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Short communication

An evaluation of metabolizable energy content of main feed ingredients for growing pigs when adding dietary lysophospholipids

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ABSTRACT

The present study was conducted to test whether the dietary supplementation of lysophospholipids (LPL) affects digestible energy (DE) content of feed ingredients, nutrient digestibility, and growth performance of growing pigs. In Exp. 1, 8 growing pigs were alternatively used for 8 dietary treatments including 4 feed ingredients (corn, soybean meal, distiller's dried grains with solubles, and animal fat), and 2 LPL concentrations (0% and 0.1%) in 6 periods to determine DE and metabolizable energy (ME) content. In Exp. 2, 200 growing pigs were randomly allotted to 4 treatments on the basis of body weight with 2 concentrations of fat (high and low) and 2 concentrations of LPL (0% and 0.1%). The experimental diets were fed for 42 d in 2 phases. In Exp. 1, gross energy (GE) digestibility, feed DE, and ME were increased in animal fat when LPL were added to the diet. In Exp. 2, the pigs fed LPL showed greater ($P < .05$) digestibility of EE, GE, crude protein (CP), and DM In phase 2. Pigs fed a high-fat diet had greater ($P < .05$) digestibility of EE, and GE. Gross energy retention was greater ($P < .05$) in pigs fed the high-fat diet compared with those fed the low-fat diet in phase 2. During phase 1, the average daily gain (ADG) of pigs fed the high-fat diet was greater ($P < .05$) than that for pigs fed the low-energy diet. During the second phase, ADG was increased in LPL and high-fat diets ($P < .05$). The overall results showed that pigs fed the LPL or high-fat treatments had greater ADG and feed to gain ratio (F/G). Considering the 2 experiments, it can be concluded that LPL increase the ME of animal fat and improves ADG and F/G in pigs.

1. Introduction

The mode of action of emulsifiers refers to the incorporation of fatty acids into micelles, which is able to improve fat digestibility in pigs (Udomprasert and Rukkwamsuk, 2006). Among emulsifiers, lysophospholipids (LPL) are known to be one of the most important micelle enhancers. Emulsification for the micellar formation of fat is essential in fat digestion within the gastrointestinal tract because fatty acids are insoluble in water. Lysophospholipids alter membrane fluidity as a membrane transducer to accelerate the diffusion through the cell lipids (Lundbæk et al., 1994). The first aim of this study is to investigate the effect of LPL on common feed materials and predict the true digestible energy (DE) to re-balance the diet based on changes in feed ingredients.

The DE and metabolizable energy content (ME) in corn, soybean meal (SBM), distiller's dried grains with solubles (DDGS), and animal fat have been previously estimated and presented in standard references (NRC, 2012). To our knowledge, DE and ME have not been reported for corn, SBM, DDGS, and animal fat when an emulsifier was used in the diet. The additional amount of animal fat is less than 5% in pigs' diet; this is a relatively small inclusion, but changing the digestibility may be able to increase the total DE considerably. Jones et al. (1992) used LPL in pig diet to improve the digestibility of the fat of lipids, but reported a minimal effect on pig performance. There are many other studies on the positive influence of emulsifiers on the digestibility of energy in pigs (Jin et al., 1998; Zhao et al., 2015) and chickens (Gheisar et al., 2015), however, the excess dietary DE may produce nutritional imbalance. In addition, most performance studies did not consider the exact altered DE, which may give further insight into the effects of LPL on DE. Therefore, it can be concluded that there is room for upgrading the DE of feed ingredients following supplementation with LPL. Experiments were conducted with the aim of

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Table 1
Ingredient and composition of experimental diets, as-fed basis (Exp. 1).[a]

Item	Corn		SBM		DDGS		Animal fat	
LPL:	-	+	-	+	-	+	-	+
Ingredients (%)								
Corn	96.48	96.48	67.05	67.05	47.05	47.05	87.05	87.05
SBM	-	-	30.00	30.00	-	-	-	-
DDGS	-	-	-	-	50.00	50.00	-	-
Animal fat	-	-	-	-	-	-	10.00	10.00
Celite	0.10	-	0.10	-	0.10	-	0.10	-
LPL	-	0.10	-	0.10	-	0.10	-	0.10
Limestone	1.38	1.38	1.00	1.00	1.00	1.00	1.00	1.00
MDCP	1.19	1.19	1.00	1.00	1.00	1.00	1.00	1.00
Choline chloride (50%)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Mineral premix[b]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix[c]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Calculated composition								
ME (kcal/kg)	3,090	3,090	3,141	3,141	3,208	3,208	3,589	3,589
Crude protein (%)	6.52	6.52	18.33	18.33	16.78	16.78	5.88	5.88
Ca (%)	0.70	0.70	0.62	0.62	0.57	0.57	0.53	0.53
Available P (%)	0.32	0.32	0.32	0.32	0.45	0.45	0.27	0.27
P (%)	2.87	2.87	2.44	2.44	6.16	6.16	12.47	12.47

