By-product of Tropical Vermicelli Waste as a Novel Alternative Feedstuff in Broiler Diets

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ABSTRACT: Two experiments were conducted to determine physical and chemical properties of vermicelli waste (VW) and effect of VW inclusion levels on growth performance of broilers. In experiment 1, VW samples were randomly collected from vermicelli industry in Thailand to analyze nutritional composition. Vermicelli waste contained 9.96% moisture, 12.06% CP, 32.30% crude fiber (CF), and 0.57% ether extract (EE), as DM basis. The ratio of insoluble:soluble non-starch polysaccharide (NSP) was 43.4:8.9. A total of 120 chicks (6 pens per treatment and 10 chicks per pen) were fed a corn-soybean meal-based diet or 20% VW substituted diet to determine the apparent metabolizable energy corrected for nitrogen retention (AME_n) of VW. The AME_n of VW was 1,844.7±130.71 kcal/kg. In experiment 2, a total of 1,200 chicks were randomly allotted to 1 of 4 dietary treatments for 42-d growth assay. There were 300 chicks with 6 pens per treatment and 50 chicks per pen. The dietary treatments contained 0%, 5%, 10%, or 15% VW, respectively. All diets were formulated to be isocaloric and isonitrogenous. From 0 to 18 d of age chicks fed VW diets had higher ($p < 0.001$) feed conversion ratio (FCR) compared with those fed the control diet. No difference was observed during grower and finisher phase (19 to 42 d). Chicks fed VW diets had lower relative weight of abdominal fat ($p < 0.001$) but higher relative weight of gizzard ($p < 0.05$) than those of chicks fed the control diet. Increasing VW inclusion levels increased ileal digesta viscosity ($p < 0.05$) and intestinal villus height of chicks ($p < 0.001$). For apparent total tract digestibility assay, there were 4 metabolic cages of 6 chicks that were fed experimental treatment diets (the same as in the growth assay) in a 10-d total excreta collection. Increasing VW inclusion levels linearly decreased ($p < 0.05$) apparent total tract digestibility of DM and CF. (**Key Words:** Apparent Metabolizable Energy, Apparent Total Tract Digestibility, Broiler, Growth, Vermicelli Waste)

INTRODUCTION

Current predictions indicated that within ten years time, many traditional animal feedstuffs will be in short supply and become expensive. Factors contributing to this shortage include competition with human requirements such as corn used for ethanol production and expansion of intensive livestock industries around the world, particularly in Asia (Robinson and Singh, 2001). Mung bean (*Vigna radiate* (L.) R. Wilczek) ranges within top-ten highest production quantity, producing nearly 110,000 MT per year (The Office of Agricultural Economics, 2009) in Thailand, most of which is used for vermicelli industry. Likewise, a study by Robinson and Signh (2001) has shown that 90% of the world's production of mung bean originates in India, Myanmar, Thailand, China, and Indonesia. Processing of mung bean in a vermicelli industry consists of seed-milling, starch extracting and protein segregating and the by-product of this process is referred to as vermicelli waste (VW). Vermicelli waste mainly contains the seed coat and kernel pulp; therefore, VW may contain a high fiber content which limits its usage as feedstuff in a poultry diet. Similar results can be found in other by-products of feedstuffs such as rice bran (9.5% to 13.2% crude fiber = CF), wheat bran (2.93% to 11.68% CF), oat hull (24.9% CF), and soy hull (29.3% CF) which are considered as the high fiber ingredients (Mujahid et al., 2003; González-Alvarado et al., 2007). Fiber can be defined as a nutritional fraction resistant to animal's digestive enzymes (Wilson and Beyer, 2000). Fiber is a nutritionally, chemically and physically

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heterogeneous material with a functional property affecting animal health. Fibrous components of feedstuffs negatively influence animal growth performance, especially young chicks. Some researchers have reported that an appropriate type and amount of fiber might provide a beneficial improvement to the gastrointestinal tract (GIT) of poultry in recent productive systems, and reduce digestive disturbances under a scenario without in-feed antibiotics (Montagne et al., 2003). However, due to the lack of adequate information on the nutritional composition of VW and its nutritional value to animals, the by-product of vermicelli processing has been underutilized in broiler diets. Therefore, this study was conducted to measure the nutritional composition of VW and to determine the effect of VW inclusion levels on growth performance, carcass quality, intestinal histomorphology, and apparent total digestibility in broilers.

MATERIALS AND METHODS

General

The experiment protocol used in this study was conducted under the guide for the use of animals of Kasetsart University, Nakhon Pathom, Thailand. Five samples of VW, by-product of the vermicelli industry for human consumption, were obtained from Sitthinan Co., Ltd. (Pathumthani, Thailand). Samples were ground through a 1-mm screen, and then stored for further analysis. The nutritional composition is shown in Table 1. Nutritional compositions of VW were determined for CP, CF, EE, and DM (AOAC, 1990), amino acid concentration (AOAC, 2005; method 994.12), and soluble and insoluble NSP (Englyst et al., 1994).

