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Heat production and performance of broilers can be changed by inclusion of glycerin in their diet

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ABSTRACT
Glycerin has low heat increment and earlier studies on broilers evaluated its effects during the entire rearing period or in two phases at most. This study aimed to evaluate the effects of crude glycerin in diets of poultry on the performance and heat production of broiler chickens. For this, four evaluation phases (1-7, 8-21, 22-34, and 35-42 days of age) were established and 540 Cobb male broilers were distributed in a completely randomized design in six groups, each one with four replicates. The broilers were fed with diets containing 0 (control), 2.5, 5.0, 7.5, 10.0 and 12.5% glycerin. Feed consumption, weight gain, feed conversion ratio, and heat production were evaluated in each phase. The inclusion of up to 12.5% glycerin had a linear effect ($P < 0.05$), resulting in an improvement in feed conversion ratio, with no change in weight gain and feed consumption in the phase 1-7 days. There was no effect of the glycerin levels on the performance characteristics in the phases 8-21, 22-34, and 35-42 days of age. Some effect on heat production could be observed only in the phase 1-7 days of age ($P<0.05$), which was linear and decreasing. Glycerin can be added to the diets in up to 12.5% in all phases, not causing negative effects on the performance of broiler chickens. The addition of 12.5% glycerin reduced heat production in the phase 1-7 days of age.

Key words: birds, caloric increase, glycerol

Produção de calor e o desempenho de frangos de corte podem ser alterados pela inclusão de glicerina na dieta

RESUMO
A glicerina apresenta baixo incremento calórico, porém pesquisas em frangos de corte avaliaram seus efeitos durante período total de criação ou em duas fases, no máximo. Este estudo teve como objetivo avaliar o desempenho e produção de calor de frangos de corte alimentos com inclusão glicerina bruta nas dietas. Para isso, foram avaliadas as dietas em quatro fases de criação (1 a 7, 8 a 21, 22 a 34 e 35 a 42 dias). 540 frangos Cobb foram distribuídos em um delineamento inteiramente casualizado em seis tratamentos, cada um com quatro repetições. Os frangos foram alimentados com dietas contendo 0 (controle), 2,5, 5,0, 7,5, 10,0 e 12,5% de glicerina. O consumo de ração, o ganho de peso, a conversão alimentar e a produção de calor foram avaliados em cada fase. A inclusão de até 12,5% de glicerina teve um efeito linear ($P <0,05$), resultando em uma melhoria na taxa de conversão alimentar, sem alteração no ganho de peso e consumo de ração na fase 1-7 dias. Não houve efeito dos níveis de glicerina nas características de desempenho nas fases 8-21, 22-34 e 35-42 dias de idade. O efeito observado na produção de calor apenas na fase de 1 a 7 dias ($P <0,05$), foi linear e decrescente. A glicerina pode ser adicionada às dietas em até 12,5% em todas as fases, não causando efeitos negativos no desempenho de frangos de corte. A adição de 12,5% de glicerina reduziu a produção de calor na fase 1-7 dias de idade.

Palavras-chave: aves, incremento calórico, glicerol

INTRODUÇÃO

Many by-products have been tested in animal feeding as substitutes for dietary ingredients aiming at reducing production costs, because of periods of increased

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demand and consequently prices of ingredients used in the formulation of poultry diets, such as corn and soybean meal, which has a direct impact on the profit margin of the poultry farmer.

In this scenario, studies on the use of alternative feeds has been increasing in the last few years, especially those involving by-products or waste generated from the industrial processing of agricultural products (Gomes et al., 2007). In this regard, Waldroup (2007) describes glycerin as a potential energy supplement to be used in diets for broilers, for being a source of calories that can provide energy for the maintenance and growth without any adverse effects on the meat quality. This product has an energy value of 3,696 Kcal/kg of gross energy and 3,510 Kcal/kg of metabolizable energy for birds (Rostagno et al., 2011), so glycerin can partially replace energy ingredients of diets, especially because it is a liquid ingredient.

