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≪Research Note≫

Evaluation of Sodium Stearoyl-2-Lactylate and 1, 3-Diacylglycerol Blend Supplementation in Diets with Different Energy Content on the Growth Performance, Meat Quality, Apparent Total Tract Digestibility, and Blood Lipid Profiles of Broiler Chickens

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We evaluated the effects of supplementing an emulsifier blend (sodium stearoyl-2-lactylate and 1, 3-diacylglycerol) in diets with different energy content (normal and 100 kcal/kg reduced) on the growth performance, meat quality, apparent total tract digestibility (ATTD), and blood lipid profile of broiler chickens. Male broiler chickens (n = 1024), with an initial body weight (BW) of 43.60 ± 0.2 g, were used in a 35-day trial. Broiler chickens of similar body weight were randomly allocated to one of four treatment groups in a 2 × 2 factorial arrangement with two levels of dietary energy content and with or without emulsifier blend. Broiler chickens fed on emulsifier blend supplemented diet had a higher body weight gain (BWG) during d 7–21, d 21–35, and overall period ($P < 0.05$), higher BW during overall period ($P < 0.05$), and lower feed conversion ratio (FCR) during d 7–21, d 21–35, and overall period ($P < 0.05$) compared with broilers fed on diets without emulsifier supplementation. Broiler chickens fed on the diet with low energy content had a lower BWG during d 1–7, d 21–35, and overall period ($P < 0.05$), lower BW during overall period, and higher FCR during d 1–7, d 21–35, and overall period ($P < 0.05$). The ATTD of energy tended to decrease in response to low-energy content diet ($P < 0.10$). Drip loss at 7 d post slaughter tended to decrease in response to dietary emulsifier blend supplementation ($P < 0.10$). However, no interactive effects of dietary energy content and emulsifier blend supplementation ($P > 0.10$) were observed on the growth performance, ATTD, blood lipid profiles, meat quality and relative organ weight. In conclusion, dietary emulsifier blend supplementation could improve growth performance, while low dietary energy content would decrease growth performance and ATTD of energy.

Key words: apparent total tract digestibility, blood lipid profile, broiler chickens, emulsifier blend, growth performance

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Introduction

As energy intake is greatly determined by dietary compositions, the latter is known to affect the body composition of broiler chickens (Boekholt *et al.*, 1994). Energy is a major cost component in the diets of broiler chickens. Therefore, strategies to develop low energy diets for broiler chickens, while maintaining similar growth performance, and thus, reducing the cost of feed, comprise a topic of great interest. Lipids (fats and oil) are the main source of energy for poultry animals (Birkett and de Lange, 2001). However, due to the presence of an immature digestive tract in newly hatched chicks, the production and secretion of endogenous emulsifiers such as bile salts and lipases are restricted (Carew *et al.*, 1972; Tancharoenrat *et al.*, 2014), thereby limiting capacity of lipid digestion and absorption in broiler chickens. Consequently, emulsifiers as feed additives in poultry diets have garnered much interest.

An emulsifier is a molecule with both water-soluble (hydrophilic) and fat-soluble (lipophilic) components, which accelerate the incorporation of fatty acids into micelles and enhance fat digestibility, thus, improving the growth performance of chicks (Polin, 1980). Several previous studies have documented the positive effects of emulsifier supplementation on the growth performance and nutrient digestibility of livestock (Zhang *et al.*, 2011; Zhao *et al.*, 2015; Wang