Experimental design

In Exp. 1, a total of 120 twenty eight-d-old male Ross 308 chicks was randomly distributed to 2 dietary treatments using 6 metabolic cages per treatment and 10 chicks per cage (length×width×height: 0.7 m×0.7 m×0.7 m). The dietary treatments were a corn-soybean meal-based diet and a basal diet with 20% VW substituted (Table 2) (Matterson et al., 1965). Water and feed were offered *ad libitum*. The chicks were housed in a room with controlled temperature, ventilation, and lighting (23 h/d). The duration of the experiment was 10 d with 7-d preliminary period and 3-d test period. Chromic oxide (Cr_2O_3) was included in the diet at the inclusion rate of 5 g/kg of feed as an indigestible marker to determine the onset and the end of fecal collection. During the tested period, excreta samples were collected from individual cage 3 times a day. Feed intake and refusal feed were carefully separated and recorded daily. Chicks were weighed at the beginning and the end of the

Table 1. Nutritional composition of vermicelli waste used in Exp. 1 and Exp. 2 (% DM)[1]

Item (%)	Vermicelli waste[1]
GE (kcal/kg)	4,185.65
Moisture	9.96
CP	12.06
CF	32.30
EE	0.57
Ash	4.52
NFE	50.55
Ca	0.48
P	0.07
Indispensable amino acids (%)	
Arg	0.55
Gly	0.65
His	0.61
Ile	0.14
Leu	0.57
Lys	0.52
Met	0.42
Trp	0.12
Phe	0.51
Ser	0.64
Thr	0.50
Val	0.34
Dispensable amino acids (%)	
Ala	0.57
Asp	1.06
Cys	0.10
Glu	1.30
Pro	0.60
Tyr	0.30

[1] Five samples from Sitthinan Co., Ltd.
[2] Data were shown as mean.

assay period. Excreta samples were oven dried at 70°C for 24 h and ground through 1-mm screen for further analysis. All feed and excreta samples were analyzed for DM (AOAC, 1990) and chromium (Bolin et al., 1952). Concentration of GE was also analyzed using a Parr adiabatic oxygen bomb calorimeter (Parr Instrument Co., Moline, IL). All analyses were performed in triplicate. The AME_n of VW was calculated according to Hill and Anderson (1958). The AME was corrected to N equilibrium for the total nitrogen retained or lost from body tissue using a factor of 34.39 kJ/g N retained. This represents the energy equivalent of uric acid per gram of nitrogen (Hill and Anderson, 1958).

In Exp. 2, experimental diets were produced in pelleted form. They were corn-soybean meal based diet with VW inclusion levels of 0%, 5%, 10%, and 15%. Each of the experimental diet was mixed and steamed conditioned to a steady-state temperature of 65°C to 75°C and then pelleted

Table 2. Ingredient composition of basal diet (Exp. 1, % as fed)

Ingredient	Corn-soybean meal-based diet
Ingredient (%)	
Corn	53.87
Soybean meal (44% CP)	24.81
Full fat soybean meal	13.00
Raw rice bran oil	4.00
L-Lysine HCl (98%)	0.04
DL-methionine	0.22
Monodicalcium phosphate	1.71
Calcium carbonate	1.19
Sodium chloride	0.42
Choline chloride (50%)	0.001
Vitamin-mineral premix[1]	0.25
Cr_2O_3	0.50
Calculated nutrient composition[2] (%)	
AME (kcal/kg)	3,150.00
CP	20.00
EE	8.50
CF	3.74
Ca	0.85
Available P	0.42
NaCl	0.50
Lys	1.10
Met	0.53

[1] The composition of 1 kg of vitamin-mineral premix: vitamin A, 4,000,000 IU; vitamin D, 50,000 IU; vitamin E, 4,480 IU; vitamin K_3, 30,680; vitamin B_1, 520; vitamin B_2, 2,000; vitamin B_6, 680; vitamin B_{12}, 5,600; folic acid, 170; nicotinic acid, 6,800; pantotenic acid, 3,360; biotin, 14; choline chloride, 200,000; Mn, 2,640; Fe, 1,720; Zn, 2,640; Cu, 3,200; I, 320; Se, 30; preservative, 4,800.