In view of these circumstances, studies on the inclusion of glycerin in broiler diets are essential to establish its use as an alternative feed and provide knowledge of the limitations of this ingredient for the different developmental stages of poultry. The effects of inclusion of glycerin in diets for broilers on their performance, and their carcass evaluation and composition under heat stress still need further investigation, as well as the caloric heat increment by glycerin, since animals reared in high-temperature environments have different productive rates as compared with those in a thermal-comfort zone. Previous studies show the effects of glycerin inclusion during the entire rearing period or in two phases at most (Cerrate et al., 2006; Guerra et al., 2011; Silva et al., 2012), but they do not evaluate the four rearing phases separately, as described by Rostagno et al. (2011). Thus, this study aimed to evaluate the effects of glycerin inclusion in broiler diets on their performance and heat production in the phases 1-7, 8-21, 22-34 and 35-42 days of age.

MATERIALS AND METHODS

Ethics Statement

This study was conducted in strict accordance with the recommendations of the Guide for the Care and Use of Laboratory Animals of the National Institutes of Health. The protocol was approved (registration number 022/09) by the Ethics Committee for Animal Experimentation of the Federal University of Piauí (Piauí, Brazil).

Birds and Housing

The experiment was conducted in the Poultry Farming Sector of the Technical College of Bom Jesus. The laboratory analyses were performed at the Animal Nutrition Laboratory in the Campus Professora Cinobelina Elvas (CPCE), Federal University of Piauí, Bom Jesus, and in the Department of Animal Sciences, São Paulo State University, UNESP, Jaboticabal, SP, Brazil.

A total of 540 male Cobb broilers were used. In each phase, 1-7 (pre-starter), 8-21 (starter), 22-33 (grower), and 34-42 (finisher/slaughter) days of age, 135 birds were distributed in a completely randomized design with six treatments (increasing levels of glycerin inclusion) and four replicates of five birds each, in addition to three cages for collection of endogenous losses, totaling 27 experimental units (metal cages measuring 1 m × 1 m × 0.6 m length, width and height, respectively) provided with gutter-type feeders, a gutter-type drinker made from PET bottles, and 150-W incandescent bulbs for heating whenever necessary. Trays were placed under each cage to collect the excreta.

Diets and Feeding Program

The experimental treatments consisted of diets containing 0%, 2.5%, 5.0%, 7.5%, 10.0% and 12.5% glycerin. The birds that were not used during the experimental phase were kept in a separate shed with similar conditions, receiving water and feed according to the recommendations of Rostagno *et al.,* (2011).

Corn-soybean meal-based diets were formulated to meet the nutritional requirements of male broilers (Rostagno *et al.*, 2011), except for chlorine and sodium, which were adjusted according to the inclusion of glycerin in the diet because it has high content of these ionic minerals (Table 1). In each phase, the different levels of glycerin in the experimental diets (Table 2) were obtained by mixing the diet containing the lowest level (0%) of glycerin (T1) with that containing the highest level (12.5%) of this ingredient (T6); treatments T2, T3, T4 and T5 were obtained by the dilution technique. Feed (experimental diets) and water were available *ad libitum*.

Data and Sample Collection

Humidity and maximum and minimum temperatures within the shed were monitored by a thermo-hygrometer placed in the center of the shed at the height of the back of the birds. Readings were taken daily. Water was supplied ad libitum, and changed twice to prevent heating and fermentation. A continuous lighting program (natural + artificial light) was adopted, and diets were also supplied ad libitum.

At the end of the experimental phases, the following variables were calculated: feed intake (FI), obtained as the difference between the amount of feed supplied and the feed remainder; weight gain (WG), determined as the difference between the weights of the birds at the end and start of the phase; and feed conversion (FC), calculated based on feed intake and weight gain in the period. The FI and average WG were calculated as a function of the number of birds per plot, and, in cases of mortality, they were defined as a function of the corrected number of birds as described by Sakomura and Rostagno (2016).

Heat production was determined according to equations described by Sakomura and Rostagno (2016), in which it was determined by knowing the true metabolizable energy intake and the retained energy by difference.

To determine the retained energy, slaughters were performed at the beginning and at the end of each experimental phase; both to analyze the body composition of the birds. In the first slaughter period, twelve birds (six replicates of two birds) were used, and in the second one, two birds with weight similar to the plot average weight at the beginning and end of the phase, respectively, were taken from each experimental plot.

Table 1. Nutritional, physicochemical and energy composition of glycerin used in diets for broilers.

