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Insoluble Fiber Prepared from Rice Hulls for the Dietary Supplementation of Growing-Finishing Pigs

Tartrakoon W.*, N. Taksinanan, C. Koedchuen and T. Incharoen

Faculty of Agriculture, Natural Resources, and Environment, Naresuan University, Phitsanulok, 65000, Thailand.

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Rice hulls consist of mostly insoluble dietary fiber. When insoluble fiber is ingested, it is not broken down in the gut, but rather, absorbed into the bloodstream. This increases the rate of passage and fecal bulk, which helps to keep pigs regular and prevent constipation. This experiment aims to determine the effects of insoluble fiber that is prepared from ground rice hulls in terms of growth performance in growing-finishing pigs and the nutrient digestibility of growing pigs. The growth performance of growing-finishing pigs is studied using basal diets that contain different levels of insoluble fiber from rice hull meal (RHM). Three treatment groups with body weights (BW) of 20–50, 50–80, and 80–100 kg receive 0/0/0, 0.5/1.0/2.0, and 1.0/2.0/3.0 percent of RHM, respectively. Thirty pigs (initial weight 20±0.10 kg) are used in this study. They are housed in individual pens and fed diets containing corn-soybean meal and rice bran as the main ingredients. All of the groups show similar average daily gains (ADG) compared to the control (T1) group, whereas the T3 and T4 animals show significantly better (P<0.05) feed conversion at 20–50 kg BW compared to the control group. This result is related to the lower feed intake in the T3 animals. The T2 and T3 animals have significantly higher feed intake (P < 0.05) and worse FCR than the control group in the finishing pig1 (50-80 kg BW) period. No significant differences are observed in terms of growth performance during the finishing-2 (80-100 kg BW) period or throughout the whole period from 20–100 kg BW. The nutrient digestibility of growing pigs is studied in five pigs (initial BW= 20±0.5 kg). The pigs are allotted five treatments in a replicated 5×5 Latin square and are provided a corn-soybean meal-rice bran control diet or a diet in which rice bran is partly replaced by 0.5%, 1%, 2%, and 3% RHM. The apparent total tract digestibility (ATTD) of the nutrients and energy are measured. For the RHM supplemented diets, the ATTD of dry matter, ash, and crude fiber decrease with as the inclusion of RHM (P<0.05) increases. There are no differences in the ATTD of crude protein and ether extract in terms of digestible and metabolizableenergy. In conclusion, the diets of growing-finishing pigs could be supplemented with 3% RHM. The metabolic utilization of dietary energy and crude protein are not affected by the inclusion of RHM up to 3% in growing pigs under the conditions of the present study.

Keywords: dietary fiber, rice hull, digestibility, growing pigs, finishing pigs.

* **Corresponding Author:** Wandee Tartrakoon; **E-mail address:** wandeeta@nu.ac.th

Introduction

Optimizing nutritional efficiency has become a greater challenge as agricultural by-products contain increasingly higher levels of fiber and the variation in nutrient digestibility between feed ingredients becomes larger (Huang *et al.*, 2015). The variation in nutrient digestibility reduces nutritional efficiency, increases the necessity of safety margins, and increases the cost of swine feeding programs (Huang *et al.*, 2015). Rice (*Oryza sativa*) is the main cereal crop in Thailand and provides most of the world's food, especially in Asian countries. Thailand's rice production target in 2017–2018 is 29.50 metric tons (Varinruk, 2017). Rice is the primary product (70%) of milling with some unconsumed portions, including rice hull (20%), rice bran (8%), and rice germ (2%) (Van Hoed *et al.*, 2006; de Deckere, 1996). The dietary fibers account for 67.53% of rice hulls (Fadaei and Salehifar, 2012) and dietary fiber comprise more than 80% insoluble fiber because they contains 30% cellulose, 20% hemicellulose, and 20% lignin (Esa *et al.*, 2013). A major concern when including fiber in diets for mono-gastric animals is that high dietary fiber content is associated with decreased nutrient utilization and low energy net values (Noblet and Goff, 2001). However, dietary fiber plays an important role in pig and poultry diets, and a minimum level of dietary fiber must be included to maintain normal physiological functioning of the digestive tract (Wenk *et al.*, 2001). The negative effects of dietary fiber on nutrient utilization and net energy values are determined by the fiber properties and may differ considerably between fiber sources. The ability of pigs to digest diets that are more fibrous without compromising production performance is fundamental to improving opportunities to reduce the costs per kilogram in the pig industry.