[2] Calculated nutrient composition was based on recommendation nutrient requirement of NRC for broiler (1994).

using a pellet die with length to die hole ratio of 50 mm:3 mm with a 125-horsepower pellet mill (Model SZLH40, Jiang Zhengchang, China). Pellet mill throughput was adjusted for each diet so that the pellet mill motor was constant to produce an acceptable quality of pellets. There were 1,200 one-d-old Ross 308 commercial broilers with average initial BW of 40.24 g used to determine the effects of VW inclusion levels on growth performance. Chicks were randomly allotted to one of four dietary treatments and housed in environmentally controlled room with rice hull floor. There were 50 chicks per pen with 2.5 m×3.0 m and 6 pens per treatment (3 pens of males and 3 pens of females). All diets were corn-soybean meal-based diets. Treatments were differed in the inclusion levels of VW; 0%, 5%, 10%, and 15%. The results of nutritional composition of VW and AME_n derived from the Exp. 1 were used in the matrix of VW in a feed formulation program to formulate treatment diets. Chicks were fed diets formulated to meet or exceed the National Research Council (NRC, 1994). All diets were produced in pelleted form, except for starter diet which was produced as a crumble form to facilitate feed consumption

of young chicks. The ingredient composition and nutrient content of the experimental diets are shown in Table 3. Body weight and feed consumption by pen were recorded on d 17, 35 and 42 to calculate body weight gain (BWG), ADFI and feed conversion ratio (FCR). Mortality was recorded daily. At the end of Exp 2, five chicks from each pen were randomly selected for carcass evaluation, making a total of 120 chicks. These chicks were slaughtered by cervical dislocation, defeathered after immersing in boiled water, plucked and eviscerated. Gizzard, liver, and heart were removed and weighted after the eviscerating process. Dress weight of each chick was obtained. The eviscerated chicks were then chilled at approximately 7°C for 1 h and individual chick weight was obtained as chilled weight. Each chick was deboned, each individual organ was weighted and recorded; head and neck, wing, breast and skin, drum, abdominal fat, and skeleton. The weights of the organs were expressed as a relative weigh (g per 100 g carcass weight) (Maharrery and Mohammadpour, 2005). Besides, two chicks per pen were randomly selected and then killed by a cervical dislocation for further determination of intestinal histomorphology. The whole intestinal tract was removed and segment tissues taken from the jejunum (midpoint between the end of pancreas to mackel's diverticulum) and the ileum (determined at 1 inch above from ileo-caecal junction). Segments were fixed in 10% neutral buffered formalin solution and embedded in paraffin wax. The histological study was performed on 5 μm sections, stained by haematoxylin and eosin, and examined by Olympus AX70 microscope (Olympus Cooperation, Tokyo, Japan) at ×40 magnification. The villus width and crypt depth were measured. The villus height was measured from the villus tip to villus crypt junction, while crypt depth was defined as the depth of investigation between 2 villi (Awad et al., 2008). Ten villi from each intestinal-cross section of each sample were evaluated. The average villus height from 12 chicks was represented as mean villus height, villus width and crypt depth for a treatment group (Gracia et al., 2003).

For Exp. 2, a total of 96 male chicks (28-d of age, Ross 308) with an average initial BW of 1,615 g were also used to determine the effect of VW inclusion levels on apparent total tract digestibility. Chicks were allotted to a stainless steel wire-bottom metabolic cage (length×width×height: 0.7 m×0.7 m×0.7 m) according to dietary treatments and randomly fed pelleted grower diets with 4 VW inclusion levels of 0%, 5%, 10%, and 15%. The experimental diets were formulated the same as the treatment diets of growth assay (3,150 kcal of AME/kg; 20% CP; 1.2% Lys). There were 4 metabolic cages per treatment and 6 chicks in each cage. Water and feed were offered *ad libitum*. The experimental duration was 10 d with 7-d preliminary period and 3-d tested period. Chromic oxide was added into the

Table 3. Ingredients and calculated nutritional composition of the experimental diets (Exp. 2, % as fed)

Item	Starter diet (0 to 18 d)				Grower diet (19 to 35 d)				Finisher diet (36 to 32 d)			
	0%	5%	10%	15%	0%	5%	10%	15%	0%	5%	10%	15%
Ingredient (%)												
Corn	51.29	45.25	39.27	33.36	57.57	51.53	45.60	39.71	63.78	57.78	51.96	46.04
Vermicelli waste	-	5.00	10.00	15.00	-	5.00	10.00	15.00	-	5.00	10.00	15.00
Raw rice bran oil	1.33	2.66	3.98	5.27	2.49	3.82	5.12	6.42	2.91	4.21	5.55	6.80
Soybean meal (46% CP)	18.52	18.36	18.11	17.78	21.24	21.07	20.74	20.41	20.04	19.71	19.37	19.04
Full fat soybean	25.00	25.00	25.00	25.00	15.00	15.00	15.00	15.00	10.00	10.00	10.00	10.00
L-lysine-HCl (98%)	0.11	0.03	-	-	0.07	-	-	-	-	-	-	-
DL-methionine	0.23	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.22	0.22	0.22	0.21
Choline chloride (50%)	0.04	0.05	0.05	0.06	0.02	0.03	0.04	0.05	-	-	-	-
Dicalcium carbonate	2.16	2.20	2.23	2.27	2.01	2.05	2.08	2.12	1.92	1.95	1.99	2.02
Calcium carbonate	0.45	0.37	0.28	0.19	0.49	0.40	0.32	0.23	0.48	0.39	0.31	0.22
Salt	0.41	0.40	0.40	0.40	0.41	0.41	0.40	0.40	0.41	0.41	0.40	0.40
Vitamin-mineral premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Drug premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	-	-	-	-
Calculated nutrient composition[3] (%)												
ME (kcal/kg)	3,100	3,100	3,100	3,100	3,150	3,150	3,150	3,150	3,200	3,200	3,200	3,200
CP	22.00	22.00	22.00	22.00	20.00	20.00	20.00	20.00	18.00	18.00	18.00	18.00
EE	7.83	8.97	10.08	11.18	7.44	8.57	9.67	10.76	7.71	8.26	9.36	10.46
CF	3.69	5.18	6.66	8.14	3.52	5.00	6.48	7.96	3.35	4.83	6.30	7.78
Ca	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.90	0.90	0.90	0.90
Available P	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42	0.40	0.40	0.40	0.40
Lysine	1.25	1.25	1.28	1.33	1.10	1.10	1.16	1.21	0.92	0.98	1.03	1.08
Methionine	0.57	0.57	0.57	0.57	0.53	0.53	0.53	0.53	0.51	0.51	0.51	0.52
Methionine+cysteine	0.92	0.92	0.92	0.92	0.85	0.85	0.85	0.85	0.80	0.80	0.80	0.80