Characteristics	Result
Sulphated ash[1] %	7.20
Chlorine[1] %	3.55
NaCl[1] %	5.84
Residual Methanol[1] %	0.003
Sodium[1] %	2.29
Monoglycerides [1] %	1.30
Glycerol[1] %	80.95
Humidity[1] %	10.60
Density at 20°C[1] g/ml	1.26
Acidity[1] %	0.90
pH[1]	6.20
Gross power kcal/kg	3774
Energy Metab.[2] kcal/kg	3585

[1]Data provided by the laboratory of ADM's Brazil LTDA; [2]Ajustment based on the metabolization coefficient value of gross energy (95%), analyzed at the LANA/CCA - UFPI, as recommended by Rostagno et al., (2011).

Table 2. Proximate composition and calculated levels of the nutrients in the basal diet and in the diet with glycerin in the phases studied for broilers.

Ingredients (%)	PHASES (days of age)							
	1–7		8–21		22–34		35–42	
	T1	T6	T1	T6	T1	T6	T1	T6
Corn grain	57.18	42.73	62.94	48.44	65.37	50.82	68.51	53.93
Soybean meal	37.29	39.91	32.16	34.80	29.68	32.32	26.24	28.89
Soy oil	1.11	0.97	0.93	0.81	1.47	1.36	1.67	1.56
Dicalcium Phosphate	1.93	1.97	1.49	1.53	1.24	1.28	1.47	1.51
Limestone	0.87	0.84	1.03	1.00	0.92	0.89	0.79	0.76
DL-Methionine	0.41	0.43	0.31	0.34	0.27	0.29	0.24	0.26
L-Lysine HCl	0.30	0.26	0.25	0.20	0.20	0.15	0.24	0.19
Salt	0.26	0.00	0.24	0.00	0.22	0.00	0.20	0.00
Supl.Min. Vit[1].	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Na bicarbonate	0.25	0.00	0.25	0.00	0.24	0.00	0.25	0.00
Glycerin ADM	0.00	12.50	0.00	12.50	0.00	12.50	0.00	12.50
Nutritional Composition and Energy								
Linoleic acid (%)	1.944	1.607	1.921	1.593	2.239	1.919	2.383	2.060
Calcium (%)	0.920	0.920	0.860	0.860	0.750	0.750	0.751	0.751
Chlorine (%)	0.200	0.481	0.190	0.481	0.180	0.481	0.167	0.480
ME. (kcal/Kg)[2]	2.925	2.925	2.980	2.980	3.050	3.050	3.100	3.100
Phosphor avail. (%)[2]	0.470	0.470	0.384	0.384	0.335	0.335	0.374	0.374
Dig. lysine (%)[2]	1.304	1.304	1.141	1.141	1.045	1.045	0.992	0.992
Dig. Met+Cystine (%)[2]	0.939	0.939	0.822	0.822	0.763	0.763	0.714	0.714
Potassium (%)	0.563	0.547	0.526	0.510	0.507	0.491	0.481	0.460
Crude protein (%)	22.00	22.00	20.00	20.00	19.00	19.00	17.74	17.74
Sodium (%)	0.220	0.335	0.210	0.332	0.200	0.330	0.191	0.320

