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CROP SCIENCE

Energy levels and lysine, calcium and phosphorus adjustments on broiler nutrient digestibility and performance

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Abstract: Chicken broilers digestibility and performance fed with different ME levels, with and without adjustments of digestible lysine, calcium, and available phosphorus, were evaluated. For digestibility, 210 male Cobb 500 chicken broilers were used and distributed into a 3x2+1 factorial arrangement, with three ME levels (3050; 3125 and 3200 kcal/kg) with and without nutrient adjustment, plus one control treatment (2975 kcal ME/kg), totaling seven treatments including six repetitions with five birds into each repetition. For initial performance, 1120 birds were distributed randomly with eight replications within treatments and 20 birds for each replication. For final performance, 1008 chickens were distributed with eight replications and 18 birds for each replication. The DCDM and DCCP were improved ($P<0.05$) according to the increase of ME and the adjustment in dietary nutrients, as well as GE digestibility. The final performance showed no interaction ($P>0.05$) between energy and nutrient adjustment, but the increase in energy levels improved the feed conversion ratio (FCR=1.370). Increasing energy density with nutrient adjustment improves both nutrient utilization and bird performance.

Key words: amino acids, animal nutrition, calorie, minerals.

INTRODUCTION

Broiler nutrition is one of the poultry farming segments which has most contributed to its development. Thus, defining the energy level to be used in bird diets is an important decision, since the energetic ingredients are expensive and increment the diet total cost (Karomy et al. 2019). Moreover, the proper calorie-nutritional balance relationship in the diet may affect protein synthesis or degradation, the utilization of the other supplied nutrients and carcass yield (Sayed et al. 2017).

In this perspective, metabolizable energy (ME) is considered a strategic nutritional factor since feed intake in birds is regulated, mainly, by the diet calorie density. Therefore, the amino acids requirements and other nutrients should be expressed as a function of the diet ME level (Karomy et al. 2019). Hence, these nutrients should be proportionally adjusted when the energy level of the diet is increased, in order to prevent excessive protein deposition and maintain growth rate (Leeson & Summers 2001).

Scientific literature has demonstrated the beneficial effect of diets with a higher energy density and adjustments in lysine, calcium and phosphorus nutrients on birds performance and carcass traits (Hidalgo et al. 2004, Dozier et al. 2011). Diets without adjustments for calorie-to-amino acid ratio may affect plasma and tissues amino acid concentrations, resulting in decrease of feed intake and animal growth (Sayed et al.

2017). Therefore, this concept indicates is the existence of an optimal balance between energy and amino acids (Aftab 2019).

Likewise, minerals act synergistically with energy density. Rostagno et al. (2011) found positive correlation between weight gain rate and phosphorus and calcium requirements. Thus, when increasing the ME inclusion in broiler diets, also is important the adjustments of calcium and phosphorus levels, so that skeletal development can be enhanced to support weight gain (Leeson & Summers 2001). Additionally, those minerals participate in several metabolic and structural reactions for life maintenance, especially in fast-growing chickens, requiring adequate nutritional supply. According to Shafey et al. (1990), insufficient or excessive supply of one or both minerals alters homeostasis, compromising growth rate and bone mineralization.

Given the above considerations, defining the energy level of broiler diets is essential to meet the correct energy requirements, as well as making nutritional adjustments as a function of ME, providing and maximizing production performance. In the same way, the impact of energy values on nutrients digestibility must also be evaluated. Thus, the present study aimed to determine nutrient diets digestibility and broilers performance fed with formulated diets with different metabolizable energy levels, with and without adjustments in digestible lysine, calcium and available phosphorus.

MATERIALS AND METHODS

Ethical Considerations

All experimental procedures applied in this study were approved by the Animal Ethics Committee of the Federal University of Viçosa - MG, Brazil (approval no. 002/2015).