[a] LPL: Lysophospholipids; SBM: soybean meal; DDGS: distiller's dried grains with solubles; MDCP: mono-dicalcium phosphate; ME: metabolizable energy.
[b] Supplied per kilogram diet: 62.1 mg Fe; 4.1 mg Cu; 59 mg Zn; 2.1 mg Mn; 0.19 mg Se; and 0.14 mg I.
[c] Supplied per kilogram diet: 1,400 IU vitamin A; 160 IU vitamin D_3; 12 IU vitamin E; 0.51 mg vitamin K_3; 1.1 mg thiamine; 2.7 riboflavin; 9 mg pantothenic acid; 35 mg niacin; 1.1 mg pyridoxine; 0.07 mg biotin; 0.4 mg folic acid; 10 μg vitamin B12; and 350 mg choline.

evaluating the energy value of main feed ingredients for pigs through the use of supplemental LPL.

2. Material and methods

The experiments were conducted at the Kangwon National University farm facility and approved by the Institutional Animal Care and Use Committee of Kangwon National University, Chuncheon, Republic of Korea. The lysophospholipid (Lipidol) was obtained from soybean lecithin with the exclusive proprietary technology (EASY BIO System Inc., Seoul, South Korea).

2.1. Experimental design and procedure

In Exp. 1, Eight barrows with an initial body weight (BW) of 22.3 ± 2.4 kg were used alternatively in 6 periods to determine DE and ME content of 4 feed sources (Corn, SBM, DDGS, and animal fat) and 2 LPL concentrations (totally 8 treatments) in 6 periods and each experimental period lasted 13 d (7 days adaptation period to experimental diets followed by a 6-d total collection of feces and urine).

The pigs were individually housed in metabolism cages that measured 1.2 × 1 m and equipped with a feeder, fully slatted floors, and urinary trays, which allowed separate collection of urine and fecal materials from each pig. The temperature of the rooms housing the pigs was maintained at 21 °C, and the lights were kept on 24 h a day. The experimental diets were specially formulated as shown in Table 1. The corn diet contained 96.48% corn as the sole source of energy. The other additional diets were formulated by mixing corn with SBM (30%), DDGS (50%) and animal fat (10%). Vitamins and minerals were added to all diets according to requirement estimates (NRC, 2012). Feed was provided at daily amounts of 2.5 times the estimated maintenance requirement for energy (2.5 × 197 kcal of ME/kg of $BW^{0.60}$; NRC, 2012). The daily feed allowance was divided into 2 equal meals and provided to pigs at 0900 and 1700 h.

In Exp. 2, A total of 200 growing pigs (Yorkshire × Landrace × Duroc) with an initial BW of 32.2 ± 1.2 kg were randomly allotted to 4 treatments in a 2 × 2 factorial arrangement with 2 concentrations of fat and 2 concentrations of LPL (0% and 0.1%). There were 5 pens in each treatment, with 10 pigs per pen. Each 1.5- by 5-m pen had a 2-hole dry self-feeder and a nipple water to allow ad libitum access to feed and water. The experimental diets were fed for 42 d in 2 phases: phase 1 (d 0–21) and phase 2 (d 22–42). For a feeding trial, pigs were housed in partially slatted, concrete floor pens.

The ME values of ingredients (Corn, SBM, DDGS, and animal fat) in this feeding trial were calculated with or without dietary LPL (Exp. 1). As calculated in equation I, the predicted ME for low fat diet (3298 kcal/kg of ME; Exp. 2) supplemented with LPL was predicted to be 52 kcal higher than energy values evaluated for non-LPL-supplemented diets based on NRC (2012). The diets were formulated to meet or exceed the requirement of NRC (2012), and experimental diet formula and chemical compositions are presented in Table 2.

$$DL = [C \times (ME_{2C} - ME_{1C})] + [S \times (ME_{2S} - ME_{1S})] + [D \times (ME_{2D} - ME_{1D})] + [A \times (ME_{2A} - ME_{1A})], \quad (1)$$

where DL = The predicted energy difference between LPL and without LPL in diet, C = Corn ratio in the diet, S = Soybean ratio in the diet, D = DDGS ratio in the diet A = Animal fat ratio in the diet, ME_1 = Predicted ME in Exp. 1 without LPL, ME_2 = Predicted ME in Exp. 1 with LPL.

