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**Research article**

Efficiency of fresh and fermented banana stems in low protein diet on nutrient digestibility, productive performance and intestinal morphology of crossbred pig; (Thai native x Meishan) x Duroc

Chaiwat Arjin¹, Chanmany Souphannavong¹, Apinya Sartsook¹, Mintra Seel-Audom¹,
 Supamit Mekchay^{1,2} and Korawan Sringarm^{1,2,*}

¹ Department of Animal and Aquatic Sciences, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand

² Cluster of Research and Development of Pharmaceutical and Natural Products Innovation for Human or Animal, Chiang Mai University, Chiang Mai 50200, Thailand

Abstract

Banana stem is a common feed component for raising pigs in mountainous Southeast Asia. However, its nutritive value and digestibility are low. This study was carried out to investigate the effects of fresh and fermented banana stems on crossbred pigs concerning nutrient digestibility, productive performance, and intestinal morphology of crossbred pigs. Initially, an *in vitro* ileal digestibility test was performed for the following feedstuffs: fresh banana stem (BS), fermented banana stem (FBS), concentrate (C), fresh banana stem + concentrate (BSC), and fermented banana stem + concentrate (FBSC). For the 120-days experiment, 16 crossbred pigs were divided into two groups fed with BSC and FBSC. They were placed in individual cages and subsequently moved to metabolic cages for seven days to determine apparent total tract digestibility (ATTD). Finally, all pigs were slaughtered and their small intestines were analyzed for intestinal morphology. The results show that pure fresh and fermented banana stems had low digestibility. However, their digestibility increased by 50% when mixed with concentrate. Crossbred pigs fed BSC and FBSC did not exhibit significant differences in their performance, but the intestinal morphology of the FBSC group had improved intestinal morphology, especially the villi height. In conclusion, both fresh and fermented banana stems can be recommended in a low protein diet as feed for crossbred pigs in an improved production system. This is relevant for raising pigs in mountainous areas, as it has the potential to reduce feed cost and maintain production performance.

Keywords: Crossbred pig, Banana stem, Fermented banana stem, Digestibility, Intestinal morphology

Corresponding author: Korawan Sringarm, Department of Animal and Aquatic Sciences, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand. E-mail: korawan.s@cmu.ac.th

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INTRODUCTION

The highland areas in most countries of mainland Southeast Asia are underdeveloped. In contrast to the fast-developing urban centers of the region, inhabitants of mountainous areas live in rural communities and depend on agriculture, characterized by a high subsistence level, generating no or little monetary income (Evaluation, 2014). In highland communities, pigs play an important role not only as a source of nutrition but also as a major source of family income and raising funds for particular purposes, such as tuition for children, culture, and paying a debt (Deka et al., 2014). Highland farmers raise native pigs or breeds of indigenous and exotic races, such as 'Rad', 'Phuang', or 'Kwai' (Charoensook et al., 2013). These pigs are well-adapted to a hot and humid climate, resistant to disease and internal parasites, and survive on feeds of low quality, often derived from by-products of agricultural production, such as cassava leaves, rice bran, corn cobs, banana leaves, or banana stems (Nakai, 2008; Rattanaronchart, 1994). Even though the native pig can be ably fed the by-products from agricultural production but the nutrient inside not enough for them that affects on productive performance. Phengsavanh et al. (2010) described that the performance of pigs in smallholder systems was generally very poor, as it was affected negatively by nutritionally imbalanced diets and underfeeding. Anywise, farmers can neither afford to purchase concentrate or deliberately grow feed-grains on a portion of their lands that lead to an increase in the production cost. In this way, they can raise pigs with a minimum of additional inputs, mainly relying on what is left-over from agricultural activities such as such as banana stem, rice bran, maize grain (Nakai, 2008) also herb for pig health (Ruamrungsri et al., 2016; Arjin et al., 2020). However, this system of raising pigs has low productivity and has limited potential for additional income generation. Therefore, in an attempt to improve productivity, breeding programs were started for cross-breeding indigenous races with commercial breeds. The aim was to breed a pig with high productivity that at the same time would conserve the positive adaptation characteristics. While it was possible to improve the genetic potential by cross-breeding, in practice, pigs did not grow well due to the low-quality feedstuffs used.

Among the numerous other by-products, banana stem plays an important role in upland areas. As a by-product after harvesting field-grown bananas, as well as wild bananas or those from house gardens, it is widely available and it has no other use for the local population. Thus, it is considered suitable to be used as a cheap pig feed. However, in terms of nutrition, banana stem can be considered a feedstuff of inferior quality: Firstly, it has a high water content (93.4%). Secondly, the nutritive value is low; on a dry matter (DM) basis, the levels of crude protein (CP) and lipids are at 6.5% and 1.5%, respectively (Sokchea et al., 2018). Furthermore, the high fiber content makes banana stem difficult for pigs to digest, and feeding fresh banana stem results in wastage of the major part of the content used in animal nutrition. However, ensiling or creating silage from banana stem can make it suitable feedstuff or feed additive at needed periods, making it a valuable source of feed for livestock (Duponte et al., 2016). An important effect of producing silage from banana stems is to make fibrous parts more digestible for the pig's stomach. This is achieved through partial fermentation while keeping the material under anaerobic

conditions. Technically, this can be done in air-tight containers of any material, such as in earthen holes or piled on a plain and compacted underground with a cover. Thus, it is relatively simple, effective, and provides an economical way of preserving and enhancing more nutritive quality and usefulness as pig feed (Duponte et al., 2016). Even though the production of silage is a well-known process and is widely applied, especially for feeding ruminants, little is known about the use of fermented feedstuff for the nutrition of monogastric animals. Until now, there have been quite a few studies on the use of silage on pig's diet in general, but the actual properties of the fermented banana stem, in particular, have not yet been investigated in terms of nutritional value and digestibility for pigs.

