PHILIPP AGRIC SCIENTIST
Vol. 105 No. 1, 1-9
March 2022

ISSN 0031-7454

Concentrations of Digestible, Metabolizable, and Net Energy in Coconut Co-products Fed to Growing Pigs

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Received: January 16, 2019/ Revised: October 19, 2021/ Accepted: February 14, 2022

This experiment was conducted to determine the concentration of digestible (DE), metabolizable (ME), and net energy (NE), and to develop prediction equations for DE and ME in coconut co-products (CCP) fed to growing pigs. The CCP used were copra meal (CM), protein enriched copra meal (PECM), and white copra (WC) obtained from the different sources in the Philippines. Twenty-two growing barrows (PIC L337 × C24; initial BW 18.74 ± 0.91 kg) were individually housed in metabolism cages that allowed for a total but separated collection of feces and urine. Pigs were arranged in a replicated 11 × 3 Youden square design with 11 dietary treatments at three periods each. A basal diet that contained 96.26% corn, and ten additional diets consisting of 70% basal diet and 30% CCP were formulated. All diets have the same proportion of corn and other ingredients. Fecal, urine, diet, and CCP samples were analyzed for gross energy (GE) using bomb calorimetry. The DE and ME concentrations of CCP diets and ingredients were calculated. The NE of diets and ingredients were estimated using the prediction equation (NE = 0.870 × ME – 442). The DE, ME, and NE concentrations differed ($P < 0.001$) among CCP and ranged from 1,843 to 3,284, 1,666 to 3,211, and 1,008 to 2,352 kcal/kg DM, respectively. The DE (3,193 kcal/kg DM), ME (3,074 kcal/kg DM), and NE (1,774 kcal/kg DM) concentrations of CM was greater ($P < 0.001$) than PECM (1,859, 1,717, and 1,052 kcal/kg DM, respectively) but with similar DE (2,657 kcal/kg DM), ME (2,562 kcal/kg DM), and NE (1,787 kcal/kg DM) of WC. However, the DE, ME, and NE of WC was greater ($P < 0.001$) than PECM. A positive correlation ($r \geq 0.72$; $P < 0.05$) was observed between the DE and ME and acid detergent fiber (ADF) in 8 CCP (excluding WC samples). The DE and ME concentrations in CCP may be predicted using the following equations: 1) DE = -715.30 + 101.42 × % ADF ($R^2 = 0.52$, RMSE = 403.85, $P = 0.04$); and 2) ME = -983.16 + 106.13 × % ADF ($R^2 = 0.51$, RMSE = 427.42, $P = 0.04$). In conclusion, DE and ME concentrations differ among CCP sources fed to growing pigs. Moreover, DE and ME values in CCP can be predicted using ADF as independent variable.

Keywords: coconut co-products, energy concentration, copra meal, pigs

Abbreviations: ADF—acid detergent fiber, ATTD—apparent total tract digestibility, CCP—coconut co-products, CM—copra meal, CP—crude protein, CF—crude fiber, DE—digestible energy, EE—ether extract, GE—gross energy, ME—metabolizable energy, NE—net energy, PECM—protein enriched copra meal, WC—white copra

INTRODUCTION

Coconut co-products (CCP) are co-products derived from the production of coconut oil and virgin coconut oil including also, to some extent, the rejects from the manufacturing of desiccated coconut. Copra meal (CM) is considered as the largest locally available feed protein in many tropical countries (Stein et al. 2015) including the Philippines. It is an important feed ingredient and the by-product of the oil extraction from dried coconut kernels (copra) (Heuze et al. 2015). Due to differences in oil extraction method, residual oil content of CM ranges from 1 to 22% (Gohl 1982), which may affect its energy value. There are, however, limited studies conducted to measure energy concentrations of CM fed to growing pigs (Son et al. 2012; Sulabo et al. 2013). White copra (WC) is another co-product produced from the production of virgin coconut oil and also from rejects in the production of desiccated coconut. In the Philippines, depending on the processing methods (dry or wet process) used, about 52 to 88% of the available oil in the fresh coconut meat is recovered in the production of virgin coconut oil (www.pca.gov.ph). Hence, we believed that WC still contains high level of residual oil compared to CM. Protein-enriched copra meal (PECM) is a product of a solid-state fermentation process using *Aspergillus niger* to increase the nutritive value of raw CM. To fully utilize WC and PECM in swine diets, energy concentrations need to be established.

