Effects of metabolizable energy and emulsifier supplementation on growth performance, nutrient digestibility, body composition, and carcass yield in broilers

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ABSTRACT This study aimed to investigate the effect of metabolizable energy (**ME**) levels and exogenous emulsifier supplementation on growth performance, apparent ileal digestibility (**AID**), body composition, and carcass yield in broilers. The experiment was designed as a 2 × 2 factorial arrangement with ME levels (control ME vs. reduced 100 kcal/kg ME) and exogenous emulsifier supplementation (0 vs. 0.05 %). A total of 1,000 one-day-old male Cobb 500 broilers were randomly allocated into 4 treatments with 10 replicates and 25 birds per floor pen for 42 d (starter, d 0−14; grower, d 14−28; and finisher, d 28−42). Growth performance was measured biweekly, and AID was evaluated using the indigestible indicator method during d 21 to 28. Body composition was measured at d 35 using Dual-Energy X-Ray Absorptiometry (**DXA**), and carcass yield was evaluated at d 42. Data were analyzed using the GLM procedure for 2-way ANOVA. Results indicated reduced ME decreased body weight gain and feed intake ($P < 0.05$). Exogenous emulsifier supplementation improved FCR during the finisher and overall periods ($P < 0.05$). Reduced ME decreased AID of dry matter (**DM**), fat, and gross energy ($P < 0.05$) but increased AID of Val ($P = 0.013$). Exogenous emulsifier supplementation increased AID of DM, crude protein, His, Ile, Lys, Thr, Val, Pro, Ala, and Tyr ($P < 0.05$). Reduced ME decreased dressing rate and the relative weight of abdominal fat ($P < 0.05$). DXA results indicated that reduced ME decreased bone mineral density and fat ($P < 0.001$) but increased bone mineral contents and muscle ($P < 0.05$). Therefore, a reduction of 100 kcal/kg ME in the diet had adverse effects on the growth performance and carcass characteristics, but the use of exogenous emulsifier supplementation improved growth performance and nutrient digestibility.

Key words: broiler, emulsifier, digestibility, DXA, growth performance

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INTRODUCTION

Reducing the cost of poultry production while producing high-quality products is a long-standing task in the poultry industry. Optimizing nutrient utilization of feed further contributes to efficient and sustainable poultry production (Maharjan et al., 2021). In general, the benefits of emulsifier supplements have been primarily attributed to enhancing fat digestibility (Siyal et al., 2017). Therefore, exogenous emulsifiers can be considered potential feed supplements to improve dietary energy utilization and maintain efficient productivity in broilers.

Natural or synthetic emulsifiers such as bile salt, lecithin, sodium stearoyl lactylate, glycerol stearate, diacylglycerol, phospholipid, and sorbitan esters have been applied in poultry as a single or blended form of exogenous emulsifiers (Siyal et al., 2017; Chen et al., 2019; Ge et al., 2019; Saleh et al., 2020; Wang et al., 2020). Recent studies have been focusing on the evaluation of emulsifiers for improving metabolizable energy (**ME**) in the poultry diet. The application of exogenous emulsifiers in low ME diets has shown partial or full improvement in growth performance, nutrient digestibility, and carcass yield (Raju et al., 2011; Zhang et al., 2011; Wang et al., 2016; Zhao and Kim 2017; Papadopoulos et al., 2018; Chen et al., 2019; Wang et al., 2020). The ameliorative effect of emulsifiers in poultry has been explained by improving ME in diet and involving lipid metabolism (Roy et al., 2010; Jansen 2015; Zhao and Kim 2017; Wang et al., 2020).

Body growth and carcass yield were affected not only by dietary energy but also by the complex metabolism

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of other nutrients such as protein and amino acids, which were fundamental sources for muscle growth. Few studies reported that exogenous emulsifiers positively impacted nitrogen retention in broilers (Jansen et al., 2015; Zhao and Kim 2017). This evidence may imply that amphipathic exogenous emulsifiers in the intestine interact with protein and hydrophobic amino acids derived from diets. However, limited information on the interaction between emulsifiers and protein or amino acids in the digestive mechanism is available. In addition, for the accurate evaluation of the interaction between emulsifiers and a variety of nutrients, body compositions can provide us with further understanding of the mode of action of emulsifier impact in poultry. Therefore, the objective of this study was to evaluate the effect of ME levels and emulsifier supplementation on growth performance, apparent ileal digestibility (**AID**), body composition, and carcass yield in broilers.

MATERIALS AND METHODS

The experiment was approved by Institutional Animal Care and Use Committee in the University of Georgia (A2019 07-005).

Experimental Design, Birds, Management, and Experimental Diets

A total of 1,000 one-day-old Cobb500 male broiler chicks (45.97 ± 0.06 g) were obtained from a commercial hatchery (Cleveland, GA) and randomly allocated into 40 floor pens in a 2 × 2 factorial arrangement of treatments which included 10 replicated pens (25 birds per pen). The main factors included two ME levels [control (Cobb 500 recommendation): starter, 2,980 kcal/kg; grower, 3,025 kcal/kg; finisher, 3,100 kcal/kg and 100 kcal/kg ME reduction of control] and two emulsifier supplementation levels (0 and 0.05%). Feeding phases in this study included starter (d 0−14), grower (d 14−28), and finisher (d 28−42).

