Effects of Different Energy Sources and Sulfur Amino Acids to Lysine Ratios in Diets on Growth Performance, Nutrients Digestibility and Intestinal Morphology of Post Weaning Pigs

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Abstract

This study was conducted to evaluate the effects of energy sources (broken rice and cassava) and standardized ileal digestibility sulfur amino acids to lysine ratio (SID SAA: Lys ratio) in diets on growth performance, nutrients digestibility and intestinal morphology of piglets. One hundred and twenty eight castrated male weaning pigs (Large White x Landrace x Duroc; initial BW, 6.67 ± 0.05 kg) were randomly divided into 8 treatments with 4 replications of 4 pigs. The experimental design was a 2 x 4 factorial treatment arrangement in Completely Randomized Design. Main effects were 2 energy sources (broken rice and cassava) and 4 ratios of SID SAA: Lys (45, 56, 64 and 72 percentage). Piglets fed with broken rice had higher ADG, ADFI and digestibility of DM and OM than those fed with cassava diet (P<0.01). Increasing SID SAA: Lys ratios linearly improved FCR (P=0.01). Consequently, to maintain the identical growth rate, dietary level of SID SAA: Lys ratio of piglets fed with cassava was higher than that of broken rice diet. Feeding cassava diet increased fiber intake, duodenal villous height and ileal crypt depth compare to the broken rice diet (P<0.05). The interaction effects of energy source and SAA: Lys ratio on intestinal morphology was found (P<0.05). High and low ratio of SID SAA: Lys in broken rice and cassava diets additionally increased duodenal villous height, respectively. Feeding piglets with broken rice resulted in higher growth rate and nutrients digestibility, lower SAA: Lys ratio requirement and shorter villous height than that of cassava diet. Morphological response seemed to be involved with synergic effects between fiber and SAA intake.

Keywords: Broken Rice, Cassava, Sulfur Amino Acids, Productive Performance, Weaning pigs

ผลของแหล่งพลังงานในสูตรอาหารและสัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีนต่อสมรรถภาพการผลิต ค่าการย่อยได้ของสารอาหาร และสัณฐานวิทยาของลำไส้เล็กในสุกรหลังหย่านม

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บทคัดย่อ

การศึกษาผลของแหล่งพลังงานในสูตรอาหาร (ปลายข้าวและมันสำปะหลัง) และสัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีนต่อสมรรถภาพการผลิต ค่าการย่อยได้สารอาหาร และสัณฐานวิทยาลำไส้เล็กของสุกรหลังหย่านม โดยใช้สุกรหย่านมเพศผู้ตอนจำนวน 128 ตัว (ลาร์จไวท์ x แลนด์เรซ x ดูร็อค) น้ำหนัก 6.67±0.05 กก. สุ่มแบ่งสุกรออกเป็น 8 กลุ่มๆละ 4 คอก แต่ละคอกมีสุกร 4 ตัว วางแผนการทดลองแบบ 2 x 4 แฟคทอเรียลในแผนแบบสุ่มสมบูรณ์ โดยมีแหล่งพลังงาน 2 แหล่ง (ปลายข้าวและมันสำปะหลัง) และสัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีน 4 ระดับ (45, 56, 64 และ 72 เปอร์เซ็นต์) ลูกสุกรกินสูตรปลายข้าวมีอัตราการเจริญเติบโต ปริมาณการกินได้และค่าการย่อยได้ของวัตถุแห้ง และอินทรียวัตถุสูงกว่าสูตรมันสำปะหลัง ($P<0.01$) การเพิ่มสัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีนเพิ่มประสิทธิภาพของอัตราการเปลี่ยนอาหารเป็นน้ำหนัก ($P=0.01$) ลูกสุกรกินสูตรมันสำปะหลังมีความต้องการสัดส่วนกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบสูงกว่าสูตรปลายข้าว การได้รับสูตรมันสำปะหลังทำให้ปริมาณเยื่อใย ความสูงวิลไล และอัตราส่วนความสูงวิลไลและความลึกของคริปต์ที่ลำไส้เล็กส่วนต้นสูงขึ้นกว่าสูตรปลายข้าว ($P<0.05$) พบปฏิกิริยาร่วมแหล่งพลังงานและสัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีนต่อสัณฐานวิทยาลำไส้เล็ก ($P<0.05$) สัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีนที่สูงและต่ำในสูตรมันสำปะหลังและปลายข้าวเพิ่มความสูงของวิลไลที่ลำไส้เล็กส่วนต้น ส่วนสูตรปลายข้าวมีอัตราการเจริญเติบโตและการย่อยได้สูง มีความต้องการสัดส่วนของกรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบต่อไลซีนต่ำ และความสูงวิลไลต่ำกว่าสูตรมันสำปะหลัง มีอิทธิพลร่วมของเยื่อใยและกรดอะมิโนที่มีซัลเฟอร์ต่อสัณฐานวิทยาของลำไส้เล็ก