Therefore, this study aims to determine the effects of insoluble fiber prepared from ground rice hulls on the growth performance of growing-finishing pigs and the nutrient digestibility of growing pigs

Materials and methods

Animals and facilities

The Naresuan University Animal Care and Use Committee (NUACUC, certificate No. 5801001) approved the experimental protocols and procedures used in these experiments. This study was conducted at Naresuan University in Phitsanulok, Thailand. In Experiment 1, 30 crossbred pigs (Large White×Landrace×Duroc) weighing 20.00±0.50 kg were selected for growth performance evaluation. In Experiment 2, five crossbred pigs (Large

White×Landrace×Duroc) weighing 40.00 ± 0.50 kg were selected for nutrient digestibility evaluation. The pigs were individually housed in 1.2×0.7× 0.90 m stainless steel metabolism cages. All of the pigs were housed in a room with negative pressure ventilation and an evaporative cooling system.

Experimental procedure

Growth performance trial

In Experiment 1, 30 pigs were fed diets containing corn-soybean meal and rice bran as the main ingredients. Three treatment groups supplemented 0/0/0, 0.5/1.0/2, and 1/2/3 percent of rice hull meal (RHM) in the pigs' diets at BW of 20–50, 50–80, 80–100 kg, respectively. Table 1 presents the composition and proximate analyses of the diets. The nutrient compositions of all of the diets followed the recommendations of the NRC (1998). The pigs were housed individually in pens that gave them *ad libitum* access to feed and water. Feed consumption, BW gain, and initial BW was measured at the beginning of the experiment, with subsequent BW and feed disappearance measurements obtained once a week until the end of the experiment. BW and feed intake were used to determine the average daily gain (ADG), average daily feed intake (ADFI), feed conversion ratio (feed: grain; FCR), and feed cost per gain (FCG).

Digestion trial

In Experiment 2, the total tract nutrient digestibility (%) of dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), and ash were determined, and the dietary energy (DE) and metabolizable energy (ME) were evaluated. Table 2 presents the composition and proximate analysis of the diets. The nutrient compositions of all of the diets followed the recommendations of the NRC (1998). Titanium dioxide (TiO_2) was added to the feed with a 0.5% dosage for the first day and the last day of the collection period as an indigestible marker. Each pig was randomly fed for 10 days with a 5-day adjustment period followed by a 5-day collection period when their diet was maintained. Fresh fecal samples were mixed, pooled, and stored in a freezer at 20ºC until analyzed. Before the chemical analysis, each fecal sample was thawed and dried at 60ºC for 72 h, at which time it was ground finely and deposited onto a 1-mm screen for chemical analysis. The collected urine was weighed, and 10% of the daily urine volume was stored at −20°C. All of the feed and fecal samples were then analyzed for DM, CF, EE, and CP, following the procedures outlined by the AOAC (1995). Gross energy was determined using a bomb calorimeter. Dietary fiber and insoluble fiber in all the feedstuffs were analyzed following the TE-CH-076 in-house method based on AOAC (2016) 985.29 and AOAC (2010).

Statistical analysis

All of the data were subjected to a statistical analysis through a one-way analysis of variance (ANOVA) using the SPSS statistical software (Ver. 15 for Windows, SPSS Inc., Chicago, IL, USA). The differences between treatments were examined using Duncan's multiple range tests, which were considered significant at $P < 0.05$. The means and standard errors are presented.