[1]Amount/kg- Pre-starter: folic acid = 200.00 mg; biotin = 10.00 mg; chlorohydroxyquinoline = 7,500.00 mg; Zn = 17.50 g; vit. A = IU 1,680,000.00; vit. B1 = 436.50 mg; vit. B12 = 2,400.00 mcg; vit. B2 = 1,200.00 mg; vit. B6 = 624 mg; vit. D3 = 400,000.00 IU; vit. E = 3,500.00 IU; vit. K = 3-360.00 mg; niacin = 8,399.00 mg; nicarbazin = 25.00 g; pantothenic acid = 3,120.00 mg; choline = 78.10 g; Se = 75.00 mg; Fe = 11.25 g; Mn = 18.74 g; Cu = 1,997.00 mg; I = 187.00 mg. Starter: folic acid = 199.00 mg; biotin = 10.00 mg; chlorohydroxyquinoline = 7,500.00 mg; Zn = 17.50 g; vit. A = 1,680,000.00 IU; vit. B1 = 436.50 mg; vit. B12 = 2,400.00 mcg; vit. B2 = 1,200.00 mg; vit. B6 = 624.00 mg; vit. D3 = 400,000.00 IU; vit. E = 3,500.00 IU; vit. K = 3-360.00 mg; niacin = 8,400.00 mg; monensin = 25.00 g; pantothenic acid = 3,119.00 mg; choline = 80.71 g; Se = 75.00 mg; Fe = 11.25 g; Mn = 18.74 g; Cu= 1,996.00 mg;; I = 187.47 mg. (Growth): folic acid = 162.50 mg; chlorohydroxyquinoline = 7,500.00 mg; Zn = 17.50 g; vit. A = 1,400,062.50 IU; vit. B1 = 388.00 mg; vit. B12 = 2,000.00 mcg; vit. B2 = 1,000.00 mg; vit. B6 = 520.00 mg; vit. D3 = 360,012.00 IU; vit. E = 2,500.00 IU; vit. K = 3-300.00 mg; niacin = 7,000.00 mg; salinomycin = 16.50 g; pantothenic acid = 2,600.00 mg; choline = 71.59 g; Se 75.00 mg; Fe = 11.25 g; Mn = 18.74g; Cu = 1,996.00 mg; I = 187.47 mg. Slaughter phase: folic acid = 162.50 mg; zinc oxide = 17,500 mg; Se = 75 mg; vit. A = 1,400.00 IU; vit. B1 = 388 mg; vit. B12 = 2,000 mcg; vit. B2 = 1,000 mg; vit. B6 = 520 mg; vit. D3 = 1600 IU; vit. E = 2,500 mg; vit. = K 3 - 300 mg; Zn = 70 ppm; niacin = 7,000 mg; pantothenic acid = 2,600 mg; choline = 71,593.49 mg, Fe = 11,250 mg; Mn = 18,750 mg; Cu = 2,000 mg; I = 187.50 mg; antioxidant additive = 25,000 mg; halquinol = 7,500 mg; salinomycin = 16,500 mg.

After the birds were slaughtered, they were placed in labeled plastic bags and transported to the laboratory for processing.

For processing, birds were weighed, placed in specific containers in an autoclave at 127ºC and pressure of 1 atm, according to the procedure described by Mendonça et al. (2008).

After autoclaving, samples were homogenized in an industrial blender, dried in a forced air-circulation oven at 55ºC for 72 hours and ground in a micro-mill. Subsequently, energy values were determined using calorimetric bombs, and thus the energy retained in the carcass was determined.

The total excreta collection method was adopted to determine the true metabolizable energy, in accordance with Sakomura and Rostagno (2016). For each collection period, four days were used for acclimation to the diet and other four days to collect the excreta. At the end of the collection period, excreta were homogenized and aliquots of approximately 200 g were taken from each experimental unit and dried in a forced air-circulation oven at 55ºC for 72 hours. After drying, they were ground and the gross energy and dry matter values were analyzed according to the methodes described by Silva and Queiroz (2002). The calculations to determine the true metabolizable energy were performed according to equations described by Sakomura and Rostagno (2016).

Statistical Analysis

All data were analyzed using the mixed-models procedure of SAS. Data were subjected to homogeneity and normality analyses. The identified outliers were removed. Afterward, the data were subjected to analysis of variance using the General Linear Model of SAS software (Statistical Analysis System, 9.01). Orthogonal polynomial contrasts were used to assess the significance of linear or quadratic models to describe the response of the dependent variable to the increasing glycerin levels.

RESULTS AND DISCUSSION

Bird mortality during the experimental period was 3.70, 1.48, 1.48 and 0% in the pre-starter, starter, grower, and finisher phases, respectively.

The average temperatures of 31.5, 28.4, 27.6 and 28.6ºC and humidity of 58.7, 45.0, 49.5 and 41.9% were recorded during the experimental period in the pre-starter, starter, grower, and finisher phases, respectively. These values indicated that the birds were in thermal discomfort (Abreu and Abreu, 2011) during the experimental periods, because the recommended thermal comfort zone for chicks in the first week of life is between 32 and 35ºC, and between 23 and 26ºC for animals in the last week of life, with a relative humidity between 60 and 70%.

Performance

No difference was observed ($P \geq 0.05$) for weight gain and feed intake in relation to the levels of glycerin included in the diets.