คำสำคัญ : ปลายข้าว มันสำปะหลัง กรดอะมิโนที่มีซัลเฟอร์เป็นองค์ประกอบ สมรรถภาพการผลิต ลูกสุกร

Introduction

Feed is most expensive input in commercial pork production representing more than 50% of the total cost of production. The greatest production of this cost is associated with the energy component, thus making energy the most important dietary in terms of cost. The energy sources feedstuffs make up to 50% to 85% of the ingredients in pig ration, which in turn provide much of the energy to the animal (Velayudhan et al., 2015). Energy sources feedstuffs such as corn, broken rice and cassava have been used for pigs in Thailand. It seems that well productive performance of piglets is shown when fed with broken rice based diet (Mateos et al., 2007), while the cost of broken rice is always more expensive that those of corn and cassava. Although it is classified as the cheapest energy source feedstuffs, cassava is not a main ingredient for pig diets due to several limiting factors such as high fiber content, low protein content or amino acids profile and high variation of starch percentage (Montagnac et al., 2009b). Never theless, in broiler chickens, feeding cassava chips and cassava pellet diets showed higher villous surface area, absorptive cells in the jejunum and cell proliferation in the small intestine than those of fed with corn diet (Promthong et al., 2006). Due to low quality and quantity of protein in cassava, cassava based diets require higher amounts of protein sources such as soybean meal and synthetic amino acids to obtain an adequate of protein and amino acids balance. Therefore, the economic feasibility of using cassava as a substitute for conventional energy source feedstuffs would depend not only on the relative price of cassava but also on the price of protein supplement needed.

For pigs, Lysine (Lys) is always classified as the first limiting amino acid and must be supplemented in pig diets. Although Methionine (Met), an essential sulfur amino acid (SAA) is the second or third rank of critical limiting amino acids. Synthetic Met should be added when poor digestible feed ingredients are used (Bunchasak, 2009). In addition, cysteine (Cys), a non-essential sulfur amino acid, can be synthesized from Met, and it played a key role in cellular redox function and oxidative stress susceptibility in pig intestine (Riedijk et al., 2007). Therefore, deficiency of SAA suppresses epithelial growth and induces intestinal villous atrophy in neonatal pigs (Bauchart-Thevret et al., 2009). In order to achieve maximal growth performance and minimal production cost, optimal SAA (Met + Cys) or SAA: Lys ratio have to be concerned.

Feeding different diets always affect to growth and development of digestive system especially small intestine. Morphology of the small intestine of piglets undergoes rapidly and dramatic changes at weaning (Hampson and Kidder, 1986). Turnover of the intestinal epithelium reflects a dynamic equilibrium between the production of enterocytes in the crypts and their subsequent desquamation from the villous (Pluske et al., 1997). A shortening of the villous height decreased the surface area for nutrient absorbed, increased secretion in the gastrointestinal tract, diarrhea and lower overall performance Furthermore, the villous height to crypt depth ratio was a useful criterion for assess intestinal health and function (Pluske et al., 1997).

Recently, NRC (2012) suggested that the standardized ileal digestibility sulfur amino acids to lysine ratio (SID SAA: Lys ratio) estimated of 5-10 kg pigs was 54.8% of diets and of 10-20 kg pigs was 58.5% respectively. However, these suggestions were mainly evaluated based on corn-soybean meal-based diets, while bioavailability of SAA in basal diets or feed ingredients also influence SAA requirement (Chung and Baker, 1992b). Thailand and a lot of tropical countries, broken rice or cassava are the major feed ingredients feeding high lean-genotype pigs. So this suggestion might not be possible to achieve the highest performance. Besides, Information about SID SAA: Lys ratio in rice and cassava based diets in the tropical environment are extremely limited. Therefore, the comparison of using broken rice and cassava as energy sources, and optimal level of SID SAA: Lys ratios on productive performance and small intestine morphology of piglets were investigated.