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et al., 2016; Upadhaya *et al*., 2017; Zhao and Kim, 2017), as well as the reduction of serum cholesterol and triglyceride in animals (Zhao *et al*., 2015; Zhao and Kim, 2017). Sodium stearoyl-2-lactylate (SSL), a sodium salt with a long-chain carboxylic acid and two ester linkages, is widely used in the modern food industry. It has also been used as an emulsifier (EFSA, 2013). Furthermore, Cho *et al*. (2012) demonstrated that supplementation with 0.05% SSL improved the growth performance and relative organ weight in broiler chickens fed on a low-energy reduced diet. Diacylglycerols (DAGs) are important amphiphilic emulsifiers and surfactants that are widely used in food, pharmaceutical and cosmetic industries (Wang *et al*., 2015). 1, 3- DAG consists of 70% medium-chain fatty acids (MCFA) and 30% long-chain fatty acids, of which, MCFA are easily absorbed by the body due to their short chain length. As emulsifiers, DAGs have synergistic effects with monoacylglycerol (Phuah *et al*., 2015). Most previous studies have evaluated the effects of single exogenous emulsifier supplementation in livestock diets, whereas the evaluation of emulsifier blend supplementation with different dietary energy content is limited. Boyd *et al*. (1971) reported that a suitable combination of emulsifiers could enhance stability relative to an individual emulsifier. Therefore, we hypothesized that SSL and 1, 3- DAG, when used together as an exogenous emulsifier blend, might have a beneficial effect on the performance of broiler chickens fed on low-energy diet.

Therefore, the objective of the present study was to evaluate the effect of addition of SSL and 1, 3- DAG as an emulsifier blend in diets with different energy content on the growth performance, meat quality, apparent total tract digestibility, and blood profiles of broiler chickens.

Materials and Methods

Experimental protocols describing the management and care of animals were reviewed and approved by the Animal Care and Use Committee of Dankook University (Approval No. DK-1-1731), Republic of Korea.

Tested Product

The tested product, sodium stearoyl-2-lactylate, comprised 95% sodium stearoyl-2-lactylate, and about 5% starch, which was supplied by a commercial company (Il Shin Wells, Seoul, Korea). 1,3-diacylglycerol (55%) mixed with a carrier was obtained from a commercial company (Il Shin Wells, Seoul, Korea). It consisted of 70% medium-chain triglycerides and 30% long-chain triglycerides. According to the manufacturer's information, the fatty acid profile of the tested product comprises lauric, capric, and myristic + palmitic acids, at a ratio of 50:20:30, respectively. The crude fat of the product consisted of monoacylglycerol, diacylglycerol, and triacylglycerol, at a ratio of 20:60:20, respectively.

Experimental Design, Animals, and Diets

A total of 1024 male broiler chickens (1-d-old, Ross 308) were obtained from a commercial hatchery. Broiler chickens of similar body weight (43.60±0.2 g) were randomly distributed into four groups (256 birds in 16 cages per treatment, 16 birds per cage). The broiler chickens were housed in a temperature-controlled room with 3 floors of stainless steel battery cages (124 cm－[width]×64 cm－[length]×40 cm －[height]), which allowed them free access to feed and water during the experimental period. They were kept under a light regimen of 22L: 2D for the entire 35-d period. The ambient temperature was maintained at 33℃ for the first week and then gradually reduced to 20℃ by the fifth week. The relative humidity was gradually increased from 60% (d 1 to 21) to 70% (d 22 to 35).

The broiler chickens were fed a corn/soybean-based basal diet for 35 d, divided into 3 phases: Phase 1 (d 1 to 7), Phase 2 (d 8 to 21), and Phase 3 (d 22 to 35) (Table 1). The experimental diets, provided in a mashed form, were formulated to meet and exceed the nutrients requirements specified by NRC (1994). The treatments were arranged in a 2×2 factorial, with two levels of energy (normal energy diet or reduced energy diet) and with or without an emulsifier blend (SSL, 0.05%; 1, 3- DAG, 0.10%).

Experimental Procedure, Sampling, and Assay

Growth Performance

Body weight (BW) and feed intake (FI) per cage were recorded on d 7, 21, and 35, and the feed conversion ratio (FCR) was calculated as the feed intake divided by the body weight gain (BWG). Mortality was recorded daily, and percentage mortality was calculated throughout the study.