2.2. Sampling and measurements

In Exp. 1, the initial 7 d of the experiment were considered an adaptation period to the diet. On d 8, a marker (0.5% chromic oxide) was mixed into the morning meal. Fecal samples were collected as the marker appeared in the feces. On d 13, a second marker (0.5% ferric oxide) was included in the morning meal. Fecal collection was quantitatively continued until the second marker appeared in the feces (Adeola, 2001). Urine collection started at 0900 h on d 8 and ceased at 0900 h on d 13. Urine was collected in a urine bucket over 50 mL of 6 *N* HCl. The total quantities of feces and 20% of the collected urine were stored at −20 °C immediately after collection. The DE and ME of each experimental ingredient were calculated using the difference method with the chromium oxide (Cr; 0.25%) concentration of feed, digesta, and feces (Adeola, 2001). Fecal samples were dried in an air-forced

Table 2
Formula and chemical composition of experimental diets, as-fed basis (Exp. 2). [a].

Item	Phase 1				Phase 2			
ME (kcal/kg):	3,350		3,298		3,350		3,298	
LPL:	-	+	-	+	-	+	-	+
Ingredients (%)								
Yellow corn	56.26	56.16	57.87	57.77	60.00	59.90	61.60	61.50
SBM	22.82	22.82	22.81	22.81	21.43	21.43	21.39	21.39
DDGS	11.44	11.44	11.02	11.02	9.05	9.05	8.71	8.71
Animal fat	2.23	2.23	1.03	1.03	2.26	2.26	1.04	1.04
Molasses	3.97	3.97	3.99	3.99	4.00	4.00	4.00	4.00
$_{L}$-Thr (98%)	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03
$_{L}$-Lys·HCl (78%)	0.37	0.37	0.37	0.37	0.34	0.34	0.34	0.34
$_{DL}$-Met (50%)	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13
Choline chloride (50%)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Limestone	1.22	1.22	1.21	1.21	0.77	0.77	0.78	0.78
MDCP	0.75	0.75	0.76	0.76	1.09	1.09	1.08	1.08
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Mineral premix[b]	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30
Vitamin premix[a]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Phytase	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
LPL	-	0.10	-	0.10	-	0.10	-	0.10
Analyzed composition (%):								
Crude protein	18.11	18.11	18.02	18.02	16.91	16.91	17.03	17.03
Ether extract	5.30	5.30	4.12	4.12	5.18	5.18	4.01	4.01
Calculated composition:								
ME (kcal/kg)	3,350	3,350	3,298	3,298	3,298	3,298	3,350	3,350
Ca (%)	0.70	0.70	0.70	0.70	0.65	0.65	0.65	0.65
Available P (%)	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.30
Digestible Lys (%)	0.98	0.98	0.98	0.98	0.92	0.92	0.92	0.92
Digestible Met + Cys (%)	0.55	0.55	0.55	0.55	0.52	0.52	0.52	0.52
Digestible Thr (%)	0.59	0.59	0.59	0.59	0.54	0.54	0.54	0.54
Digestible Trp (%)	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16

[a] ME: metabolizable energy; LPL: Lysophospholipids; SBM: Soybean meal; DDGS: distillers dried grain with solubles; MDCP: mono di calcium phosphate; SID: standardized ileal digestibility.

[b] Supplied per kilogram diet: 62.1 mg Fe; 4.1 mg Cu; 59 mg Zn; 2.1 mg Mn; 0.19 mg Se; and 0.14 mg I.

[c] Supplied per kilogram diet: 1,400 IU vitamin A; 160 IU vitamin D_3; 12 IU vitamin E; 0.51 mg vitamin K_3; 1.1 mg thiamine; 2.7 riboflavin; 9 mg pantothenic acid; 35 mg niacin; 1.1 mg pyridoxine; 0.07 mg biotin; 0.4 mg folic acid; 10 μg vitamin B12; and 350 mg choline.

drying oven at 60 °C and ground before analysis, and urine samples were dried in a freeze drier before analysis. Diet, fecal, and urine samples were analyzed for gross energy (GE) using a bomb calorimeter (Model 1241, Parr Instrument Co., Molin, IL, US).