Digestibility Trial

A total of 210 Cobb 500 male broiler chicks with an initial weight average of 490± 2g were subjected to the experimental treatments in the initial phase from 14 to 21 days of age. Those birds were evaluated in a randomized complete block design with a 3×2+1 factorial arrangement, where block factor was the shed, also were adopted three ME levels, and with and without nutrients adjustment (Dig Lys, Ca and AP), plus one control treatment, completing seven treatments with six replicates for each treatment and five birds per experimental unit. The following treatments were tested:

Treatment 1: 3050 kcal ME/kg, without nutritional adjustments;

Treatment 2: 3125 kcal ME/kg, without nutritional adjustments;

Treatment 3: 3200 kcal ME/kg, without nutritional adjustments;

Treatment 4: 3050 kcal ME/kg + 2.5% nutritional adjustment; (Dig Lys, Ca and AP);

Treatment 5: 3125 kcal ME/kg + 5.0% nutritional adjustment (Dig Lys, Ca and AP);

Treatment 6: 3200 kcal ME/kg + 7.5% nutritional adjustment (Dig Lys, Ca and AP);

Treatment 7: 2975 kcal ME/kg (control).

The experimental diets are detailed in Table I. The nutritionally adjusted diets had digestible lysine, calcium and available phosphor increased by 2.5, 5.0 and 7.5%, respectively, for the three ME levels tested, while the diets without nutritional adjustments showed the same digestible lysine, calcium and available phosphor as control diet, but ME levels of 3050, 3125 and 3200 kcal/kg. Control diet contained 2975 kcal ME/kg, 1.174% of digestible lysine, 0.819% of calcium and 0.391% of available phosphor, and was formulated meeting the nutritional requirements of medium-performance broilers, as proposed by Rostagno et al. (2011).

Table I. Ingredients and calculated nutritional composition of the experimental basal diets (8 to 21 days).

Ingredients	Without adjustment			With adjustment			Control
	0.0%			2.5%	5.0%	7.5%	0.0%
Corn (7.88%)	52.07	52.07	52.07	52.07	52.07	52.07	52.07
Soybean meal (45%)	33.33	33.33	33.33	33.33	33.33	33.33	33.33
Corn gluten meal (60%)	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Soybean oil	3.85	4.71	5.56	3.92	4.73	5.51	3.00
Dicalcium phosphate	1.54	1.54	1.54	1.59	1.65	1.70	1.54
Limestone	0.92	0.92	0.92	0.93	0.95	0.97	0.92
Sodium chloride	0.43	0.43	0.43	0.43	0.43	0.43	0.43
L-Lysine HCl (78%)	0.23	0.23	0.23	0.27	0.31	0.35	0.23
DL-Methionine (99%)	0.23	0.23	0.23	0.25	0.27	0.29	0.23
L-Threonine (98%)	0.05	0.05	0.05	0.05	0.06	0.08	0.05
L-Arginine (98%)	-	-	-	-	0.03	0.06	-
L-Valine (96.5%)	-	-	-	-	0.02	0.04	-
L- Glycine (99%)	-	-	-	-	0.01	0.06	-
Mineral supplement[1]	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Vitamin supplement[2]	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Starch	0.85	0.85	0.85	0.60	0.60	0.60	0.85
Inert[3]	2.27	1.42	0.57	2.33	1.32	0.29	3.13
	Calculated Nutritional Composition						
ME, kcal/kg	3050	3125	3200	3050	3125	3200	2975
CP, %	22.00	22.00	22.00	22.04	22.17	22.36	22.00
Fat, %	6.551	7.400	8.250	6.617	7.426	8.201	5.701
Starch, %	35.874	35.874	35.874	35.654	35.654	35.654	35.874
Digestible Lysine[4], %	1.174	1.174	1.174	1.203	1.233	1.262	1.174
Digestible meth+Cys, %	0.846	0.846	0.846	0.868	0.888	0.910	0.846
Digestible threonine, %	0.789	0.789	0.789	0.789	0.802	0.822	0.789
Digestible Valine, %	0.936	0.936	0.936	0.936	0.950	0.973	0.936
Digestible Gly+Ser, %	1.804	1.804	1.804	1.804	1.814	1.858	1.804
Digestible Arginine, %	1.309	1.309	1.309	1.309	1.333	1.365	1.309
Sodium, %	0.188	0.188	0.188	0.188	0.188	0.188	0.188
Calcium[4], %	0.819	0.819	0.819	0.839	0.860	0.880	0.819
Available phosphorus[4],%	0.391	0.391	0.391	0.401	0.410	0.420	0.391