Meat Quality and Relative Organ Weight

For physicochemical properties of the breast meat, one bird per pen ($n=16$) from each treatment was killed by cervical dislocation after collection of blood sample. Immediately after the birds were killed, organs such as the gizzard, breast meat, bursa of Fabricius, liver, spleen, and abdominal fat were removed by trained personnel and weighed. The weight of collected organs was expressed as a percentage of body weight. The Hunter CIE lightness (L*), redness (a*), and yellowness (b*) values for breast muscle were determined using a Minolta CR410 chromameter (Konica Minolta Sensing Inc., Osaka, Japan), while duplicate pH values for breast muscle in each sample were measured using a pH meter (Fisher Scientific, Pittsburgh, PA, USA). The water-holding capacity (WHC) was analyzed according to the method described by Kauffman *et al*. (1986). Drip loss was measured using approximately 2 g of meat sample, following the plastic bag method described by Honikel (1998).

Apparent Total Tract Digestibility

To determine the apparent total tract digestibility (ATTD), 0.2% chromic oxide was added to the experimental diets, d 7 prior to the collection period. Excreta were collected daily until d 7 of the experiment, and a representative sample was stored in a freezer at －20℃ until analysis. For analysis, the sample was dried in a 60℃ oven for 72 h, following which it was pulverized to pass through a 1-mm screen. Subsequently, the dry matter (DM), nitrogen (N), calcium (Ca), and phosphorus (P) content in the diets and excreta were analyzed (methods 934.01, 968.06, 984.01, and 965.17, respectively; AOAC, 2000). Fat content in the excreta was determined using a standard procedure (method 954.02; AOAC International, 2005). The samples were first hydro-

Table 1. **Ingredient composition of experimental diets as-fed basis**

	Starter[1]		Grower[1]		Finisher[1]	
	0	−100	0	−100	0	−100
Ingredient, %						
Corn	49.67	51.73	56.31	59.15	63.74	65.50
Rice	—	3.4	—	—	—	—
Soybean meal, 45%	34.57	33.55	25.21	24.76	16.95	17.39
Corn gluten meal	0.87	—	—	—	—	—
Sesame Meal	—	—	2	2	2	2
DDGS, Corn	3	3	5	5	5	5
Meat meal, 60%	2.0	3.0	3.0	3.0	5.0	4.5
Yellow grease	5.6	1.0	4.5	2.1	3.8	2.0
Limestone	1.07	1.19	0.87	0.87	0.70	0.76
Mono-dicalcium phosphate	1.64	1.53	1.27	1.27	1.05	1.09
Salt	0.33	0.31	0.24	0.24	0.19	0.21
$NaHCO_3$	—	—	—	—	0.02	0.01
DL-Methionine, 99%	0.38	0.39	0.39	0.39	0.36	0.35
L-lysine, 50%	0.54	0.57	0.73	0.74	0.73	0.73
Threonine, 98.5%	—	—	0.18	0.18	0.16	0.16
Vitamin premix[2]	0.1	0.1	0.1	0.1	0.1	0.1
Choline, 50%	0.13	0.13	0.10	0.10	0.10	0.10
Mineral premix[3]	0.1	0.1	0.1	0.1	0.1	0.1
Chemical composition, %[4]						
CP	22.5	22.5	20.5	20.5	18.5	18.5
ME, kcal/kg	3050	2950	3149	3051	3248	3150
CA	1.0	1.0	0.9	0.9	0.9	0.9
P	0.7	0.8	0.7	0.7	0.7	0.7
Lys	1.5	1.5	1.4	1.4	1.2	1.2
Met + Cys	1.1	1.1	1.0	1.0	0.9	0.9

[1] Starter phase, d 0–7; Grower phase, d 7–21; and finisher phase, d 21–35.
[2] Provided per kg of complete diet: 11,025 IU vitamin A, 1,103 IU vitamin D3, 44 IU vitamin E, 4.4 mg vitamin K, 8.3 mg riboflavin, 50 mg niacin, 4 mg thiamine, 29 mg d-pantothenic, 166 mg choline, and 33 μg vitamin B12.
[3] Provided per kg of complete diet: 12 mg Cu (as $CuSO_4 \cdot 5H_2O$), 85 mg Zn (as $ZnSO_4$), 8 mg Mn (as MnO_2), 0.28 mg I (as KI), 0.15 mg Se (as $Na_2SeO_3 \cdot 5H_2O$).
[4] Calculated values.