Each floor pen was equipped with nipples, feeders, and sawdust as bedding material. All birds were provided feed and water ad libitum. Temperature, humidity, and light and dark cycle in the house were controlled by an automatic environment management system following Cobb management guide (Cobb-Vantress, 2018a) during the whole experimental period.

The formulation and nutrient contents of basal diets used in this study are presented in Table 1. The control ME basal diets were formulated to meet or exceed the

Table 1. Diet formulation and calculated nutrient composition.[1]

	Starter (0−14 d)		Grower (14−28 d)		Finisher (28−42 d)	
Items	Control	Reduced	Control	Reduced	Control	Reduced
Ingredients, %						
Corn	54.22	53.35	59.48	57.86	61.19	60.31
Soybean meal, 48%	33.79	33.81	28.78	28.87	26.65	26.67
DDGS	5.00	5.00	5.00	5.00	5.00	5.00
Dicalcium phosphate	1.51	1.52	1.40	1.39	1.19	1.19
Soybean oil	2.07	1.12	2.01	1.01	2.85	1.90
Limestone	1.20	1.20	1.16	1.15	1.08	1.07
Rice hulls	-	1.75	-	2.48	-	1.76
L-Lysine HCl	0.20	0.20	0.24	0.24	0.18	0.18
DL-Methionine	0.28	0.28	0.26	0.27	0.23	0.24
Common salt	0.30	0.30	0.30	0.35	0.30	0.35
Sand	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin Premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Threonine	0.09	0.09	0.05	0.05	-	-
Mineral Premix[3]	0.08	0.08	0.08	0.08	0.08	0.08
Sum	100.00	100.00	100.00	100.00	100.00	100.00
Calculated values						
DM, %	86.09	85.99	86.15	86.07	86.51	86.42
ME, kcal/kg	2,980	2,880	3,025	2,925	3,100	3,000
CP, %	22.00	22.00	20.00	20.00	19.00	19.00
EE, %	4.76	3.78	4.83	3.79	5.71	4.74
Ca, %	0.90	0.90	0.84	0.84	0.76	0.76
Total P, %	0.71	0.71	0.67	0.67	0.62	0.62
Available P, %	0.45	0.45	0.42	0.42	0.38	0.38
Digestible Lys, %	1.22	1.22	1.12	1.12	1.02	1.02
Digestible Met, %	0.61	0.61	0.57	0.57	0.53	0.53
Digestible Cys, %	0.30	0.30	0.28	0.28	0.27	0.27
Digestible. Met + Cys, %	0.91	0.91	0.85	0.85	0.80	0.80
Digestible Thr, %	0.83	0.83	0.73	0.73	0.66	0.66
Digestible Val, %	1.10	1.09	0.99	0.99	0.95	0.94
Digestible Ile, %	0.91	0.91	0.82	0.82	0.78	0.78
Digestible Arg, %	1.36	1.36	1.21	1.21	1.15	1.15
Digestible Typ, %	0.28	0.28	0.25	0.25	0.23	0.23

[1] Control ME diets (Cobb 500 standard ME), Reduced ME diets (100 kcal/kg ME reduction).

[2] Supplied per kilogram of diet: vitamin A, 5,511 IU; vitamin D3, 1,102 ICU; Vitamin E, 11.02 IU; vitamin B12, 0.01 mg; Biotin, 0.11 mg; Menadione, 1.1 mg; Thiamine, 2.21 mg; Riboflavin, 4.41 mg; d-Pantothenic Acid, 11.02 mg; Vitamin B6, 2.21 mg; Niacin, 44.09 mg; Folic Acid, 0.55 mg; Choline, 191.36 mg.

[3] Supplied per kilogram of diet: Mn, 107.2 mg; Zn, 85.6 mg; Mg, 21.44 mg; Fe, 21.04; Cu, 3.2 mg; I, 0.8 mg; Se, 0.32 mg.

nutrient specifications for Cobb500 (Cobb-Vantress, 2018b). However, the reduced ME basal diets were balanced with a 100 kcal/kg ME reduction between corn and soybean oil in a ratio of 50:50. After producing basal diets as mash form, the emulsifier was added into the diets at the level of 0.05%. The exogenous emulsifier used in this study contained sodium stearoyl lactylate, glycerol monostearate, and glycerol distearate and was provided by Ecolex Animal Nutrition (Lipo AMP, Selangor, Malaysia). Crumble diets were produced for the starter period, and pellet diets were used for grower and finisher periods.

Growth Performance

The average body weight (**BW**) of the birds in each pen was measured weekly. For calculating feed intake (**FI**), the weights of provided diets and leftovers in the feeder were also recorded weekly. The dead birds were monitored for adjusting FI daily. All the growth performance parameters in this study were presented according to the feeding phases.

