (2017) indicated that the ileal endogenous loss of amino acids was affected by numerous factors, including procedures to collect samples, such as slaughter technique, re-entrant cannulas, simple T cannulas and post valve T caecum cannulas. In our study, the slaughter technique was used to collect the ileal digesta.

Digestibility of amino acids in feed ingredients have been determined by either direct procedure or difference procedure. A direct procedure has been widely to determine the SID of protein and amino acid feedstuff rather than a difference method (Cervantes-Pahm and Stein, 2010; Oliveira *et al*., 2020). In this study, the direct procedure has been applied with rich-energy feedstuffs which consisted of 60% as diet dry matter. Wu *et al*. (2024) reported that paddy rice could be included at up to 30% in pig diets without compromising growth performance. Feng *et al*. (2024) formulated the diet with 40% paddy rice in the ileal digestibility in pigs of 15 kg. Feng *et al*. (2024) reported that the average SID value of EAAs in 10 paddy rice varieties was 79.05% (ranges 68.72-86.16%), that was higher than our finding of 74.85%. In rice bran, Feng et al. (2024) indicated that the AID values of individual EAAs in 5 bran sources ranged 50.9-86.1% and concluded that the difference in CF content in the rice bran resulted in different AID of EAAs. Casas *et al*. (2018) reported that the AID values of full-fat rice bran and defatted rice bran averaged 66.4% (45.6-78.7%) and 59.5% (41.7-74.7%), respectively. Similarly, the average SID value of 83.6% (76.1-94.3%) in full-fat rice bran was higher than in defatted rice bran 72.8% (63.5-86.7%). In this study, rice bran was 36% as diet dry matter which was close to 40% in the report of Casas *et al* (2018). In our finding, the average AID and SID values of individual EAAs was 77.98% (76.15-82.33%) and 79.59% (76.14-82.33%), respectively. In broken rice, found that the AID of individual EAAs in the BR ranged from 81.8% in lysine to 92% in arginine, and the SID values of individual EAAs ranged from 92.2% in threonine to 95.9% in arginine. In our study, the AID and SID values of individual EAAs range 74.78 – 80.22% and 76.14 - 82.33%, respectively.

The different results between the present study and previous onces on an apparent and standardized ileal digestibil- ity could be derived from many reasons such as chemical composition and levels of feedstuffs in testing diets, grow- ing phase of animals, the procedure of ileal digesta collec- tion, or event sample size limitation. Jang and Kim (2023) indicated the importance of including the testing feedstuffs at practical levels when evaluating digestibility. Concluded that digestibility of amino acids in- fluenced by animal body weight but not feed intake levels. Jang and Kim (2023) concluded that the SID of EAAs in fermented soybean meal when included at practical lev- els using the direct procedure were similar to those from the difference procedure. However, Soomro et al. (2017) reported that the slaughter techniques were differed from re-entrant cannulas or simple T cannulas and post valve T caecum cannulas in term of nutrient digestibility values.

In this study, the lowest SID values of EAAs in paddy rice could be probably affected by high content of crude fiber in the paddy-based diet. Paddy rice and rice bran in this study contained higher crude fiber (9.6 and 8.03%) than in broken rice (0.1% CF), and the diet contained 60% as DM paddy rice and the CF concentration was 57.6 g/kg. Fiber was a usual component in the pig diet and when included within reasonable concentrations, it promoted normal gastrointestinal tract function (Wenk, 2001). On the other hand, the negative effect of fiber on nutrient use was dependent on its physical and chemical properties which differ among feedstuffs (Lenis *et al*., 1996). In addition, chemical properties of fiber in paddy rice and rice bran were differed. Acid detergent fiber and lignin contents in paddy rice were higher in rice bran (Kinh, 2003; Thong *et al*., 2012). A large number of studies have been carried out to study the effect of dietary fiber on ileal digestibility in pigs and reported that fiber content of the diet could impair SID of nutrients (Souffrant, 2001). The author re-

ported also that the endogenous nitrogen losses were most twice as high after feeding barley endosperm fiber as compared to barley hulls.

CONCLUSIONS AND RECOMMENDATIONS

The total basal ileal endogenous loss of essential amino acids was 1.22 g/kg DMI in growing pigs fed nitrogen-free diet based on dextrose. The means of standardized ileal digestibility of essential amino acids in broken rice were highest (ranged 81.37-84.54%), and lowest in paddy rice (ranged 72.21-76.28%). The values of AID and SID of most essential amino acids were higher in broken rice than in paddy rice and rice bran. In recommendation, the broken rice, rice bran and paddy rice contained readily digestible essential amino acids and could be included upto 60% as dry matter in the diet for the pig.

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NOVELTY STATEMENT

This study firstly provides database on the apparent and standardized ileal domesticity of amino acids of common paddy rice, broken rice and rice bran in Vietnam. These information are important in animal diet formulation.

AUTHOR'S CONTRIBUTIONS

La Van Kinh: Conceptualizing and designing the experiment, investigating, supervising, editing and finalizing the manuscripts.
Nguyen Vu Thuy Hong Loan: Investigating and preparing the manuscript.
Le Duc Ngoan: supervising, editing the manuscripts.
La Thi Thanh Huyen: investigating and analyzing data.
All authors: Editing and finalizing the manuscripts.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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