lyzed using hydrochloric acid and transferred to tubes. Crude fat was extracted by a mixture of diethyl ether and petroleum ether. The solvents were then decanted into a preweighed conical flask, and evaporated by placing the flask on a steam bath, followed by drying in the oven at 100℃ for 90 min. After thawing, the weight of the flask with fat was recorded and the fat content was calculated. Energy was determined using a Parr 6100 oxygen bomb calorimeter (Parr Instrument Co., Moline, IL, USA) and N was measured using a Kjeltec 2300 analyzer (Foss Tecator AB, Hoeganaes, Sweden). Chromium concentration was determined by atomic absorption spectrophotometry (UV-1201, Shimadzu, Kyoto, Japan) following the method described by Williams *et al.* (1962). The equation for calculating digestibility was as follows:

$$ATTD\ (\%) = (\{1 - [(Nf \times Cd / Nd \times Cf)]\}) \times 100$$

where, Nf = nutrient concentration in feces (% DM), Nd = nutrient concentration in diet (% DM), Cd = chromium concentration in diet (% DM), and Cf = chromium concentration in feces (% DM).

Blood Lipid Profiles

At the end of the experiment (35 d), blood samples were collected from the left wing vein in vacuum tubes (Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ), and stored at 4℃. For serum analysis, blood samples (approximately 3 mL) were centrifuged at 4,000 × *g* for 15 min at 4℃, to separate the serum. The total cholesterol, high density lipoprotein (HDL), low density lipoprotein (LDL), and triglyceride content in the serum samples were analyzed with an autoanalyzer (Advia 120, Bayer, Tarrytown, NY, USA) using commercial kits (MAK043, MAK045, and TR0100, Sigma Diagnostics, MO, USA) according to the manufacturer's protocol.

Statistical Analysis

The data were analyzed as a completely randomized 2 × 2 factorial design, using a mixed model in SAS (SAS Institute, 2002), with the cage as the experimental unit. The data were tested for the main effects of emulsifier blend and energy content, as well as their interaction. The significance level was set at $P < 0.05$, whereas $0.05 < P < 0.10$ was considered to present a trend.

Table 2. **Effect of dietary emulsifier blend supplementation on the growth performance in broiler chickens[1]**

Energy	High energy		Low energy		SEM	P-value		
EB[2]	−	+	−	+				
Items	CON	TRT1	NC1	TRT2		Energy	EB[2]	E×EB
Body weight, g								
initial	43.64	43.51	43.59	43.64	0.16	0.8318	0.8088	0.5712
finish	1704[b]	1769[a]	1646[c]	1729[b]	11.46	0.0006	<.0001	0.5061
d 1–7								
BWG[2], g	133[ab]	138[a]	125[c]	129[bc]	2.41	0.0007	0.0647	1.0000
FI[2], g	157	158	159	160	3.13	0.4772	0.6595	0.8476
FCR[2]	1.175[b]	1.152[b]	1.286[a]	1.252[ab]	0.04	0.0032	0.4028	0.8682
d 7–21								
BWG, g	547[ab]	564[a]	531[b]	556[ab]	8.73	0.1941	0.0229	0.6986
FI, g	767	769	772	772	8.40	0.6481	0.9398	0.9112
FCR	1.412[ab]	1.367[b]	1.457[a]	1.391[ab]	0.03	0.1835	0.0348	0.6695
d 21–35								
BWG, g	980[b]	1023[a]	946[c]	1000[ab]	11.98	0.0372	0.0005	0.6893
FI, g	1703	1715	1718	1722	8.61	0.2389	0.3958	0.6704
FCR	1.741[b]	1.680[b]	1.823[a]	1.725[b]	0.02	0.0137	0.0023	0.4619
Overall								
BWG, g	1660[b]	1725[a]	1603[c]	1685[b]	11.46	0.0006	<.0001	0.5141
FI, g	2627	2642	2649	2653	12.47	0.2198	0.4864	0.6966
FCR	1.583[b]	1.533[c]	1.655[a]	1.576[b]	0.01	0.0004	<.0001	0.3419

[1] Each mean represents values from 16 replicates (16 birds /replicate).
[2] EB, emulsifier blend; BWG, body weight gain; FI, feed intake; FCR, feed conversion ratio.
[a, b, c] Means in the same row with different superscripts differ significantly from each other ($P<0.05$).