In this study, a simple fermentation process without additives was used, which makes it easy for highland farmers to reproduce the results. The objective of this study was to investigate the properties of the fresh and fermented banana stems in terms of *in vitro* ileal digestibility and apparent total tract digestibility. Furthermore, feedstuffs from the fresh and fermented banana stems were analyzed for nutrient utilization, productive performance, and gastrointestinal health of crossbred pigs ((Thai native x Meishan) x Duroc).

MATERIALS and METHODS

Feedstuff analysis

Fermented banana stem preparation

For all feedstuffs used in the experiment, the banana stem was chopped into 1–2 cm lengths. For the preparation of fermented banana stem (FBS), chopped banana stems were filled into plastic tanks in layers of 10 kg. After filling one layer, salt (NaCl) and sugar were added at 100 g each. After that, the layer was pressed and compacted to ensure complete anaerobic conditions before the next layer was filled. This was repeated five times before the container was sealed. Each tank held a total of 50 kg of banana stems, 500 g of salt, and 500 g of sugar. The tanks were sealed and kept for 21 days before being used as pig feed.

In vitro ileal digestibility

Five samples of ground feed were analyzed in terms of *in vitro* ileal digestibility: fresh banana stem (BS), fermented banana stem (FBS), fresh banana stem mixed with commercial feed (BSC), fermented banana stem mixed with commercial feed (FBSC), and commercial feed (C). All samples were sieved (<1 mm) and stored in air-tight containers until digestibility analysis. The *in vitro* ileal digestibility method applied in this study was described by Kong et al. (2015) to estimate the digestibility of five samples. Briefly, 1 g of sample was weighed into a 250 mL conical flask, to which 25 mL of phosphate buffer (0.1 N, pH 6) and 10 mL 0.2 N HCl was added. The pH of the solution was adjusted to 2 by using 1 N HCl and 1 N NaOH. Then added 1 mL freshly prepared pepsin (10 mg/mL) and 0.5 mL chloramphenicol solution to the mixture. The flasks were incubated in a shaking incubator at 39°C for 6 h. After that, added 10 mL of phosphate buffer (0.2 M, pH 6.8) and

5 mL of 0.6 M NaOH to the mixture. The pH was adjusted to 6.8 by 1 N HCl or 1 N NaOH. The freshly prepared pancreatin solution (50 mg/mL) was then added 1 mL to the mixture. The flasks were shaking incubated again at 39°C for 18 h. After the incubation, the enzymatic activity in all flasks was stopped by adding 5 mL 20% sulfosalicylic acid solution. The flasks were incubated at room temperature for 30 min, then filtered through filter paper, and rinsed with 10 mL 95% ethanol followed by 99.5% acetone. The undigested sample residues were dried at 100°C overnight. The residue was cooled in a desiccator and weighed. All samples were stored for proximate analysis by [AOAC \(2006\)](#). [Table 1](#) shows the compositions of all the feedstuffs used in the experiments.

Table 1 Ingredient composition of the experimental diets: BSC—fresh banana stem + concentrate, FBSC—fermented banana stem + concentrate, BS—fresh banana stem, FBS—fermented banana stem, and C—concentrate

Ingredients	BSC (%)	FBSC (%)	BS (%)	FBS (%)	C (%)
Corn	20.50	20.50	-	-	40.10
Broken rice	20.50	20.50	-	-	40.10
Rice barn	2.50	2.50	-	-	5.00
Soybean meal	4.00	4.00	-	-	8.00
Fish meal	1.25	1.25	-	-	2.50
Dicalcium phosphate (DCP)	1.00	1.00	-	-	2.00
Salt (NaCl)	0.125	0.125	-	-	0.25
Vitamin Premix ^a	0.125	0.125	-	-	0.25
Fermented banana stem	-	50.00	-	100.00	-
Fresh banana stem	50.00	-	100.00	-	-
Total	100.00	100.00	100.00	100.00	100.00

^a Vitamin premix (U or mg provided per kilogram of diet): vitamin A, 12,000U; vitamin D3, 4500U; vitamin E, 70U; vitamin K, 3.5mg; vitamin B1, 3mg; vitamin B2, 7.5mg; vitamin B3, 30mg; vitamin B5, 65mg; vitamin B6, 4.3 mg; vitamin B9, 2 mg; vitamin B12, 0.025 mg; biotin, 0.3 mg; choline chloride, 800 mg.

Chemical analysis of feed and feces

Samples of feed and feces were oven-dried at 60 °C for 48 hours, subsequently ground and sieved through a 1-mm sieve. The chemical compositions of feed and feces were determined according to [AOAC \(2006\)](#), and the gross energy in the sample was measured by an adiabatic bomb calorimeter (CAL 2k, ECO, CALORIMETER).

