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Environmental temperature and broiler age on corn energy value

Temperatura ambiente e idade do frango de corte sobre o valor energético do milho

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Abstract

This study aimed to assess the effects of environmental temperature and age of broilers on the energy value of corn. A total of 288 Cobb 500 chicks were distributed in a complete randomized design with a split-plot arrangement and six replications of six chicks each. The main plot consisted of three temperatures (cold: 18 °C; thermoneutral: 25 °C; and hot: 33 °C), while the secondary plot consisted of age (initial: 11 to 14 days; growing: 25 to 28 days; and final: 39 to 42 days). The basal diet was based on corn and soybean meal. The test diet was produced by replacing the basal diet for test food: 40% corn + 60% basal diet. The mean values of AMEn observed for broiler chicks under cold, thermoneutral, and hot temperatures were 3322, 3279, and 3233 kcal/kg of natural matter, respectively, and 3215, 3218, and 3400 kcal/kg of natural matter for the initial, growing, and final phases, respectively. Overall, the metabolizable energy values of corn and the balance and coefficients of metabolizability of nutrients in the test diet increased with the broiler age, but the true metabolizable energies of corn were not affected by environmental temperature. The balance and coefficients of metabolizability of nutrients in the test diet decreased due to heat exposure during the growing and final phases.

Keywords: nitrogen balance; metabolizable energy; heat stress; cold stress; metabolizability of nutrients.

Resumo

O objetivo deste trabalho foi determinar o efeito da temperatura ambiente e da idade da ave sobre o valor energético do milho. Foram utilizados 288 pintos de corte, da linhagem Cobb 500, distribuídos em delineamento experimental inteiramente casualizado em esquema de parcelas subdivididas no tempo, sendo as parcelas as três temperaturas de criação (fria: 18 °C; termoneutra: 25 °C e quente: 33 °C) e as subparcelas as três idades de avaliação (inicial: 11 a 14; crescimento: 25 a 28 e final: 39 a 42 dias), com seis repetições de seis aves cada. A dieta basal foi composta por milho e farelo de soja. A dieta

teste foi produzida substituindo a dieta basal pelo alimento teste: 40% de milho + 60% da dieta basal. Encontraram-se valores médios de energia metabolizável aparente, corrigida pelo balanço de nitrogênio (EMAn) do milho, para aves criadas em 18 °C; 25 °C e 33 °C de 3322, 3279 e 3233 kcal/kg de matéria natural, respectivamente, e para as fases de 11 a 14; 25 a 28 e 39 a 42 dias de 3215, 3218 e 3400 kcal/kg de matéria natural, respectivamente. De um modo geral, os valores de energia metabolizável do milho, os balanços e os coeficientes de metabolizabilidade dos nutrientes da dieta teste aumentam com a idade do frango de corte, porém as energias metabolizáveis verdadeiras do milho não foram afetadas pela temperatura ambiente. Os balanços e os coeficientes de metabolizabilidade dos nutrientes da dieta teste foram reduzidos em estresse por calor para aves na fase de crescimento e final.
Palavras-chave: balanço de nitrogênio; energia metabolizável; estresse por calor; estresse por frio; metabilizabilidade de nutrientes.

Introduction

The nutritional composition of ingredients and their respective energy values must be as accurate as possible in feed formulation, justifying the determination of the chemical composition and metabolizable energy values of national foods commonly used in animal nutrition.

The update of nutrient requirements in feed formulations is important because of the productivity and maintenance of broilers, which are altered due to genetic improvement and other factors, such as age, sex, lines, and environmental temperature,[1] which modify the use of energy and protein.

Corn is the main energy ingredient in poultry feed, but it also contributes a good part to dietary protein. It is responsible for approximately 25% of the total crude protein in chicken diets,[2] with its greatest limitation, as a source of nutrients, the low content of the amino acids lysine and tryptophan.