Precise determination of available energy (DE and ME) in feedstuff is essential for accurate diet formulations in order to optimize feed efficiency and minimize feed cost for swine production. A number of studies were conducted to develop prediction equations to estimate energy values in feed ingredients used in swine diets (Noblet and Perez 1993; Noblet et al. 1994; Park et al. 2012; Son et al. 2012). However, there have been no prediction equation developed for specifically for CCP. Therefore, the objectives of this study were to determine the energy concentrations in CCP and to develop prediction equations for estimation of DE and ME values in CCP when fed to growing pigs.

MATERIALS AND METHODS

Collection and Selection of CCP Samples

A total of 10 CCP samples were collected from Luzon (6), Visayas (2), and Mindanao (2), Philippines, which represent the widest variability in terms of gross energy (GE), crude protein (CP), crude fiber (CF), and ether extract (EE) (Table 1). The CCP samples used in this study consisted of 7 CM, 1 PECM, and 2 WC.

Animals, Diets, and Experimental Design

The experimental protocol was reviewed and approved by the Institutional Animal Care and Use Committee at the University of the Philippines Los Baños (Protocol No.: IDS-2016-008). A total of 22 growing barrows (PIC L337 × C24; average initial BW 18.74 ± 0.91 kg) were used to determine the energy concentrations in 10 CCP sources. The pigs were randomly allotted to 11 dietary treatments using a replicated 11 × 3 Youden square design. There were 6 replicates per treatment. Pigs were placed in metabolism cages equipped with a feeder and a nipple drinker, fully slatted floors, screen floor and urine trays, which allowed for the total, but separate collection of feces and urine from each pig.

A basal diet (with 96.26% corn) and additional 10 treatment diets were formulated by mixing 70% (as fed basis) of the basal diet with 30% (as fed basis) of CCP sample (Table 2). All treatment diets have the same proportion of corn and other ingredients. Vitamins and minerals were included in all diets to meet or exceed the requirement estimated for growing pigs (NRC 2012). At the start of each experimental period, the quantity of feed

Table 1. Analyzed chemical composition and instrumental color of 10 copra co-products (DM basis)[1].

Item	Coconut Co-product											
	CM									PECM	WC	
	3	6	10	12	16	21	27	Ave	% CV		24	28
Chemical composition, %												
DM	90.87	93.61	89.49	90.56	94.41	91.88	89.96	91.54	2.03	92.80	93.68	90.26
GE, kcal/kg	4484	5010	4661	4596	4769	4990	4747	4751	4.10	4608	5127	4789
CP (N×6.25)	21.16	20.51	18.65	19.69	19.58	20.69	19.78	20.01	4.19	26.27	12.40	15.19
EE	7.42	13.30	7.95	14.20	9.26	12.22	9.22	10.51	25.65	8.07	21.15	12.15
CF	15.44	16.02	14.03	15.65	17.15	15.76	18.18	16.03	8.24	11.13	19.9	13.46
NDF	61.15	61.94	60.63	62.33	61.95	61.26	60.78	61.44	1.05	51.04	52.20	41.43
ADF	31.69	32.56	32.83	40.04	30.75	32.27	32.16	33.19	9.33	26.00	28.89	25.38
ADL	7.70	8.85	7.22	13.30	9.10	8.80	9.43	9.20	21.41	5.92	2.29	3.54
Starch	1.30	1.28	2.37	2.25	2.29	3.40	3.66	2.36	38.86	1.81	8.40	4.69
Ash	7.88	6.36	7.06	7.07	7.14	7.10	6.93	7.08	6.28	8.61	4.84	5.77
Ca	0.34	0.31	0.17	0.15	0.78	0.29	0.45	0.36	59.56	0.65	0.29	0.45
P	0.52	0.51	0.55	0.57	0.67	0.52	0.57	0.56	9.92	0.86	0.35	0.46
Instrumental color[2]												
L*-value	54.05	50.72	55.52	52.3	50.2	51.45	56.82	53.01	4.74	52.44	83.58	80.81
a*-value	8.14	7.08	7.58	7.19	7.39	7.08	7.93	7.49	5.61	6.98	4.13	4.88
b*-value	14.31	12.26	14.17	11.97	12.27	12.1	14.79	13.12	9.39	13.04	18.59	19.66

[1]CM – copra meal; PECM – protein enriched copra meal; WC – white copra.
[2]L* – lightness; a* – redness; b* – yellowness.

Table 2. Ingredient composition of experimental diets (as-fed basis)[1].