Feeding experiment

Animals

This study was carried out in strict accordance with the recommendations in the Guide for the Care and Use of Agricultural Animals in Research and Teaching. All of the animal protocols were approved by the Animal Care and Use Committee Chiang Mai University (2561/AG-0004) before the experiment. This experiment was conducted at the Mae Hia Agriculture Resource Demonstrative and Training Center, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand.

To test the performance of the feedstuff on pigs, a total of 16 crossbred pigs ((Thai native × Meishan) × Duroc) with an initial weight of 14.00 ± 2.00 kg were selected, eight each of males and females, respectively. These groups were submitted to two different dietary treatments: BSC and FBSC. During the experiment all pigs were kept individually in concrete-floored pens, each containing a feeding trough, and they were offered drinking water at all times. Before the experiment started, all pigs were dewormed and vaccinated.

The individual live weights of pigs were measured in one-week-intervals until the end of the experimental period of 120 days to calculate average daily feed intake (ADFI), average daily gain (ADG), and feed conversion ratio (FCR).

Apparent total tract digestibility (ATTD)

The ATTD was determined according to [Li et al. \(2015\)](#). Briefly, after reaching a body weight (BW) of $30.00 \text{ kg} \pm 2.00 \text{ kg}$, the 16 crossbred pigs divided into two different dietary treatments were transferred to individual metabolism crates ($1.5 \times 1.5 \text{ m}$), which allowed a certain degree of freedom of movement. Chromic oxide was added to the diets as a marker. Each period consisted of a 7-day adaptation period and a 5-day collection period. During the collection period, fresh fecal samples were collected every day in the morning and immediately stored at $-20 \text{ }^\circ\text{C}$.

Slaughter and intestinal sample collection

The main experiment lasted for 120 days. At the end of the experiment, the feed was withheld for 12 h for all pigs from both groups. They were slaughtered by the use of an electric stunner and the small intestine was collected. The small intestine was separated into three parts: duodenum, jejunum, and ileum. The samples were cleaned by normal saline and immediately fixed with 10% formalin solution. The cecum contents were collected to determine the microbial population in the cecum.

Histomorphology

Intestinal tissues were dehydrated by immersing into a series of alcohol of increasing concentration (from 70% to absolute), infiltrated with xylene, and embedded in paraffin. A rotary microtome was used for cutting paraffin sections of $5.0 \text{ }\mu\text{m}$ thickness, which were placed on a glass slide and stained with hematoxylin and eosin. The slices were examined on a microscope (Zeiss Axioscope 1, Jena, Germany) fitted with a digital camera (Canon EOS-6D,

Canon Inc., Tokyo, Japan). The images were analyzed using stereological image software, Motic Images Plus 2.0 (Causeway Bay, Hong Kong) to measure villus height, villus width, and crypt depth. The values were measured with an oculometer at a magnification of 40X under a light microscope fitted with the stage micrometer.

Microbial population in the cecum digesta

The cecal microbial population was determined according to the methodology described by (Barrow and Feltham, 1993). After slaughter, cecal digesta contents were collected, and 10-fold serial dilutions were made from the cecal contents with peptone water (0.1% w/v) in test tubes for bacterial enumeration. *Lactobacillus* spp., *Bifidobacterium* spp., and *Escherichia coli* were determined by conventional microbiological techniques using selective agar media. These processes were repeated twice, and the results were expressed as colony-forming units (CFU) per gram of sample (CFU/g).

Statistical analyses

All statistical analyses were performed using the SPSS 23.0 software (SPSS Inc., Chicago, IL, USA) with a significance level of P-value of ≤ 0.05 . The results were analyzed using analysis of variance to determine the main effect of *in vitro* digestibility. All *in vivo* studies were analyzed and compared using the T-test. The statistical analysis for all data used each pig as a replication. Results were shown as the mean \pm standard deviation (SD).

RESULTS

The chemical compositions of all feedstuffs used in the study were analyzed and are represented in Table 2.

In vitro ileal and apparent total tract digestibility

Table 3 shows the *in vitro* ileal digestibility of the five diets. BS and FBS have the lowest digestibility with respect to dry matter (DM), crude fiber (CF), crude protein (CP), ether extract (EE), and Ash ($P < 0.05$). Conversely, C has the highest digestibility. However, when combined with concentrate, banana stem (BSC and FBSC) showed a significantly higher digestibility than in BS and FBS ($P < 0.05$). From the above result, we decided to perform an apparent total tract digestibility test for the two dietary treatments (BSC and FBSC). The pigs fed BSC and FBSC had a similar result of the ATTD on DM, CF, CP, Ash, EE, and GE parameters (Table 4). There were not difference in statistic between the two types of diet.