Materials and Methods

The trial protocol was approved by the Institutional Committee for Animal Use and Ethics of The Kasetsart University. Throughout the trials, the animals were handled in compliance with local laws and regulations and in accordance to the principles and guidelines for pig welfare.

Animal Managements and Experimental Diets

The 128 weaning pigs (Large White x Landrace x Duroc) with an initial body weight 6.67 ± 0.50 kg were used. The piglets were divided into 8 groups; each group consisted of 4 replications of 4 pigs. In order to determine the effects of energy sources and SID SAA: Lys ratio requirement, broken rice-soybean and cassava-soybean based diets were formulated, and the synthetic DL-Methionine (Sumitomo Chemical, Japan) was supplemented to increase SID SAA: Lys ratio in each energy source. The study was arranged by a 2 x 4 factorial arrangement of treatment in Completely Randomized Design. Two main effects were investigated: 1) two energy sources (broken rice and cassava) and 2) four levels of SID SAA: Lys ratios (45, 56, 64 and 72%). The compositions of experimental diets are presented in Table 1. Chromic oxide (Cr_2O_3) was added (0.25%) to the diets as an indicator for determination of digestibility values as apparent total tract digestibility.

Piglets were kept in closed house on slat floor. The environmental temperature in house was controlled by evaporative cooling system at 32°C in the first week, and then was kept at an average temperature of 29°C. Each pen (4 m^2) was equipped with five-hole automatic feeder and one nipple water to allow *ad libitum* consumption of feed and water throughout the experimental period. The vaccinations were provided according to commercial practice. The duration of the trial was 42 days and piglets were weighed initially and at the end of experiment for calculation of weight gain (BW), average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR).

Determination of apparent tract total digestibility (ATTD)

Estimations of ATTD were based on pooled feces samples from each replicate for each diet, the feces samples were dried at 70°C for 48 h and stored at -20°C until chemical analysis. Before analysis, feces samples were thawed overnight, homogenized and ground (1-mm screen). Chromium was analyzed via UV absorption spectrophotometry following the method described by Bolin et al. (1952). Based on the method of AOAC (1990), concentration of Chromic oxide (Cr_2O_3), dry matter (DM) and crude protein (CP) in feed and digesta were determined for calculation of apparent total tract digestibility (ATTD) of DM, CP and organic matter (OM). The ATTD was calculated using the following formula:

ATTD (% as DM) = {1-[(NfxCd) / (NdxCf)]} x 100,

in which Nf = nutrient concentration in feces (% as DM), Cd = chromium concentration in diet (% as DM), Nd = nutrient concentration in diet (% as DM), and Cf = chromium concentration in feces (% as DM), as described by Stein et al. (2006)

Morphology of Small Intestinal Determination

At the end of the trial (day 42) tissue samples were collected from eight pigs per treatment. Then these animals were euthanasia and processed to take samples for the intestinal histological test. The pig in terms of growth performance and were fasted for six hours before slaughter.

From each sample, 2 cm segment samples of the duodenum (10 cm distal to the pylorus), jejunum (middle of the small intestine) and ileum (5 cm proximal to the end of the small intestine) were collected immediately from each pig. Intestine samples were rinsed with ice-cold saline and fixed in 10% neutral buffer formalin. Cross - section of intestinal samples from formalin preserved segments were prepared by standard paraffin embedding techniques and cut approximately 6 μm thick with a microtome and stained with azur A and eosin. The stained sections were observed for villous height and crypt depth at 100x magnification by light microscope (CH30;

Olympus, Tokyo, Japan) in accordance with Nunez et al. (1996).

Statistical Analysis

Data were analyzed by GLM procedure of SAS (Statistical Analysis System, Version 6.12, 1998, SAS Institute Inc., Cary, NC, USA) using factorial arrangement of treatments in complete randomized design and pens were considered as experimental units.

The statistical model is $Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}$ Where; Y_{ijk} was observed, τ_i was energy source effect, β_j was SID SAA:Lys ratio effect, $(\tau\beta)_{ij}$ was interaction effect and ε_{ijk} was experimental error, ε_{ijk} ~ NID $(0,ó^2)$. Effect of SSA: Lys ratio was further analyzed by linear and quadratic polynomial contrasts. Statistical significance level was at P<0.05 and trend at P < 0.10. The differences between the means were determined by Duncanís new multiple range test at P<0.05.