Item	Diet										
	Basal	CM-3	CM-6	CM-10	CM-12	CM-16	CM-21	CM-27	PECM	WC-24	WC-28
Ingredient, %											
Yellow Corn	96.26	67.38	67.38	67.38	67.38	67.38	67.38	67.38	67.38	67.38	67.38
CM-3	-	30	-	-	-	-	-	-	-	-	-
CM-6	-	-	30	-	-	-	-	-	-	-	-
CM-10	-	-	-	30	-	-	-	-	-	-	-
CM-12	-	-	-	-	30	-	-	-	-	-	-
CM-16	-	-	-	-	-	30	-	-	-	-	-
CM-21	-	-	-	-	-	-	30	-	-	-	-
CM-27	-	-	-	-	-	-	-	30	-	-	-
PECM	-	-	-	-	-	-	-	-	30	-	-
WC-24	-	-	-	-	-	-	-	-	-	30	-
WC-28	-	-	-	-	-	-	-	-	-	-	30
MDCP	1.07	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Limestone	1.91	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
Salt	0.57	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Mineral premix[3]	0.14	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	100	100	100	100	100	100	100	100	100	100	100
Analyzed composition, %											
DM	85.53	85.47	86.2	85.16	85.95	86.32	85.25	84.14	83.87	85.68	83.34
GE, kcal/kg	3519	3240	3407	3485	3500	3453	3214	3310	3129	3322	3083
CP (N×6.25)	7.85	11.83	12.01	12.25	11.99	11.97	11.20	11.27	12.77	10.19	11.16
EE	2.57	1.77	2.95	1.09	4.15	4.59	3.51	1.93	0.72	6.41	2.62
CF	1.91	5.28	5.56	5.94	6.37	6.21	5.49	4.89	4.83	5.89	4.03
Ash	4.52	5.44	4.99	5.38	5.27	5.22	5.11	5.19	5.38	4.58	5.28
Ca	0.89	0.74	0.77	0.76	0.79	0.80	0.76	0.60	0.83	0.74	0.60
P	0.45	0.48	0.45	0.48	0.49	0.47	0.46	0.47	0.51	0.42	0.47

[1]10 coconut co-product samples: CM – copra meal; PECM – protein enriched copra meal; WC – white copra.

[2]The vitamin premix provided the following quantities per kilogram of complete diet: At 0.3 and 0.4 % inclusion, vitamin A as retinyl acetate, 15000 and 20000 IU; vitamin D3 as cholecalciferol, 2700 and 3600 IU; vitamin E as DL-*α*-tocopheryl acetate, 60 and 80 mg; vitamin K3 as menadione nicotinamide bisulfite, 2.7 and 3.6 mg; thiamine as thiamine mononitrate, 2.7 and 3.6 mg; riboflavin, 6.6 and 8.8 mg; pyridoxine as pyridoxine hydrochloride, 4.2 and 5.6 mg; vitamin B12, 0.03 and 0.04 mg; D-pantothenic acid as D-calcium pantothenate, 21 and 28 mg; niacin, 45 and 60 mg; folic acid, 3 and 4 mg; biotin, 0.3 and 0.4 mg.

[3]The micro mineral premix provided the following quantities per kilogram of complete diet: At 0.3 and 0.4 % inclusion, Cu, 2.25 and 3.0 mg as copper sulfate; Fe, 37.5 and 50 mg as iron sulfate; I, 0.05 and 0.1 mg as potassium iodate; Mn, 7.5 and 10 mg as manganese sulfate; Se, 0.09 and 0.1 mg as sodium selenite; Co, 0.15 and 0.2 mg; and Zn, 37.5 and 50 mg as zinc oxide.

provided daily was calculated as 3 times their estimated requirement for maintenance energy (106 kcal ME per kg $BW^{0.75}$; NRC 1998) and divided into 2 equal meals that were provided at 0800 and 1500 h. Water was made available at all times.

Sample Collection, Chemical Analyses and Determination of Instrumental Color

Each experimental period has a total of 7 days with 4 days adaptation and 3 days collection. Feces and urine were collected according to the marker-to-marker approach as described by Adeola (2001) using Cr_2O_3 as indigestible marker. Urine was collected over a preservative of 50 ml of 6N HCl during the entire duration of urine collection. Total feces and urine collected were weighed and a 20% sub-sample was obtained and stored at -20°C immediately after collection for subsequent analysis.

At the conclusion of the experiment, fecal and urine samples collected during the 3-day collection period were thawed and pooled within animal and diet. Fecal samples were dried in a forced-air oven and finely ground before analysis. Fecal, urine, diet and CCP samples were analyzed in duplicate for GE using bomb calorimetry (Model 6200; Parr Instruments, Moline, IL, USA) and the apparent total tract digestibility (ATTD) of GE in each diet was calculated (Adeola 2001). The concentrations of DE and ME in each of the 11 dietary treatments were calculated using the amount of energy lost in the feces and urine following the procedures by Adeola (2001). To determine the contribution from the corn diet to the DE and ME in each of the diets containing 10 different CCP samples, the DE and ME in the corn diet was multiplied by 70%. Then the DE and ME in each of the 10 CCP were calculated by difference (Widmer et al. 2007). The net energy (NE) of diets and ingredients were estimated using the prediction equation (NE = 0.870 × ME – 442) developed by Noblet et al. (1994).