[1]The mineral supplement contained per kg of diet: iron: 55.0 mg; Copper: 11.0 mg; Manganese: 77.0 mg; Zinc: 71.5 mg; Iodine: 1.10 mg; Selenium: 0.22mg. [2] The vitamin supplement contained per kg of diet: vitamin A: 8250 U.I.; Vitamin D3: 2090 U.I.; Vitamin E: 31.0 U.I.; Vitamin B1: 2.20 mg; Vitamin B2: 5.50 mg; Vitamin B6: 3.08 mg; Vitamin B12: 0.013 mg; Pantothenic acid: 11.0 g; Biotin: 0.077 mg; Vitamin K3: 1.65 mg; Folic acid: 0.77 mg; Nicotinic acid: 33.0 mg. [3]Inert: Washed sand. [4]Adjustment applied to nutrients Digestible Lysine, Calcium and Available phosphorus.

Washed sand (inert) and starch were used to adjust the digestible lysine, calcium and available phosphor.

Birds were housed in a shed with concrete floor with wood shavings from the 1st to 13th days of age where both feed and water were offered *ad libitum*. After this period, they were transferred to metabolic cages (0.60×0.50×0.40 m) equipped with trough feeders and nipple drinkers, where the chicks were kept during the entire first experimental period (14 to 21 days of age). The first five days were used as adaptation period to the diets and metabolic cages; thereafter, excreta samples were collected as recommended by Sakomura & Rostagno (2016).

$$\text{Metabolizability of nutrients}\,(\%) = \frac{\left(\text{Nutrient}_{ingested} - \text{Nutrient}_{\text{excreted}}\right)}{\text{Nutrient}_{ingested}}$$

After the end of the collection period, the excreta samples were thawed, homogenized, pre-dried at 55 °C for 72 hours in a forced-air oven, ground through a ball mill and prepared for laboratory analyses of dry matter (DM) (Method 934.01; AOAC Int., 2012), nitrogen (Method 990.03; AOAC Int., 2012) and ether extract (Method 920.39; AOAC Int., 2012). Gross energy (GE) was determined using a bomb calorimeter (Calorimeter System C200, IKA), with benzoic acid as standard calibration. The metabolizability coefficients of DM, GE and CP and nitrogen retention were estimated in accordance with Sakomura & Rostagno (2016).

Performance Trial

All birds were acquired with 1 day of age and kept until the 7th day in shed with concrete floor covered by wood shavings, provided with heating system recommended for this production phase, fed with corn feed and soybean meal, receiving water and feed *ad libitum*.

The performance trial was divided into two productive phases, birds in the initial phase from 8 to 21 days and, later on, both the growing and finishing phase from 22 to 42 days of age. At the end of the initial phase, the birds were redistributed and introduced into the performance experiment for the next phase.

Birds were housed in a shed with concrete floor lined by wood shavings, which was divided into fifty-six cages of 2 m^2 (1.0 m × 2.0 m) containing one semiautomatic trough feeder, one cup-type nipple drinker, light bulbs for heating and wood shavings bedding.

The initial phase performance trial (8 to 21 days) involved 1120 male broilers with an initial weight average of 190±0.19g. The experimental design and treatments were similar to those adopted in the digestibility trial. For the performance trial in growing and finishing production phase (22 to 42 days of age), 1008 broilers with an initial weight average of 855±6 g were evaluated in a completely randomized design, into a 3×2+1 factorial arrangement, with seven treatments and eight replicates by treatment, and 18 birds per experimental unit.