Table 2 Chemical composition of diets according to own analysis: BSC—fresh banana stem + concentrate, FBSC—fermented banana stem + concentrate, BS: fresh banana stem, FBS—fermented banana stem, and C—concentrate

Compositions	As fed basis				Air dry basis			
	BS	FBS	BSC	FBSC	BS	FBS	BSC	FBSC
Gross energy, GE (Mcal/kg)	3.18	3.10	3.83	3.73	3.18	3.10	3.83	3.73
Crude protein, CP (%)	0.23	0.44	4.81	5.56	3.11	4.36	11.97	12.56
Crude fiber, CF (%)	3.00	3.07	3.15	3.82	42.91	30.72	7.87	8.68
Ether extract, EE (%)	0.06	0.19	1.53	1.89	0.85	1.95	3.83	4.29
Neutral detergent fiber, NDF (%)	4.04	5.53	15.23	18.23	57.78	55.30	38.08	41.44
Acid detergent fiber, ADF (%)	3.00	3.73	7.77	9.28	42.81	37.29	19.42	21.10
Acid detergent lignin, ADL (%)	0.45	0.52	1.31	1.82	6.46	5.20	3.27	4.13

n = 3 (triplicate analysis)

Table 3 The *in vitro* ileal digestibility of five formula diet

% Digestibility	BS	FBS	BSC	FBSC	C	P-value
Dry Matter	30.42±7.83 ^a	34.77±1.25 ^b	63.90±1.62 ^c	65.65±1.32 ^c	77.46±2.80 ^d	<0.001
Crude Fiber	17.24±0.31 ^a	19.54±1.07 ^a	27.25±1.39 ^b	28.06±2.60 ^b	48.32±0.91 ^c	<0.001
Crude Protein	42.74±1.39 ^b	34.82±0.45 ^a	59.18±0.58 ^c	68.06±2.14 ^d	104.67±0.38 ^e	<0.001
Crude Fat	40.68±1.43 ^b	31.69±0.73 ^a	65.86±0.84 ^d	51.41±2.03 ^c	90.50±3.27 ^e	<0.001
Ash	17.25±0.68 ^a	15.53±0.62 ^a	46.96±1.39 ^c	55.84±1.20 ^d	39.55±1.58 ^b	<0.001
Gross Energy	36.66±0.04 ^a	38.71±0.17 ^b	70.63±0.17 ^c	73.38±0.42 ^d	81.61±0.33 ^e	<0.001

^{a, b, c, d, and e} Means on the same line with different superscripts differ (P<0.001). The *in vitro* digestibility was the measurement of an individual (n = 5).

Table 4 Effect of fresh and fermented banana stem in low protein diet on apparent total tract digestibility (ATTD) of crossbred pigs. BSC: fresh banana stem + concentrate and FBSC: fermented banana stem + concentrate

Compositions	% Digestibility		P-value
	BSC	FBSC	
Dry Matter	85.43 ± 1.12	84.61 ± 1.78	0.376
Crude Fiber	70.64 ± 1.27	68.91 ± 5.35	0.554
Crude Protein	91.41 ± 0.80	90.89 ± 3.11	0.702
Crude Fat	85.93 ± 2.42	83.83 ± 1.55	0.166
Ash	74.57 ± 2.54	72.27 ± 2.90	0.278
Gross Energy	68.51 ± 0.23	68.64 ± 0.24	0.910

The apparent digestibility was the measurement of an individual pig (n = 8).

Growth performances

The dietary effect of BSC and FBSC on productive performance is presented in Table 5. There was no significant effect of diets BSC and FBSC on final weight, average daily feed intake (ADFI), average daily gain (ADG), or feed conversion ratio (FCR) throughout the experimental period ($P > 0.05$). The final weights of pigs after the experimental period were 69.51 and 68.20 kg in BSC and FBSC, respectively. Interestingly, the FCRs of the pigs were comparatively high in both groups (6.27 and 6.52 on BSC and FBSC, respectively).

Table 5 Effect of the fresh and fermented banana stems as part of a low protein diet on the productive performance of crossbred pigs. BSC: fresh banana stem + concentrate and FBSC: fermented banana stem + concentrate

Items	BSC	FBSC	P-value
Initial weight (kg)	14.12 ± 2.00	14.14 ± 1.39	0.305
Final weight (kg)	69.51 ± 3.02	68.20 ± 2.96	0.944
average daily feed intake, ADFI (kg)	2.90 ± 0.17	2.92 ± 0.13	0.740
average daily gain, ADG (kg)	0.46 ± 0.02	0.45 ± 0.03	0.568
feed conversion ratio, FCR	6.27 ± 0.47	6.52 ± 0.54	0.414

n = 8 measurements of individual pigs

Microbial population

The dietary of BSC and FBSC did not influence the microbial populations (*Escherichia coli*, *Bifidobacterium* spp., and *Lactobacillus* spp.) in the cecum digesta of pigs (Figure 1). The population of *Bifidobacterium* spp. of pigs fed the FBSC had a trend to higher ($P = 0.09$) than those fed BSC but not difference in statistic (7.21 ± 0.16 vs. 6.53 ± 0.32 CFU/g.).

