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ANIMAL PRODUCTION

Energy dynamics of broiler in thermoneutral or heat stress environments with different levels of metabolizable energy

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ABSTRACT: Two experiments evaluated the effect of different levels of metabolizable energy (ME) on nutrient metabolizability, energy balance, and broiler performance under thermoneutral and cyclic heat stress conditions. A total of 672 male Cobb™ broilers were used, with ME levels of 2980, 3080, 3180, and 3280 kcal/kg in the diets. In a thermoneutral environment (experiment 1), higher ME levels improved the ether extract metabolizability coefficient, apparent metabolizable energy corrected for nitrogen balance (AMEn), and net energy (NE). However, increased ME from oil inclusion did not affect feed intake, apparent ME intake, retained energy, total and fasting heat production, caloric increment, or the efficiency of energy use for AMEn and NE. It did enhance weight gain, productive efficiency index, and feed conversion but reduced viability and increased feed cost per kg of live chicken. Under cyclic heat stress (experiment 2), the metabolizability coefficient of crude protein and ether extract rose with increased ME. Higher ME reduced the caloric increment up to an estimated 3021.5 ME and increased AMEn and NE. Improved feed conversion was noted, but feed cost per kg of live broiler also rose. In conclusion, the increase in energy levels positively affected the performance parameters of broilers from 20 to 41 days of age, particularly feed conversion, but it also raised production costs.
Key words: respirometric chamber, digestibility, net energy, heat stress, caloric increment.

Dinâmica energética de frangos de corte em ambientes termoneutros ou de estresse térmico com diferentes níveis de energia metabolizável

RESUMO: Dois experimentos avaliaram o efeito de diferentes níveis de energia metabolizável (EM) sobre a metabolizabilidade de nutrientes, balanço energético e desempenho de frangos de corte em condições termoneutras e de estresse cíclico por calor. Um total de 672 frangos de corte machos Cobb™ foram utilizados, com níveis de EM de 2980, 3080, 3180 e 3280 kcal/kg nas dietas. Em um ambiente termoneutro (experimento 1), os níveis mais altos de EM melhoraram o coeficiente de metabolizabilidade do extrato etéreo, a energia metabolizável aparente corrigida para o balanço de nitrogênio (EMAn) e a energia líquida (EL). No entanto, o aumento da EM proveniente da inclusão de óleo não afetou o consumo de ração, a ingestão de EM aparente, a energia retida, a produção de calor total e em jejum, o incremento calórico, ou a eficiência do uso de energia para EMAn e EL. Houve, no entanto, aumento no ganho de peso, no índice de eficiência produtiva e na conversão alimentar, mas a viabilidade foi reduzida e o custo da ração por kg de frango vivo aumentou. Sob estresse térmico cíclico (experimento 2), o coeficiente de metabolizabilidade da proteína bruta e do extrato etéreo aumentou com o aumento da EM. Níveis mais altos de EM reduziram o incremento calórico até um valor estimado de 3021,5 EM e aumentaram a EMAn e a EL. A melhor conversão alimentar foi observada, mas o custo da ração por kg de frango vivo também subiu. Em conclusão, o aumento dos níveis de energia afetou positivamente os parâmetros de desempenho de frangos de corte de 20 a 41 dias de idade, especialmente a conversão alimentar, mas também elevou os custos de produção.
Palavras-chave: câmara respirométrica, digestibilidade, energia líquida, estresse térmico, incremento calórico.

INTRODUCTION

Thermal stress is one of the greatest challenges in broiler production. This phenomenon, increasingly common due to climate change, has significant effects on the performance and well-being of the birds, impacting their feed intake, metabolism, and growth (NAWAB et al., 2018; ATTIA et al., 2020). A possible alternative for broilers raised at high temperatures is to increase the energy levels in their diets by using lipids as an energy source (NOBLET, 2007; SOARES et al., 2020). However, feed costs represent a substantial portion of the expenses in poultry production, and energy is one of the main components of these costs (TAY-ZAR et al., 2024). Additionally, the energy efficiency of the diets may

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vary depending on the environmental conditions in which the birds are raised (BARZEGAR et al., 2020).