In this phase, the nutritionally adjusted experimental diets contained digestible lysine, calcium and available phosphor increased by 2.5%, 5.0% and 7.5%, respectively (Table II). The unadjusted diets had the same digestible lysine, calcium and available phosphor as control diet, with variations only in ME (3100, 3175 and 3250 kcal/kg). Washed sand (inert) and starch were used to adjust the ME, digestible lysine, calcium and available phosphor values. Lastly, control diet consisted of 3025 kcal ME/kg, 1.050% digestible lysine, 0.685% calcium and 0.320% available phosphor, following the Rostagno et al. (2011) nutritional recommendations for medium-performance broilers.

A 23:1 lighting program (23 light hours and 1 dark hour) was adopted, with feed and water available *ad libitum*. The temperature was

Table II. Feed ingredients and calculated nutrients composition of the experimental diets (22 to 42 days).

Ingredients	Without adjustment			With adjustment			Control
	0.0%			2.5%	5.0%	7.5%	0.0%
Corn (7.88%)	57.76	57.76	57.76	57.76	57.76	57.76	57.76
Soybean meal (45%)	30.13	30.13	30.13	30.13	30.13	30.13	30.13
Corn gluten meal (60%)	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Soybean oil	3.957	4.810	5.663	3.949	4.795	5.644	3.104
Dicalcium phosphate	1.178	1.178	1.178	1.224	1.267	1.311	1.178
Limestone	0.812	0.812	0.812	0.824	0.841	0.858	0.812
Sodium chloride	0.400	0.400	0.400	0.400	0.400	0.400	0.400
L-Lysine HCl (78%)	0.189	0.189	0.189	0.223	0.256	0.289	0.189
DL-Methionine (99%)	0.216	0.216	0.216	0.234	0.253	0.272	0.216
L-Threonine (98%)	0.016	0.016	0.016	0.033	0.050	0.068	0.016
L-Arginine (98%)	-	-	-	-	-	0.029	-
L-Valine (96.5%)	-	-	-	-	0.023	0.044	-
Mineral supplement[1]	0.110	0.110	0.110	0.110	0.110	0.110	0.110
Vitamin supplement[2]	0.110	0.110	0.110	0.110	0.110	0.110	0.110
Starch	0.800	0.800	0.800	0.731	0.639	0.519	0.800
Inert[3]	2.317	1.464	0.611	2.267	1.361	0.451	3.170
	Calculated Nutritional Composition						
ME, kcal/kg	3100	3175	3250	3100	3175	3250	3025
CP, %	19.70	19.70	19.70	19.75	19.83	19.95	19.70
Fat, %	6.769	7.619	8.468	6.761	7.604	8.449	5.919
Starch, %	39.08	39.018	39.018	38.957	38.876	38.771	39.018
Digestible lysine[4], %	1.050	1.050	1.050	1.076	1.102	1.128	1.050
Digestible meth+Cys, %	0.767	0.767	0.767	0.785	0.804	0.823	0.767
Digestible threonine, %	0.683	0.683	0.683	0.699	0.716	0.733	0.683
Digestible Valine, %	0.838	0.838	0.838	0.838	0.86	0.88	0.838
Digestible Gly+Ser, %	1.627	1.627	1.627	1.627	1.627	1.627	1.627
Digestible Arginine, %	1.189	1.189	1.189	1.189	1.189	1.218	1.189
Sodium, %	0.177	0.177	0.177	0.177	0.177	0.177	0.177
Calcium[4], %	0.685	0.685	0.685	0.702	0.719	0.736	0.685
Available phosphorus[4],%	0.320	0.320	0.320	0.328	0.336	0.344	0.32