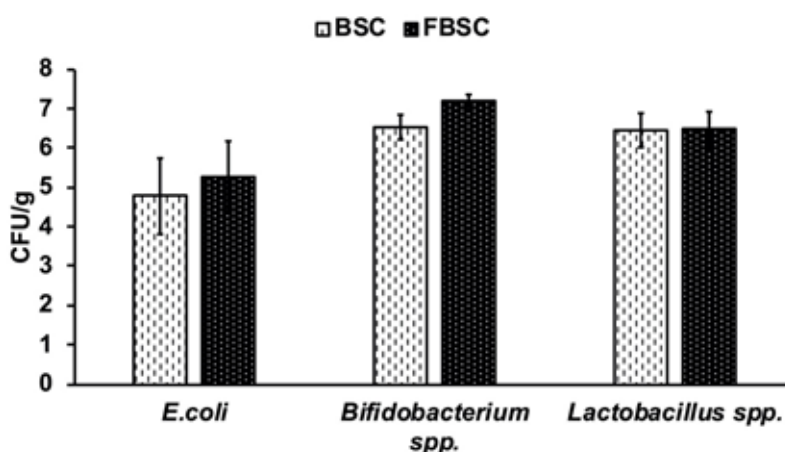


Figure 1 Microbial population in the ceca of crossbred pigs with either fresh banana stem mixed with concentrate (BSC) and fermented banana stem with concentrate (FBSC) diets.

Intestinal morphology

The effects of dietary BSC and FBSC on the intestinal morphology of crossbred pigs are shown in Table 6 and Figure 2. The duodenum, jejunum, and ileum of the FBSC group had significantly higher ($P < 0.05$) villi heights compared to those of the BSC group. Similarly, those villi widths in the jejunum in the FBSC group were significantly higher than those of the BSC group. Conversely, the villi widths in the duodenum and crypt depth of the BSC group was significantly higher than in the FBSC group. Regarding the ratio between villus height and crypt depth, the results were similar to the villi height; the FBSC group exhibited a significantly better ($P < 0.05$) ratio than the BSC group.

Table 6 Effect of the fresh and fermented banana stems as part of a low protein diet on intestinal morphology on crossbred pigs. BSC—fresh banana stem + concentrate and FBSC—fermented banana stem + concentrate

Items	BSC	FBSC	<i>P</i> -value
Villus height (μm)			
Duodenum	313.28 \pm 18.11	363.65 \pm 13.69	<0.01
Jejunum	262.81 \pm 6.16	328.55 \pm 16.21	<0.01
Ileum	258.65 \pm 7.66	362.50 \pm 42.13	<0.01
Width (μm)			
Duodenum	106.34 \pm 5.54	97.54 \pm 5.55	<0.01
Jejunum	102.28 \pm 4.22	122.48 \pm 5.90	<0.01
Ileum	149.04 \pm 38.33	150.95 \pm 4.07	0.788
Crypt depth (μm)			
Duodenum	311.50 \pm 5.89	277.31 \pm 30.97	<0.01
Jejunum	282.66 \pm 4.36	258.41 \pm 25.30	<0.01
Ileum	270.29 \pm 9.27	247.02 \pm 14.69	<0.01
Villus height: Crypt depth			
Duodenum	1.01 \pm 0.03	1.32 \pm 0.11	<0.01
Jejunum	0.93 \pm 0.01	1.27 \pm 0.07	<0.01
Ileum	0.95 \pm 0.01	1.46 \pm 0.08	<0.01

n = 20

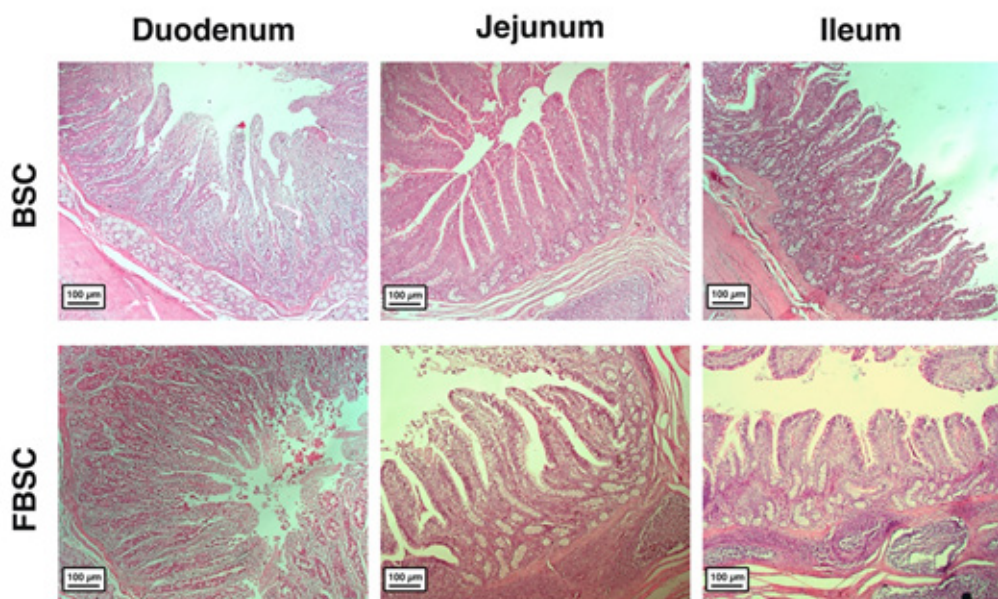


Figure 2 Histological analysis of small intestine tissues (Hematoxylin & Eosin staining) in crossbred pigs after feeding fresh banana stem mixed with concentrate (BSC) and fermented banana stem with concentrate (FBSC). Microscopic pictures at 40X amplification, reference scale bar = 100 μm ; Duodenum (D), jejunum (J), and ilium (I).