Experimental diets and ingredients were analyzed for DM (duplicate samples at 135°C for 2 h following Method 930.15; AOAC Int. 2007), CP (Method 981.10; AOAC Int. 2007), EE (Method 2003.06; AOAC Int., 2007), CF (Method 962.09; AOAC Int. 2007), ash (Method 942.05; AOAC Int. 2007), Ca, and P (Method 985.01 A, and Method 975.03 B (b); AOAC Int. 2007).

The instrumental color of each CCP samples was determined measuring the L* (lightness), a* (redness) and b* (yellowness) values using a chroma meter (Model CR-410; Konica Minolta, Tokyo, Japan) with illuminant D65. The chroma meter was calibrated using white title following the procedure of the manufacturer. The L*, a* and b* values of each sample were calculated as average of 3 readings.

Statistical Analysis

Descriptive statistics were used for the chemical analysis of each CCP sources. Data were analyzed using MIXED procedure of SAS (SAS Institute, Cary, NC, USA) with pig as the experimental unit. The model included dietary treatment as fixed effect and pig, period and run as random effects. Least square means were determined for each of the independent variable. When effect of diet is significant, least square means were separated using the PDIFF option of SAS and adjusted using the Tukey-Kramer test. Pre-planned, single-df orthogonal contrasts were performed for the following: 1) CM vs WC, 2) CM vs PECM, and 3) PECM vs WC. Statistical significance were set at $P \leq 0.05$.

Development of Prediction Equations

Correlation analysis was performed using PROC CORR of SAS among chemical components, instrumental color and DE and ME in CCP. Stepwise regression analysis using PROC REG of SAS was done in parameters with significant correlations to develop prediction equation for estimation of DE and ME values. The prediction equation with significant *P*-value, the least root mean square error (RMSE), which is a measure of precision, and with highest R^2 (coefficient of determination), which is the degree of variation that is influenced by the model was considered the optimal model.

RESULTS

Gross Energy, Nutrient Composition, and Instrumental Color of Ingredients

On a DM basis, GE of 7 CM samples used in this experiment was between 4,484 to 5,010 kcal/kg (Table 1). The highest GE was observed in one of the WC samples (WC-24) with 5,127 kcal/kg. On the other hand, PECM had 4,608 kcal/kg. PECM had the greatest CP (26.27%) whereas WC-24 has the least CP (12.4%). The fat content of 7 CM samples range from 7.42 to 14.20%. The highest fat content was observed in WC-24 which also has the highest GE value. In terms of instrumental color, the WC-24 and WC-28 has the highest L* value of 83.58 and 80.81, respectively. CM-16 has the lowest L* value of 50.20 among the 10 CCP samples.

Daily Energy Balance

The DM intake of the pigs did not differ in this experiment (Table 3). However, GE intake of pigs differed

Table 3. Daily energy balance (DM basis) of growing pigs fed diets containing coconut co-products[1].

Item	Diet											SEM	*P*-value
	Basal (Corn)	CM-3	CM-6	CM-10	CM-12	CM-16	CM-21	CM-27	PECM	WC-24	WC-28		
DM intake, kg	1.01	0.91	0.84	0.93	0.85	0.86	0.92	0.89	0.88	0.82	0.94	0.07	0.07
GE intake, kcal	4,158^{a}	3,441^{ab}	3,311^{b}	3,789^{ab}	3,447^{ab}	3,451^{ab}	3,466^{ab}	3,484^{ab}	3,292^{b}	3182^{b}	3468^{ab}	276.94	0.006
Fecal output, g	111.47^{ab}	108.39^{ab}	91.25^{ab}	128.05^{ab}	99.13^{ab}	125.34^{ab}	131.2^{a}	125.99^{ab}	118.08^{ab}	76.78^{b}	86.45^{ab}	12.59	0.01
Fecal GE output, kcal	510.55	508.43	443.56	598.25	459.86	588.08	631.77	595.58	554.31	384.17	407.79	59.24	0.02
ATTD of GE, %	87.76^{ab}	85.66^{abc}	86.58^{abc}	84.41^{abc}	86.33^{abc}	83.14^{abc}	81.85^{abc}	82.69^{bc}	82.83^{abc}	87.68^{ab}	88.02^{a}	1.17	<0.001
Urinary output, g	437.92	522.94	558.23	525.43	590.06	558.73	848.48	532.42	554.25	518.91	572.33	109.33	0.48
Urinary GE output, kcal	52.50	59.63	54.99	61.14	50.49	61.71	81.25	67.79	69.68	54.54	61.06	11.5	0.67
DE of diet, kcal	3,611^{a}	3,248^{de}	3,422^{abcd}	3,455^{abc}	3,514^{ab}	3,326^{bcd}	3,086^{e}	3,252^{cde}	3,089^{e}	3,398^{bcd}	3,257^{cde}	46.01	<0.001
ME of diet, kcal	3,559^{a}	3,184^{cde}	3,355^{bcd}	3,386^{abc}	3,454^{ab}	3,256^{bcd}	2,996^{e}	3,175^{de}	3,010^{e}	3,328^{bcd}	3,195^{cde}	47.28	<0.001
NE* of diet, kcal	2,654^{a}	2,328^{cde}	2,477^{bcd}	2,504^{abc}	2,563^{ab}	2,390^{bcd}	2,165^{e}	2,321^{de}	2,177^{e}	2,453^{bcd}	2,338^{cde}	41.14	<0.001