In Exp. 2, for the analysis of nutrient digestibility, Cr was used as indigestible marker in each phase diet to calculate digestibility coefficients. All pigs in all pens were fed diets mixed with chromic oxide from d 14–21 and d 35–42. Fecal grab samples were collected from the floor of each pen during the last 4 d of each phase. The feces collected were pooled to represent one pen and dried in an air-forced drying oven at 60 °C for 72 h and ground in a 1-mm screen Wiley mill for chemical analysis. Fecal samples were dried in an air-forced drying oven at 60 °C and ground before analysis. Diet and fecal samples were analyzed for gross energy (GE) using a bomb calorimeter (Parr Adiabatic Calorimeter 1241, Parr Instrument Co., Molin, IL, US).

On d 21 and d 42 of Exp. 2, a 10-mL blood sample was collected by jugular vein puncture from 2 randomly selected pigs in each pen using a disposable Vacutainer tube containing sodium heparin as an anticoagulant (Becton Dickinson, Franklin, NJ, US) at 9:00 a.m. A serum automatic biochemical analyser (Fuji Dri-chem 3500i, Fujifilm, Tokyo, Japan) was applied to measure the concentrations of total protein (TP), blood urea nitrogen (BUN), total cholesterol (TCHO), glucose (GLU),

Table 3
The effect of lysophospholipids (LPL) on energy value of each experimental feed ingredient in growing pigs (Exp. 1).[a].

Item	Corn		SEM	SBM		SEM	DDGS		SEM	AF		SEM	*P*-value			
LPL:	-	+		-	+		-	+		-	+		Corn	SBM	DDGS	AF
GE (kcal/kg)	3,843	3,839	-	3,947	3,949	-	4,249	4,252	-	4,611	4,606	-	-	-	-	-
Feed consumption (kcal/d)	1.18	1.23	-	1.13	1.29	-	1.22	1.31	-	1.04	1.13	-	-	-	-	-
GE intake (kcal/kg)	4,549	4,735	-	4,454	5,091	-	5,197	5,588	-	4,798	5,216	-	-	-	-	-
Fecal energy (kcal/kg)	553	538	42	575	604	14	953	976	113	808	817	21	0.929	0.622	0.254	0.606
Energy digestibility (%)	87.7	88.6	0.2	87	88.1	0.3	81.3	82.3	0.4	83.2	84.4	0.7	0.008	0.138	0.136	0.531
Feed DE (kcal/kg)	3,371	3,402	11	3,434	3,477	11	3,456	3,497	14	3,836	3,886	29	0.012	0.179	0.121	0.506
Urinary energy (kcal/d)	90	79	2.9	133	155	16	155	157	9	81	84	19	0.629	0.751	0.218	0.963
Feed ME (kcal/kg)	3,295	3,337	10	3,316	3,356	18	3,329	3,380	17	3,756	3,811	32	0.001	0.270	0.266	0.450
DE in ingredients (kcal/kg; DM)	3,985	4,022	77	4,107	4,189	13	4,150	4,209	46	8,087	8,314	38	0.163	0.179	0.412	0.473
ME in ingredients (kcal/kg; DM)	3,896	3,945	50	3,861	3,902	21	3,916	3,984	59	7,968	8,145	64	0.083	0.271	0.753	0.624

[a] SBM: Soybean meal; DDGS: distillers dried grain with solubles; AF: animal fat; GE: gross energy; DE: digestible energy; ME: metabolizable energy; SEM: Standard error of means.

Table 4
Effect of dietary fat concentrations and lysophospholipids (LPL) supplementation on apparent total tract digestibility of nutrients (%) of growing pigs (Exp. 2).

Item	Fat:	High		Low		SEM[a]	*P*-value		
LPL:		-	+	-	+		Fat	LPL	Fat × LPL
Phase 1 (d 0 to 21)									
Dry matter		80.8	82.0	79.2	81.1	0.8	0.130	0.073	0.670
Gross energy		81.4	82.3	79.0	80.9	0.8	0.023	0.081	0.526
Crude protein		77.0	77.1	75.4	76.7	0.8	0.224	0.110	0.709
Ether extract		65.9	67.1	64.7	65.6	0.5	0.026	0.066	0.859
Phase 2 (d 21 to 42)									
Dry matter		80.0	81.3	78.6	80.5	0.7	0.143	0.042	0.665
Gross energy		80.0	81.9	77.4	79.7	0.8	0.012	0.028	0.859
Crude protein		75.2	76.4	74.6	76.0	0.6	0.414	0.046	0.414
Ether extract		65.2	66.8	64.0	66.2	0.8	0.095	0.013	0.766

[a] SEM: standard error of means

Table 5
Effect of dietary fat concentrations and lysophospholipids (LPL) supplementation on growing performance of growing pigs (Exp. 2).[a].