Table 3. **Effect of dietary emulsifier supplementation on the meat quality in broiler chickens[1]**

Energy	High energy		Low energy		SEM[3]	P-value		
Emulsifier[2]	−	+	−	+				
Items	CON	TRT1	NC1	TRT2		Energy	EB	E×EB
pH value	5.65	5.55	5.65	5.58	0.05	0.8207	0.1584	0.8615
Breast muscle color								
Lightness (L*)	52.37	52.10	51.37	52.84	0.88	0.8791	0.4962	0.3237
Redness (a*)	11.16	10.40	11.11	10.67	0.46	0.8102	0.2024	0.7281
Yellowness (b*)	7.43	7.40	7.50	7.55	0.24	0.6144	0.9682	0.8664
Cooking loss, %	33.82	33.29	33.79	33.26	2.69	0.9913	0.8360	0.9997
WHC, %	54.73	56.94	54.94	55.81	2.12	0.8440	0.5119	0.7760
Drip loss, %								
d 1	2.60	2.71	2.77	2.69	0.25	0.7605	0.9624	0.6901
d 3	5.63	5.58	5.54	5.62	0.43	0.9637	0.9735	0.8702
d 5	8.29	8.02	8.61	8.08	0.28	0.4845	0.1496	0.6396
d 7	10.31	10.03	10.53	10.22	0.17	0.2280	0.0816	0.9192
Relative organ weight, %								
Breast muscle	19.21	19.29	19.20	19.24	0.70	0.9680	0.9218	0.9751
Liver	2.71	2.80	2.75	2.77	0.11	0.9676	0.6498	0.7764
Bursa of Fabricius	0.11	0.12	0.11	0.12	0.01	0.7516	0.2621	0.7516
Abdominal fat	3.20	3.17	3.21	3.18	0.11	0.8948	0.7739	0.9745
Spleen	0.13	0.14	0.13	0.16	0.01	0.3186	0.2052	0.4687
Gizzard	1.09	1.12	1.17	1.11	0.07	0.6407	0.8040	0.5123

[1] Each mean represents values from 16 replicates (16 birds /replicate).
[2] EB, emulsifier blend.
[3] Standard error of means.

Table 4. **Effect of dietary emulsifier blend supplementation on the apparent total tract digestibility in broiler chickens[1]**

Energy	High energy		Low energy		SEM[3]	P-value		
EB[2]	−	+	−	+				
Items, %	CON	TRT1	NC1	TRT2		Energy	EB[2]	E×EB
Dry matter	70.85	71.54	70.58	71.33	0.55	0.3664	0.3552	0.9947
Nitrogen	69.24	70.20	69.20	69.76	0.62	0.6944	0.4852	0.7912
Energy	70.39[a]	70.55[a]	68.05[b]	70.63[a]	0.58	0.0530	0.1063	0.1046
Fat	79.83[a]	80.97[a]	77.55[b]	79.94[a]	0.67	0.0358	0.0259	0.4078

[1] Each mean represents values from 16 replicates (16 birds /replicate).
[2] EB, emulsifier blend.
[3] Standard error of means.

Table 5. **Effect of dietary emulsifier blend supplementation on the blood lipid profile in broiler chickens[1]**

Energy	High energy		Low energy		SEM[3]	P-value		
EB[2]	−	+	−	+				
Items[2], mg/dL	CON	TRT1	NC1	TRT2		Energy	EB	E×EB
Cholesterol	143	147	140	142	5.49	0.4202	0.5481	0.8033
Triglyceride	81	85	88	84	6.45	0.7054	0.9665	0.5570
HDL/C	100	104	103	105	3.46	0.5755	0.2800	0.7415
LDL/C	39	36	38	34	3.29	0.6556	0.2499	0.8723

[1] Each mean represents values from 16 replicates (16 birds /replicate).
[2] EB, emulsifier blend; HDL/C, high density lipoprotein cholesterol; LDL/C, low-density lipoprotein cholesterol.
[3] Standard error of means.