[1] The composition of 1kg of vitamin-mineral premix: vitamin A, 4,000,000 IU; vitamin D, 50,000 IU; vitamin E, 4,480 IU; vitamin K_3, 30,680; vitamin B_1, 520; vitamin B_2, 2,000; vitamin B_6, 680; vitamin B_{12}, 5,600; folic acid, 170; nicotinic acid, 6,800; pantotenic acid, 3,360; biotin, 14; choline chloride, 200,000; Mn, 2,640; Fe, 1,720; Zn, 2,640; Cu, 3,200; I, 320; Se, 30; preservative, 4,800.

[2] This premix provided salinomycin 60 µg/kg as an anticoccidial agent.

[3] Calculated nutrient composition was based on recommendation nutrient requirement of NRC for broiler (1994).

diet at the inclusion of 5 g/kg of feed as a visible marker to determine the onset and end of fecal collection. During the tested period, the total collection of excreta samples was collected from an individual cage every two hours in each day for the last three days of the experimental period. Feed intake and refusal feed were carefully separated and recorded every day. Chicks were weighed at the beginning and the end of the experiment. Excreta samples were stored at -20°C until further analysis. Total excreta were weighed and oven dried at 70°C for 24 h. Feed and excreta samples were ground to pass a 1-mm screen and mixed thoroughly before analysis. DM, CP (N×6.25, macro-Kjeldahl), CF, and EE were determined in feed and excreta (AOAC, 1990). All analyzes were performed in triplicate. The apparent total tract digestibility values were calculated using the following equation: (nutrient intake − nutrient in excreta/nutrient intake)×100.

Statistical analysis

The growth performance, carcass quality, intestinal histomorphology and apparent total tract digestibility studies were analyzed as randomized complete block design, using GLM procedure of SAS software (SAS, 2003). Sex was defined as the block factor. Treatment comparisons were made using orthogonal contrasts to determine: i) the main effect of VW inclusion levels (control diet vs treatment diets, ii) the linear effect of VW inclusion levels, and iii) the quadratic effect of VW inclusion levels. The differences amongst treatments were considered significant at p-value <0.05.

RESULTS

Nutritional composition of vermicelli waste

The VW by-product samples contained moisture at 9.96%. It had a high fiber content at 32.30% whereas VW contained low levels of EE, Ca, and P at 0.57%, 0.48%, and 0.07%, respectively. Crude protein composition in VW was 12.06%. The average indispensable and dispensable amino acid composition in VW is shown in Table 1. As to amino acid content in VW, the values of lysine, methionine, threonine and tryptophan were 0.52%, 0.42%, 0.50%, and 0.12%, respectively. The amount of soluble and insoluble NSP of VW is shown in Table 4. The VW contained higher ratio of insoluble NSP compared to soluble NSP at 43.3:8.9. For insoluble NSP, xylose (9.3%) and arabinose (6.2%)

Table 4. Non-starch polysaccharide constituents of vermicelli waste (% DM)[1]

Fraction	Neutral sugar[2]								Total-NSP	SD
	Rha	Fuc	Ara	Xyl	Man	Gal	Glu	GalA		
Soluble	0.4	0.0	2.3	0.3	0.1	0.9	0.2	4.7	8.9	0.4
Insoluble	0.1	0.1	6.2	9.3	0.3	0.9	3.0	3.3	43.3	0.4
Total	0.5	0.1	8.6	9.7	0.4	1.8	23.1	7.9	52.2	0.4

[1] Data were analyzed as mean and standard deviation which were expressed as g per 100 g of sample.