Nutrient Digestibility

During d 21 to 28, Cr_3O_2 was added at 0.3% in all of the treatment diets as an indigestible indicator for determining AID of dry matter (**DM**), crude protein (**CP**), fat, and gross energy (**GE**). At d 28, five birds were randomly selected from each pen, weighed, and euthanized by CO_2 gas. Ileal digesta from 5 selected birds were pooled by pen and lyophilized to analyze the nutrients. Lyophilized digesta and diet samples were ground by a small grinder and stored at −20°C before analysis. The Cr_3O_2 concentration in digesta and diet samples was determined following the method described by Dansky and Hill (1952). GE in digesta and diets were measured by a bomb calorimeter (IKA Calorimeter C1; IKA Works Inc, Wilmington, NC). The analyses for CP and fat concentrations in digesta and diets were conducted by the Agricultural and Environmental Services Laboratories at the University of Georgia following the method described by AOAC (2006). The analysis for the amino acid profile in digesta and diets was performed by the Agricultural Experiment Station Chemical Laboratory at the University of Missouri according to the AOAC (2006). All samples were duplicated, and the average values were used as an experimental unit.

The AID of nutrients was calculated using the following equation:

$$\textit{Apparent ileal digestibility}\ (\%) = \left[1 - \left(\frac{C_i}{C_o} \times \frac{N_o}{N_i}\right)\right] \times 100$$

Where Ci is Cr_3O_2 concentration (%) in the diet as DM basis; Co is Cr_3O_2 concentration (%) in the ileal digesta as DM basis; Ni is the nutrient concentration (%) in the diet as DM basis; No is the nutrient concentration (%) in the ileal digesta as DM basis.

Body Composition

At d 35, three birds/pen were randomly selected from each pen. These birds were weighed and euthanized by cervical dislocation. After euthanizing, Dual-Energy X-Ray Absorptiometry (**DXA**, GE Healthcare, Lunar technology, Madison, Wisconsin) scanning was performed to determine the bone mineral density (**BMD**), bone mineral content (**BMC**), and total body fat and muscle of the birds. Scanning and DXA data analysis by software (Lunar Prodigy from GE, encore software version 12.20.023) were conducted following the method described by Chen et al. (2020) and White et al. (2022). BMD, BMC, and total body fat and muscle were expressed as g/cm^2, g, and % of live BW, respectively. The body composition data collected from the 3 birds/pen was averaged and was considered as an experimental unit.

Carcass Yield

At the end of the trial, 5 birds per pen were randomly selected and individually received patagial wing tags for carcass yields. The slaughter process was conducted at the UGA Poultry Research Center Processing Plant (Athens, GA). Twelve h prior to processing, selected birds were withdrawn from feed and allowed only water. The live BW of selected birds was recorded individually before processing. After recording the live BW, birds were hung on shackles of the conveyor line and automatically stunned by electrocution, then slaughtered by trained personnel. All feathers on the skin were removed by a de-feathering and washing machine. The paws were removed, followed by evisceration. After weighing the hot carcasses, hot carcasses were chilled in water at 1°C for 4 h and then weighed to obtain cold carcass weights. Pectoralis major, pectoralis minor, wing, leg, and fat pad were separated by trained personnel and weighed for the carcass yield.

Statistics

Each pen (25 birds) was considered the experimental unit in this study. All experimental data were analyzed by SAS software (SAS version 9.3, SAS Ins., Cary, NC), and the GLM procedure was used for 2-way ANOVA. The model consisted of two levels of ME and two levels of emulsifier supplementation as main effects, and their interaction effects. Standard error of the means (**SEM**) indicates the variability of the date. For the significant interaction effects, means differences were separated using Tukey test. Statistical significance set at $P \leq 0.050$, and the tendency set at $0.050 < P \leq 0.100$ (Teng et al., 2021).

RESULTS

Growth Performance

There was a significant ME × emulsifier interaction effect detected for BWG of birds during the finisher period ($P = 0.01$) (Table 2). BWG of birds fed the reduced ME levels without emulsifier supplementation was significantly lower (1,641 g) compared to the BWG of birds fed reduced ME levels with emulsifier supplementation (1,781 g; $P = 0.001$). However, no significant interactions were detected for BWG of birds during the starter, grower periods and overall. Reduced ME decreased BWG compared to the control ME group during the starter, grower, and overall periods ($P < 0.01$). Emulsifier supplementation tended to increase BWG during the starter and overall periods however the P values were not significant. The interaction effect between the main factors (ME levels × emulsifier supplementation) was found in FI during the starter period ($P = 0.037$). The FI of birds fed the control ME levels without emulsifier supplementation was significantly higher (620 g) compared to the FI of birds fed the reduced ME diet without emulsifier supplementation (474 g; $P < 0.001$). However, there was no significant interaction for FI during the grower, finisher, and overall periods. Reduced ME decreased FI during the grower, finisher, and overall periods ($P < 0.001$). However, emulsifier supplementation did not affect FI during the whole experimental period. There were no significant interaction effects detected for FCR, therefore, only the main effects will be discussed. Reduced ME increased FCR during the start and grower periods ($P = 0.019$ and $P = 0.012$, respectively). The FCR tended to be increased in the control ME group compared to the reduced ME group, but it was not significant ($P = 0.073$). Emulsifier supplementation improved FCR during the finisher and overall periods ($P = 0.041$ and $P = 0.017$, respectively).