[1]Data are least square means with 6 replicates per treatment. CM – copra meal; PECM – protein enriched copra meal; WC – white copra.

[a-e] Values within a row without a common superscript significantly differ ($P \leq 0.05$).

*Value was estimated using the prediction equation by Noblet et al. (1994): Net energy (NE) = 0.870 x ME kcal/kg DM – 442.

(P < 0.01) among treatments. Lower GE intake was observed in pigs fed with CM-6, PECM and WC-24 diets compared to pigs that received the basal diet. On the average, no significant differences in GE intake were observed among pigs fed diets with CCP. Fecal output of pigs fed diet with CM-21 was greater (P = 0.01) compared to pigs fed diet with WC-24 but not different from the other treatments. Fecal and urinary output, and urinary GE output did not significantly differ among the treatments. The greatest (P < 0.001) ATTD of GE was observed in WC-28 diet (88.02%), however it did not differ from the other diets except for CM-27 diet which was lower (P < 0.001) than WC-28 diet. The ME and NE of the pigs fed basal diet was greater (P<0.001) compared to pigs fed diets with CCP except for those pigs that received CM-10 and CM-12 diets. Similarly, those pigs that received the basal diet has higher DE compared to the rest of the treatment except for CM-6, CM-10 and CM-12 diets. The DE, ME and NE of CM-21 and PECM diets were different (P < 0.001) from the rest of CCP treated diets except for CM-3, CM-27 and WC-28 diets. Among the 7 CM diets, CM-21 has the least (P < 0.001) DE, ME and NE, except for CM-3 and CM-27. No significant differences were observed between the two WC diets (WC-24 and WC-28).

Energy Concentration in CCP

The DE, ME and NE concentrations differed (P < 0.001) among CCP (Table 4). The DE, ME and NE values of 10 CCP sources ranged from 1,694 to 2,974, 1,531 to 2,908 and 890 to 2,088 kcal/kg on as fed basis, respectively, and from 1,843 to 3,284, 1,667 to 3,211 and 1,008 to 2,352 kcal/kg on a DM basis. On an as fed basis, the DE, ME and NE of corn was greater (P < 0.001) than most of the CCP sources except in CM-6, CM-10, CM-12 and WC-24. On a DM basis, the DE of corn was greater (P < 0.001) than in most of the CCP sources except CM-10 and CM-12. Also, the ME and NE of corn was greater (P < 0.001) than most of the CCP sources except in CM-12. The DE, ME and NE of CM-21 and PECM was lower (P < 0.001) compared to most of the CCP sources (CM-6, CM-10, CM-12, CM-16 and WC-24). Among the CM sources, CM-12 has greater (P < 0.001) DE, ME and NE than CM-3, CM-21 and CM 27, but it did not differ from CM-6, CM-10 and CM-16. On the other hand, the DE, ME and NE values of WC-24 were not different from WC-28. On average, the DE (3,193 kcal/kg DM), ME (3,074 kcal/kg DM) and NE (1,774 kcal/kg DM) concentrations of CM was greater (P < 0.001) compared with PECM (1,859, 1,717 and 1,052 kcal/kg DM, respectively) but were not significantly different with the average DE (2,657 kcal/kg DM), ME (2,562 kcal/kg DM) and NE (1,787 kcal/kg DM) of WC. However, the DE, ME and NE values of WC were greater (P < 0.001) compared with PECM.

Correlations and Prediction Equations

No significant correlation was observed between the energy concentration and the chemical components and instrumental color of CCP (Table 5). However, when correlation analysis was performed using only CM samples, acid detergent fiber (ADF) was positively correlated ($r \geq 0.72$; P < 0.05) to DE and ME (Table 6). Using ADF as independent variable, DE and ME values in CM can be predicted using the equations presented in Table 7. The models explained 52 and 51% of the variability in DE and ME concentrations, respectively, in CM.