[1]The mineral supplement contained per kg of diet: iron: 55.0 mg; Copper: 11.0 mg; Manganese: 77.0 mg; Zinc: 71.5 mg; Iodine: 1.10 mg; Selenium: 0.22mg. [2] The vitamin supplement contained per kg of diet: vitamin A: 8250 U.I.; Vitamin D3: 2090 U.I.; Vitamin E: 31.0 U.I.; Vitamin B1: 2.20 mg; Vitamin B2: 5.50 mg; Vitamin B6: 3.08 mg; Vitamin B12: 0.013 mg; Pantothenic acid: 11.0 g; Biotin: 0.077 mg; Vitamin K3: 1.65 mg; Folic acid: 0.77 mg; Nicotinic acid: 33.0 mg. [3]Inert: Washed sand. [4]Adjustment applied to nutrients Digestible Lysine, Calcium and Available phosphorus.

measured using a thermo-hygrometer at the height of the birds.

Birds were weighed weekly and feed supply was recorded to determine the performance parameters. Mortality was checked daily to adjust the feed conversion ratio.

The following performance parameters were evaluated in each experimental period: final weight (g/bird), weight gain (g/bird), feed intake (g/bird) and feed conversion ratio (g/g). These variables were calculated based on the recorded mortality.

Statistical Analysis

The experimental results were analyzed using SAS 9.0 software (SAS Institute Inc. 2004), in which the GLM procedure was applied within a linear model containing two factors: ME levels and nutrient adjustment, and their interaction. Arithmetic means were compared by Tukey's test at the 5% significance level. Control diet was compared to the other experimental diets by contrast analysis to determine the effects of energy and nutrients.

RESULTS

The average temperature recorded during the experimental period was 27.6 °C (minimum 22.7 °C; maximum 32.5 °C).

Effect of Diets on Digestibility

There was an interaction effect ($P<0.05$) between ME level and nutritional adjustment on the digestibility coefficients of dry matter (DCDM) and crude protein (DCCP). Birds fed with high ME diets adjusted for 7.5% nutrients (Dig. Lys, Ca and AP) showed better CDMS and CDPB digestibility (Table III).

In contrast, for the unadjusted treatments, only the diet with 3050 kcal ME/kg improved DCDM. Nevertheless, nutritional adjustment improved DCDM at the three energy levels when compared to the energy level of control diet.

The higher nutrient supply through the adjusted diets influenced DCGE ($P<0.05$), improving energy utilization in relation to the unadjusted diets (Table III). Nitrogen retention did not respond ($P>0.05$) to the treatments. In addition, diets were adjusted with 5.0% of nutrients providing numerical increase of 119 kcal AME/kg compared to the diet without nutritional adjustment (Table IV).

Effect of energy and nutrient adjustment on initial bird performance

There was no interaction effect ($P>0.05$) between the ME levels and nutritional adjustment on the initial performance variables (Table V). However, the diets with higher ME inclusion led to an increase of up to 24 g in weight gain and an improvement in feed conversion, compared to the diets including 3050 kcal ME/kg.

The contrast between the control and test treatments revealed that weight gain increased with the energy density of the diets (WG=726 g), thus feed conversion was also affected by the greater ME inclusion into diets ($P<0.05$).

Effect of energy and nutritional adjustment on performance of broilers in the growing-finishing phase

No interaction effect ($P>0.05$) between ME levels and nutritional adjustment (Dig. Lys, Ca and AP) was observed on broiler performance during growing and finishing phases (Table VI). The factors analysis separately showed that feed intake (FI) decreased ($P<0.05$) as ME was elevated (3250 kcal/kg), which proportionally led to improve FCR.

Contrast analysis showed that control diet (3025 kcal ME/kg) provided the lowest weight gain, but similar FI to those obtained with the diets containing 3100 and 3175 kcal ME/kg, with and without nutritional adjustments. In contrast, control diet (FI=3347g) differed ($P<0.05$) only from that with the treatment with the highest energy level (3250 kcal/kg) plus nutritional adjustments, which provided the lowest feed intake (3144 g).