Results

Dietary fiber composition in experimental diets

The content of dietary fiber, insoluble fiber, and soluble fiber in the RHM was 67.80, 59.85, and 7.96 %, respectively. The composition of the dietary fiber, insoluble fiber, and soluble fiber in the experimental diet ranged from 13.85–16.33, 11.52–12.46, and 4.28–5.02, respectively in experiment 1 (see Table 1), and 13.70–14.95, 12.04–13.30 and 4.24–4.26, respectively, in experiment 2 (see Table 2). The increasing levels of dietary fiber and insoluble fiber depended on the increasing levels of RHM in the same period of diet. However, this did not affect the content of soluble fiber in the diet.

Growth performance

All of the groups showed similar average daily gains (ADG) compared to the control group (T1 = 0% RHM). Meanwhile, the T2 (0.5% RHM) and T3 (1.0% RHM) animals showed significantly better ($P<0.05$) feed conversion ratios at 20–50 kg BW compared to the control group, which was related to the lower feed intake in the T3 animals. The T2 and T3 animals had significantly higher feed intakes ($P < 0.05$) and worse FCR than the control group during the finishing pig-1 (50-80 kg BW) period. There were no significant differences between the treatments in terms of growth performance during the finishing pig-2 (80-100 kg BW) period and throughout the entire growing-to-finishing period (20–100 kgBW).

Table 1. Composition of experimental treatments and formulated analysis in the growth performance experiment.

Ingredient	**Growing Pigs (20-50 kgBW)**			**Finishing Pigs 1 (50-80 kgBW)**			**Finishing Pigs 2 (80-100 kgBW)**		
	RHM (%)			RHM (%)			RHM (%)		
	0	0.5	1.0	0.5	1.0	2.0	1.0	2.0	3.0
Corn	56.75	56.75	56.75	60.80	60.80	60.80	61.20	61.20	61.20
Fine rice bran	12.00	11.50	110.0	14.50	14.00	13.00	19.00	18.00	17.00
Rice hull meal[b]	0.00	0.50	1.00	0.50	1.00	2.00	1.00	2.00	3.00
Soybean meal	27.00	27.00	27.00	20	20	20	14.00	14.00	14.00
Plant oil	2.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00	3.00
Dicalcium phosphate	0.60	0.60	0.60	0.50	0.50	0.50	0.40	0.40	0.40
$CaCO_3$	1.00	1.00	1.00	1.10	1.10	1.10	0.80	0.80	0.80
L-Lysine	0.05	0.05	0.05	-	-	-	-	-	-
$NaCl_2$	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and mineral premix[a]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Chemical composition (g/kg DM basis)									
Crude protein	18.18	18.22	17.97	15.78	15.63	15.42	13.71	13.56	13.45
Crude fiber	4.00	4.16	4.32	4.03	4.23	4.55	4.26	4.66	4.90
Dietary fiber	16.33	14.91	15.19	14.23	14.51	15.06	13.85	14.45	14.95
Insoluble fiber	12.05	12.25	12.46	11.62	11.83	12.24	11.52	11.93	12.34
Soluble fiber	4.28	4.28	4.28	4.66	4.66	4.66	5.01	5.01	5.02
Gross energy (kcal/kg)	3,220	3,215	3,210	3,230	3,220	3,190	3,275	3,250	3,220

[a] Vitamin and mineral premix provided per kilogram of diet: 450 mg Fe; 400 mg Cu; 250 mg Zn; 150 mg Mn; 0.5 mg I; 0.25 mg Se; 8,000 IU vitamin A; 2,000 vitamin D_3; 37.5 mg vitamin E; 0.925 mg vitamin K-3; 8.43 mg vitamin B_2; 0.04 mg vitamin $B_{12;}$ 34.5 mg nicotinic acid; 26 mg pantothenic acid.

Table 2. Ingredient composition, energy, and nutrient levels in the growing-finishing pigs' diets during the nutrient digestibility experiment.