Nutrient Digestibility

There were no interaction effects between the main factors (ME levels × emulsifier supplementation) for AID of DM, CP, and GE (Table 3). Although not significant, there was a tendency for the interaction effect between the main factors (ME levels × emulsifier supplementation) for AID of fat ($P = 0.095$). Reduced ME decreased AID of DM ($P < 0.001$), fat ($P < 0.001$), and GE ($P = 0.028$) as compared to the control ME group. Emulsifier supplementation improved AID of DM ($P < 0.001$) and CP ($P = 0.001$). In addition, emulsifier supplementation had a tendency to increase AID of GE ($P = 0.082$), but was not significant.

A significant ME levels × emulsifier supplementation interaction effect was detected in the AID of Arg ($P = 0.027$) (Table 4); AID of Arg in the reduced ME group with emulsifier supplementation was higher than the AID of Arg in the reduced ME group without emulsifier supplementation (87.71 vs. 89.13 %; $P = 0.027$). Reduced ME increased AID of Val ($P = 0.013$). Emulsifier supplementation increased AID of His ($P = 0.005$), Ile ($P = 0.013$), Lys ($P = 0.001$), Thr ($P < 0.001$), and Val ($P = 0.007$). Emulsifier had a tendency to increase AID of Leu ($P = 0.062$), Met ($P = 0.062$), and Phe ($P = 0.051$).

Significant ME × emulsifier interactions were detected for AID of Asp, Ser, Gly, Cys, and Tyr ($P < 0.05$) (Table 5). AID of Asp and Gly in the reduced ME group with emulsifier supplementation was higher than AID of Asp and Gly in the reduced ME group without emulsifier ($P = 0.003$ and $P < 0.001$, respectively). AID of Ser, Tyr and Cys in the reduced ME group without

Table 2. Effect of ME levels and emulsifier supplementation on growth performance.

			BWG, g/bird				FI, g/bird				FCR			
Items	ME levels	Emulsifier	Starter	Grower	Finisher	Overall	Starter	Grower	Finisher	Overall	Starter	Grower	Finisher	Overall
	Control	−	481	1,236	1,842^{a}	3,560	620^{a}	1,917	3,026	5,562	1.29	1.55	1.65	1.56
	Control	+	500	1,273	1,798^{a}	3,570	638^{a}	1,972	2,905	5,515	1.28	1.55	1.62	1.55
	Reduced	−	348	985	1,641^{b}	2,974	474^{b}	1,565	2,678	4,717	1.36	1.59	1.63	1.59
	Reduced	+	351	993	1,781^{a}	3,125	456^{b}	1,579	2,656	4,691	1.31	1.60	1.50	1.50
SEM			1.829	3.613	3.163	7.317	2.157	4.945	5.698	11.616	0.002	0.001	0.003	0.002
Main effects														
ME levels														
	Control		491^{a}	1,255^{a}	1820	3,565^{a}	629	1,945^{a}	2,966^{a}	5,539^{a}	1.29^{b}	1.55^{b}	1.64	1.56
	Reduced		350^{b}	989^{b}	1711	3,050^{b}	465	1,572^{b}	2,667^{b}	4,704^{b}	1.34^{a}	1.60^{a}	1.57	1.55
Emulsifier supplementation														
		+	426	1,133	1,790	3,348	547	1,776	2,781	5,103	1.30	1.58	1.56^{b}	1.53^{b}
		−	415	1,111	1,742	3,267	547	1,741	2,852	5,140	1.33	1.57	1.64^{a}	1.58^{a}
P-values														
ME levels × Emulsifier			0.203	0.444	0.010	0.108	0.037	0.342	0.383	0.877	0.385	0.775	0.156	0.128
ME levels			<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	0.019	0.012	0.073	0.642
Emulsifier			0.085	0.230	0.170	0.066	0.995	0.115	0.206	0.589	0.124	0.924	0.041	0.017

BWG, body weight gain; FCR, feed conversion ratio; FI, feed intake; ME, metabolizable energy; SEM, standard error of mean.
Starter (d 0−14); Grower (d 14−28); Finisher (d 28−42); Overall (d 0−42).
Means with different superscripts (a and b) within the same column indicate significant differences ($P < 0.05$).

Table 3. Effect of ME levels and emulsifier supplementation on AID of DM, CP, and GE.

			AID, %			
Items	ME levels	Emulsifier	DM	CP	Fat	GE
	Control	–	71.02	77.55	92.80	75.08
	Control	+	72.13	79.52	90.99	78.52
	Reduced	–	69.31	77.82	86.90	73.88
	Reduced	+	70.98	80.36	88.38	74.51
SEM			0.228	0.349	0.588	0.617
Main effects						
ME levels						
	Control		71.58^{a}	78.54	91.90^{a}	76.80^{a}
	Reduced		70.14^{b}	79.09	87.64^{b}	74.20^{b}
Emulsifier supplementation						
		+	71.55^{a}	79.94^{a}	89.69	76.51
		–	70.16^{b}	77.68^{b}	89.85	74.48
P-values						
ME levels × Emulsifier			0.412	0.649	0.095	0.226
ME levels			<0.001	0.370	<0.001	0.028
Emulsifier			<0.001	0.001	0.866	0.082

AID, apparent ileal digestibility; DM, dry matter; GE, gross energy; ME, metabolizable energy; SEM, standard error of mean.
Means with different superscripts (a and b) within the same column indicate significant differences ($P < 0.05$).