DISCUSSION

Gross Energy, Nutrient Composition and Instrumental Color of Ingredients

The WC-24 had the greatest GE which may be attributed mainly to its high residual oil (EE of 21.40%) and starch (8.40%) content. However, WC-28 has lower GE and EE compared to WC-24 which may be due to the difference in the processing method that the two WC has undergone. The oil residue of copra ranges from 1 to 22%,

Table 4. Concentrations of digestible (DE), metabolizable (ME) and net energy (NE) in corn and in 10 coconut co-products fed to growing pigs[1].

Item	Ingredient											SEM	*P*-value
	Corn	CM-3	CM-6	CM-10	CM-12	CM-16	CM-21	CM-27	PECM	WC-24	WC-28		
As fed basis													
DE, kcal/kg	3,293[a]	2,171[cd]	2,779[abc]	2,759[abc]	2,974[ab]	2,500[bc]	1,694[d]	2,156[cd]	1,726[d]	2,722[abc]	2,173[cd]	137.69	<0.001
ME, kcal/kg	3,248[a]	2,093[cde]	2,687[abc]	2,666[abc]	2,908[ab]	2,395[bcd]	1,531[e]	2,033[de]	1,594[e]	2,626[abcd]	2,095[cde]	141.07	<0.001
NE*, kcal/kg	2,383[a]	1,379[cde]	1,895[abc]	1,877[abc]	2,088[ab]	1,642[bcd]	890[e]	1,327[de]	945[e]	1,843[abcd]	1,381[cde]	122.73	<0.001
DM basis													
DE, kcal/kg	3,741[a]	2,390[de]	2,969[bcd]	3,083[abc]	3,284[ab]	2,649[bcd]	1,843[e]	2,397[de]	1,858[e]	2,905[bcd]	2,408[cde]	149.61	<0.001
ME, kcal/kg	3,690[a]	2,304[cde]	2,871[bcd]	2,980[bc]	3,211[ab]	2,538[bcd]	1,666[e]	2,261[de]	1,717[e]	2,802[bcd]	2,321[cde]	152.95	<0.001
NE*, kcal/kg	2,768[a]	1,563[cde]	2,055[bcd]	2,151[bc]	2,352[ab]	1,766[bcd]	1,008[e]	1,525[de]	1,052[e]	1,996[bcd]	1,577[cde]	133.07	<0.001

[1]Data are least square means with 6 replicates per treatment. CM – copra meal; PECM – protein enriched copra meal; WC – white copra.

[a-e] Values within a row without a common superscript significantly differ (P < 0.05).

*Value was estimated using the prediction equation by Noblet et al. (1994): Net energy (NE) = 0.870 x ME kcal/kg DM – 442.

Table 5. Correlation coefficients between energy concentrations (DE and ME) and instrumental color of 8 coconut co-products[1,2].

Item	Correlation Coefficient (r)				
	L*-Value	a*-Value	b*-Value	DE	ME
L*-value	-	0.70	0.91**	0.04	0.04
a*-value		-	0.83*	0.08	0.09
b*-value			-	-0.09	-0.09
DE				-	0.999***

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

[1]L* – lightness; a* – redness; b* – yellowness; DE – digestible energy; ME – metabolizable energy.

[2]Correlation analysis was done in 8 CCP samples (excluding WC-24 and WC-28).

depending on the oil extraction method (Gohl 1982). On the other hand, CM-3 has the least GE and fat content among the CCP samples but the value is within the reported range (Sauvant et al. 2004; Sundu et al. 2009; NRC 2012; Sulabo et al. 2013; Heuze et al. 2015; Lee and Kim 2017). The PECM has the greatest CP among the CCP samples, because it is a product of fermentation. The WC-24 has the least CP which may be due to its greater proportion of fat and starch content. The values obtained in this experiment were slightly lower than the published CP of CM (Sundu et al. 2009; NRC 2012; Stein et al. 2015; Lee and Kim 2017). In terms of instrumental color, the WC-24 and WC-28 has the lightest color (greatest L*) since WC samples did not undergo high degree of heat treatment during the production of virgin coconut oil and desiccated coconut compared to CM. In contrast, CM-16 has the lowest L* value which indicates that it has the darkest color among the 10 CCP samples. The variation in color of CCP may be an indication of the varying degree of heat treatment that the material has undergone. In the production of virgin coconut oil, fresh coconut meat are used and temperature during oil extraction does not exceed 70°C (Jayasekara and Gunathilake 2007), whereas in the production of coconut oil dried copra is used and the temperature during oil extraction is about 90°C. To the best of our knowledge, there have been no previous study that evaluated instrumental color in CCP.