DISCUSSION

In this study, different types of feedstuffs based on banana stems were analyzed and compared concerning their nutritional composition. To evaluate the difference between fresh and fermented banana stem, two feed mixtures were compared in terms of their productive performance in feeding crossbred pigs. The experimental set-up followed realistic conditions in a typical small-holder production system: using a completely mixed ration, avoiding the purchase of compound feedstuff, and using the banana stems to enhance the feed with locally available feed material.

As found in previous studies, the analysis of banana stem showed its low nutritional value: The chemical composition, CP (0.23%) and EE (0.06%) were even lower than previously reported (Sokchea et al., 2018). The fermentation process was therefore not only used to preserve feedstuff for the dry season but also to improve the nutritional value of feedstuff. This was done successfully in this study as the CP content of fermented banana stem on the as-fed basis was nearly doubled as compared to the fresh banana stem. The reason that even the fermented banana stem had still comparatively low nutritional value because the experimental design was based on a simple fermentation process, designed in a way that farmers in the highlands of Thailand would be able to replicate it. One benefit was that the smell of the fermented product was appealing and increased the palatability of the feedstuff.

After the analysis of the chemical properties of fermented and fresh banana stem, digestibility was tested both *in vitro* and *in vivo*. The *in vitro* ileal digestibility test of BSC nutrients were lower than FBSC except for the CF. Also, analyzing the ATTD from pigs fed BSC and FBSC showed that a high level of fiber in the diet leads to a low digestibility of nutrients. In the present

study, the fermented feed did not increase the total tract digestibility of nutrients. In agreement with results reported by Pederson and Stein (2010) and Le et al. (2016), the fermented feed did not increase the total tract digestibility of nutrients in growing pigs. Generally, the main sources of fiber include cell wall components such as cellulose, hemicellulose, and other structural and non-structural compounds resistant starch (RS), inulin, chitin, pectin, β -glucan, and oligosaccharides (Jha et al., 2019). While in the gastrointestinal tract of monogastric animals there is a low level of digestion of fiber by endogenous enzymes, fiber is still degradable by microbial fermentation. Moreover, dietary fiber may reduce the digestibility of dry matter and energy at this site of the digestive tract because of its resistance to digestion with endogenous enzymes secreted into the small intestine (Bach Knudsen, 2001). Even though there was no significant difference in the productive performance of both groups there is still a positive influence on the general productive performance of crossbred pigs. Likewise, the low nutritional value of the diet (CP 3–4% DM basis) is an important factor affecting the productive performance of crossbred pigs. In the present study, pigs fed fresh and fermented banana stem had a high FCR in BSC and FBSC (6.27 and 6.52, respectively), growing at the rate of AGD 0.46 kg/day. The high feed conversion is because the studied pigs were bred based on an indigenous pig breed, and the resulting breed maintains the ability to grow well on low-quality feedstuff. It was shown in earlier studies that the improved digestibility by indigenous pigs is due to a longer retention time of digesta in the digestive system (Ngoc et al., 2013) and the improved contact between digesta, digestive enzymes and absorptive surfaces (Guixin et al., 1995), as well as between digesta and the gut microbiota (Freire et al., 2000). Also this result agreement with Ndindana et al. (2002), who reported that the indigenous pig (Mukota pig) was received the diet that high contain fiber had a low ADG (0.46 g/day).

Our study found that the diets of BSC and FBSC did not affect cecal microflora in a crossbred pig. Surprisingly, we found that the *E. coli* level in cecal contents was slightly higher on pigs fed FBSC, but it was not a significant difference. Normally, the fermented feed contains high concentrations of lactic acid, several volatile fatty acids (VFA; acetic acid, butyric acid, and propionic acid), and large numbers of lactic acid bacteria, as well as a low pH (van Winsen et al., 2001). However, in our results, the *E. coli* content was relatively lower than lactic acid bacteria (*Lactobacillus* spp. and *Bifidobacterium* spp.) in the cecum because the dietary fiber affects fermentation in the GIT by stimulating the growth or metabolism of special bacterial species (Williams et al., 2001) that enable the production of VFA and lead to decreased pH. Bouhnik et al. (2004) explained that a decrease in pH promotes the growth of beneficial bacteria (e.g., *Bifidobacteria* spp., *Lactobacilli* spp.), at the expense of pathogenic ones like *Clostridium* or *Salmonella*, which contributes to enhancing the health of host species. Moreover, the diet of BSC and FBSC influenced the intestinal morphology of crossbred pigs, particularly FBSC. While low in nutrition, the high fiber content of both diet formulations may improve intestinal health because fiber is necessary for the stimulation of the intestinal compartments (Longland et al., 1994). Also, when the fiber is fermented, the microbial fermentation products can promote the proliferation of the mucosal epithelium by increasing gut length, mass, and villus height

that lead to increases in the intestinal surface area to increase the absorptive capacity (Agyekum and Nyachoti, 2017). Besides, the increase of villi height might be associated with beneficial bacteria in the gastrointestinal tract such as *Bifidobacterium* and *Lactobacillus*. The increase of the villus height to crypt depth ratio produced an intestinal structure more oriented to digestion, with improved absorptive and hydrolysis potential, as well as requiring fewer nutrients to be directed towards intestinal maintenance (Pluske et al., 1996). Therefore, the dietary fiber ingestion has influenced not only the utilization of nutrients also the effect on intestinal functions in the pigs as well.