Results

Productive Performance and Digestibility

Effects of energy sources and SID SAA: Lys ratios on productive performance and ATTD are presented in Table 2. There were no interactions between energy source and SID SAA: Lys ratios for productive performance parameters (P>0.05). Piglets fed with broken rice based diet had greater ADG and ADFI than those of cassava diet (P<0.01), while fiber intake was high in cassava based diet group (P<0.01). The SID SAA: Lys Ratios seem to have less effect on productive performance and digestibility than expectation. Only SAA intake and FCR were highly significant positive affected (P=0.01). ADG of piglets ate difference SID SAA: Lys ratio (45-72%) was not significantly different. The SID SAA: Lys ratio 45% had the least SAA intake (P=0.05), whereas the other level (56, 64, and 72%) was not differences. Both low and high SID SAA: Lys ratios (0.45 and 0.72) increased feed intake (P<0.05), whereas ratios of SID SAA: Lys at 56%, 64% and 72% had better FCR than that of 45% (P<0.01). There were no significant interactions between energy sources and SID SAA: Lys ratios on ATTD of the diets (P>0.05).The ATTD of DM and OM of broken rice based diet was higher than that of cassava based diet (P<0.01). Piglets fed broken rice based diets had highly significant better digestibility of DM, and OM than those fed cassava based diet at P<0.01). They ate more lysine and SAA but less fiber than cassava based diet (P<0.01).

Results of the parameters fitting to the SAA: Lys ratio linear and quadratic for each energy sources. SAA: Lys ratio had highly significant linear effect only on FCR. The predicted FCR equation of broken rice based diet was Y = 1.8788 - 0.5721X (P<0.01, r^2 = 0.38, n=16) and cassava diet equation was Y = 1.8223 - 0.4618X (P<0.01; r^2 = 0.41, n = 16). Effect of SAA: Lys ratio on productive performances of piglets fed broken rice-, or cassava-soybean based diets are presented in Table 3.

Small Intestinal Morphology

The morphology of 3 intestinal segments is shown in Table 4. Pigs fed cassava based diets had significantly higher duodenum villous (P<0.05) and ileum crypt depth (P<0.05) than those of broken rice based diets, as well as the villous height/crypt depth ratio of duodenum (P<0.05), but opposite to jejunum segment. The jejunum villous height/crypt depth ratio of pigs fed broken rice diet was higher than those fed cassava. However, the dietary energy source did not show any effects on villous height at the jejunum and ileum or crypt depth at duodenum and jejunum. The SID SAA: Lys ratio have significantly linear increasing the villous height in duodenum (P<0.05) and ileum (P<0.05) but not for the crypt depth and villous height to crypt depth ratio (P>0.05). There were interactions between energy sources and SID SAA: Lys ratios on morphology throughout the small intestinal tract (P<0.05), except ileal crypt depth and duodenal villus height to crypt depth ratio. High SID SAA: Lys ratio (64-72%) in cassava diet and lower SID SAA: Lys ratio in broken rice diet (45-56%) increased villous height, crypt depth or ratio of villous to crypt depth (P<0.05). In exceptional, 45% SID SAA: Lys ratio in broken rice showed lower crypt depth in jejunum sector than those of other groups P<0.05).

Table 1. Ingredients and composition of experimental diets.