The determination of the metabolizable energy values of ingredients considering the age may contribute to the caloric adequacy of diets. The digestive capacity of the poultry increases as their age advances, with increased use of nutrients due to the development of accessory organs and the digestive system.[3] Thus, the formulation using the metabolizable energy values of the food adjusted to the poultry age can lead to a higher optimization in the formulation and less waste of nutrients in the feed, improving feed conversion and, consequently, decreasing the food cost.

In general, the recommendations on nutrition and feeding of broilers are carried out at an environmental temperature within the comfort range of growing poultry, which is not adequate to meet their energy requirements in a heat or cold stress environment, which may be one of the causes for the decrease in broiler performance.

Considering that poultry voluntarily reduce food intake as the environmental temperature rises above the thermal comfort range,[4] a feed formulated for thermoneutral conditions would not be adequate to meet their energy requirements in a heat-stress environment.

This study was developed to determine the effect of the environmental temperature and broiler age on the energy value of corn.

Material and methods

The experiment was conducted at the School of Veterinary Medicine and Animal Science, UNESP, campus of Botucatu, at the Laboratory of Poultry Nutrition, according to the ethical principles in animal experimentation approved by the Committee on Ethics in Animal Experimentation (Protocol No. 160/2007-CEEA). A total of 288 male Cobb 500 broiler chicks were used. The experimental design was completely randomized in a split-plot scheme in time, with the plots consisting of three temperatures (18, 25, and 33 °C) and the subplots consisting of three ages of assessment (initial: 11 to 14 days; growth: 25 to 28 days; and final: 39 to 42 days), with six replications of six animals.

A total of 216 out of the 288 broiler chicks were distributed in 36 galvanized wire cages, measuring 0.50 m high, 0.50 m wide, and 0.60 m deep, distributed in three temperature-controlled chambers (hot, thermoneutral, and cold) with the cages arranged in two batteries of two floors each, totaling 12 cages/chamber. The remaining 72 broiler chicks were used in an extra treatment (fasting for 72 hours) to assess endogenous and metabolic losses at each age of assessment within the three climatic chambers to determine a correction factor to estimate the true metabolizable energy of corn.[5]

The basal diet was formulated based on corn and soybean meal, and the food composition and nutritional requirements were obtained from Rostagno *et al.*[6] (Table 1). The test diet was obtained by replacing part of the basal diet with the test food (40% corn + 60% basal diet).

All animals remained in a hot chamber until six days of age in order not to compromise their initial performance. Then, they were randomly distributed in the three chambers (cold, thermoneutral, and hot). The values of environmental temperature, relative air humidity, and temperature-humidity index (THI), determined in the climatic chambers during the experimental period, are shown in Table 2. The values of environmental temperature and relative air humidity were collected using a thermo-hygrometer, and a globe thermometer was used to calculate THI. The equipment remained inside the climatic chambers throughout the experimental period. Data collection was carried out in the morning and at the end of the day.

Three metabolic tests with four days of adaptation (7 to 10, 21 to 24, and 35 to 38 days of age) and four days of total excreta collection (11 to 14, 25 to 28, and 39 to 42 days of age) were performed to assess the use of metabolizable energy and the metabolization of corn nutrients with increasing age.