These combinations between intake and gain influenced feed conversion, which worsened ($P<0.05$) in the animals fed the control diet with

Table III. Digestibility coefficient of dry matter (DCDM), crude protein (DCCP), gross energy (DCGE) and nitrogen retention (NR) in broilers fed diets with different metabolizable energy levels with/without nutrients adjustment[1].

		DCDM (%)	DCCP (%)	DCGE (%)	NR (%)
ME (kcal/kg)					
3050		79.4	74.7	82.7	75.1
3125		79.4	74.6	82.5	74.6
3200		81.3	76.5	81.9	74.1
SEM[2]		0.272	0.324	0.274	0.490
Nutrient adjustment					
NA		79.0	74.0	81.9 b	74.1
WA		81.3	76.5	82.9 a	75.1
SEM[2]		0.222	0.414	0.224	0.400
Energy x Adjustment					
3050	NA	79.5 bd	74.2 b	82.4	74.5
	WA	79.3 bd	75.2 b	83.0	75.7
3125	NA	78.4 bde	74.1 b	81.6	73.9
	WA	80.4 bcf	75.0 b	83.5	75.4
3200	NA	79.0 bd	73.8 b	81.7	73.9
	WA	83.7 a	79.2 a	82.0	74.4
SEM[2]		0.384	0.718	0.388	0.693
P-Value					
Energy		<.0001	0.0183	0.0798	0.4339
Adjustment		<.0001	0.0003	0.0052	0.0679
Energy x Adjustment		<.0001	0.0046	0.0879	0.7950
Contrast: Control vs test[3]					
2975		78.5	74.4	82.0	7.0
3050	NA	79.7 *	74.2 ns	82.4 ns	74.5 ns
	WA	79.8 **	75.2 ns	83.0 *	75.7 ns
3125	NA	78.4 ns	74.1 ns	81.6 ns	73.9 ns
	WA	80.4 ***	75.0 ns	83.5 **	75.4 ns
3200	NA	79.0 ns	73.8 ns	81.7 ns	73.9 ns
	WA	83.7 ***	79.2 ***	82.0 ns	74.4 ns

Capital letters refer to significant differences between metabolizable energy levels. [1]Nutrient adjustment: increase of 2.5; 5.0 e 7.5% digestible lysine, calcium and phosphorus available, respectively at ME levels 3050, 3125 e 3200 kcal/kg. [2]Mean standard error. [3]Metabolizable energy of the control diet (2975 kcal ME/kg) versus metabolizable energy of the test diets. *P≤0.05; **P≤0.01; ***P≤0.001; NS: not significant by the Tukey test at 5% significance. NA: diets without nutrient adjustments; WA: diets with nutrient adjustment.

Table IV. Crude protein, apparent metabolizable energy (AME kcal/kg) observed as a result of experimental treatments[1], and feed intake (FI) of broilers, 14 to 21 days old.

	Without adjustment			With adjustment			Control
	0.0%			2.5%	5.0%	7.5%	0.0%
ME (kcal/kg)	3050	3125	3200	3050	3125	3200	2975
CP, %	21.3	21.9	21.2	21.7	21.09	21.03	21.0
AME, kcal/kg	2992	3096	3112	3111	3168	3150	2952
FI, g/bird	112.5	112.5	107.6	110.0	108.0	105.6	114.4

[1]Nutrient adjustment: increase of 2.5; 5.0 e 7.5% digestible lysine, calcium and phosphorus available, respectively at ME levels 3050, 3125 e 3200 kcal/kg.

the least metabolizable energy (FCR= 1.746) compared to the others.

DISCUSSION

In general, it can be observed the positive effect of the most energetic adjusted diets on DCDM, birds fed with the diet of 2975 kcal ME/kg (control diet) provided the lowest DCDM in relation to diets with nutrient adjustment. This demonstrates, therefore, the additive effect of increasing minerals and amino acids.