Table 4. Effect of ME levels and emulsifier supplementation on AID of indispensable amino acids.

			AID of indispensable amino acids, %								
Items	ME levels	Emulsifier	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Val
	Control	–	88.70^{ab}	84.33	81.13	83.37	85.79	91.99	83.01	76.14	79.76
	Control	+	88.54^{ab}	84.78	81.51	83.62	86.74	92.11	83.17	77.27	80.42
	Reduced	–	87.71^{b}	83.87	81.16	82.39	85.72	91.51	82.22	74.78	80.31
	Reduced	+	89.13^{a}	85.95	83.41	84.23	87.51	92.67	84.12	78.01	82.51
SEM			0.183	0.236	0.285	0.28	0.215	0.172	0.268	0.327	0.294
Main effects											
ME levels											
	Control		88.62	84.55	81.32	83.49	86.27	92.05	83.09	76.7	80.09^{b}
	Reduced		88.42	84.91	82.29	83.31	86.61	92.09	83.17	76.39	81.41^{a}
Emulsifier supplementation											
		+	88.84	85.36^{a}	82.46^{a}	83.92	87.13^{a}	92.39	83.65	77.64^{a}	81.46^{a}
		–	88.21	84.10^{b}	81.15^{b}	82.88	85.75^{b}	91.75	82.61	75.46^{b}	80.04^{b}
P-values											
ME levels × Emulsifier			0.027	0.060	0.069	0.151	0.267	0.129	0.097	0.062	0.133
ME levels			0.566	0.403	0.062	0.738	0.358	0.899	0.882	0.571	0.013
Emulsifier			0.073	0.005	0.013	0.062	0.001	0.062	0.051	<0.001	0.007

AID, apparent ileal digestibility; ME, metabolizable energy; SEM, standard error of mean.
Means with different superscripts (a and b) within the same column indicate significant differences ($P < 0.05$).

Table 5. Effect of ME levels and emulsifier supplementation on AID of dispensable amino acids.

			AID of dispensable amino acids, %								
Items	ME levels	Emulsifier	Asp	Ser	Gly	Glu	Pro	Ala	Cys	Tyr	Trp
	Control	–	79.97^{b}	82.06^{a}	77.78^{b}	86.75	81.61	82.56	72.48^{abc}	82.92^{a}	85.00
	Control	+	80.19^{ab}	82.57^{a}	78.62^{ab}	86.74	82.15	83.36	73.38^{ab}	83.47^{a}	87.26
	Reduced	–	79.43^{b}	79.45^{b}	77.02^{b}	86.30	80.53	81.84	70.83^{c}	80.95^{b}	85.51
	Reduced	+	81.87^{a}	82.05^{a}	80.13^{a}	87.60	82.50	83.91	75.66^{a}	83.61^{a}	87.00
SEM			0.257	0.310	0.281	0.214	0.272	0.278	0.408	0.288	0.269
Main effects											
ME levels											
	Control		80.08	82.31	78.20	86.74	81.88	82.96	72.93	83.20	86.13
	Reduced		80.65	80.75	78.58	86.95	81.51	82.88	73.25	82.28	86.25
Emulsifier supplementation											
		+	81.03	82.31	79.38	87.17	82.32^{a}	83.63^{a}	74.52	83.54	87.13^{a}
		–	79.70	80.76	77.40	86.52	81.07^{b}	82.20^{b}	71.66	81.93	85.26^{b}
P-values											
ME levels × Emulsifier			0.016	0.046	0.015	0.124	0.169	0.224	0.003	0.037	0.410
ME levels			0.205	0.004	0.403	0.628	0.477	0.874	0.614	0.066	0.796
Emulsifier			0.005	0.004	<0.001	0.131	0.019	0.009	<0.001	0.002	<0.001

AID, apparent ileal digestibility; ME, metabolizable energy; SEM, standard error of mean.
Means with different superscripts (a, b, and c) within the same column indicate significant differences ($P < 0.05$).

Table 6. Effect of ME levels and emulsifier supplementation on body composition.

Items	ME levels	Emulsifier	BMD, g/cm^2	BMC, g	Muscle, %	Fat, %
	Control	–	0.169	24.51	81.07^{bc}	15.35^{ab}
	Control	+	0.176	25.33	80.65^{c}	15.79^{a}
	Reduced	–	0.161	20.54	82.61^{ab}	13.59^{bc}
	Reduced	+	0.159	19.43	83.21^{a}	13.19^{c}
SEM			0.002	0.037	0.269	0.293
Main effects						
ME levels						
	Control		0.173^{a}	24.92^{a}	80.86^{b}	15.57^{a}
	Reduced		0.160^{b}	19.96^{b}	82.91^{a}	13.39^{b}
Emulsifier supplementation						
		+	0.168	22.38	81.93	14.49
		–	0.165	22.53	81.84	14.47
P-values						
ME levels × Emulsifier			0.059	0.201	0.248	0.387
ME levels			<0.001	<0.001	<0.001	<0.001
Emulsifier			0.285	0.841	0.846	0.974

ME, metabolizable energy; SEM, standard error of mean.