Table 1. Composition and calculated values of experimental diets

Ingredient	Raising phase (days old)			
	1 to 7	8 to 21	22 to 35	36 to 42
Corn	61.175	64.910	66.600	70.600
Soybean meal	28.300	24.710	18.000	14.520
Meat meal	2.000	2.500	5.500	5.500
Common salt	0.240	0.220	0.170	0.160
Vitamin and mineral suppl.	0.500[1]	0.400[1]	0.400[2]	0.200[3]
Calcitic limestone	0.800	0.750	0.450	0.395
Dicalcium phosphate	1.450	1.150	0.250	0.120
DL-methionine	0.185	0.130	0.130	0.130
L-lysine	0.510	0.370	0.420	0.455
Protenose	4.500	4.510	4.770	4.700
Sodium bicarbonate	0.340	0.350	0.310	0.290
Starch			3.000	3.130
Total	100.000	100.000	100.000	100.000
Calculated values				
MB (kcal/kg)	2950	3000	3099	3152
CP (%)	22.04	20.79	19.42	18.55
Calcium (%)	0.94	0.89	0.82	0.76
Available phosphorus (%)	0.47	0.44	0.41	0.38
Methionine (%)	0.52	0.48	0.43	0.41
Methionine + cystine (%)	0.82	0.74	0.70	0.67
Lysine (%)	1.33	1.14	1.07	1.02
Threonine (%)	0.72	0.68	0.62	0.57
Potassium (%)	0.73	0.69	0.61	0.56
Sodium (%)	0.22	0.22	0.21	0.20
Chlorine (%)	0.20	0.19	0.18	0.17
Linoleic acid (%)	1.38	1.43	1.42	1.46

[1]Vitamin and mineral supplement Vaccinar Nutrição e Saúde Animal (per kg of feed): folic acid 1.25 mg, pantothenic acid 12.5 mg, BHT 2.5 mg, biotin 0.125 mg, copper 12.5 mg, choline 750.0 mg, iron 62.62 mg, iodine 0.025 mg, manganese 67.5 mg, niacin 37.5 mg, selenium 0.225 mg, vitamin A 12,500 IU, vitamin B1 2.5 mg, vitamin B12 25 mg, vitamin B2 5.0 mg, vitamin B6 5.0 mg, vitamin D3 2500 IU, vitamin E 25.0 mg, vitamin K3 2.5 mg, zinc 68.75 mg, avilamycin 7.5 mg, monensin 125.0 mg. [2]Vitamin and mineral supplement Vaccinar Nutrição e Saúde Animal (per kg of feed): folic acid 1.0 mg, pantothenic acid 10.0 mg, BHT 2.0 mg, biotin 0.1 mg, copper 10.0 mg, choline 600.0 mg, iron 50.1 mg, iodine 0.02 mg, manganese 54.0 mg, niacin 30.0 mg, selenium 0.18 mg, vitamin A 10,000 IU, vitamin B1 2.0 mg, vitamin B12 20.0 mg, vitamin B2 4.0 mg, vitamin B6 4.0 mg, vitamin D3 2000 IU, vitamin E 20.0 mg, vitamin K3 2.0 mg, zinc 55.0 mg, avilamycin 6.0 mg, monensin 100.0 mg. [3]Vitamin and mineral supplement Vaccinar Nutrição e Saúde Animal (per kg of feed): folic acid 0.5 mg, pantothenic acid 5.0 mg, BHT 1.0 mg, biotin 0.05 mg, copper 5.0 mg, choline 300.0 mg, iron 25.05 mg, iodine 0.01 mg, manganese 27.0 mg, niacin 15.0 mg, selenium 0, 09 mg, vitamin A 5,000 IU, vitamin B1 1.0 mg, vitamin B12 10.0 mg, vitamin B2 2.0 mg, vitamin B6 2.0 mg, vitamin D3 1,000 IU, vitamin E 10.0 mg, vitamin K3 1.0 mg, zinc 27.5 mg, avilamycin 3.0 mg, monensin 50.0 mg.

Table 2. Environmental conditions and temperature-humidity index (THI) observed in climatic chambers during the experimental period

	Environmental temperature (°C)			Relative humidity (%)			THI[1]
Chamber	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Mean
Cold	17.63	20.29	18.96	61.70	83.03	72.37	66.08
Thermoneutral	24.63	26.81	25.76	59.65	76.88	68.28	75.24
Hot	29.42	31.87	30.56	48.94	62.78	55.86	82.19

[1]THI: dry-bulb thermometer temperature (°C) + (0.36 × wet-bulb thermometer temperature (°C)) + 41.5.[7]

Samples of feed and excreta were stored frozen (−16 °C) for the analyses of dry matter (DM), nitrogen (N), and ether extract (EE), according to the methodology described by Silva & Queiroz.[8] The results allowed calculating the coefficients of apparent and true metabolizability of dry matter (CMDM and CMDMT), ether extract (CMEE and CMEET), and nitrogen (CMN and CMNT) of the test diet.