[2] Rha = Rhamnose; Fuc = Fucose; Ara = Arabinose; Xyl = Xylose; Man = Mannose; Gal = Galactose, Glu = Glucose; GalA = Galacturonic acid.

dominated in VW whereas for the soluble NSP fraction, galacturonic acid (4.7%) and arabinose (2.3%) were predominately found. Regarding substitution method for AME_n evaluation, the result showed that calculated AME_n of VW for broilers was 1,844.71±130.71 kcal/kg.

Growth performance

Young chicks fed VW diets had poorer FCR (p<0.01) compared to chicks fed the control diet and there was a negative linear response of FCR (p<0.001) with increased VW in the diet (Table 5). However, FCR was not significantly different (p>0.05) among grower and finisher chicks fed VW dietary treatments. Moreover, BWG and FI were not affected (p>0.05) by VW inclusion in the diets for all phases of age. There was not a significant difference (p>0.05) of growth performance of chicks throughout the experimental period (1 to 42 d of age). Mortality of chicks was not related to treatment (p>0.05). Vermicelli waste inclusion levels had a linear effect (p<0.05) on live weight and eviscerating weight of chicks (Table 6). Increasing VW

inclusion levels in the diets decreased (p<0.05) live weight and eviscerated weight of chicks. Carcass percentage of chicks fed the control diet was higher (p<0.05) than those of chicks fed VW diets for 84.71% and 83.7%, respectively. The relative weights of gizzard were heavier in chicks fed VW diets compared to those fed the control diet (p<0.05). The opposite effect was observed in the abdominal fat. Chicks fed VW diets had lower (p<0.001) abdominal fat (2.03%) than those (2.61%) fed the control diet. Feeding diets containing 0, 5, 10, and 15% VW to chicks had no effect (p>0.05) on the relative weights of liver, heart, head and neck, wing, breast and skin, drum, and skeleton.

For the intestinal histomorphology result, the jejunal and ileal villus heights of chicks fed diets containing VW were higher (p<0.01) than those fed the control diet (Table 7). Moreover, villus height in jejunum and ileum significantly increased as VW levels in the diets increased from 921.88 μm to 944.64 μm (p<0.05) and 902.92 μm to 974.95 μm (p<0.01), respectively. Jejunal villus width of chicks fed dietary VW were greater (p<0.01) than those fed

Table 5. The effects of VW inclusion levels on growth performance of broiler over 42 d[1]

Period	Item	Vermicelli waste inclusion level (%)				SE	Contrasts[2]		
		0	5	10	15		1	2	3
0 to 18 d	BWG (g)	612	600	584	567	12.2	NS[3]	NS	NS
(starter)	FI (g)	768	763	763	767	10.9	NS	NS	NS
	FCR	1.26	1.27	1.31	1.35	0.01	**	***	NS
	Mortality rate (%)	0.00	0.00	0.00	0.00	ND	ND	ND	ND
19 to 35 d	BWG (g)	1,531	1,489	1,494	1,439	67.1	NS	NS	NS
(grower)	FI (g)	2,955	2,921	2,919	2,857	76.1	NS	NS	NS
	FCR	1.94	1.97	1.96	1.99	0.04	NS	NS	NS
	Mortality rate (%)	1.33	0.33	0.33	0.67	0.46	NS	NS	NS
36 to 42 d	BWG (g)	489	468	522	507	30.6	NS	NS	NS
(finisher)	FI (g)	1,461	1,478	1,437	1,485	47.4	NS	NS	NS
	FCR	3.00	3.17	2.79	2.96	0.12	NS	NS	NS
	Mortality rate (%)	0.33	1.33	0.33	0.00	0.41	NS	NS	NS
0 to 42 d	BWG (g)	2,636	2,514	2,560	2,489	107.1	NS	NS	NS
(overall)	FI (g)	5,188	5,174	5,119	5,091	124.6	NS	NS	NS
	FCR	1.98	2.06	1.98	2.05	0.04	NS	NS	NS
	Mortality rate (%)	1.67	1.67	0.67	0.67	0.53	NS	NS	NS

[1] A total of 1,200 broilers (50 chicks per pen and 6 pens per treatment) with an initial BW of 40.24 g.

[2] Contrasts were i) the main effect of VW inclusion levels (control diet vs treatment diets), ii) the linear effect of VW inclusion levels, and iii) the quadratic effect of VW inclusion levels.

[3] *** p<0.001; ** p<0.01; * p<0.05; NS = Not significant (p>0.05); ND = Not determine.