The DCDM reflects the digestibility of nutrients; i.e., its increase means better nutrients absorption (Abdulla et al. 2016), this fact may be related to the increase of diets energy density, which is mainly obtained by including soybean oil on it. This lipid source can inhibit gastric emptying when reaching duodenum and, consequently, increasing the time that food stays inside the intestine (Honda et al. 2009, Kim et al. 2013), favoring the digestive enzymes actions and improving nutrients digestibility (Hu et al. 2018). Mandalawia et al. (2017), observed that adding oils to broiler diet increased nutrient retention, possibly due to the lower rate of passage (Mateos et al. 1982).

Another factor that may influence dry matter digestibility is the presence of minerals, Wilkinson et al. (2014), observed that increasing calcium supply (0.64 to 1.0%) is propitious to increase dry matter digestibility in broilers up to 22 days of age. Corroborating with the present study data, in which diets adjusted to 7.5% with about 0.88% of Ca, provided greater CDMS, when compared to diets without adjustments.

The effects of increasing ME and nutrient levels were also observed on DCCP, indicating that low-energy diets (2975 kcal/kg) without nutritional adjustments reduce the protein digestibility and, consequently, performance. Regarding DCGE, can be inferred that the better utilization of the energy components of the diets is related to the adjustment of lysine, that through ideal protein methodology, changed all the amino acids of the diets, being Gly and Ser one of them. According to Ospina-Rojas et al. (2013), glycine promotes increase of dietary fat digestibility, which is mainly because it is a component of the bile salts (Moran 2014).

Values found for AME of the diets showed the importance of correcting its ME, Chrystal et al. (2020) infer that AME values tend to decrease when birds have low feed intake.

Although the increasing on adjustment of diet nutrients (Dig. Lys, Ca and AP) and respective ME levels, positively affected DCDM and DCCP, initial performance was not improved. As stated by Liu et al. (2017), the energy level of a diet, which is obtained from starch, protein and lipids, influences weight gain and feed conversion. Nevertheless, digestibility and

Table V. **Weight gain (WG), feed intake (FI) and feed conversion ratio (FCR) of broilers (8 to 21 days old), fed diets with different metabolizable energy levels with/without nutrients adjustment[1].**

		WG (g)	FI(g)	FCR(g/g)
ME(kcal/kg)				
3050		702 b	1003	1.428 B
3125		714 ab	1004	1.406 B
3200		726 a	995	1.370 A
SEM[2]		0.0064	0.0103	0.0085
Nutrient adjustment				
NA		707	993	1.405
WA		721	1007	1.398
SEM[2]		0.0051	0.0081	0.0069
Energy x Adjustment				
3050	NA	697	998	1.434
	WA	708	1007	1.422
3125	NA	708	994	1.405
	WA	720	1013	1.407
3200	NA	718	988	1.377
	WA	734	1001	1.364
SEM[2]		0.0089	0.0142	0.0129
P-Value				
Energy		0.0421	0.7780	0.0001
Adjustment		0.0818	0.2451	0.4782
Energy x Adjustment		0.9734	0.9320	0.7716
Contrast: Control *vs* test[3]				
2975		701	1014	1.446
3050	NA	697 ns	998 ns	1.434 ns
	WA	708 ns	1007 ns	1.422 ns
3125	NA	708 ns	994 ns	1.405 **
	WA	720 ns	1013 ns	1.407 *
3200	NA	718 ns	988 ns	1.377 ***
	WA	734 **	1001 ns	1.364 ***

Capital letters refer to significant differences between metabolizable energy levels. [1]Nutrient adjustment: increase of 2.5; 5.0 e 7.5% digestible lysine, calcium and phosphorus available, respectively at ME levels 3050, 3125 e 3200 kcal/kg. [2]Mean standard error. [3]Metabolizable energy of the control diet (2975 kcal ME/kg) versus metabolizable energy of the test diets. *P≤0.05; **P≤0.01; ***P≤0.001; NS: not significant by the Tukey test at 5% significance. NA: diets without nutritional adjustments; WA: diets with nutrient adjustment.

performance do not always walk hand-in-hand since the combination of higher levels of starch and protein, in certain diets, leads to better performance results, but not necessarily to better digestibility.