The gross energy values of diets and excreta were obtained using an Ika Works C-200 calorimeter, which allowed calculating the apparent and true metabolizable energy (AME and TME), subsequently corrected by the nitrogen balance (AMEn and TMEn) in the natural matter using the equations proposed by Matterson *et al.*[9] The metabolizability coefficients of food energy were determined based on the values of gross energy, AME, AMEn, TME, and TMEn.

Statistical analyses were performed using analysis of variance by the software SAEG.[10] Significant differences between the means of treatments were verified using the Tukey test (5% probability).

Results and discussion

The chemical composition of corn in the natural matter used in the experiment was 87.84% dry matter, 7.5% crude protein, 3.4% ether extract, and 3968 kcal/kg of crude energy. The protein value obtained for corn was lower than those found by Rodrigues *et al.*[11] of 8.07%, Mello *et al.*[12] of 7.91%, and Kato *et al.*[13] from 8.60 to 9.60%, and higher than those mentioned by D'Agostini *et al.*[14] of 7.33% and Nery *et al.*[15] of 7.26%. The frequency of nitrogen fertilization can influence the crude protein content of the grain.[13] The gross energy was higher than that found by Nery *et al.*[15] of 3939 kcal/kg and lower than the result of D'Agostini *et al.*[14] of 4089 kcal/kg and Mello *et al.*[12] of 4009 kcal/kg. These differences occur because soil fertility, climate, genetics, storage, and processing are factors that interfere with the chemical composition of food.[16]

An interaction was observed between environmental temperature and raising phase for AME, AMEn, TME, and TMEn (Table 3). Broilers at the growing phase (25 to 28 days of age) raised in the cold chamber used the energy from corn better when compared to animals raised under thermoneutral temperature (AME) (P=0.0315) and better than animals raised under thermoneutral and hot temperature after correction by the nitrogen balance (P=0.048). The correction of endogenous losses (TME and TMEn) canceled the differences between temperatures, with no differences in the metabolizable energies assessed within the raising phases.

Table 3. Slicing of the interaction between raising phase and environmental temperature for the metabolizable energy values of corn (kcal/kg) expressed in the natural matter for broilers

Temperature	Cold	Thermoneutral	Hot	Mean	CV[1] (%)
Phase		[2]AME (kcal/kg)			
Initial	3332	3288b	3180 b	3267	
Growing	3397 A	3191 Bb	3273 ABb	3287	2.57
Final	3445	3524 a	3374 a	3447	
Mean	3391	3335	3275		
		[2]AMEn (kcal/kg)			
Initial	3265	3246 b	3135 b	3215	
Growing	3322 A	3132 Bb	3200 Bb	3218	2.34
Final	3379	3459 a	3362 a	3400	
Mean	3322	3279	3233		
		[2]TME (kcal/kg)			
Initial	3434	3375 b	3293 b	3367	
Growing	3563	3389 b	3446 b	3466	3.01
Final	3525	3709 a	3637 a	3624	
Mean	3507	3491	3459		
		[2]TMEn (kcal/kg)			
Initial	3336	3312 b	3226 b	3291	
Growing	3441	3286 b	3334 b	3354	2.88
Final	3437	3593 a	3549 a	3526	
Mean	3405	3397	3369		

[A,B,a,b]Means followed by different uppercase letters in the row and lowercase letters in the column differ from each other (P<0.05) by the Tukey test.

[1]CV, coefficient of variation.

[2]Apparent (AME) and true metabolizable energy (TME), as well as corrected by the nitrogen balance (AMEn and TMEn).