Table 6. The effect of vermicelli waste inclusion levels on carcass quality of broilers over 42 d[1]

Item	Vermicelli waste inclusion level (%)				SE	Contrasts[2]		
	0	5	10	15		1	2	3
Live weight (g)	2,686.79	2,584.63	2,773.08	2,783.75	52.695	NS[3]	*	NS
Eviscerating weight (g)	2,275.50	2,153.33	2,335.19	2,317.32	47.305	NS	*	NS
Carcass (%)	84.71	83.29	84.21	83.60	0.373	*	NS	*
Liver[4]	2.37	2.42	2.50	2.35	0.061	NS	NS	NS
Heart[4]	0.56	0.55	0.52	0.54	0.014	NS	NS	NS
Gizzard[4]	0.97	1.09	1.08	1.11	0.044	*	NS	NS
Head and neck[4]	7.69	7.95	7.64	7.46	0.175	NS	NS	NS
Wing[4]	9.13	8.77	8.70	8.91	0.241	NS	NS	NS
Breast and skin[4]	25.17	26.22	24.99	25.68	0.403	NS	NS	*
Drum[4]	11.70	11.86	11.42	11.83	0.311	NS	NS	NS
Abdominal fat[4]	2.61	2.08	1.99	2.02	0.118	***	NS	NS
Skeleton[4]	22.27	21.82	21.39	21.17	0.536	NS	NS	NS

[1] A total of 120 broilers (5 chicks per pen and 6 pens per treatment).

[2] Contrasts were i) the main effect of VW inclusion levels (control diet vs treatment diets), ii) the linear effect of VW inclusion levels, and iii) the quadratic effect of VW inclusion levels.

[3] *** p<0.001; ** p<0.01; * p<0.05; NS = Not significant (p>0.05).

[4] Data were shown as the relative weight (g per 100 g of carcass).

the control diet for 368.52 μm vs 301.48 μm. Jejunal and ileal crypt depth in chicks fed VW diets were also greater (p<0.01) than those fed the control diet for 636.94 μm vs 305.97 μm and 324.74 μm vs 262.23 μm, respectively. Increased VW inclusion levels had a significant linear effect (p<0.05) on jejunal and ileal crypt depth. However, the ratios of villus height to crypt depth of jejunum and ileum were unaffected by dietary VW (p>0.05) inclusion levels.

Apparent total tract digestibility

Increasing VW inclusion levels in the diets from 5% to 15% dramatically decreased (p<0.05) apparent total tract digestibilities of DM (from 80.08% to 77.41%) and CF (from 26.83% to 13.59%; Table 8).

DISCUSSION

This present study provided results on the nutritional composition of VW and its effects in the diet on growth performance, carcass quality, intestinal histomorphology, and apparent total tract digestibility in broilers. VW contained a low moisture content at 9.96% due to the processes of vermicelli production. After seed-milling, starch extracting, and protein segregating, the VW had slurry characteristics due to the addition of water during the process. To avoid storage problems and mycotoxin contamination, slurry VW was subjected to sun drying. Grinding was the final step to facilitate the use in animal feed. Thus, the sun drying process was a key factor leading to low moisture content. The average CP contained in VW

Table 7. The effect of vermicelli waste inclusion levels on the characteristics of the digesta viscosity and morphological change of broilers[1]

Item	Vermicelli waste inclusion level (%)				SE	Contrasts[2]		
	0	5	10	15		1	2	3
Jejunum (μm)								
Villus height	768.87	921.88	959.17	944.64	51.101	**	*	NS
Villus width	301.48	401.25	357.08	347.22	17.426	**	NS	**
Crypt depth	305.97	359.38	373.85	358.58	17.306	**	*	*
Villus height:crypt depth	2.66	2.62	2.63	2.66	0.190	NS	NS	NS
Ileum (μm)								
Villus height	765.52	902.92	956.88	974.95	37.458	**	**	*
Villus width	338.33	425.14	365.42	351.39	25.342	NS	NS	NS
Crypt depth	263.23	321.04	329.79	329.39	18.191	**	*	NS
Villus height:crypt depth	2.96	2.88	3.04	3.14	0.198	NS	NS	NS

[1] A total of 48 broilers (2 chicks per pen and 6 pens per treatment), ten villus units were measured for each intestinal cross-section of each sample.

[2] Contrasts were i) the main effect of VW inclusion levels (control diet vs treatment diets), ii) the linear effect of VW inclusion levels, and iii) the quadratic effect of VW inclusion levels.

[3] *** p<0.001; ** p<0.01; * p<0.05; NS = Not significant (p>0.05).