Results

Growth Performance

The effects of dietary treatment on growth performance are presented in Table 2. Broiler chickens fed the diet with emulsifier blend supplementation presented a higher BWG during d 7–21, d 21–35, and overall period ($P<0.05$), as well as an increased tendency of BWG during d 1–7 ($P<0.10$). We also observed a higher BW during overall period ($P<0.05$), and a lower FCR during d 7–21, d 21–35, and overall period ($P<0.05$). Broiler chickens fed on the low-energy content diet had a lower BWG during d 1–7, d 21–35, and overall period ($P<0.05$), lower BW during overall period, as well as higher FCR during d 1–7, d 21–35, and overall period ($P<0.05$), than the chickens fed the high-energy content diet. However, no difference in FI was observed among treatments during any of the periods ($P>0.10$). No interactive effect on growth performance was observed among treatments ($P>0.10$).

Meat Quality and Relative Organ Weight

The breast muscle color, cooking loss, WHC, drip loss, and the relative weight of breast muscle, liver, bursa of Fabricius, abdominal fat, spleen, and gizzard were not affected by the emulsifier blend or energy content among treatments. However, drip loss at 7 d post slaughter tended to decrease in response to dietary emulsifier blend supplementation ($P<0.10$). No interaction between emulsifier blend and energy content was observed on meat quality and relative organ weight (Table 3).

Apparent Total Tract Digestibility

The effects of dietary treatment on ATTD are presented in Table 4. In the current study, emulsifier blend supplementation and energy content had no significant main effects or interactive effects on the ATTD of DM, N, and energy ($P>0.05$). However, a higher ($P<0.05$) ATTD for fat was observed in response to emulsifier blend supplementation, and a lower ($P<0.05$) ATTD for fat was observed in response to low-energy content diet. Furthermore, the ATTD of energy tended to decrease in response to low-energy content diet ($P<0.10$).

Blood Lipid Profiles

The effects of dietary treatments on the blood lipid profiles are presented in Table 5. In the current study, emulsifier blend supplementation and energy content had no significant main effects or interactive effects on the blood lipid profile ($P>0.05$).

Discussion

Interactive Effects between Emulsifier Blend Supplementation and Dietary Energy Content

In the current study, no interactive effects between emulsifier blend supplementation and dietary energy content were observed on the growth performance, apparent total tract digestibility, and blood lipid profiles of broiler chickens. This is similar to the results of previous studies, which also reported the absence of an interactive effect between emulsifier and dietary energy content on growth performance, nutrient digestibility, blood lipid profiles, meat quality and relative organ weight (Upadhaya *et al*., 2016; Zhao and Kim, 2017). The exact reason for this is unknown. Therefore, further studies should be conducted to evaluate the effect of interaction between emulsifier blend supplementation and dietary energy content.

Effects of Emulsifier Blend Supplementation

Previous studies demonstrated that exogenous emulsifiers have beneficial effects in livestock as diet supplements (Roy *et al*., 2010; Zhao *et al*., 2015; San *et al*., 2016; Upadhaya *et al*., 2016). Owing to the lack of data on the use of SSL and 1, 3- DAG emulsifier blend supplementation in broiler chickens, we had to draw a comparison with studies that used other emulsifiers. The current results indicated that the emulsifier blend improved the BWG and decreased the FCR. These results are in agreement with those of Upadhaya *et al.* (2017), who reported that BWG of broiler chickens fed diets supplemented with the SSL and Tween 20 blend linearly increased with increasing concentration of the blend. Furthermore, Ali *et al*. (2017) demonstrated that chicks fed on diet with low-energy content diet and 0.05% SSL had a greater daily weight gain and FCR compared with those fed diets without SSL, during week 1–3. The positive effects of SSL may be due to the improved synthesis and recirculation of bile salts, which would improve the fat digestion capacity of chicks. In addition, Upadhaya *et al.* (2016) indicated that there was no effect of 1, 3- DAG supplementation with low-energy content diet on the BWG and FCR during week 3–5. Ali *et al.* (2017) showed that there was no effect of SSL supplementation with low-energy content diet on the FCR during week 3–6. In contrast, the results of this study showed positive effects of emulsifier blend supplementation on the BWG and FCR of starter, grower, as well as finisher broiler chickens. This lends supported to the hypothesis that emulsifier blends are more stable than individual emulsifiers, thus, making them a more suitable supplement for improving the growth performance of broiler chickens. Emulsifier blend compensation may cause an energy reduction without reducing the growth parameters, thus, reducing the feed cost.