Geraert *et al.*[17] and Faria Filho *et al.*[18] found that the metabolizable energy content of the feed is not changed by the exposure of chickens to heat, while Keshavarz & Fuller[19] observed higher energy levels and Yamazaki & Zi-yi[20] found reduced energy levels (12-month-old Leghorn roosters) with increasing temperature. These different results can be attributed to the specific experimental conditions of each study, such as line, nutritional levels, ingredients, sex, and assessment period (age).

An explanation for these findings was proposed by Hai *et al.*[21], who compared the effect of temperature (5, 21, and 32 °C) on the digestive process of broilers and found that the enzymatic activity of trypsin and amylase decreased due to heat, not being influenced by low temperature. The pair-feeding approach of this experiment allowed the authors to conclude that, although at a low intensity, the food restriction imposed by exposure to heat improved the digestibility of all nutrients in the diet. The occurrence of these antagonistic effects is one of the justifications for the difficulty in finding and accurately predicting the response of broilers to the thermal challenge, in addition to being the cause of many of the discrepant results presented in the literature.

The mean values of the temperature-humidity index (THI) for the thermal comfort range of poultry are between 71 and 76.[22] Therefore, the THI value of 82.19 (Table 2) for the hot chamber shows that the animals were stressed by heat, but it was not enough to affect the use of corn energy. The lower relative humidity (RH) in the hot chamber during the experiment may have reduced the effect of stress.

Another cause of the absence of the effect of heat stress on ME may be due to the low percentage of protein in the diet with 40% corn (mean of 15% CP), which promoted a reduction in the caloric increase, usually caused by protein-rich diets.[23] However, even the high-energy feed (3250 kcal) under a heat stress environment did not impede for the broilers to maintain the same feed intake and weight gain adequate at 35 and 42 days of age.[24]

The absence of a sanitary challenge in the experiment may also have assisted in maintaining the use of ME even under heat stress. Broilers infected by *Salmonella* and raised at a temperature of 31 °C from 35 to 41 days of age presented lower weight gain and feed intake and worse feed conversion.[25]

Animals raised in the cold chamber showed no difference between ages (Table 3) for all calculated energies. The results of the thermoneutral and hot chambers showed that older animals (final phase) had better use of the energy from corn than the other ages in the initial and growing phases (P<0.001). This result may be related to the maturation of the gastrointestinal tract, which, according to Uni *et al.*,[26] is established at 16 days of age in broilers.

The determination of the metabolizable energy of feed ingredients before 14 days of age may present lower values than those obtained with older birds, and the metabolizable energy values determined in older broilers may overestimate the availability of energy for younger birds.[27]

Sakomura *et al.*[28] found a linear increase in the activity of amylase, trypsin, and lipase with the advancing age of broilers (1 to 7, 8 to 14, 15 to 21, and 22 to 28 days), and the phase of the highest increase occurred between the first and second weeks of age, coinciding with the maximum allometric growth of pancreas.

Batal & Parsons[29] studied the effect of age on carbohydrate digestibility and found that the AMEn values of corn increased from 12 to 15% with age. In the current study, the increase in AMEn in broilers at 14 days for 42 days of age was around 5.5%. Mello *et al.*[12] found no differences in the metabolizable energy of corn with increasing age in metabolic assays with broilers from 10 to 17, 26 to 33, and 40 to 47 days of age and 25-week old Leghorn roosters.

The results of AMEn found for corn were lower than those presented by the Brazilian Tables for Poultry and Swine[30] (corn with 7.86% protein and 3364 kcal/kg in the natural matter), except for broilers raised at cold and thermoneutral temperatures at the final phase (3379 and 3459 kcal/kg) for AMEn. However, the values found by Rostagno *et al.*[30] are compilations of studies with broilers at different ages and roosters. This study showed lower values for heat stress temperature than those found by Rostagno *et al.*[30] and, therefore, feed formulation for broilers under stress based on metabolizable energy values acquired at thermoneutral temperature can cause a reduction in the animal performance.