Item	Fat:	High		Low		SEM	*P*-value		
LPL:		-	+	-	+		Fat	LPL	Fat × LPL
Phase 1 (d 0 to 21)									
ADG (g)		741	750	702	730	10	0.014	0.096	0.390
ADFI (g)		1,563	1,558	1,552	1,566	18	0.916	0.818	0.621
F/G		2.11	2.08	2.21	2.15	0.05	0.101	0.297	0.714
Phase 2 (d 21 to 42)									
ADG (g)		830	874	798	828	16	0.039	0.047	0.706
ADFI (g)		1,953	1,949	1,941	1,957	14	0.894	0.691	0.468
F/G		2.36	2.24	2.43	2.36	0.05	0.065	0.070	0.603
Overall (d 0 to 42)									
ADG (g)		786	812	750	779	7	0.001	0.003	0.809
ADFI (g)		1,758	1,753	1,746	1,761	14	0.894	0.731	0.500
F/G		2.24	2.16	2.33	2.26	0.03	0.006	0.030	0.869

[a] ADG: average daily gain; ADFI: average daily feed intake; F/G: feed to gain ratio; SEM: standard error of means.

triglycerides (TG), albumin, and globulin. After centrifugation (3000 × *g* for 20 min at 4 °C), plasma samples were separated and stored at −20 °C and later analyzed for concentrations of blood parameters.

Additionally, proximate analysis in experimental diets and fecal samples in 6 periods (n = 6 samples/treatment) was conducted using the method of AOAC (2007). The gross energy (GE) of ingredients and diets was measured using a bomb calorimeter (Parr Instrument Co). The experimental diets and fecal samples were analyzed for Cr concentration Fenton and Fenton (1979) using a spectrophotometer (Jasco V−550; Jasco Corp, Tokyo, Japan).

2.3. Statistical analysis

All data were analyzed using SAS (SAS Inst. Inc., Cary, NC, US). In Exp. 1, 8 barrows were allotted to 8 dietary treatments and 6 periods, which were analyzed using the GLM procedure with each pig as the experimental unit. In Exp. 2, data were analyzed as a 2 × 2 factorial arrangement of treatments in a completely randomized design. The main effects of diet fat concentrations, LPL and their interaction were determined by the GLM procedure of SAS (SAS Inst. Inc). The pen was used as the experimental unit for the analysis of growth performance and nutrient digestibility data. For the analysis of blood metabolites, the mean of 2 selected pigs from each pen was used as the experimental unit. Statistical significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$.

3. Results

In Exp.1, adding LPL to the diets did not affect fecal energy, DE rate, feed DE, urinary energy, and feed ME from corn, SBM and DDGS, but DE rate, feed DE, and ME were increased ($P < 0.05$) in animal fat when LPL was added to the diet (Table 3). In Exp. 2, There were no interactions between fat concentrations and LPL in any of parameters. Digestibility of ether extract (EE; $P = 0.066$), GE ($P = 0.081$), and DM ($P = 0.073$) tended to increase slightly in pigs fed LPL in phase 1 (Table 4); however, the digestibility of crude protein (CP) was not affected. In phase 2, pigs fed LPL showed greater ($P < 0.05$) digestibility of EE, GE, CP, and DM. Pigs fed the high-fat diet had greater ($P < 0.05$) digestibility of EE and GE, but there was no effect of fat concentration on the digestibility of DM and CP in phase 1. Ether extract digestibility tended to decrease ($P = 0.095$) and GE retention was greater in pigs fed the high-fat diet compared with those fed the low-fat diet in phase 2.

In Exp. 2, the average daily gain (ADG) of pigs fed the high-fat diet was higher (Table 5; $P < 0.05$) than that for those fed the low-fat diet, moreover, ADG in LPL-supplemented diet tended to be greater than that for the non-supplemented diet ($P = 0.096$) in phase 1. However, pigs fed diets supplemented with LPL or a high-fat diet exhibited similar ADFI and feed-to-gain ratio (F/G) at day 21. During the second phase, no effect was observed on ADFI, but ADG was increased ($P < 0.05$) in the LPL and high-fat diets. There was a tendency for F/G in pigs to increase with an decreasing fat concentration ($P = 0.065$) or supplementary LPL ($P = 0.070$) during phase 2. Overall pigs fed the LPL or high-fat treatments had greater ($P < 0.05$) ADG and F/G, however, there was no difference in ADFI. The high-fat and LPL-supplemented diets did not show any significant changes in the blood metabolites, such as TCHO, TGs, GLU, BUN, TP, albumin, and globulin, of pigs in both phases 1 and 2 (data not shown).