Ingredient	RHM (%)				
	0	0.5	1.0	2.0	3.0
Corn	57.70	58.50	58.00	56.00	55.00
Fine rice bran	11.80	10.00	10.00	10.00	10.00
Rice hull meal[b]	0.00	0.50	1.00	2.00	3.00
Soybean meal	26.80	26.80	26.80	26.80	26.80
Plant oil	1.50	2.00	2.00	3.00	3.00
Dicalcium phosphate	0.60	0.60	0.60	0.60	0.60
$CaCO_3$	1.0	1.0	1.0	1.0	1.0
$NaCl_2$	0.35	0.35	0.35	0.35	0.35
Vitamin-mineral premix[a]	0.25	0.25	0.25	0.25	0.25
Total	**100**	**100**	**100**	**100**	**100**
Analytical Chemical composition (g/kg DM basis)					
Crude protein	18.04	17.88	17.93	17.71	17.66
Ether extract	1.55	1.56	2.71	2.76	2.72
Crude fiber	3.57	4.09	4.20	4.73	5.14
Dietary fiber	13.74	13.70	13.97	14.40	14.95
Insoluble fiber	12.04	12.05	12.32	12.77	13.30
Soluble fiber	4.32	4.26	4.26	4.24	4.24
Gross energy (kcal/kg)	3,644	3,545	3,473	3,567	3,564

[a] Vitamin and mineral premix provided per kilogram of diet: 450 mg Fe; 400 mg Cu; 250 mg Zn; 150 mg Mn; 0.5 mg I; 0.25 mg Se; 8,000 IU vitamin A; 2,000 vitamin D_3; 37.5 mg vitamin E; 0.925 mg vitamin K-3; 8.43 mg vitamin B_2; 0.04 mg vitamin $B_{12;}$ 34.5 mg nicotinic acid; 26 mg pantothenic acid.

Table 3. Productive performance of growing pigs (20–50 kgBW) fed experimental diets.

Item	RHM (%)			SEM	P-value
	0	**0.5**	**1.0**		
Initial wt. (kg/pig)	20.04	19.99	20.06	0.03	0.64
Final wt. (kg/pig)	49.86	50.01	49.86	0.06	0.50
Experimental period (day)	42	45	41	0.7	0.14
ADG (kg/day)	0.71	0.67	0.73	0.01	0.19
Total FI)kg(	56.36[a]	51.29[ab]	48.88[b]	1.17	0.02
ADFI (kg/day)	1.34	1.14	1.19	0.04	0.07
FCR (kg/wt. gain)	1.89[a]	1.71[b]	1.64[b]	0.04	0.02
Feed cost (Baht/kg.wt.gain)	25.12	22.67	21.73		

[a,b] Superscripts differ ($P<0.05$) within a row; SEM = standard error of the mean.

Table 4. Productive performance of finishing pigs (50–80 kgBW) fed experimental diets.

Item	RHM (%)			SEM	P-value
	0.5	**1.0**	**2.0**		
Initial wt. (kg/pig)	49.86	50.01	49.86	0.06	0.50
Final wt. (kg/pig)	79.91	80.00	80.00	0.03	0.30
Experimental period (day)	37	39	37	0.71	0.70
ADG (kg/day)	0.81	0.78	0.81	0.01	0.67
Total FI)kg(	76.43[b]	85.12[a]	80.59[ab]	3.10	0.03
ADFI (kg/day)	2.07	2.18	2.18	0.04	0.07
FCR (kg/wt. gain)	2.54[a]	2.84[b]	2.67[ab]	0.04	0.02
Feed cost (Baht/kg.wt.gain)	31.80	35.44	33.24		

[a,b] Superscripts differ (P<0.05) within a row; SEM = standard error of the mean.

Table 5. Productive performance of finishing pigs (80–100 kgBW) fed experimental diets.