Several studies have assessed the energy value of corn. D'Agostini *et al.*[14] found mean values of AME and AMEn of 3246 and 3235 kcal/kg in the natural matter, respectively, for corn. Vieira *et al.*[31] also found that the apparent metabolizable energy, corrected for the mean of corn hybrids, reached 3744 kcal/kg, ranging from 3405 to 4013 kcal/kg of DM. Generoso *et al.*[32] found mean values of apparent metabolizable energy, corrected by the nitrogen balance of corn, of 3351 and 3524 kcal/kg in the natural matter determined in broilers at the growing (21 to 30 days of age) and final phases (41 to 50 days), respectively.

The AME values were higher than the AMEn values in all treatments due to the positive nitrogen balance. This characteristic is normal when ME values are determined in growing broilers, as this phase presents higher retention of nitrogen for the deposition of protein tissue. This difference is more pronounced when the correction for endogenous and metabolic losses is performed.[15]

The TME values of corn were, on average, 5.3% higher than the AME values for broilers raised in the hot chamber, a difference higher than that of the other chambers, that is, 3.3 and 4.5% for the cold and the thermoneutral chambers, respectively. The methodology consisted of total excreta collection, with the animals fed ad libitum and no interference in the intake volume. Consequently, the AME and TME values were similar. However, the reduction in intake due to heat stress in the hot chamber overestimated the result of TME, increasing the difference between AME and TME.

An interaction ($P<0.001$) was observed between environmental temperature and age of broilers for the apparent and true nitrogen (NB and TNB) and ether extract (EEB and TEEB) balance of the test diet (Table 4). The results at the initial phase (11 to 14 days of age) showed no interference of the environmental temperature for the evaluated variables (NN, TNB, EEB, and TEEB). The apparent and true nitrogen balances were higher for broilers stressed by cold at the growing (P<0.001) and final phases (P<0.001). The worst nitrogen balance for broilers under heat stress has occurred due to the lower efficiency of nitrogen retention, with protein metabolization reduced by heat, regardless of sex and diet.[18,33,34,35]

Table 4. Slicing of the interaction between the raising phase and environmental temperature for nitrogen balance and ether extract values of the test diet for broilers

Temperature	Cold	Thermoneutral	Hot	Mean	CV[1] (%)
Phase	Apparent nitrogen balance in grams (NB)				
Initial	13.70 c	13.98 c	11.83 b	13.14	
Growing	29.71 Aa	24.44 Ba	22.27 Ca	25.47	6.00
Final	26.96 Ab	21.03 Bb	12.32 Cb	20.10	
Mean	23.46	19.79	15.47		
	True nitrogen balance in grams (TNB)				
Initial	18.37 c	17.30 c	14.80 c	16.83	
Growing	45.59 Aa	38.77 Ba	31.26 Ca	38.54	4.12
Final	38.49 Ab	31.87 Bb	20.50 Cb	30.29	
Mean	34.15	29.31	22.18		
	Apparent ether extract balance in grams (EEB)				
Initial	33.38 c	36.36 c	31.55 b	33.76	
Growing	82.07 Ab	69.31 Bb	63.45 Ba	71.61	4.26
Final	97.41 Aa	81.30 Ba	57.79 Ca	78.83	
Mean	70.95	62.32	50.93		
	True ether extract balance in grams (TEEB)				
Initial	34.39 c	37.144 c	32.51 b	34.68	
Growing	86.02 Ab	74.09 Bb	66.33 Ba	75.48	4.09
Final	98.58 Aa	84.14 Ba	59.71 Ca	81.48	
Mean	73.67	65.12	52.85		

[A,B,C,a,b,c]Means followed by different uppercase letters in the row and lowercase letters in the column differ from each other (P<0.05) by the Tukey test.
[1]CV, coefficient of variation.