4. Discussion

The addition of LPL increased the DE of animal fat. The potential of LPL for increase fat digestibility has been investigated previously by others (Jin et al., 1998; Zhao et al., 2015). The reason for the measured concentration of energy in the LPL-treated diet compared with the control diet is most likely the extra DE can compromise the diet nutrient balance.

The apparent total tract digestibility (ATTD) of EE tended to increase for LPL in the first phase, which was consistent with the significant improvement in digestibility of EE in phase 2. Previous research by Zhao et al. (2015) showed that the addition of LPL improved EE digestibility. Jin et al. (1998) also reported an improvement in tallow digestibility in weaning pigs as lecithin was added to the diet. The incorporation rate of lipids into micelles is limited by the extent of digestion within the small intestine and stomach. The supplementation of LPL in growing pig diets may be able to explain the fat digestion. In growing pigs, a greater digestibility of nutrients seems mainly due to the high rate of emulsification when feed was supplemented with emulsifier, however, an increase in the bile salt micelle capacity and the interior capacity of micelles in the intestine to increase long-chain saturated fatty acid solubilisation in the presence of phospholipids may have also contributed to this effect (Reynier et al., 1985). Therefore, the greater digestibility of EE in the presence of LPL in the current experiment can be explained by the mixed micelles in the gut environment, which are the most important structures that contribute to the lipid solution in aqueous systems. Numerous factors may contribute to an increase in membrane fluidity, including the incorporation of LPL in bilayers (Lundbæk et al., 1994). Several studies with emulsifiers have confirmed positive effects on the intestinal morphology in pigs and poultry (Khonyounga et al., 2015; Mitchaothai et al., 2010). Clearly, under such circumstances, the use of an emulsifier improve the small intestinal fat digestion and consequently enhance GE availability. This observation may be attributed to the high digestibility of EE because

dietary fat maintains a large share of energy in the diet.

Interestingly, in this study, the ATTD of GE and EE were affected by the fat concentration. The greater EE content in diets may have reduced the digesta transit time and improved fat digestion because of the slow movement of high-fat digesta through the intestinal tract. In a related work, Vieira et al. (2015) found that fat addition increased the rate of GE digestion that was attributed to its ability to suppress the passage rate.

The performance results shows that the greater effects of LPL on ADG. The results support the data of Udomprasert and Rukkwamsuk (2006) indicating that, the ADG of pigs improved by 19.6 g/d in a three-phase feeding regime when an exogenous emulsifier was mixed with soybean oil-treated diets compared with control diets. Zhao et al. (2015) reported increased ADG when LPL was added to weanling pigs' feed contained tallow, which is in agreement with the results of the current study. In contrast, Mitchaothai et al. (2010) did not find any beneficial effect from the inclusion of emulsifiers in the diet on BW gain in growing wild pigs. The present study demonstrated that pigs in the LPL group showed greater overall F/G. Dietary LPL is considered an important contributor to the increase in nutrient transfer through the enterocyte by altering the structure of phospholipids in cell membranes (Lundbæk et al., 1994). Emulsifiers have had inconsistent effects on growth performance in swine. The inconsistencies observed in the effects of including emulsifiers in the diet on the growth performance of pigs might be associated with differences in the concentration of fat inclusion, fat types or AA to energy balance (Jones et al., 1992; Zhao et al., 2015; Zou et al., 2014).

In this study, no difference in the ADFI of pigs with or without LPL diets was shown, as was observed by the previous work (Zhao et al., 2015). However, in contrast to the results of the current study, increased feed intake has mainly been attributed to its ability to increase palatability with the addition of an emulsifier (Overland and Sundstol, 1995). From a productive perspective, our results showed that the overall growth performance was affected by either dietary LPL or a high-fat diets. Our results also revealed that the ATTD of DM, CP, GE, or EE improved in pigs fed high-fat diets compared with those fed low-fat diets.

5. Conclusion

In conclusion, the present study showed that LPL improved the digestibility of animal fat. It is possible that the difference in growth performance is a result of differences in the digestibility of dry matter, gross energy, crude protein and ether extract.

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Conflict of interest

There is no conflict of interest.

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