CONCLUSION

In conclusion, the result of the present study shows that fresh banana stem and fermented banana stem in a low protein diet can be efficiently used as feed on crossbred pigs. The *in vitro* ileal digestibility of FBSC was better than BSC. The ATTD and productive performance of crossbred pigs fed BSC and FBSC did not differ. However, the FBSC influenced the intestinal morphology of crossbred pigs. Most importantly, the fresh and particularly the fermented banana stem in a low protein diet has the potential to be used as a feed of pigs in highland areas to reduce feeding cost, which is a crucial aspect for small-holder farmers. Moreover, The banana stem that easy to find in the tropical highland. The use of the banana stem in fresh and fermented form could reduce the Feed cost up to 60%. In addition, the banana stem's fermentation can increase digestibility, produce a palatable feedstuff, and help conserve the feed over an extended time.

There have been quite a few studies on the use of silage in pig diets. This study used the simple fermentation process that is easier for a farmer in the highland area to perform. In the future, attention should be given to further improving banana stem fermentation by the use of different additives and apply improved silage as a feedstuff component for pig diets.

CONFLICT of INTEREST

The authors declare that they have no conflicts of interest.

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AUTHOR CONTRIBUTIONS

Chaiwat Arjin: Investigation, Writing - Original Draft, Methodology, Writing - Review & Editing
 Chanmany Souphannavong: Investigation, Writing - Original Draft
 Apinya Sartsook: Resources, Investigator
 Mintra Seel-Audom: Data Curation
 Supamit Mekchay: Data Curation
 Korawan Sringarm: Conceptualization, Methodology, Data Curation, Writing - Review & Editing

REFERENCES

- Agyekum, A.K., Nyachoti, C.M., 2017. Nutritional and metabolic consequences of feeding high-fiber diets to swine: A review. *Engineering* 3, 716–725. <https://doi.org/10.1016/J.ENG.2017.03.010>
- AOAC, 2006. Official methods of analysis of AOAC International. AOAC International, Gaithersburg, Maryland.
- Arjin, C., Pringproa, K., Hongsihsong, S., Ruksiriwanich, W., Seel-audom, M., Mekchay, S., Sringarm, K., 2020. In vitro screening antiviral activity of Thai medicinal plants against porcine reproductive and respiratory syndrome virus. *BMC Vet. Res.* 16(102), 1-9. <https://doi.org/10.1186/s12917-020-02320-8>
- Bach Knudsen, K.E., 2001. The nutritional significance of “dietary fibre” analysis. *Anim. Feed Sci. Technol.* 90, 3–20. [https://doi.org/10.1016/S0377-8401\(01\)00193-6](https://doi.org/10.1016/S0377-8401(01)00193-6)
- Barrow, G.I., Feltham, R.K.A. (Eds.), 1993. *Cowan and Steel’s manual for the identification of medical bacteria*. Cambridge University Press. <https://doi.org/10.1017/CBO9780511527104>
- Bouhnik, Y., Raskine, L., Simoneau, G., Vicaut, E., Neut, C., Flourié, B., Brouns, F., Bornet, F.R., 2004. The capacity of nondigestible carbohydrates to stimulate fecal bifidobacteria in healthy humans: a double-blind, randomized, placebo-controlled, parallel-group, dose-response relation study. *Am. J. Clin. Nutr.* 80, 1658–1664. <https://doi.org/10.1093/ajcn/80.6.1658>
- Charoensook, R., Knorr, C., Brenig, B., Gatphayak, K., 2013. Thai pigs and cattle production, genetic diversity of livestock and strategies for preserving animal genetic resources. *Maejo Int. J. Sci. Technol.* 7, 113–132.
- Deka, R.P., Grace, D., Lapar, M.L., Lindahl, J., 2014. Sharing lessons of smallholders’ pig system in South Asia and Southeast Asia: a review. *Natl. Conf. Oppor. Strateg. Sustain. Pig Prod. Organ. by ICAR-National Res. Cent. Pig, Rani, Guwahati India* 1–14.
- Duponte, M.W., Cowell, K., Jha, R., 2016. Banana silage : an alternative feed for swine. *Livest. Manag.* 8, 1-8.
- Evaluation, S.D., 2014. *The Research Cooperation for Sustainable Farming Systems in the Lower Mekong Basin (2008-2012)*.
- Freire, J.P., Guerreiro, A.J., Cunha, L., Aumaitre, A., 2000. Effect of dietary fibre source on total tract digestibility, caecum volatile fatty acids and digestive transit time in the weaned piglet. *Anim. Feed Sci. Technol.* 87, 71–83. [https://doi.org/10.1016/S0377-8401\(00\)00183-8](https://doi.org/10.1016/S0377-8401(00)00183-8)
- Guixin, Q., Verstegen, M.W.A., Bosch, M.W., 1995. Variation of digestive capacity between genetically different pig populations: a review. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 73, 233–242. <https://doi.org/10.1111/j.1439-0396.1995.tb00423.x>
- Jha, R., Fohhse, J.M., Tiwari, U.P., Li, L., Willing, B.P., 2019. Dietary fiber and intestinal health of monogastric animals. *Front. Vet. Sci.* 6 (48), 1-12. <https://doi.org/10.3389/fvets.2019.00048>
- Kong, C., Park, C.S., Kim, B.G., 2015. Effects of an enzyme complex on in vitro dry matter digestibility of feed ingredients for pigs. *Springerplus* 4, 1–4. <https://doi.org/10.1186/s40064-015-1060-1>