Previous studies demonstrated that the drip loss is an important factor affecting meat quality traits, because some nutrients may be lost in the exudates by water loss, which is reflected in a loss of juiciness, tenderness, or flavor of the meat (Chen *et al*., 2012). In the current study, drip loss at 7 d post-slaughter tended to decrease in response to emulsifier blend supplementation in diet, although the underlying mechanisms for this are unknown. Emulsifiers can promote the intestinal absorption of fat, accelerate the circulation of lipids in the body, and promote the conversion of fat into body components (Zhang, 2010). Moreover, the fat content can affect the drip loss of meat. Therefore, the decreased drip loss in current study, owing to the addition of emulsifier blend, may be related to an improvement in fat absorption. Further studies are needed to determine the mechanism of meat quality improvement in broiler chickens due to emulsifier blend supplementation.

Dietary supplementation with emulsifier blend had no significant effects on the ATTD of DM, N, and energy. The mechanism of action of emulsifier blend could not be clearly established. However, in agreement with our results, Soares and Lopez-Bote (2002) had reported that lecithin did not cause differences in the DM, crude protein, and crude fiber digestibility. Nevertheless, the results are rather inconsistent across studies. For instance, some studies have reported that dietary supplementation with emulsifiers has positive effects on ATTD in livestock (Dierick *et al*., 2004; San *et al*., 2016; Li *et al*., 2017). In general, emulsifiers can promote the formation of emulsified droplets via reduction in the surface tension, stimulate the formation of micelles, increase the concentration of monoglycerides in the intestine, and promote nutrient transport through the membrane, for better absorption and utilization of energy (Yordan *et al*., 2013). In addition, each type of exogenous emulsifiers may have a different effect on intestinal digestion (Jones *et al*., 1992). The lack of improvement in the ATTD of DM, N, and energy in the present study may be associated with the type or concentration of the emulsifier blend used. In our study, the ATTD of fat in broiler chickens fed on emulsifier blend diets was found to be increased. This agrees with the results from our previous studies using different emulsifiers such as 1, 3 diacylglycerol, SSL and Tween 20 blend, and lysophospholipid; we also observed an improvement in fat digestibility when a basal diet was supplemented with emulsifiers in broilers and weaning pigs (Zhao *et al*., 2015; Upadhaya *et al*., 2016; Upadhaya *et al*., 2017). It is likely that supplementation with emulsifiers leads to better emulsified oil-in-water lipids in the intestine, thus, enhancing the fat absorption in broiler chickens. The improved fat digestibility, in turn, may also explain the positive effect of emulsifier blend supplementation on growth performance, as observed in the current study.

Blood profile concentrations, such as total cholesterol, triglyceride, HDL, and LDL, can be used to assess the glucose and lipid N metabolism (Hosoda *et al*., 2006). In the current study, cholesterol, triglyceride, HDL, and LDL were not affected by dietary emulsifier blend supplementation. In agreement with our results, Zhao *et al*. (2015) indicated that the addition of emulsifier had no effect on the total cholesterol, HDL, and triglyceride levels. Likewise, Yordan *et al*. (2013) reported that the LDL, HDL, cholesterol, and triglyceride concentrations in broiler chicks were not affected by exogenous emulsifier supplementation. Furthermore, Wang *et al*. (2016) did not indicate any difference in serum triglyceride, total cholesterol, HDL, and LDL concentrations of broiler chickens on d 35 of SSL supplementation in low-energy content treatments. On the contrary, Cho *et al*. (2012) claimed that broiler chickens fed on a diet containing 0.05% emulsifier (SSL) had lower serum triglyceride levels compared with those fed with high-energy content diet without emulsifier. In addition, Roy *et al*. (2010) reported that supplementation of an emulsifier led to a decrease in the LDL and total cholesterol concentrations in broiler chickens on d 20 but showed no differences on d 39. The inconsistency across the results of individual studies can be explained by differences in the type of emulsifier blend used, and the age of the broiler chickens. The mechanism by which emulsifier blend supplementation in broiler chicken diet influences lipid profile is still unclear. The use of emulsifier blend to modulate lipid metabolism in poultry needs to be investigated further.