Based on these results, glycerin can be considered an energy source easy to be used by birds of 1-7 days of age (Table 3). Inclusion of glycerin up to 12.5% resulted ($P \leq 0.05$) in

Table 3. Mean values of weight gain (WG), feed intake (FI) and feed conversion (FC) in broilers of 1-7 days of age fed diets containing different glycerin levels (GL).

Glycerin (%)	Variable		
	WG(g)	FI(g)	FC
0.0	79.41 ± 8.84	93.59 ± 8.49	1.18 ± 0.06
2.5	82.00 ± 4.09	97.80 ± 9.72	1.20 ± 013
5.0	84.33 ± 4.03	89.94 ± 8.97	1.07 ± 0.07
7.5	83.63 ± 4.95	95.79 ± 5.12	1.15 ± 0.12
10.0	85.67 ± 5.85	88.53 ± 10.50	1.03 ± 0.09
12.5	82.74 ± 4.79	82.26 ± 7.13	1.00 ± 0.03
Probability (ANOVA)	0.2812	0.0630	0.0090
Regression	NS	NS	Linear[1]
Probability of Regression	-	-	0.0026
CV (%)	6.54	9.08	8.21

NS = not significant; CV = coefficient of variation. [1]FC = 1.1991 - 0.0154 DF, R^2 = 0.7314.

an improved feed conversion in birds in the pre-starter phase. The broilers fed diets containing glycerin showed weight gain and feed intake similar to those of animals fed the basal diet.

Similar weight gain data were found by Cerrate *et al.* (2006), who observed no effect on weight gain at 14 days of age, by including levels of 0, 5 and 10% of glycerin in diets for broilers. However, Silva *et al.* (2012) found a linear increase ($P \leq 0.05$) in weight gain when they included increasing levels of glycerin in diets for broilers of 1-7 days of age.

The results obtained for feed intake are not in line with those found by Jung and Batal (2011), who observed that levels of 5 and 7% glycerin in diets for broilers of 1-5 days of age caused a decrease in their feed intake.

Cerrate *et al.* (2006), including glycerin levels of up to 10% in diets for broilers of 1-14 days of age, obtained increased feed intake. Silva *et al.* (2012) found that the inclusion of increasing levels of glycerin in diets for broilers of 1-7 days of age increased their feed intake and weight gain linearly ($P \leq 0.05$), and attributed the increased feed intake to the inclusion of glycerin, because this ingredient can improve food texture and palatability, in addition to reducing feed dust.

A decreasing linear effect ($P \leq 0.05$) was found in feed conversion (FC = 1.1991 - 0.0154 DF, R^2 = 0.7314), in which feed conversion improved as the glycerin level increased up to 12.5% in the diets for broilers of 7 days of age, reducing by 0.0154 per level of glycerin included. This improvement in FC can be explained by the fact that feed intake and weight gain have not been affected by the composition of the diets; however, because the glycerol is absorbed passively, it can supply energy with a lower heat increment, thereby improving the use of the nutrients.

Conflicting results for feed conversion were found by Cerrate *et al.* (2006), who supplied birds of 0-14 days of age with diets containing levels of up to 10% inclusion of glycerin. Nevertheless, Silva *et al.* (2012) observed no effect of glycerin inclusion up to 10% on feed conversion in chicks in the pre-starter phase, thus corroborating these results.

No effect was observed ($P \geq 0.05$) on weight gain, feed intake or feed conversion in the starter phase (8-21 days of age) of broilers fed increasing levels of glycerin (Table 4).

However, this result may be a consequence of a better digestive adaptation, because in this period, birds already have a formed digestive system, without significant alterations, except for the physiological cell renewal process, which occurs at every two-to-five days (Ito; Miaji; Lima, 2004). Moreover, the diets were isocaloric and isoproteic, so they caused no changes in the gain.

Similar results were found by Jung and Batal (2011) for weight gain and feed intake with inclusion of glycerin up to 7% in diets for broilers of 16-34 days of age. Silva *et al.* (2012) found no effects on weight gain, feed intake and feed conversion in 21-day-old broilers by including up to 10% glycerin in the diets, corroborating the results of the present study.

Guerra et al. (2011), who found that glycerin inclusion levels above 6% in diets for 21-day-old broilers influence their performance and feed conversion, observed diverging results.