Table 8. The effect of vermicelli waste inclusion levels on nutrient digestibility of broilers[1]

Digestibility (%)	Vermicelli waste inclusion level (%)				SE	Contrasts[2]		
	0	5	10	15		1	2	3
Dry matter	81.76	80.07	78.57	77.41	1.210	NS[3]	*	NS
Protein	77.05	73.90	74.84	74.93	1.362	NS	NS	NS
Fiber	27.72	26.83	22.82	13.59	4.452	NS	*	NS

[1] A total of 96 broilers (6 chicks per pen and 4 pens per treatment).
[2] Contrasts were i) the main effect of VW inclusion levels (control diet vs. treatment diets), ii) the linear effect of VW inclusion levels, and iii) the quadratic effect of VW inclusion levels.
[3] *** $p<0.001$; ** $p<0.01$; * $p<0.05$; NS = Not significant ($p>0.05$).

was 12.06%, which was close to those in other fiber ingredients. It also had a low level of fat at 0.57%. This was in agreement with Robinson and Signh (2001) who found that mung bean naturally contained low oil content (7 g/kg to 10 g/kg) similar to others legumes. Mung bean's protein is recognized as low quality due to a deficiency of sulfur-containing amino acids, including methionine and cysteine (Mubarak, 2005). Similarly, isoleucine, valine, and methionine were discovered at less than one-third of indispensable amino acids in VW which were 0.14%, 0.34%, and 0.42%, respectively. Cysteine was found to be in the least amount of the dispensable amino acids at 0.10% in VW. Nevertheless, mung bean has proven to be an excellent source of lysine and tryptophan. Considering that methionine is the first-limiting amino acid of poultry, an amino acid profile of finished feed should be concerned to optimize amino acid requirements of poultry. Mendoza et al. (2001) has documented that the improvement of mung bean nutritional quality by increasing its methionine content will contribute to a greater nutritional value for human consumption. The average fiber content was typically high (32.30%) compared with the other by-products such as wheat bran (6.84%), oat hull (8.70%) and rice bran (11.35%) (Mujahid et al., 2003; González-Alvarado et al., 2007; Wan et al., 2009). Although CF is normally used to evaluate feedstuffs for poultry and swine, it is probably not a reliable indicator referred to the function influencing gut health of animals. Crude Fiber has been used to define the remnants of plant material after extraction with acid and alkali (Trowell, 1976). Some soluble fractions, such as hemicellulose, mucilage, and gum, are proven to be lost during the acid-alkali solubility processes which lead to an underestimation of fiber content. Consequently, the value of CF is generally lower than NSP which is similar to the result of this study. The fiber component of cereal and grain consists predominantly of NSP composing part of the plant's cell wall. The NSP shows greater relevance to nutritional value utilized through GIT of animals due to their solubility property; soluble NSP (viscous soluble NSP) and insoluble NSP (non-viscous NSP). Recently, gas-liquid chromatography has been developed to analyzed fiber content of feedstuffs (Englyst et al., 1994). It is more reasonable to measure soluble and insoluble NSP, since they

have direct impact on nutrient utilization of monogastric animals (Johnson et al., 2003). In the present study, monosaccharide constituents in NSP were evaluated based on their water solubility property. For total NSP value, VW was found to contain an insoluble fraction approximately 5 times higher than that of the soluble fraction (43.3:8.9). Xylose, arabinose, and galaturonic acid were revealed as major monosaccharides of insoluble NSP whereas galacturonic acid, arabinose, and galactose ranged as third highest amounts in soluble NSP. Similarly, insoluble NSP of the other by-products, including rice bran, wheat bran, oat bran, and soybean hull are mostly higher than the soluble fraction (Annison et al., 1996). High insoluble NSP content could affect nutrient digestibility and growth performance of chicks. In addition, no research has currently been conducted to evaluate AME_n of VW in broilers. The AME_n is necessary for estimating feedstuff's nutrient utilization and is useful for feed formulation. In the present study, AME_n of VW determined by the substitution method (Matterson et al., 1965) was 1,844.71±130.71 kcal/kg. The low AME_n value of VW found in this study was due to the inclusion of VW containing high fiber, which might limit nutrient utilization in chicks. This result agrees with the study of Villamide and San Juan (1998) that true metabolizable energy contents of feedstuffs are negatively correlated with CF, neutral detergent fiber, acid detergent fiber, lignin, hemicellulose, and cellulose.

The inclusion of VW in diets had negative effect on growth performance of starter chicks (0 d to 18 d of age), especially FCR. There was a tendency of reduction in BWG of chick fed diets containing high levels of VW. Vermicelli waste contained a low level of sulfur-containing amino acids and a high level of lysine. Therefore, increasing VW levels in the diets possibly resulted in an imbalance of digestible amino acids in the diets and consequently retarded animal performance. Even though total amino acid concentrations in all treatment diets of each phase were formulated to be a similar level, chicks fed diets with a high VW inclusion level could not appropriately utilize those amino acids. Moreover, increasing VW inclusion levels increased fiber levels in the diets which can also have a large influence on nutrient utilization and animal performance. This was in agreement with Sklan et al.