Item	RHM (%)			SEM	P-value
	1.0	**2.0**	**3.0**		
Initial wt. (kg/pig)	79.91	80.00	80.00	0.03	0.30
Final wt. (kg/pig)	100.00	100.00	100.00	0.01	100.
Experimental period (day)	27	27	28	0.85	0.89
ADG (kg/day)	0.76	0.74	0.72	0.02	0.81
Total FI)kg(	68.08	66.27	69.06	2.62	0.91
ADFI (kg/day)	2.52	2.45	2.47	0.10	0.44
FCR (kg/wt. gain)	3.39	3.31	3.45	0.20	0.91
Feed cost (Baht/kg.wt.gain)	41.02	39.89	41.43		

SEM = standard error of the mean.

Table 6. Productive performance of growing to finishing pigs (20–100 kgBW) fed experimental diets.

Item	RHM (%)[1/]			SEM	P-value
	0/0.5/1.0	0.5/1.0/2.0	1.0/2.0/3.0		
Initial wt. (kg/pig)	20.04	19.99	20.06	0.03	0.64
Final wt. (kg/pig)	100	100	100	0.01	0.10
Experimental period (day)	107	111	107	0.75	0.58
ADG (kg/day)	0.75	0.72	0.75	0.01	0.56
Total FI)kg(	200.87	202.68	198.53	2.30	0.32
ADFI (kg/day)	1.88	1.83	1.86	0.07	0.21
FCR (kg/wt. gain)	2.51	2.53	2.48	0.03	0.64
Feed cost (Baht/kg.wt.gain)	31.60	31.77	30.97		

[1] 0/0.5/1.0, 0.5/1.0/2.0, and 1.0/2.0/3.0= percentage of RHM in experimental diets when the body weight of the pigs is 20-50, 50–80, and 80–100 kg, respectively; SEM = standard error of the mean.

Nutrient digestibility

Table 7 shows that rice bran was partly replaced by 0.5, 1, 2, and 3% RHM, and the ATTD of DM, CF, and ash decreased as the level of RHM increased (P<0.05). There were no differences between the ATTD of the CP, EE and the energy in terms of digestibility and metabolizing energy.

Table 7. Effects of rice hull meal (RHM) on apparent total tract digestibility (ATTD) of dry matter, protein, energy, and the available energy of diets in growing-finishing pigs.

Item	RHM (%)				
	0	0.5	1	2	3
ATTD, %					
Dry matter	0.92^{a}	0.90^{ab}	0.89^{ab}	0.89^{ab}	0.87^{b}
Crude protein	0.87	0.86	0.85	0.86	0.86
Ash	0.69^{a}	0.60^{ab}	0.56^{ab}	0.60^{ab}	0.52^{b}
Crude fiber	0.78^{a}	0.73^{ab}	0.69^{b}	0.63^{bc}	0.60^{c}
Ether extract	0.88^{ab}	0.84^{b}	0.88^{ab}	0.90^{a}	0.89^{ab}
Energy content of diets, kcal/kg					
Digestible energy	3,313	3,223	3,157	3,243	3,240
Metabolizable energy	3,296	3,206	3,139	3,225	3,222

[a,b,c] Superscripts differ (P<0.05) within a row.