A similar result was observed for EEB and TEEB, with a worse balance for animals under heat stress. However, broilers raised under thermoneutral temperature at the growing phase had no differences compared to animals raised under hot temperature. Broilers exposed to heat have higher water intake, which can cause less digestibility of nutrients by increasing the feed passage rate.[36] Heat is also responsible for reducing the size of organs[37] and the surface of intestinal villi.[38]

The effect of broiler age within the climatic chambers was better for NB (P<0.001) and the TNB (P<0.001) at all temperatures and the growing phase (25 to 28 days of age). Proteins are essential in the nutritional and metabolic aspects for broilers, as they are related to body processes such as the formation of structural tissues (muscle). Protein deposition in skeletal muscles in growing animals contributes about 65% of all protein deposited daily.[39]

Older broilers had the highest EEB and TEEB (cold and thermoneutral temperature), not differing from the growing phase for heat-stressed broilers. The presence of substrate in the digestive tract in young broilers seems to induce a higher production of enzymes. Thus, the activity of digestive enzymes, both pancreatic and membrane, increases with the broiler age, reaching higher levels at 10 days of age, on average.[40] Rapid changes in the digestive tract enable an increase in feed intake and alter nutrient digestibility.[4] The higher ether extract balance obtained in broilers at the final phase was probably due to the higher production of enzymes for digesting lipids compared to the young animals.

A significant interaction between temperature and age was observed for the variables CMDM (P=0.0130), CMDMT (P=0.0150), CMN (P<0.001), CMNT (P<0.001), and CMEE (P<0.001), except for CMEET, which presented an exclusive effect of the raising phase (P=0.0404) (Table 5).

The best metabolization of dry matter in the feed at the initial phase was observed for broilers under thermoneutral temperature, but broilers under cold stress showed better results with the increase of age, not differing from the thermoneutral temperature at the final phase. The temperature did not affect the results of broilers at the initial phase when CMDM was corrected for endogenous losses (CMDMT), with the best coefficients for birds raised in the thermoneutral chamber at the final phase, not differing from the cold chamber at the growing phase.

The use of nitrogen (CMN) showed an interference of temperature only for older broilers, in which heat stress reduced nitrogen use. A temperature effect was observed for all age phases when endogenous losses (CMNT) were removed. Broilers at the initial phase showed better coefficients when raised under cold stress, not differing from the thermoneutral temperature at the growing phase. Heat or cold stress in older broilers reduced nitrogen uptake.

The ability of broilers to deal with oxidative stress gradually decreases as the environmental temperature increases.[41] These negative effects also interfere with the intake of feed and nutrients[4] and, consequently, nutrient use is reduced.

CMEE was not influenced by the temperature at the growing phase (P=0.5316). Cold stress for young broilers caused a reduction in the coefficient, with the best results for older broilers (final phase) raised at thermoneutral temperature. When CMEE was corrected by endogenous losses (CMEET), only the age effect influenced this variable, confirming better use of the ether extract by older broilers.

Table 5. Slicing of the interaction between raising phase and environmental temperature for the coefficient of metabolizability of nutrients (%) in the test diet for broilers