Ingredients (%)	Broken rice				Cassava			
	SID SAA: Lys ratio 1 (%)				SID SAA: Lys ratio (%)			
	45	56	64	72	45	56	64	72
Broken rice	49.54	49.54	49.54	49.54	-	-	-	-
Cassava	-	-	-	-	41.53	41.53	41.53	41.53
Soybean meal	19.67	19.67	19.67	19.67	25.67	25.67	25.67	25.67
Soy extrude	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Whey	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Rice Bran Oil	0.65	0.65	0.65	0.65	3.12	3.12	3.12	3.12
DCP 21%	2.34	2.34	2.34	2.34	2.30	2.30	2.30	2.30
$CaCO_3$	1.16	1.16	1.16	1.16	0.84	0.84	0.84	0.84
Salt	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16
L-Lysine HCL	0.34	0.34	0.34	0.34	0.28	0.28	0.28	0.28
DL-Methionine	0.06	0.21	0.29	0.42	0.08	0.23	0.31	0.44
L-Threonine	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Premix[2]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Corn starch	0.48	0.33	0.25	0.12	0.43	0.28	0.20	0.07
Total	100	100	100	100	100	100	100	100
Calculated nutrient content in the diets, %								
CP	21.00	21.09	21.15	21.22	21.02	21.11	21.18	21.24
ME, Kcal/Kg	3400	3402	3404	3406	3400	3403	3405	3407
Fat	6.05	6.05	6.05	6.05	8.25	8.25	8.25	8.25
Fiber	2.426	2.426	2.426	2.426	3.745	3.745	3.745	3.745
Lysine	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Methionine	0.327	0.479	0.590	0.702	0.321	0.469	0.582	0.693
Met+Cys	0.635	0.784	0.896	1.008	0.635	0.784	0.896	1.008
SID lysine	1.273	1.273	1.273	1.273	1.275	1.275	1.275	1.275
SID methionine	0.316	0.460	0.537	0.662	0.265	0.450	0.527	0.651
SID Met+Cys	0.570	0.714	0.812	0.916	0.571	0.715	0.815	0.917
Threonine	0.860	0.860	0.860	0.860	0.860	0.860	0.860	0.860
Tryptophan	0.263	0.263	0.263	0.263	0.265	0.265	0.265	0.265

[2]Ingredients: vitamin A 2,000,000 IU, vitamin D_3 400,000 IU, vitamin E 4,000 IU, vitamin K 0.3 g, vitamin B_1 0.2 g, vitamin B_6 0.4 g, vitamin B_{12} 0.004 g, Panthothenic acid 1.8 g, Nicotinic acid 3 g, Biotin 0.02 g, copper 30 g, manganese 10 g, zinc 20 g, iron 30 g, iodine 0.1 g, cobalt 0.04 g, selenium 0.06 g, flavor 0.5 g, preservative 0.15 g; filler add to 1 kg.

[1]SID SAA: Lys ratio = Standardized lieal digestibility sulfur amino acid per lysine ratio

Table 2. Effects of energy sources and SID SAA:Lys ratio on growth performance and digestibility of post weaning pigs.

Items	Energy Source		SID SAA: Lys ratio (%)				SEM	P-value		
	B.Rice	Cassava	45	56	64	72		E	S	E*S
Performance										
Initial BW (kg)	6.67	6.66	6.67	6.67	6.66	6.67	0.05	0.10	0.86	0.65
Final BW (kg)	27.05^{A}	24.41^{B}	25.41	25.79	25.22	26.49	0.26	0.01	0.13	0.48
ADG (kg)	0.49^{A}	0.42^{B}	0.45	0.46	0.45	0.47	0.01	0.01	0.23	0.54
ADFI (kg)	0.736^{A}	0.654^{B}	0.734^{A}	0.686^{BC}	0.671^{C}	0.709^{AB}	0.01	0.01	0.01	0.16
SAA intake (g)	6.07^{A}	5.42^{B}	4.67^{C}	5.38^{B}	6.00^{B}	6.92^{B4}	0.18	0.01	0.01	0.13
Lys intake (g)	10.29^{A}	9.16^{B}	10.30	9.61	9.39	9.60	0.17	0.01	0.10	0.36
Fiber intake (g)	17.84^{B}	24.49^{A}	22.26	20.99	20.40	21.02	0.65	0.01	0.10	0.29
FCR	1.54	1.55	1.65^{A}	1.51^{B}	1.52^{B}	1.50^{B}	0.02	0.67	0.01	0.23
Digestibility (ATTD)[1]										
DM	83.05A	77.52B	79.93	78.87	80.17	82.18	0.96	0.01	0.59	0.27
CP	81.05	80.57	81.93	78.39	81.18	81.73	0.84	0.79	0.47	0.32
OM	84.47A	79.56B	81.95	80.44	82.47	83.18	0.78	0.01	0.54	0.24

E = Energy Source, S = SAA: Lys Ratio (%) E*S = Interaction between E and S
^{A,B} = Means with different superscripts in the same row are significantly different. (P<0.05)
[1]ATTD = Apparent total tract digestibility

Table 3. Effects of SAA: Lys ratio in diets on productive performance of piglets.