Daily Energy Balance

The lack of differences in DM intake of pigs suggest that the bulk density and water holding capacity of CCP used in the diets did not affect the DM intake of pigs. However, lower GE intake was observed in pigs fed diets with CM-6, PECM and WC-24 compared to pigs that received the basal diet. The GE content of CCP does not affect the GE intake of pigs fed diets with CCP. The significantly greater fecal output of CM-21 compared to pigs fed diet with WC-24 may be due to the numerically greater DM intake of CM-21 than WC-24. The CCP sources does not influenced the fecal and urinary GE outputs of pigs. Differences in % ATTD of GE was observed across diets which was due to the variations observed in fiber and fat content. Published literatures suggest that the digestibility of energy decreases if pigs were fed high-fiber diets (Jaworski et al. 2015; Navarro et al. 2018). This differences in % ATTD of GE resulted to differences in the DE, ME and NE of the diets. Despite the high GE and EE values of WC-24 diet, it was observed that its DE, ME and NE values were lower than the basal corn diet and not different from most of CCP diets. This suggests that possibly the chemical components and compositions in WC reduced its energy digestibility. This observation cannot be explained as of yet. The ME and NE of basal diet (corn) were higher than most of CCP diets (except in 2 CCP sources CM-10 and CM-12). This is in agreement with previous reports that basal diet (Son et al. 2012) and corn (NRC 2012; Sulabo et al. 2013; Stein et al. 2015) has higher energy concentration than CM. However, Son et al. (2012) reported DE and ME of basal diet were not different in CM diet.

Table 6. Correlation coefficients between energy concentrations and chemical composition of 8 coconut co-products[1,2].

Item	Correlation Coefficient (r)											
	CP	EE	CF	NDF	ADF	ADL	Starch	Ash	Ca	P	DE	ME
GE	-0.21	0.55	0.34	0.29	-0.03	0.06	0.29	-0.65	-0.02	-0.32	-0.11	-0.13
CP	-	-0.26	-0.74*	-0.92	0.68	-0.53	-0.30	0.81*	0.45	0.78	-0.66	-0.64
EE		-	0.29	0.43	0.67	0.75	0.08	-0.6	-0.43	-0.37	0.36	0.35
CF			-	0.82*	0.44	0.56	0.42	-0.72*	-0.04	-0.63	0.27	0.26
NDF				-	0.72*	0.63	0.16	-0.81*	-0.44	-0.87**	0.57	0.57
ADF					-	0.90**	0.12	-0.57	-0.71*	-0.61	0.72	0.72*
ADL						-	0.23	-0.52	-0.39	-0.39	0.56	0.56
Starch							-	-0.24	-0.03	-0.12	-0.28	0.30
Ash								-	0.41	0.74*	-0.59	-0.57
Ca									-	0.70	-0.48	-0.47
P										-	-0.41	-0.41
DE											-	0.999***

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

[1]GE – gross energy; CP – crude protein; EE – ether extract; CF – crude fiber; NFE – nitrogen free extract; NDF – neutral detergent fiber; ADF – acid detergent fiber; DE – digestible energy; ME – metabolizable energy

[2]Correlation analysis was done in 8 CCP samples (excluding WC-24 and WC-28)

Table 7. Prediction equations for DE and ME in coconut co-products fed to growing pigs[1,2].

Equation No.	Parameter	Model	R^2	RMSE	*P*-value
1	DE	-715.3013 + 101.418 × ADF	0.5190	403.85	0.04
2	ME	-983.1638 + 106.131 × ADF	0.5134	427.42	0.04

[1]Parameters are on a DM basis.
[2]Regression analysis was done in 8 CCP samples (excluding WC-24 and WC-28).

Energy Concentration in CCP

Concentrations of DE and ME of corn obtained in this experiment are within the published values (Sauvant et al. 2004; Kim et al. 2009; NRC 2012; Jang and Kim 2013; Sulabo et al. 2013; Rojas et al. 2013; Navarro et al. 2018). The DE and ME values of CM were lower than published values (Thorne et al. 1989; NRC 2012; Son et al. 2012; Sulabo et al. 2013; Stein et al. 2015; Navarro et al. 2018). The DE:ME ratio of 7 CM sources used in this experiment ranges from 90 to 99%, which is greater than the published DE:ME ratio (85%) by NRC (1998). For most of the ingredients, ME is between 92 to 98% of the DE (NRC 2012). The reason for the differences in the ME:DE ratio among CM sources is not known as previously reported by Sulabo et al. (2013). However, Noblet and van Milgen (2004) reported that the differences may be partly due to the wide variation in protein digestibility among sources of CM. This is because the digestible protein concentration in the diet affects urinary nitrogen excretion and urinary energy loss, which is the main variable that affects the metabolic utilization of DE for ME.