Means with different superscripts (a and b) within the same column indicate significant differences ($P < 0.05$).

emulsifier supplementation was lower compared to the AID of Ser, Tyr, and Cys in the reduced ME group with emulsifier ($P < 0.01$). In addition, emulsifier supplementation increased AID of Pro, Ala, and Trp compared to 0 added emulsifier group ($P < 0.05$).

Body Composition

There was no significant ME × emulsifier effects for BMC, muscle, and fat from DXA (Table 6). Reduced ME decreased BMD and fat compared to the BMD and percent fat of birds fed the control ME diets ($P < 0.001$). However, the reduced ME diet increased BMC and muscle compared to the BMC and percent muscle of birds fed the control ME diets ($P < 0.001$).

Carcass yield

There were no significant ME × emulsifier effects for carcass characteristics parameters (Table 7). Reduced ME decreased dressing rate and the relative weight of abdominal fat compared to the dressing rate and abdominal fat from birds fed the control ME diets ($P = 0.033$ and $P < 0.001$, respectively). In addition, reduced ME increased the relative weight of legs and wings compared the weights of legs and wings from birds fed the control ME diets ($P = 0.002$ and $P = 0.046$, respectively).

DISCUSSION

In the broiler industry, using low-energy diets can save the production cost by modifying energy ingredients and supplementing emulsifiers. Therefore, this study was conducted to evaluate the effect of the emulsifier supplementation in low and normal energy diets on broiler performance, nutrient digestibility, body composition, and carcass yield.

Modification of nutrient density in the diet would be one of the practical strategies to maximize productivity in the broiler industry. In addition, finding proper ME

Table 7. Effect of ME levels and emulsifier supplementation on carcass yield.

					Relative weights (%)						
Items	ME levels	Emulsifier	HCW	CCW	Dressing rate	Breast	Major	Minor	Legs	Wings	AF
	Control	–	2,822	2,779	78.72	26.18	22.13	4.05	20.42	7.65	1.05
	Control	+	2,834	2,779	79.00	25.69	21.57	4.12	20.57	7.72	0.99
	Reduced	–	2,408	2,373	76.51	25.75	21.64	4.12	21.33	7.83	0.73
	Reduced	+	2,556	2,514	77.86	26.30	22.20	4.10	21.41	8.01	0.70
SEM			36.524	35.972	0.396	0.202	0.186	0.037	0.142	0.058	0.031
Main effects											
ME levels											
	Control		2,828^{a}	2,779^{a}	78.86^{a}	25.94	21.85	4.09	20.49^{b}	7.69^{b}	1.02^{a}
	Reduced		2,482^{b}	2,443^{b}	77.18^{b}	26.03	21.92	4.11	21.37^{a}	7.92^{a}	0.72^{b}
Emulsifier supplementation											
		+	2,695	2,646	78.43	26.00	21.89	4.11	20.99	7.87	0.85
		–	2,615	2,576	77.61	25.97	21.88	4.08	20.88	7.74	0.89
P-values											
ME levels × Emulsifier			0.152	0.143	0.487	0.212	0.141	0.558	0.900	0.621	0.736
ME levels			<0.001	<0.001	0.033	0.829	0.861	0.774	0.002	0.046	<0.001
Emulsifier			0.094	0.140	0.289	0.936	0.994	0.696	0.663	0.265	0.291

AF, abdominal fat; CCW, cold carcass weight; HCW, hot carcass weight; Major, pectoralis major; ME, metabolizable energy; Minor, pectoralis minor; SEM, standard error of mean.

Means with different superscripts (a and b) within the same column indicate significant differences ($P < 0.05$).

levels for applying emulsifier supplementation is important to adjust the matrix value of the emulsifier. The results from the current study indicated that the reduced ME by 100 kcal/kg had adverse effects on the growth parameters during the whole experimental period. This finding is in agreement with the results from the previous studies that fed reduced ME diets which resulted in reduced growth performance (Latham et al., 2016; Wang et al., 2020). However, the overall FCR was not affected by ME levels in the current study. This result may be explained by numerically improved FCR in the reduced ME group during the finisher period, in contrast to FCR during the starter and grower periods. Poultry can regulate FI to maintain nutritional status by controlling complex and interconnected neuronal and endocrine networks (Richards and Proszkowiec-Weglarz, 2007). Dietary nutrient concentration can affect the voluntary FI of the broiler, and most of the dietary energy consumed by the growing broiler is required for maintenance and growth (Vohra et al., 1975 ; Leeson et al., 1996; Barzegar et al., 2020). Thus, broilers fed the reduced ME diet would consume more feed to compensate for the energy shortage (Leeson et al., 1996; Massuquetto et al., 2020). However, a decrease in FI of birds fed reduced ME diets were found in the present study. In addition, several studies also reported that reduced ME did not affect FI (Hu et al., 2018; Massuquetto et al., 2020; Saleh et al., 2020; Wang et al., 2020). These conflicting results were probably due to the diet forms and reduced ME levels (Massuquetto et al., 2020; Wang et al., 2020). In the current study, reducing dietary ME by 100 kcal/kg decreased FI and increased FCR during the starter and grower periods and probably did not meet the energy requirement for maximizing the growth rate. However, the low FI and numerically improved FCR of birds fed reduced ME diets during the finisher may indicate that the reduced ME by 100 kcal/kg for the finisher was not low enough to reduce FCR compared to the starter and grower periods. These findings suggest that the ME reduction levels should be considered by the feeding phases in future studies.