In this context, it is essential to determine the optimal level of metabolizable energy (ME) under different environmental conditions, considering its effects on nutrient metabolism, energy balance, and overall bird performance. The present study was to evaluate the effect of different levels of ME in the diet on nutrient metabolism, energy balance, and performance of broilers subjected to thermoneutral and cyclic heat stress conditions.

MATERIALS AND METHODS

A total of 672 one-day-old male broiler chicks (Cobb™), with 336 allocated to experiment 1 and 336 to experiment 2, were obtained from a commercial hatchery. During the pre-experimental period (up to 19 days of age), the birds were raised until 15 days of age on the floor of a conventional shed, and after this period, they were transferred to a climate-controlled room, where they underwent a four-day adaptation period. The chicks were weighed at 15 days and distributed in a completely randomized design among experimental units with similar weights. For both experiments, the birds were assigned to one of four treatments, with each treatment consisting of six replicates (cages = experimental unit), each containing fourteen chicks per replicate (n = 24).

For both trials, the experimental period extended from day 20 to day 41, during which the chickens were housed in a climate-controlled room. The birds were kept in 24 cages equipped with nipple drinkers, feeders, and excreta collection trays, with ad libitum access to feed and water. The lighting program consisted of 20 hours of light followed by 4 hours of darkness. The applied nutritional levels followed the reference by SOARES et al. (2020). The birds received starter feed from days 1 to 19 (Table 1). At day 20, the chickens were weighed and evenly distributed among the experimental units and began receiving experimental diets formulated to meet the birds' growth phase. The evaluated treatments consisted of four isonutritive diets that differed only in ME levels (2980, 3080, 3180, and 3280 kcal/kg in the feed). Metabolizable energy levels were adjusted by including degummed soybean oil in the feed. The composition of the diets and their respective calculated nutritional levels are shown in table 1.

In experiment 1, the room was acclimatized throughout the experimental period to provide a thermoneutral temperature (23 ± 2 ºC). In experiment 2, to simulate a heat stress environment, the birds were subjected to daily cycles of 16 h at thermoneutral temperature (23 ± 2 ºC) and 8 h at thermal stress (32 ± 2 ºC). In both experiments, the relative humidity was maintained at 60 ± 2% (RH), and the birds were subjected to 20 hours of light and 04 hours of darkness while facilitating resting at thermoneutral temperatures. In experiment 2, heat stress of 8 h was applied during the light period. The thermoneutral period of 16 h corresponded to 12 h of light and 4 h of dark, with the intention that greater exposure to light would favor the recovery of feed intake with the lowest temperature.

Measurements were similar for both experiments. Nutrient metabolizability was determined by the method of total excreta collection from 25 to 29 days of the age of broilers. The amounts of feed offered, and leftovers were weighed daily, and total excreta were collected twice a day (morning collection at 7 am and afternoon collection at 6 pm), grouped, and frozen. The excreta were then dried at 55 ºC for 72 hours and ground. Analyzes for the determination of the dry matter, crude protein, ether extract, and gross energy (GE) in excreta and rations were performed according to techniques described by AOAC (1995). Subsequently, the crude protein metabolizability coefficients (CPMC), dry matter (DMMC), and ether extract (EEMC) were calculated using the formulas proposed by SAKOMURA & ROSTAGNO (2007). Apparent metabolizable energy (AME) and apparent metabolizable energy corrected by nitrogen balance (AMEn) were also calculated, according to HILL & ANDERSON (1958). Heat production and net energy determination were obtained by indirect calorimetry in an open circuit respirometric chamber (Sablesys® USA), according to NOBLET & ETIENNE (1987) and VAN MILGEN et al. (1997).