- Le, M.H.A., Galle, S., Yang, Y., Landero, J.L., Beltranena, E., Gänzle, M.G., Zijlstra, R.T., 2016. Effects of feeding fermented wheat with *Lactobacillus reuteri* on gut morphology, intestinal fermentation, nutrient digestibility, and growth performance in weaned pigs. *J. Anim. Sci.* 94, 4677–4687. <https://doi.org/10.2527/jas.2016-0693>
- Li, Y., Zhang, A.R., Luo, H.F., Wei, H., Zhou, Z., Peng, J., Ru, Y.J., 2015. In vitro and in vivo digestibility of corn starch for weaned pigs: effects of amylose: amylopectin ratio, extrusion, storage duration, and enzyme supplementation. *J. Anim. Sci.* 93, 3512–3520. <https://doi.org/10.2527/jas.2014-8790>
- Longland, A.C., Carruthers, J., Low, A.G., 1994. The ability of piglets 4 to 8 weeks old to digest and perform on diets containing two contrasting sources of non-starch polysaccharide. *Anim. Sci.* 58, 405–410. <https://doi.org/DOI:10.1017/S0003356100007352>
- Nakai, S., 2008. Decision-making on the use of diverse combinations of agricultural products and natural plants in pig feed: a case study of native pig smallholder in northern Thailand. *Trop. Anim. Health Prod.* 40, 201–208. <https://doi.org/10.1007/s11250-007-9081-6>
- Ndindana, W., Dzama, K., Ndiweni, P.N.B., Maswaure, S.M., Chimonyo, M., 2002. Digestibility of high fibre diets and performance of growing Zimbabwean indigenous Mukota pigs and exotic Large White pigs fed maize based diets with graded levels of maize cobs. *Anim. Feed Sci. and Technol.* 97, 199–208. [https://doi.org/10.1016/S0377-8401\(01\)00345-5](https://doi.org/10.1016/S0377-8401(01)00345-5)
- Ngoc, T.T.B., Len, N.T., Lindberg, J.E., 2013. Impact of fibre intake and fibre source on digestibility, gut development, retention time and growth performance of indigenous and exotic pigs. *Animal* 7, 736–745. <https://doi.org/10.1017/S1751731112002169>
- Pedersen, C., Stein, H.H., 2010. Effects of liquid and fermented liquid feeding on energy, dry matter, protein and phosphorus digestibility by growing pigs. *Livest. Sci.* 134, 59–61. <https://doi.org/https://doi.org/10.1016/j.livsci.2010.06.097>
- Phengsavanh, P., Ogle, B., Stür, W., Frankow-Lindberg, B. E., Lindberg, J. E., 2010. Feeding and performance of pigs in smallholder production systems in Northern Lao PDR. *Trop. Anim. Health Prod.* 42, 1627–1633. <https://doi.org/10.1007/s11250-010-9612-4>
- Pluske, J.R., Thompson, M.J., Atwood, C.S., Bird, P.H., Williams, I.H., Hartmann, P.E., 1996. Maintenance of villus height and crypt depth, and enhancement of disaccharide digestion and monosaccharide absorption, in piglets fed on cows' whole milk after weaning. *Br. J. Nutr.* 76, 409–422. <https://doi.org/10.1079/bjn19960046>
- Rattanarongchart, S., 1994. Present situation of Thai native pigs. Department of Animal Science, Faculty of Agriculture, Chiangmai University.
- Ruamrungsri, N., Siengdee, P., Sringarm, K., Chomdej, S., Ongchai, S., Nganvongpanit, K., 2016. In vitro cytotoxic screening of 31 crude extracts of Thai herbs on a chondrosarcoma cell line and primary chondrocytes and apoptotic effects of selected extracts. *In Vitro Cell. Dev. Biol. -Animal* 52, 434–444. <https://doi.org/10.1007/s11626-016-0006-4>
- Sokchea, H., Thi, T., Hong, T., Ngoan, L.D., Phung, L.D., Borin, K., 2018. Nutritive value of fermented banana pseudo stem (*Musa* spp) and rice bran by *Saccharomyces cerevisiae* 7(2), 209–216.
- van Winsen, R.L., Urlings, B.A., Lipman, L.J., Snijders, J.M., Keuzenkamp, D., Verheijden, J.H., van Knapen, F., 2001. Effect of fermented feed on the microbial population of the gastrointestinal tracts of pigs. *Appl. Environ. Microbiol.* 67, 3071–3076. <https://doi.org/10.1128/AEM.67.7.3071-3076.2001>
- Williams, B.A., Verstegen, M.W.A., Tamminga, S., 2001. Fermentation in the large intestine of single-stomached animals and its relationship to animal health. *Nutr. Res. Rev.* 14, 207. <https://doi.org/10.1079/NRR200127>

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