In terms of ME improvement, exogenous emulsifiers generally have been used to improve the growth parameters of young chicks (Siyal et al., 2017). Young chicks with immature gastrointestinal tracks have a limited ability to utilize fat in their diets due to the lack of bile salt and lipase secretion (Noy and Sklan, 1998). Using exogenous emulsifiers can support the action of bile salt in the intestinal tract for facilitating micelle formation, resulting in increased fat digestibility (Siyal et al., 2017; Ge et al., 2019). Subsequently, the exogenous emulsifiers would improve the growth performance of the broiler with an immature digestive system. Wang et al. (2020) reported that 1,3-diacylglycerol supplementation increased BW and FI during d 0 to 21. Hoque et al. (2022) reported that sodium stearoyl-2-Lactylate supplementation levels linearly improved FCR in broilers fed reduced ME diets during d 1 to 7 and d 7 to 21. Oketch et al. (2022) revealed that the blended emulsifier containing sodium stearoyl lactylate, glycerol monostearate, and glyceryl distearate improved the FCR during d 0 to 28. In addition, similar studies also found that exogenous emulsifier supplementation improved growth performance during the starter and grower periods (Khonyoung et al., 2015; Ge et al., 2019). However, in the present study, emulsifier supplementation did not improve growth performance during d 0 to 14 and d 14 to 28. The discrepancy in growth results during the starter and grower periods may be due to different dietary ME levels. However, emulsifier supplementation positively affected growth performance during the finisher and overall periods in the current study. The improved FCR of the emulsifier supplementation group during the finisher period may contribute to the improved overall FCR of the emulsifier supplementation group. In addition, the ME levels × emulsifier interaction effect in BWG and improved FCR by emulsifier supplementation during d 28 to 42 indicate that the emulsifier has beneficial effects on the BWG of birds fed reduced ME diets. In agreement with our result, other studies reported that using single or blended emulsifiers containing sodium stearoyl lactylate, glycerol monostearate, and glyceryl distearate improved BWG and FCR of broiler during the finisher and overall period (Wang et al., 2020; Hoque et al., 2022; Oketch et al., 2022). In addition, many studies have confirmed that exogenous emulsifiers positively affect key growth performance parameters (Jansen et al., 2015; Chen et al., 2019; Ge et al., 2019), suggesting that emulsifiers are indeed cost-effective feed additives to improve nutrient utilization and growth performance in broilers. In the current study, positive effects of emulsifiers in reduced ME diets were observed during the finisher period, not during the starter and grower periods. This result indicates that the beneficial effects of emulsifiers may depend on ME reduction levels in the diet and ME requirements during the growth periods of broilers; when ME reduction level is minimal in young broilers, emulsifiers would exhibit less beneficial effect, whereas their effects may be more pronounced when ME reduction level is higher in bigger broilers during finisher period because they need more energy during the finisher period to maintain bigger body mass.

The nutrient utilization of diets reflects the proper dietary nutrient density, and the priority of the nutrient utilization can be used for maintaining life and then efficient growth. Following this hypothesis, control ME diets showed relatively higher nutrient digestibility for DM, fat, and GE than reduced ME diets in the current study, so the control ME diets had suitable ME for broiler growth. However, reduced dietary ME decreased nutrient digestibility (Massuquetto et al., 2020; Saleh et al., 2020; Ahmadi-Sefat et al., 2022). Reduced ME had adverse effects on DM, fat, and GE digestibility but did not affect amino acid digestibility except for valine in the current study. Ahmadi-Sefat et al. (2022) found that reduced ME diets decreased DM and GE digestibility and increased FI in broilers. Massuquetto et al. (2020) reported that the nutrient digestibility was improved with increasing ME due to low FI, but inconsistent results were found in broilers fed pellets with different ME levels. Therefore, the broilers fed reduced ME diets increased FI to compensate for the reduced ME for maintaining growth, resulting in decreased GE digestibility and increased FCR (Massuquetto et al., 2020; Ahmadi-Sefat et al., 2022). Increased FI induced by reduced ME in diet may decrease nutrient digestibility (Teeter and Smith, 1985). However, decreased FI and GE digestibility due to the reduced ME diets in the present study disagreed with the previous studies that reduced ME diets increased FI (Massuquetto et al., 2020; Ahmadi-Sefat et al., 2022). Saleh et al. (2020) found a decrease in fat and CP digestibility and an increase in FCR in broilers fed the reduced ME diet, but there was no difference in FI. The decreased nutrient digestibility of reduced ME diets may be related to poor FCR (Saleh et al., 2020). However, the effect of FI on nutrient digestibility in different ME diets cannot be deduced from the current study. An increase in Val digestibility was observed in the reduced ME group, suggesting that Val may be utilized as a carbon framework for energy homeostasis to overcome energy shortage (Kim et al., 2022). However, further investigation is needed to establish the relationship between digestibility, growth performance parameters, and energy status.