According to the methodology described by SOARES et al. (2020), for the determination of total heat production (THP), retained energy (RE), caloric increment (CI), net energy (NE), and net energy of maintenance (NEm), the oxygen consumption and carbon dioxide production of broilers were monitored for 24 h, sequentially and daily by an open circuit respirometry chamber for small animals (PA-1B oxygen analyzer; CA-10A Carbon dioxide Analyzer; MA-1 Methane Analyzer; Flow-Kit- 500; Sable Systems International/USA). The experimental unit (cage) was weighed before and after placing it in the chamber. The respirometric chamber was acclimatized, as previously described for each experiment. The birds were maintained in the nutritional regimen, with the diet provided by a feeder attached to the metabolic cage kept inside

Table 1 - Percentage composition and calculated nutritional values of the rations used in the experiments.

	------------------------------------Metabolizable Energy, kcal/kg------------------------------------				
	Starter (01-19 days)	---------------------------Grower (20 - 41 days)---------------------------			
Ingredients (g/kg)	2980	2980	3080	3180	3280
Yellow corn	608.0	690.0	672.0	648.0	625.0
Soybean meal 450 g/kg	305.0	235.0	239.0	244.0	247.0
Soybean oil	10.0	-	17.0	36.0	55.0
Meat and bone meal 440 g/kg	58.0	50.0	50.0	50.0	50.0
Calcitic limestone	2.7	7.3	4.4	4.6	5.5
common salt	3.5	3.5	3.5	3.5	3.5
DL-Methionine	3.8	3.2	3.3	3.3	3.3
L-Lysine	3.7	3.7	3.6	3.5	3.5
L-Threonine	1.3	1.2	1.2	1.2	1.2
L-Tryptophan	-	0.2	0.2	0.1	0.2
L-Valine	-	1.1	1.1	1.0	1.0
L-Arginine	-	0.9	0.8	0.8	0.7
Mineral-vitamin supplement[a]	4.0	-	-	-	-
Mineral-vitamin supplement[b]	-	4.0	4.0	4.0	4.0
Total	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated analysis					
Metabolizable Energy (kcal/kg)	2980	2980	3080	3180	3280
Fat	43.5	34.5	50.7	68.7	86.8
Crude protein	220.0	190.0	190.0	190.0	190.0
digestible Methionine and cystine	9.4	8.2	8.2	8.2	8.2
digestible Lysine	13.0	11.2	11.2	11.2	11.2
digestible Threonine	8.4	7.3	7.3	7.3	7.3
digestible Tryptophan	2.2	2.0	2.0	2.0	2.0
digestible Arginine	13.3	12.1	12.1	12.1	12.1
digestible Valine	9.5	8.7	8.7	8.7	8.7
Calcium (Ca)	9.5	10.4	9.3	9.4	9.7
Sodium (Na)	1.9	1.9	1.9	1.9	1.9
P available	4.8	4.2	4.2	4.2	4.2

[a]Mineral-vitamin supplement (initial phase): Vit. A 13.685 IU, Vit. D3 3.157 IU, Vit. E 350 mg, Vit. K3 4,410 mg, Vit. B1 2,415 mg, Vit. B2 8.662,5 mg, Vit. B6 5,460 mg, Vit. B12 21,315 µg, Biotin 96,250 µg, Niacin 53,900 mg, Folic acid 1,228,5 mg, Pantothenic acid 13,860 mg, Selenium 0,3 mg, Iodine 1,0 mg, Iron 300 mg, Copper 10,0 mg, Manganese 90,0 mg, Zinc 80,0 mg.