Items	SID SAA: Lys ratio (%)				SEM	P-value	
	45	56	64	72		Linear	Quadratic
Broken rice							
ADG (g/d)	483.93	480.51	470.01	508.97	6.70	0.33	0.13
ADFI (g/d)	802.16	715.40	714.58	710.12	17.99	0.06	0.26
FCR	1.659	1.591	1.521	1.488	0.024	0.01	0.09
Cassava							
ADG (g/d)	408.63	430.21	413.76	437.80	7.68	0.30	0.97
ADFI (g/d)	669.05	657.52	626.64	662.72	8.44	0.48	0.24
FCR	1.639	1.532	1.514	1.513	0.018	0.01	0.10

Table 4. Effects of energy sources and SAA : Lys ratio on small intestinal morphology.

Items	Energy Source		SID SAA: Lys ratio (%)				SEM	P-value		
	B.Rice	Cassava	45	56	64	72		E	S	E*S
Villous height (μm)										
Duodenum	404.53^{B}	446.38^{A}	417.82^{AB}	426.28^{AB}	393.60^{B}	463.82^{A}	7.84	0.02	0.05	0.01
Jejunum	394.37	388.03	381.84	409.95	374.86	398.15	5.52	0.53	0.07	0.01
Ileum	304.79	308.53	276.90^{B}	296.13^{B}	302.80^{B}	350.81^{A}	5.06	0.68	0.01	0.01
Crypt depth (μm)										
Duodenum	371.77	358.53	372.46	338.69	370.60	378.86	6.65	0.30	0.12	0.01
Jejunum	281.13	296.24	271.79	296.43	290.02	296.52	4.75	0.11	0.20	0.05
Ileum	239.99^{B}	259.94^{A}	245.38	249.58	250.09	254.83	4.69	0.03	0.91	0.17
Villous height : crypt depth										
Duodenum	1.16^{B}	1.36^{A}	1.18	1.35	1.16	1.36	0.04	0.01	0.14	0.23
Jejunum	1.50A	1.37^{B}	1.51	1.47	1.36	1.40	0.03	0.05	0.36	0.01
Ileum	1.39	1.30	1.22	1.32	1.34	1.50	0.04	0.23	0.12	0.04

E = Energy Source, S = SAA: Lys Ratio (%) E*S = Interaction between E and S
^{A,B} = Means with different superscripts in the same row are significantly different. (P<0.05)

Discussion

Productive Performance and Digestibility

Using broken rice based diets increased the digestibility of DM and OM. Similar to Mateos et al. (2007) and Vicente et al. (2009) who found that pigs fed broken rice based diets have high ADFI and ADG that may be involved with the increase of glycemic response. In South East Asia, broken rice is widely used in piglet diets due to high digestibility of DM and OM (Vicente et al., 2009). The difference in nutrient digestibility between broken rice and cassava might be related to differences in the composition of diets, since broken rice is characterized by its high starch content, low level of non-starch polysaccharide, smaller size of starch granules (Tester et al., 2004). Therefore, rice starch is expected to be more available to enzyme action than cassava starch. Furthermore, pigs fed a cassava based diets have high fiber intake that also cause poor nutrients digestibility (Lokaewmanee et al., 2011), although Gunawardena et al. (2010) reported that digestibility of DM and CP was not affected by various sources of starch concentrate (corn, wheat and cassava). Therefore, these results were consistent to most previous reports and confirmed that broken rice is better quality and higher preference to cassava diet.

Increase of SID SAA: Lys ratio in broken rice diet tend to decline feed intake linearly and significantly improve FCR in both broken rice and cassava. This is consistence to several reports which recommend the requirement of the SID SAA: Lys ratio for 5 to 26 kg pigs for protein accretion are around 55-60% (Dean et al., 2007; NRC, 2012) while lower SAA: Lys ratio (50%) for 5 to 10 kg pigs was reported (Chung and Baker, 1992b). In the present study, increasing SID SAA: Lys ratio in either broken rice or cassava based diets improved FCR but did not affect ADG. This indicated that the requirement of SID SAA: Lys ratio for feed utilization was higher than of for the growth rate.