The performance results in growing and finishing phases suggest that the increasing energy density led to a decrease in feed intake. Studies have shown that increasing soybean oil inclusion levels in a diet may be the responsible factor for alterations in the feed passage and digestibility rates (Mateos et al. 1982), and this may explain the lower feed intake of the birds fed with diets enriched with higher amounts of soybean oil. In this sense, enlarging energy density might have led to increased secretion of

Table VI. Weight gain (WG), feed intake (FI) and feed conversion ratio (FCR) of broilers (22 to 42 days old), fed diets with different metabolizable energy levels with/without nutrients adjustment[1].

		WG (g)	FI(g)	FCR(g/g)
ME (kcal/kg)				
3050		1986	3298 AB	1.661 B
3125		2005	3330 A	1.661 B
3200		1984	3217 B	1.625 A
SEM[2]		16.82	25.715	0.0084
Nutrient adjustment				
NA		1995	3305	1.659 B
WA		1985	3258	1.639 A
SEM[2]		13.737	20.996	0.0069
Energy x Adjustment				
3050	NA	1984	3311	1.669
	WA	1987	3285	1.653
3125	NA	1984	3313	1.671
	WA	2026	3346	1.652
3200	NA	2017	3290	1.637
	WA	1951	3144	1.612
SEM2		23.794	36.367	0.011
P-Value				
Energy		0.6296	0.0104	0.0045
Adjustment		0.7180	0.1272	0.0449
Energy x Adjustment		0.0829	0.0537	0.9312
Contrast: Control *vs* test[3]				
2975		1919	3347	1.746
3050	NA	1984 *	3311 ns	1.669 ***
	WA	1987 *	3285 ns	1.653 ***
3125	NA	1984 *	3313 ns	1.671 **
	WA	2026 **	3346 ns	1.652 ***
3200	NA	2017 **	3290 ns	1.637 ***
	WA	1951 ns	3144 ***	1.612 ***

Capital letters refer to significant differences between metabolizable energy levels. [1]Nutrient adjustment: increase of 2.5; 5.0 e 7.5% digestible lysine, calcium and phosphorus available, respectively at ME levels 3050, 3125 e 3200 kcal/kg. [2]Mean standard error. [3]Metabolizable energy of the control diet (2975 kcal ME/kg) versus metabolizable energy of the test diets. *P≤0.05; **P≤0.01; ***P≤0.001; NS: not significant by the Tukey test at 5% significance. NA: diets without nutritional adjustments; WA: diets with nutrient adjustment.

cholecystokinin, hormone that acts by inhibiting gastric emptying, when the food bolus reaches the duodenum (McDonald et al. 2010). Chrystal et al. (2020), analyzing different energy inclusion levels in broiler diets up to 42 days of age, observed that using 3071 kcal ME/kg reduced birds feed intake by up to 5.0%, compared to the diet with 2870 kcal ME/kg.

These alterations in intake interfered feed conversion ratio, which was improved by 0.036 points in the diets with the highest energy level and nutritionally adjusted. Similar results were observed by Hidalgo et al. (2004) and Saleh et al. (2004). Baião & Lara (2005) stated that using oils and fats in diets, increases their palatability, reduces nutrient losses and improves feed conversion, besides other positive effects.

In conclusion, to improve broiler performance, it is essential to adjust digestible lysine, calcium and available phosphorus when the metabolizable energy content in the diet is increased from 3050 to 3200 kcal ME/kg. This will significantly improve dry matter and protein digestibility.

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