[b]Mineral-vitamin supplement (growth phase): Vit. A 9.775 IU, Vit. D3 2.255 IU, Vit. E 25,0 mg, Vit. K3 3,150 mg, Vit. B1 1,725 mg, Vit. B2 6.187,5 mg, Vit. B6 3,900 mg, Vit. B12 15,225 µg, Biotin 68,750 µg, Niacin 38,500 mg, Folic acid 0,87 mg, Pantothenic acid 9,900 mg, Selenium 0,21 mg, Iodine 1,0 mg, Iron 30,0 mg, Copper 10,0 mg, Manganese 90,0 mg, Zinc 80,0 mg.

the chamber, with free access to water. To determine NEm, fasting heat production (FHP) was considered, where the birds were subjected to a 12-hour feed suspension but with free access to water. Analyses to determine FHP commenced upon completion of excreta collections. After chamber calibration for desirable air conditioning, gas exchanges were recorded for 24 h. The outlet and inlet air samples were analyzed continuously at five-minute intervals considering temperature, humidity, flow, and atmospheric pressure. Gas analyzes were performed using Sable Systems International equipment. At the end of each measurement (24 h), the chamber was opened, and the feed residues and excreta production were measured to estimate the feed intake and energy balance of each experimental unit. The THP was calculated according to the equation proposed for birds by ROMIJN (1961): THP (kj) = 16.18 x O_2 (l) + 5.02 x CO_2 (l). THP was calculated considering the kilogram of metabolic body weight ($BW^{0,70}$), according to NOBLET et al. (2015). For these analyses, 5 replications of each treatment were used.

NE values were estimated as the difference between AMEn and CI. The CI was calculated as the difference between the heat production measured in the fed broilers minus the heat production measured in the fasted broilers, according to NOBLET & ETIENNE (1987) and VAN MILGEN et al. (1997). To calculate the efficiency of AMEn use for NE, the relationship between NE and AMEn (NE/AMEn) was used.

Productive performance was evaluated by feed intake, weight gain, feed conversion, viability, and productive efficiency index (PEI). The PEI was calculated when the birds reached 41 days of age, and the following formula was used for the calculation: daily weight gain (g) x viability (%)/feed conversion x 100. In contrast, the feed cost per kg of live broiler (CoF) was calculated by multiplying the feed cost by the feed conversion.

The variables were submitted for analysis of variance, and later regression analyzes were performed, using the statistical software Sisvar, version 4.6 (FERREIRA, 2014). The degrees of freedom of the factors were broken down into their linear and quadratic components to choose the regression model that best described the observations (SAMPAIO, 2002).

RESULTS AND DISCUSSION

Different levels of metabolizable energy in broiler diets influenced the metabolizability of nutrients, energy balance, and productive performance of broilers raised in a thermoneutral environment or heat stress.

In experiment 1, the metabolization of ether extract in the diet improved due to the increase in ME resulting from the inclusion of oil in the formulations (SOARES et al., 2020). However, in a thermoneutral environment, there was no positive impact observed from the increase in ME levels in the diets with the use of oil on the digestibility of dry matter and crude protein (Table 2). Therefore, this suggested that including lipids in the diet does not improve the metabolization and absorption of all nutrients. These findings are consistent with previous studies that have shown that the use of lipids in broiler diets can differentially influence the metabolization of different nutrients (ATTIA et al., 2018; ATTIA et al., 2020).

In experiment 2, the increase in the ME level in the diets associated with the increase in the inclusion of oil improved the metabolizability of ether extract and crude protein in broilers reared under heat stress (Table 3). Consequently, increasing ME by adding oil can be an efficient way to improve bird performance in hot regions owing to, among other factors, increased nutrient digestibility (HASSAN et al., 2018; SOARES et al., 2020).

In the thermoneutrality environment (experiment 1), the AMEn intake, RE, THP, FHP, and CI, expressed per kg of metabolic weight, were similar, regardless of the ME level (2980, 3080, 3180 and 3280 kcal/kg in the ration). There was also no difference between the efficiency of using GE for AMEn and when using AMEn for NE (Table 4). These results can be explained by the greater presence of oil replacing corn in the experimental diets (0.00, 17.0, 36.0, and 55.0 g/kg, respectively). Despite the greater energy availability of the diets, they have the potential to increase the production of endogenous heat. The increase in oil levels to replace the carbohydrate equalized the total heat production and the caloric increment. This may be due to the extra-caloric effects of the oil, which contribute to a high energy value of a low caloric increment (ATTIA et al., 2020; SOARES et al., 2020). Similar results were observed in experiment 2, where the birds were subjected to heat stress (Table 5). However, an initial reduction of CI was observed with the increase of the ME level in the ration, which reduced until the estimated level

Table 2 - Effect of dietary metabolizable energy level on the metabolizability coefficient of nutrients in broiler reared in thermoneutrality (experiment 1).