To our knowledge, this is the first study to report the DE, ME and NE values of PECM and WC in growing pigs. The DE, ME and NE values of PECM obtained in this study were less than the published values for soybean meal (NRC 2012; Sulabo et al. 2013; Stein et al. 2015; Navarro et al. 2018), but its DE:ME ratio (92%) is within the reported values of NRC (2012) for most ingredients. The average DE, ME and NE of CM and WC were greater than PECM. This means that the fermentation of CM into PECM did not resulted to increase in digestibility of energy. Also, this result may possibly be partly due to low protein digestibility in PECM which results to high nitrogen excretion and urinary energy loss as explained by Sulabo et al. (2013). The greater energy concentrations in WC than PECM may be attributed to its higher EE and GE content.

The dietary fiber concentration may also influence variation in DE values (Noblet and van Milgen 2004; Navarro et al. 2018). Generally, concentration of DE, ME and NE on a DM basis in corn were greater than the average of CM, PECM and WC. This is in agreement with published reports that DE and ME in CM are less than in corn which is due to high fiber concentration in CM and copra expellers (NRC 2012; Stein et al. 2015). However, Sulabo et al. (2013) reported DE and ME values of corn were not different from CM. The differences in DE and ME concentrations observed among sources of CM and WC may be attributed to the dietary fiber concentration (Noblet and van Milgen, 2004; Noblet and Perez, 1993). Moreover, energy values and nutrient content of CM are highly variable due to origin, environment, feed processing, and oil extraction methods (Thorne et al. 1989; Sundu and Dingle 2003; Sundu et al. 2009).

Correlations and Prediction Equations

The no correlation observed between energy concentrations (DE and ME) and the instrumental color agrees to Pedersen et al. (2007) who reported that L*, a*, and b* values were not correlated with the DE and ME in distillers dried grains with solubles (DDGS). Moreover, Navarro et al. (2018) reported that physical characteristics of feed ingredients were not correlated with the concentrations of DE and ME, which indicates that these parameters do not influence in vivo energy digestibility in feed ingredients. However, color of DDGS was negatively correlated with the digestibility of some AA (Urriola et al. 2013), which is believed to be due to overheating of DDGS, causing browning reactions in the product brought by Maillard reactions (Pedersen et al. 2007).

The positive correlation between the DE and ME values and the ADF content in CM is in contrast to previous studies, that dietary fiber reduces energy digestibility (Noblet and Perez 1993; Sulabo et al. 2013). The positive correlation between energy and fiber was supported by our observation that CM-12 which has the greatest NDF, ADF and ADL contents, also has the greatest DE, ME and NE concentration, whereas PECM which has the least NDF, ADF and ADL contents, similarly, has the least amount DE, ME and NE. Moreover, positive correlation was observed by Park et al. (2015) between ADF and GE in feeds that contain large range of fiber concentrations. The reason for such difference cannot be explained at the moment. But possibly the greater ADF (mainly cellulose and partly lignin) in CM resulted to better fermentability of CM in the hind gut because of more fibers are available during fermentation. Copra contain relatively high concentrations (approximately 47% total dietary fiber) of fermentable fiber (Stein et al. 2013). However, positive correlation of CF to N-corrected apparent metabolizable energy (AMEn) was observed in broilers (Reyes 2018). Prediction equations were developed using ADF content as independent variable to estimate DE and ME values in CCP (Table 7). The prediction of DE concentration (equation 1) using ADF content is more accurate than the prediction of ME concentration (equation 2) because it has higher R^2 and lower RMSE values. This agrees to the report of Navarro et al. (2018) that DE and ME values in feed ingredients may be predicted from some chemical constituents and from in vitro digestibility of DM. Previous studies also have developed prediction equations for estimation of DE (Thorne et al. 1989; Noblet and Perez 1993; Noblet et al. 1993; Le Goff and Noblet 2001; Son et al. 2012) and ME (Thorne et al. 1989; Noblet and Perez 1993; Noblet et al. 1993) using chemical compositions. However, available prediction equations were often developed using complete diets (NRC 2012) and were not specific to CCP.

In conclusion, DE and ME concentrations significantly differ among CCP sources. To our knowledge, there is no published data on DE and ME values and prediction equations for estimation of energy concentrations in CCP in growing pigs. In this study, we successfully developed prediction equations for the estimation of DE and ME values in CCP by using ADF as independent variable. The results in this experiment will help animal nutritionist to obtain reliable DE and ME values of CCP by simply analyzing its ADF content.

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