Temperature	Cold	Thermoneutral	Hot	Mean	CV[1] (%)
Phase	Coefficient of apparent metabolizability of dry matter (CMDM)				
Initial	77.90 Bc	78.72 Ab	77.43 B	78.02	
Growing	79.96 Ab	78.51 Bb	78.52 B	79.00	0.82
Final	81.16 Aa	82.17 Aa	78.52 B	80.62	
Mean	79.68	79.80	78.15		
	Coefficient of true metabolizability of dry matter (CMDMT)				
Initial	81.14 b	81.40 c	80.75 c	81.09	
Growing	85.96 Aa	86.52 Ab	84.05 Bb	85.51	0.78
Final	85.74 Ba	88.16 Aa	85.60 Ba	86.50	
Mean	84.28	85.36	83.47		
	Coefficient of apparent metabolizability nitrogen (CMN)				
Initial	54.34 b	55.64 b	52.08 b	53.85	
Growing	58.51 a	56.64 b	58.25 a	57.80	4.36
Final	59.44 Aa	59.84 Aa	48.26 Bb	55.85	
Mean	57.43	57.20	52.86		
	Coefficient of true metabolizability of nitrogen (CMNT)				
Initial	72.89 Ac	68.70 Bb	65.18 Cb	68.92	
Growing	89.84 Aa	89.90 Aa	81.77 Ba	87.17	3.09
Final	84.91 Bb	90.78 Aa	80.84 Ba	85.51	
Mean	82.55	83.12	75.93		
	Coefficient of apparent metabolizability of ether extract (CMEE)				
Initial	79.79 Bb	84.20 Ab	81.25 Ab	81.75	
Growing	82.52 b	81.46 b	84.57 b	82.85	1.27
Final	86.39 Ba	92.27 Aa	88.44 Ba	86.39	
Mean	82.90	85.98	84.75		
	Coefficient of true metabolizability of ether extract (CMEET)				
Initial	82.22	86.01	83.71	83.98 c	
Growing	86.49	87.07	88.42	87.33 b	1.27
Final	89.21	95.50	91.38	92.03 a	
Mean	85.97	89.53	87.83		

[A,B,C,a,b,c]Means followed by different uppercase letters in the row and lowercase letters in the column differ from each other (P<0.05) by the Tukey test.

[1]CV, coefficient of variation.

Garcia *et al.*[42] worked with the digestibility of diets containing sorghum with low or high tannin for colostomized (removal of the colon via surgery and collection of feces and uric acid separately) broilers raised at three environmental temperatures (14, 25, and 32 °C) and found that the coefficients of digestibility of dry matter and ether extract were higher in the hot chamber and lower in the cold. These higher values were associated with the lower intake observed at high temperatures, which led to a lower speed of transit of food in the digestive tract of broilers and, consequently, higher absorption of nutrients.[4] This result occurred in the current study only for CMEE at the initial phase.

There was an effect of the broiler age for the studied temperatures. The best results for CMDM were observed in broilers at the final phase raised under thermoneutral and cold temperatures. Broilers in the hot chamber used the dry matter similarly, regardless of age. After correction (CMDMT), the results in the thermoneutral chamber were maintained, not differing between broilers at the growing and final phase in the cold chamber. Age also interfered with CMDMT for broilers in the hot chamber, with better results at the final stage.

Nitrogen metabolization (CMN) was better for broilers at the final phase in the thermoneutral chamber and growing and final phases in the cold chamber. The best coefficients under heat stress were observed in broilers at the growth phase (25 to 28 days of age). The correction for endogenous losses (CMNT) did not change the results inside the chambers, and broilers in the cold, thermoneutral, and hot chambers had the lowest coefficients at the initial phase, but the growing phase in the cold chamber had the best result.

The ether extract was better used by older broilers, regardless of the environmental temperature. Broiler age not only interfered with the metabolizable energy but also with the metabolizability of nutrients in the diet. Furthermore, heat stress reduced the metabolizability of nutrients in the test diet.

Bonnet *et al.*[36] conducted a performance experiment and metabolic test using broilers from 38 to 42 days of age raised under hot (32 °C) and thermoneutral temperature (22 °C), fed ad libitum, and pair-feeding (controlled feeding). The authors observed that, even with the same intake, broilers submitted to heat stress did not obtain the same growth rate as the animals under a thermoneutral environment. Also, a reduction in feed efficiency was observed during heat stress as a direct consequence of exposure to high temperature.

Conclusions

In general, the metabolizable energy values of corn, the balances, and coefficients of metabolizability of nutrients in the test diet increased with the broiler age, but the true metabolizable energy of corn was not affected by the environmental temperature. The balances and coefficients of metabolizability of nutrients in the test diet were reduced under heat stress for broilers at the growing and final phases.

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Conflict of interest

The authors declare no conflict of interest.

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