Variables[a]	---------------Metabolizable Energy Levels, kcal/kg-------------				----SEM[b]----	------------P-value------------	
	2980	3080	3180	3280		Linear	Quadratic
DMMC (%)	75.13	74.68	74.83	72.77	0.86	0.09	0.36
CPMC (%)	62.83	61.98	65.25	62.16	0.85	0.74	0.20
EEMC (%)	68.27	75.47	79.83	81.46	0.80	0.00[1]	0,00[2]

[a]DMMC = dry matter metabolizability coefficients; CPMC = crude protein metabolizability coefficients; EEMC = ether extract metabolizability coefficients.
[b]SEM = standard error of the mean.
[1]$Y = -61.1944+0.0439x$ ($R^2 = 0.92$);
[2]$Y = -1426.5258+0.9174x-0.0001x^2$ ($R^2 = 1.00$).

Table 3 - Effect of dietary metabolizable energy level on the metabolizability coefficient of nutrients in broiler reared under heat stress (experiment 2).

Variables[a]	--------------Metabolizable Energy Levels, kcal/kg--------------				----SEM[b]---	------------P-value-------------	
	2980	3080	3180	3280		Linear	Quadratic
DMMC (%)	71.17	73.28	71.73	73.75	1,19	0.26	0.96
CPMC (%)	56.18	60.60	58.90	62.40	1.73	0.04[1]	0.79
EEMC (%)	61.41	72.98	77.63	81.44	1.61	0.00[2]	0.02[3]

[a]DMMC = dry matter metabolizability coefficients; CPMC = crude protein metabolizability coefficients; EEMC = ether extract metabolizability coefficients.
[b]SEM = standard error of the mean.
[1]$Y = 6.3353+0.0169x$ ($R^2 = 0.68$); [2] $Y = -129.2783+0.0647x$ ($R^2 = 0.92$); [3] $Y = -2027.9819+1.2795x-0.000194x^2$ ($R^2 = 0.99$).

of 3021.5 ME in the ration and, from this level, the CI increased. In the heat stress conditions, the diet with 3080 kcal/kg in the ration presented a reduction of about 30% in the CI in relation to the diet with 2980 MJ/kg in the ration; however, this difference progressively decreased with the increase of ME. Further, CI reduction may be related to the extra caloric effect of the inclusion of oil; however, even with the increase in oil levels, the increase of ME in the ration of heat-stressed broilers can progressively increase the CI. This may be related, among other factors, to the energy cost of the increased rate of muscle protein degradation and the increase in panting that occurs in heat-stressed birds (YUNIANTO et al., 1997).

Results similar to those recorded in the present study were obtained in a study by NOBLET et al. (2009) that sought to evaluate, through indirect calorimetry, the efficiency of using ME for NE in two rations produced from wheat, soybean meal, isolated soybean protein, corn starch, and rapeseed oil, to obtain a ration with low crude fat (27 g/kg crude fat and 3042.54 kcal/kg de ME) and another with a high crude fat content (96 g/kg crude fat and e 3389.1 kcal/kg ME). These authors did not observe the effect of lipid and ME levels on the metabolizable energy intake (447.84 kcal/kg^{0,70}/d), THP (215.68 kcal/kg^{0,70}/d), FHP (105.21 kcal/kg^{0,70}/d), CI (110.35 kcal/kg^{0,70}/d) and NE/ME (75.0%).