Exogenous emulsifiers generally increase ME by increasing fat digestibility and utilization of fat-soluble nutrients (Zhang et al., 2011; Jansen, 2015). Previous studies reported that the emulsifier supplementation improved fat digestibility in broilers (Zhang et al., 2011; Jansen, 2015; Upadhaya et al., 2018). Jansen (2015) found that the emulsifier supplementation increased the fat digestibility, resulting in increased apparent ME. In the current study, the exogenous emulsifier supplementation to the reduced ME diet tended to increase fat digestibility. Exogenous emulsifiers stimulate the formation of micelles in the lumen to improve fat digestion, improving ME of diet (Siyal et al., 2017). Thus, this result suggested that the exogenous emulsifier supplementation compensated for reduced ME by improving fat digestibility. The improvement in DM digestibility by the emulsifier in the current study was confirmed by previous studies (Raju et al., 2011; Zhao and Kim, 2017). The improvement in the digestibility of DM, protein, and amino acids by the emulsifier found in the current study could be explained by the physical properties of the emulsifier in the intestinal tract. The exogenous emulsifier increases the active surface of the fat on the surface of the ingested feed particles and enhances the accessibility of digestive enzymes to the particles (Al-Marzooqi and Leeson, 1999). Such changes potentially increase DM, CP, and various nutrient digestibility (Zhang et al., 2011; Zou et al., 2015; Marin et al., 2016). An in vitro study by Gass et al. (2007) found that the bile acids destabilized protein structure, resulting in increased protein digestion. According to a study by Casterlain and Genot (1994), the Try residue was changed to hydrophobicity upon adsorption of bovine serum albumin to the oil/water interface. These findings may suggest that the emulsifying effect affects the digestion of hydrophobic amino acids by involving structural alterations to the protein complex (Li Zhai et al., 2013). In our study, the digestibility of CP and hydrophobic amino acids including branched-chain amino acids was improved in the emulsifier supplementation group. In addition, significant interaction effects in amino acid digestibility were also found in this study, indicating that the emulsifier supplementation in the reduced ME diet was more effective on improving digestibility than in the control ME diet. The results of nutrient digestibility in the current study suggested that the energy for maintenance and growth of broiler drove by protein utilization rather than fat in the emulsifier supplementation group. In addition to the previous studies reporting the compensation effects of reduced ME by increasing the fat digestion efficiency through emulsifier supplementation, this study suggested that emulsifier supplementation can play an important role in energy metabolism by modulating protein and amino acid utilization, especially in reduced ME diets.

In the present study, DXA scanning results indicated that body composition was mainly affected by ME levels. The body fat percentage measured by DXA and the relative weights of abdominal fat were increased in broilers fed a control ME diets, but the emulsifier supplementation did not affect them. However, a decrease in body muscle percentage was observed in the control ME group. These results indicate that the proportion of body fat to body weight increased with the increase in ME, whereas the proportion of muscle mass to body weight decreased relatively. Calcium consumption is one of the main factors affecting bone mineralization (Kang et al., 2016). The results of BMD and BMC were consistently similar with changes in FI by dietary treatment during the same period.

The carcass yield is an essential parameter in evaluating the commercial value in the broiler industry. In the present study, the carcass yield was more affected by ME levels than emulsifier supplementation. Because carcass components develop in proportion to live BW, increased live BW typically increases the dressing rate (Brake et al., 1993). The weights of hot and cold carcass and dressing rate in control ME were higher than those in reduced ME. These results are in agreement with our finding that the improvement of BWG in the control ME group. Fat deposition in the broiler appeared in the abdominal area and indicates the inefficient utilization of dietary energy in the broilers. Excessive abdominal fat is a waste product and an indicator of wasted energy utilization in broilers (Fouad and El-Senousey, 2014). High energy diet increases fat deposition (Rosa et al., 2007; El-Senousey et al., 2019). In the current study, the relative weight of abdominal fat in the control ME group was higher than that in the reduced ME group. The high-energy diets could increase the activities of enzymes related to hepatic lipogenesis and fatty acid synthesis (Fouad and El-Senousey, 2014). In the current study, the range of the relative weight of the abdominal fat was

0.7 to 1.05%, which was lower compared to other studies (Singh et al., 2021; El-Senousey et al., 2019). This result can support that energy in the control ME diet used in the present study was proper for broiler growth.

In conclusion, the reduction of 100 kcal/kg ME in the diet was found to have adverse effects on broiler growth parameters and carcass characteristics, However, the use of the exogenous emulsifier counterbalanced the growth depression caused by the reduced ME and had positive effects on the growth performance during the finisher phase and the digestibility of protein and amino acids. In addition, it is necessary to study the effect of the emulsifier on the characteristics of protein and amino acid digestion in the intestinal tract.

DISCLOSURES

There is no conflict of interest.

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