(2003) that high fiber content in the diets reduced productive performance of young birds. These responses related to physical structure of fiber in VW. As shown in Table 3, increasing VW levels from 0% to 15% in the diets resulted in a decrease of corn and soybean meal levels, which are soluble fiber sources (Choct, 1997). This affected overall nutrient utilization (Burhalter et al., 2001). Insoluble fiber was found to shorten bowel transit time and GIT. Small intestinal epithelium of young chick is not completely mature (cellular and enzymology) during the first 2 wks of age which could result in poor performance (McNab and Smithard, 1992). Furthermore, short transit time of digesta through the gut limits the capacity of fiber to be digested by the gut microflora of chicks (Choct and Annison, 1990). Unlike older chicks which have an improved GIT, enzymology, and fiber degrading microflora. Therefore, grower and finisher chicks seem to be able to utilize high fiber diets more efficiently. The results of this study showed that ADG, ADFI, and FCR of grower (19 d to 35 d of age) and finisher chicks (36 d to 42 d of age) were not significantly affected by various VW inclusion levels. However, the use of VW had negative effects on carcass weight. It is probably due to the high fiber content in VW. Higher VW inclusion levels dramatically increased the relative weights of gizzard. The result was in agreement with a previous study that feedstuffs containing high lignin, such as oat hulls, can resist grinding in the gizzard which results in stimulating further grinding activity. The grinding enhances muscular layer development and increases organ size (Rogel et al., 1987; Gonźalez-Alvarado et al., 2008). The study of Gonźalez-Alvarado et al. (2008) reported that chicks fed diet containing 3% of oat hull had higher gizzard weight at 42 d of age. Similarly, Hetland et al. (2005) found that the increase in gizzard weight caused by fiber inclusion was greater with coarse oat hull. Fiber content in the diets acts as an anti-nutritional factor by increasing intestinal motility and transit time of digesta throughout the GIT, interfering nutrient digestion of the chicks (Hetland and Svihus, 2001). Chicks consume to meet their energy requirement. Once the energy content in the diet is diluted by high fiber content, fat deposits in their body are then metabolized for compensation (Fereidoun et al., 2007). This response was evoked in the present study since chicks fed VW diets had a reduction in abdominal fat.

Intestinal histomorphology of the small intestine, jejunum and ileum plays an important role in nutrient digestion and absorption. Intestinal villi are the protrusions of lamina propria into the intestinal lumen to enlarge the digestive and absorptive area (Yamauchi, 2002). The cell-layer lines located in the lower portion of the intestinal crypts migrate along the villus surface upward to the villus tip within a few days for maturation. The crypts are the villus factories to permit renewal of the villus as needed in response to normal sloughing or inflammation from pathogens or toxins (Yason et al., 1987). Thus, deeper crypts indicate higher cell proliferation. Additionally, ratio of villus height to crypt depth suggests intestinal epithelial cell turnover. From previous literature, it could be assumed that the increase in intestinal villus height and villus width may indicate an increasing in absorptive area, while an increase in crypt depth may indicate greater epithelial cell proliferation. An increase VW inclusion levels linearly increased villi height. It could be concluded that dietary VW had direct impact on increasing intestinal surface area, revealing greater digestive and absorptive function of the intestine. These are possibly due to the fermentation of undigested VW at the hindgut, which enhances bacteria fermentation and the production of volatile fatty acids. Volatile fatty acids, including acetate, propionate, and butyrate, are absorbed effectively in poultry (Carré et al., 1995). They have stimulatory effects on the proliferation rate and secretory activity of intestinal mucosa (Furuse et al., 1991). In addition, butyrate is considered an important metabolite which mainly serves as a nutrient for the colonic or small intestinal cell proliferation and an oxidative fuel for body tissues (Bach Knudsen, 2005). Some insoluble fiber sources such as cereal, wheat bran, and oat bran, have a beneficial effect by stimulating butyrate formation. This phenomenon is supported by Roll et al. (1978) and Hetland and Svihus (2001) who documented that insoluble fiber is generally safe as it passes through the small intestine. Therefore, the villi lengthening at jejunum and ileum of chicks fed VW diet in this study possibly occurred through the enrichment of butyrate production. However, volatile fatty acids were not determined in this study.

The apparent total tract digestibility of dry matter in chicks fed VW diets decreased noticeably when VW inclusion level was increased. VW mainly consists of fiber which is not degradable by intestinal enzymes of monogastric animals. It consequently decreased fiber digestibility in chicks fed VW diets in a linearly response to diets containing higher VW levels. Generally, high soluble fibers interfere with nutrient diffusion through the mucosal surface and thus limit digestion and absorption of nutrients (Forman and Schneeman, 1980). A highly insoluble fiber interferes with nutrient digestibility through increasing digesta transit time, reducing digestive enzymes activities.

CONCLUSION

The present study shows that VW predominantly contains high fiber content, particularly an insoluble NSP fraction. High VW inclusion levels at 10% to 15% of the diet caused detrimental effects on growth performance of starter chicks as well as decreased apparent nutrient digestibility. However, dietary VW have the positive effect

on gizzard development by increasing its weight. From our findings, the inclusion level of VW at 5% in the diet did not have any negative effects on growth performance and apparent total tract digestibility of nutrient in broilers. Therefore, VW could be considered as a potential novel feedstuff for broiler diets, especially during a feedstuff price crisis.

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