Table 4 - Effect of metabolizable energy level in the ration for growing broiler reared in thermoneutrality on the energy balance in the dry matter (experiment 1).

Variables[a]	-----------------Metabolizable Energy Levels, kcal/kg----------------				---SEM[b]---	----------P-value-----------	
	2980	3080	3180	3280		Linear	Quadratic
----------Energetic balance (kcal/kg^{0,70}/ day) ----------							
AMEn cons	328.00	328.39	330.68	337.69	20.44	0.74	0.88
RE	126.14	126.83	126.21	127.70	14.40	0.95	0.98
THP	201.85	201.56	204.47	209.99	10.80	0.58	0.79
FHP	122.74	128.62	121.90	141.08	4.92	0.06	0.21
CI	79.12	72.94	82.58	68.91	10.80	0.67	0.73
----------Energy value of rations----------							
AMEn (kcal/kg)	3306.15	3411.76	3445.69	3491.39	41.57	0.00[1]	0.48
AMEn/GE (%)	73.84	73.75	73.76	73.01	0.88	0.54	0.71
NE (kcal/kg)	2504.31	2667.07	2718.26	2808.06	83.63	0.02[2]	0.67
NE/AMEn (%)	75.74	78.14	77.56	80.30	1.91	0.14	0.93

[a]AMEn cons = apparent metabolizable energy consumption corrected by nitrogen balance; RE = retained energy; THP = total heat production; FHP = fasting heat production; CI = caloric increment; AMEn = apparent metabolizable energy corrected by nitrogen balance; GE = gross energy; NE = net energy.
[b]SEM = standard error of the mean.
[1]$Y = 1568.1487+0.5896x$ ($R^2 = 0.93$); [2]$Y = -338.0535+0.9624x$ ($R^2 = 0.95$).

Table 5 - Effect of metabolizable energy level in broiler rations reared under heat stress on energy balance in dry matter (experiment 2).

Variables[a]	------------------Metabolizable Energy Levels, kcal/kg--------------				---SEM[b]---	---------P-value----------	
	2980	3080	3180	3280		Linear	Quadratic
----------Energetic balance (kcal/kg^{0,70}/ day)----------							
AMEn cons	322.38	278.22	338.00	329.14	21.20	0.41	0.42
RE	97.72	83.56	122.64	126.36	21.70	0.22	0.69
THP	224.64	194.68	215.36	202.76	6.16	0.12	0.18
FHP	128.08	128.78	141.34	121.03	9.23	0.84	0.29
CI	96.56	65.90	74.02	81.74	6.15	0.20	0.01[1]
----------Energy value of rations----------							
AMEn(kcal/kg)	3181.28	3329.66	3302.40	3459.88	71.45	0.02[2]	0.95
AMEn/GE (%)	71.08	71.98	70.70	72.38	1.55	0.71	0.80
NE(kcal/kg)	2203.28	2545.50	2566.74	2596.30	120.51	0.04[3]	0.21
NE/AMEn (%)	68.88	76.48	77.66	74.96	2.60	0.11	0.06

[a]AMEn cons = apparent metabolizable energy consumption corrected by nitrogen balance; RE = retained energy; THP = total heat production; FHP = fasting heat production; CI = caloric increment; AMEn = apparent metabolizable energy corrected by nitrogen balance; GE = gross energy; NE = net energy.
[b] SEM, standard error of the mean.
[1]$Y = 9581.4310 - 6.0428x + 0.0009x^2$ ($R^2 = 0.85$); [2]$Y = 787.5748 + 0.8085x$ ($R^2 = 0.83$); [3]$Y = -1278.9840 + 1.2003x$ ($R^2 = 0.71$).