Effect of Energy Content

In the present study, although the difference in energy content between the normal and low-energy content diet was only reduced 100 kcal/kg, feeding the broiler chickens with normal dietary energy content led to a higher finish BW and BWG, and lower FCR, than the low-energy content diet, during d 1–7, d 21–35, and overall period. In agreement with these results, Cho *et al*. (2012) reported that increased energy content improved the BWG of broiler chickens during d 0 to 21. Similarly, Suarez-Belloch *et al*. (2013) indicated that increasing the dietary energy content reduced the FCR in finishing pigs. Generally, low-energy content diet can lead to a depression of growth performance. However, Upadhaya *et al*. (2016) reported that decreasing the dietary energy content depresses the growth performance in broiler chickens, indicated as reduced FI. On the contrary, no effects on FI were observed between normal and low-energy content diet in any of the phases. We hypothesize that the inconsistent results are due to the ability of broiler chickens to adjust and maintain a constant voluntary energy intake over a wide range of dietary energy concentrations, except during the first week of age (Leeson *et al*., 1996).

The current findings showed that the ATTD of energy and fat was reduced due to low-energy content diet. Similarly, Upadhaya *et al*. (2016) reported a reduction in the digestibility of energy and fat in broilers fed on energy-reduced diet. Lei *et al*. (2017) reported that high-energy diets (inclusion of 3% soya bean oil) improved the ATTD of gross energy in growing pigs. The energy provided by the diet is mainly used for maintenance and reproduction in animals. When broiler chickens were supplied with the reduced energy diet, the energy was first used for maintenance. Therefore, the reduced energy and fat digestibility may be due to the fact that lower energy intake led to a lower absorption of fats in the digestive tract of broiler chickens. The ATTD of DM and N were not significantly different compared with the basal diet in this study, in agreement with the results of Zhao and Kim (2017), who reported that the ATTD of DM and N were not affected by energy. Conversely, previous studies showed that low-energy content diet decreased the DM digestibility in broilers (Cho and Kim, 2013). This discrepancy in results could be due to different types of fat, and the strain and age of broilers (Ding *et al.,* 2003).

Furthermore, dietary energy content had no effect on the lipid profile, meat quality, and relative organ weight of broiler chickens. Similar results were observed by Zhao and Kim (2017), who reported that on d 14, the concentrations of HDL, LDL, total cholesterol, and triglycerides were not affected by energy. The fat source type and levels could be a possible reason for the insignificant effect on lipid profiles. Additionally, Upadhaya *et al*. (2016) showed that low-energy content diets did not have any effect on meat quality compared with basic diet. Therefore, it could be concluded that low-energy content diet had no significant adverse effect on meat quality parameters relevant to consumer acceptability. The detailed functioning mechanism of energy on the lipid profile, meat quality, and relative organ weight was unclear, which needs to be investigated in future studies.

In conclusion, the results indicated an increase in BW and BWG, and a reduction in FCR and drip loss, at 7 d post slaughter in broiler chickens administered a dietary emulsifier blend. Low-energy content diet was found to reduce the BW, BWG, and ATTD of energy, and increase the FCR of broiler chickens. The provision of emulsifier blend was enough to overcome the reduction in growth performance due to low-energy content diet in broiler chickens. Further research is needed to determine the underlying mechanisms of action of emulsifier blend supplementation in broiler chicken diets.

Conflict of Interest

We confirm that there are no conflicts of interest associated with this publication.

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