The nutritive value of amino acids was depressed by increasing fiber in diets and utilization of fiber was affected by the fiber source (Dung et al., 2002). In this study, high fiber content in cassava caused low nutrients digestibility (DM and OM), low feed intake and depress growth of piglets, amount of feed and fiber intake should be important factors affecting amino acids requirement. Accordingly, increase of SID SAA: Lys ratio in broken rice based diets trend to decrease feed intake linearly ($P = 0.06$). It can be assumed that high digestible diet may positively response to amino acids balance better than the poorer.

Small Intestinal Morphology

The presence in the lumen of high viscosity digesta may increases the rate of villus cell losses, leading to villus atrophy, a phenomenon associated with an increased crypt-cell production, and generally with increased crypt depth. Thus, dietary fiber often viscous, and generally causes an increase in the viscosity of the diet and of the intestinal contents (Montagne et al., 2003). As an example, addition of high viscosity fiber to a cooked rice and animal protein-based diet for weanling piglets led to decrease villus length and increased crypt depth (McDonald et al., 2001). In contrast, duodenal villus height of piglets fed cassava diets of present study were a higher than that of the broken rice diets. However, in growing pigs, ingestion of high fiber diets caused an enlargement of villi and deepening of the crypts in the jejunum (Jin et al., 1994). Moreover, Kalmendal et al. (2011) and Sklan et al (2003) reported that high fiber diet increased villus height in pigs and surface area of the small intestine of turkeys.

The ileal crypt depth of feeding cassava based diets was deeper than feeding broken rice based diets in this experiment. This may be caused by high fiber content in cassava diet. Several investigators reported that using high fiber increased the crypt depth of piglets (McDonald et al. 2001) and inclusion of 10% wheat straw to a low fiber diet resulted in deeper jejunal and ileal crypts depth in growing pigs and broiler chicken (Jin et al., 1994; Iji et al., 2001).

The jejunal villus height to crypt depth ratio was high in broken rice diets, while cassava diets increased duodenal villus height to crypt depth ratio. The villus height/crypt depth ratio is a useful criterion for estimating the likely digestive capacity the small intestine. As shown in piglets by Pluske et al. (1997), villus height correlates positively with body weight gain. A decrease in the villus height/crypt depth ratio is considered deleterious for digestion and absorption. Factors affecting the response of the epithelial mucosa were type of fiber (viscous vs. non-viscous), level of fiber, age of the piglets, as well as the composition of diets. For example, Jimenez-Moreno et al. (2011) reported an increase in villus height to crypt depth ratio in broilers with the inclusion of 2.5% of pea hulls, whereas increment of pea hull to 7.5% inversely affected this ratio. Vincente et al. (2009) reported that weaning pigs fed rice had higher ileal villus height to crypt depth ratio than pigs fed other diets. This indicated that type of starch or amount of fiber intake had different effects on digestive capacity, and it seemed that feeding broken rice based diet involve with the adaptation of morphology in the segment of jejunum, while feeding cassava based diet involve with duodenum.

Results obtained here showed that villus height of duodenum and ileum significantly increased with high SID SAA: Lys ratio (72%). Met can be converted to Cys (Riedijk et al., 2007), which is the precursor of glutathione (antioxidant) in gut (Bauchart-Thevret et al., 2009). These results are consistent to Kaewtapee et al. (2010) which reported that reported that high SAA intake increased villous height throughout small intestine of piglets. Therefore, SAA deficiency substantially suppresses intestinal mucosal growth, reduces intestinal epithelial cell proliferation and increases intestinal oxidative stress in piglets (Bauchart-Thevret et al., 2009). The interaction effects between energy sources and SID SAA: Lys ratios on morphological response were in accordance with the estimation of SID SAA: Lys ratio requirement. Interestingly, high SID SAA: Lys ratio (72%) in cassava and low (45%) in broken rice additionally increased villus height.Although energy and amino acids in diets were equalized thus there were some synergic effects between fiber and SAA intake on morphological response. It could be suggested that difference starch type, fiber level, SAA level or the interactions in feed ingredients would be factors affecting productive performance, amino acid requirement and morphological response of piglets.

Conclusion

The study indicated that broken rice based diets as a dietary energy sources in piglet diets could improve the growth performance, digestibility of DM and OM and villous height/crypt depth ratio in jejunum. Increasing level of SAA: Lys ratio at 72% in diets could be beneficial effect on FCR and intestinal morphology in piglets.

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