For both experiments, the availability of AMEn and NE progressively increased with increasing ME levels of the evaluated treatments (Table 4 and Table 5). In birds reared in thermoneutrality (experiment 1), the diet with 2980 kcal/kg (0.0 g/kg of oil) presented 6.1% less NE in relation to the diet with 3080 kcal/kg (17 g/kg of oil). However, this difference decreased between the other treatments. The diet with 3080 kcal/kg (17.0 g/kg of oil) presented 1.92% less NE in relation to the diet with 3180 kcal/kg (36.0 g/kg of oil) and between treatments 3180 and 3280 kcal/kg (36.0 and 55.0 g/kg of oil, respectively) the difference was 3.3%. For birds reared in cyclic heat stress (experiment 2), the diet with 2980 kcal/kg had 13.44% less NE than the diet with 3080 kcal/kg. However, the diet with 3080 kcal/kg presented 0.83% less NE in relation to the diet with 3180 kcal/kg. The difference between the treatments (3180 and 3280 kcal/kg) was 1.1%. These results, observed in a cyclical heat stress environment, coincide with the initial reduction of the CI with the increased energy level in the ration. In the heat, the diet with 3080 kcal/kg in the ration presented a reduction of about 31,7% in the CI in relation to the diet with 2980 kcal/kg in the ration. However, this difference progressively decreased with the increase of ME. Corroborating the idea that diets with oil have better energy efficiency (HASSAN et al., 2018; SOARES et al., 2020).

In experiment 1, feed intake from 20 to 41 days of age was not influenced by treatments. Increasing the ME level improved the weight gain, feed conversion, and PEI. However, it reduced viability and increased CoF in broilers reared in thermoneutrality (Table 6). Whereas, in experiment 2, both weight gain and feeding intake of broiler chickens aged 20 to 41 days raised under thermal stress were influenced by the level of metabolizable energy (ME) in their diet. Feed conversion ratio improved linearly with increasing ME level, while the cost of feed increased with the same. However, there was no significant effect of the ME level in the diet on the viability and productive efficiency index of broiler chickens raised under thermal stress conditions (Table 7). The increase in energy has a positive effect on performance parameters, mainly on feed conversion, due to greater oil inclusions in the rations and its extra caloric effects, such as improved palatability and improved nutrient use, as shown in table 2 and table 3. However, increasing energy levels increases the cost of the broiler produced.

The inclusion of oil in the diet of broiler chickens enhances feed conversion efficiency due to the properties of fats, which enhance nutrient absorption and energy efficiency. Studies by OLIVEIRA NETO et al. (2000) have shown that diets with higher energy content led to better performance and a linear improvement in feed conversion. SAKOMURA et al. (2004) supported these findings, observing that higher energy levels in the feed improved poultry performance without affecting feed consumption. Although MENDES et al. (2004) did not find a direct

Table 6 - Performance of male broilers aged 20 to 41 days kept under thermoneutral environment and fed diets with increasing levels of ME (experiment 1).

Variables[a]	------------Metabolizable Energy Levels, kcal/kg------------				---SEM[b]---	-----------P-value-----------	
	2980	3080	3180	3280		Linear	Quadratic
Weight gain (kg)	2.12	2.16	2.18	2.33	0.04	0.00[1]	0.15
Feed consumption (kg)	3.55	3.56	3.53	3.55	0.04	0.88	0.96
Feed conversion (kg/kg)	1.68	1.65	1.62	1.52	0.02	0.00[2]	0.10
Viability (%)	98.81	97.62	98.81	91.67	1.84	0.02[3]	0.12
PEI	567.68	579.87	602.36	634.70	15.62	0.00[4]	0.53
CoF (US$/kg)	0.67	0.71	0.74	0.74	0,009	0.00[5]	0.07

[a]PEI - productive efficiency index; CoF - feed cost per kg of live broiler.
[b]SEM, standard error of the mean.
[1]$Y = 0.1597+0.0006x$ ($R^2 = 0.83$); [2]$Y = 3.1328-0.0005x$ ($R^2 = 0.88$); [3]$Y = 160.0626-0.0202x$ ($R^2 = 0.58$); [4]$Y = -103.5404+0.2235x$ ($R^2 = 0.96$); [5]$Y = -0.1350+0.0003X$ ($R^2 = 0.91$).

influence on weight gain with increased metabolizable energy, they also observed an improvement in feed conversion. These results indicate that increasing energy in the diet benefits poultry performance through better nutrient utilization.