Discussion

Dietary fiber that was extracted using the enzymatic method was the preferred rice hull-derived fiber used in this study. It contains 67.53% of dietary fiber (Fadaei and Salehifar, 2012), which is nearly the same as this study, which found that rice hull meal contains 67.80% of dietary fiber. Including 0.5%, 1%, 2%, and 3% RHM in pigs' diets (Tables 1 and 2) increases dietary fiber and insoluble fiber; however, most soluble fiber must be included in all diets at all times. The growth trials in the present study, nutrients, and ME composition of diets of the three dietary treatments equally at the same period of the pigs. The total feed intake of the pigs was 0.5% and 1.0% RHM, which was lower than the group that did not receive RHM supplementation during the 20–50 kgBW trial period. Subsequently, the 1.0% and 2.0% supplemented RHM during the 50–80 kgBWcompensated for the total feed intake ($P<0.05$) and caused the FCR to increase ($P<0.05$). Therefore, the level of fiber in the pigs' diets are considered an important factor that affects palatability and feed intake, although pigs can tolerate relatively high levels of fiber (Solà-Oriol *et al.*, 2009). High fiber levels can also decrease the voluntary feed intake of animals because their guts become full, thus compromising the energy intake of pigs (da Silva *et al.*, 2012). Consequently, in pigs under thermo-neutral conditions, a decrease in energy density is commonly associated with an increase in ADFI, which compensates for the required energy intake to support maintenance and growth (Henry, 1985). However, the ability of the pig to compensate for an increased feed intake may be enhanced after a period of adaptation to a high-fiber diet (Kyriazakis and Emmans, 1995), as shown in this study during the 50–80 kgBW period. In contrast, the growth rate was maintained in growing and finishing pigs that were fed diets formulated for constant ME. These pigs tended to show improved FCR, which was evaluated the over the entire growing-to-finishing period from 20–100 kgBW. Baird *et al.* (1975) and Beaulieu *et al.* (2009) confirm these findings by showing that dietary fiber content has no effect on growth performance and suggest that pigs can tolerate a wide range of dietary fiber as long as the dietary energy density is adequate.

Insoluble dietary fiber is digested primarily in the hindgut because of fermentation (Noblet and Shi, 1993; Shi and Noblet, 1993). Pigs do not secrete enzymes that attack components of insoluble dietary fiber in the small intestine; therefore, the fiber passes through relatively untouched to the large intestine (Shi and Noblet, 1993; Varel and Yen, 1997). Insoluble dietary fiber can negatively affect total tract digestibility of CP (Shi and Noblet, 1993; LeGoff and Noblet, 2001) and EE (LeGoff and Noblet, 2001). However, in the current study, the inclusion of 3% RHM, which contained the highest level of insoluble dietary fiber (13.30%) compared to the others, did not affect CP and EE digestibility ($P>0.05$).

However, the inclusion of 0.5% RHM had lower EE digestibility (P<0.05) than the group of containing 2% RHM. The inclusion of 3% RHM, which contained 13.30% insoluble dietary fiber, may have not been too high to negatively affect. It showed no significant difference (P>0.05) from the DE and ME results in the current study. In diets formulated for constant ME, dietary energy digestibility were not reduced by the level of dietary fiber or insoluble fiber. Previous studies have reported that different sources of insoluble dietary fiber had a minimal effect on ileal digestibility and absorption of energy and nutrients (Wang *et al.*, 2002; Serena *et al.*, 2008). In spite of the reduction in digestibility of energy and nutrients with insoluble and low fermentable fiber levels from corn, the growth performance was not affected when the energy was balanced in the diet (Gutierrez *et al.*, 2013). Rezaei *et al.* (2014) found that the inclusion of 3% processed rice hulls in feed resulted in the greatest improvement in quail performance and intestinal morphology. Additionally, Fortin *et al.* (2003) demonstrated that high oat and high β-glucan diets had little effect on the growth performance and carcass traits of pigs that weighed 115–240 lbs. These studies demonstrate that fibrous feedstuffs can be fed successfully to growing-finishing pigs if the maturity of the pig is matched to the type of fiber. Some fiber sources, such as barley and wheat straw, are not appropriate pig production because they have no nutritional value for growing pigs (Just, 1982). However, the 3% RHM included in this study, contained the highest level of insoluble fiber (13.30%) compared to the others, and it reduced (P<0.05) the digestibility of DM, CF, and ash. On the other hand, this level still had no negative effect on the growth performance of the pigs.

In conclusion, the diets of growing-finishing pig can be supplemented with 3% RHM. The metabolic utilization of dietary energy and crude protein were not affected by the inclusion of RHM up to 3% in growing pigs under the conditions that were used in the present study.

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