Despite the improvements observed in the zootechnical performance of birds in experiments 1 and 2, the cost of feed per kg of broiler produced increased with the increase in ME levels provided by the increase in the inclusion of oil, which limits the use of diets with high energy and high inclusion of oil, since in the current scenario the cost of the feed is one of the biggest obstacles in broiler production. Despite their benefits, oils are expensive sources of energy. In addition to animal nutrition, they are widely used in human food (ATTIA et al., 2021). Therefore, the use of expensive inputs, such as oil, requires further evaluation to minimize their inclusion in poultry rations via formulations that require low levels of oil or energy (HAFEZ & ATTIA, 2020).

According to ROSTAGNO et al. (2024), for high-performance male broilers reared in a thermoneutral environment or at an average temperature of 26 ºC (ranging from 21 to 31 ºC), the average recommendation for metabolizable energy for the period from 17 to 41 days of age is 3100 kcal/kg. However, the nutritional requirements for Cobb 500™ broilers from 2022 recommend an average of 3033 kcal/kg for the same period. In this context, this study evaluated metabolizable energy (ME) levels of 2980, 3080, 3180, and 3280 kcal/kg in broilers reared under thermoneutral and heat stress conditions. Under thermoneutral conditions, the level of 3180 kcal/kg was found to be the most balanced,

Table 7 - Performance of male broilers aged 20 to 41 days kept under heat stress and fed diets with increasing levels of ME (experiment 2).

Variables[a]	-------------Metabolizable Energy Levels, kcal/kg------------				---SEM[b]---	------------P-value------------	
	2980	3080	3180	3280		Linear	Quadratic
Weight gain (kg)[c]	1.82	1.77	1.74	1.91	0.04	0.25	0.03[1]
Feed consumption (kg)[c]	3.07	2.98	2.85	3.00	0.05	0.18	0.04[2]
Feed conversion (kg/kg)[d]	1.69	1.69	1.64	1.58	0.02	0.00[3]	0.15
Viability (%)	96.43	94.05	96.43	90.48	2.99	0.26	0.56
PEI	471.25	449.97	464.05	500.02	27.06	0.42	0.30
CoF (US$/kg)[d]	0.67	0.72	0.75	0.77	0.01	0.00[4]	0.13

[a]PEI - productive efficiency index; CoF - feed cost per kg of live broiler.
[b]SEM, standard error of the mean.
[1]$Y = 54.3063-0.0338x+0.000005x^2$ ($R^2 = 0.90$); [2]$Y = 62.3671-0.0377x+0.000006x^2$ ($R^2 = 0.79$); [3]$Y = 2.8884-0.0004x$ ($R^2 = 0.88$); [4]$Y = -0.2721+0.0003x$ ($R^2 = 0.96$).

improving weight gain and feed conversion without substantially affecting viability. Under heat stress, the level of 3280 kcal/kg maximized feed conversion. These results indicate the need to evaluate higher ME levels, given the positive linear effect on many performance parameters, always considering the balance between the benefits and the costs of feed.

CONCLUSION

In this study, the energy level of 3280 kcal/kg showed the best feed conversion results for broiler chickens aged 20 to 41 days. At this stage, increasing metabolizable energy in the diet of broiler chickens has a positive effect on animal productivity, particularly in feed conversion, both under thermoneutral conditions and cyclic thermal stress. However, increasing energy levels in the diet also increases the production cost of broilers. Therefore, it is important to consider production system goals when determining optimal energy levels in the feed.

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DECLARATION OF CONLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

BIOETHICS AND BIOSECURITY COMMITTEE APPROVAL

Two experiments were performed and all procedures involving animals were conducted under the guidelines of local the Animal Experimentation Ethics Committee (Protocol: 063/11).

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