Some authors Waldroup (2007) and Cerrate et al. (2006) explain that glycerin influences feed intake due to changes in the physical characteristics of the diets, so it can be used for broilers of 8-21 days of age without affecting their performance provided that the economic analysis of the other dietary ingredients is taken into account.

The levels of glycerin included in the diets had no effect ($P \geq 0.05$) on the performance characteristics of broilers of 22-33 days of age (Table 5).

Some studies corroborate the results presented. Cerrate *et al.* (2006) evaluated two levels of glycerin (5 and 10%) and observed that 5% of glycerin does not affect the performance of 35-day-old broilers, but 10% negatively does

Simon *et al.* (1997), on the other hand, found that diets containing 10% glycerin do not influence the weight gain of birds of 1-31 days of age.

Table 4. Mean values of weight gain (WG), feed intake (FI), and feed conversion (FC) in broilers of 8-21 days of age fed diets containing different glycerin levels (GL).

Glycerin (%)	Variable		
	WG (g)	FI(g)	FC
0.0	593.70 ± 11.83	846.85 ± 26.87	1.43 ± 0.07
2.5	600.50 ± 19.86	835.75 ± 24.88	1.39 ± 0.03
5.0	612.95 ± 13.86	851.33 ± 59.28	1.44 ± 0.06
7.5	598.35 ± 24.78	899.02 ± 74.17	1.50 ± 0.09
10.0	584.33 ± 16.75	852.96 ± 17.80	1.46 ± 0.03
12.5	616.90 ± 9.47	908.93 ± 21.86	1.47 ± 0.03
Probability (ANOVA)	0.7834	0.1063	0.2415
Regression	NS	NS	NS
CV (%)	3.21	5.15	5.31

NS = not significant; CV = coefficient of variation.

Table 5. Mean values of weight gain (WG), feed intake (FI) and feed conversion (FC) in broilers of 22-34 days of age fed diets containing different glycerin levels (GL).

Glycerin (%)	Variable		
	WG (g)	FI (g)	FC
0.0	895.93 ± 40.36	1688.15 ± 11.42	1.91 ± 0.06
2.5	938.96 ± 39.40	1618.71 ± 83.44	1.73 ± 0.09
5.0	861.53 ± 46.80	1639.18 ± 48.92	1.91 ± 0.08
7.5	871.90 ± 38.85	1635.70 ± 42.57	1.88 ± 0.05
10.0	927.46 ± 15.32	1678.49 ± 19.79	1.81 ± 0.03
12.5	938.50 ± 55.85	1776.48 ± 86.96	1.90 ± 0.21
Probability (ANOVA)	0.0869	0.1092	0.0751
Regression	NS	NS	NS
CV (%)	3.35	4.63	6.14

NS = not significant; CV = coefficient of variation.

No influence (P≥0.05) of glycerin inclusion levels was observed on the performance characteristics (weight gain, feed intake and feed conversion) of broilers of 35-42 days of age (Table 6). Thus, inclusion of up to 12.5% glycerin in diets for these birds (finisher phase) does not impair their growth performance.

Although some authors claim that including increasing levels of glycerin in diets promotes differences in their physical properties, which will affect feed intake, this was not one of the reasons for the results obtained in the present study, because even with the addition of 12.5% glycerin, the animals had no significant preferences to consume the diets in the final rearing phase.

Similar results were found by Silva *et al.* (2012), who included glycerin up to 10% in diets for broilers of 1-42 days of age and observed no effects on any of their performance characteristics.

Jung and Batal (2011) tested four glycerin inclusion levels (0, 2.5, 5.0 and 7.5%) in diets for broilers in the final rearing phase and observed no negative effect on their performance. Berenchtein *et al.* (2010) included 9% glycerin in broiler diets and Lammers *et al.* (2008) included glycerin in pig diets and observed no effect that compromised the performance of these animals.

Authors such as Guerra *et al.* (2011) have found results different from ours, by analyzing glycerin inclusion levels of up to 10% in diets for broilers of 21-42 days of age. These authors observed a decreased weight gain, increased feed intake and, consequently, worse feed conversion in these animals.

Based on the performance results obtained in this study, glycerin may play an increasingly important role as energy source for birds, because with the expansion in biodiesel production and increased use (inclusion) of glycerin, the rapid pace of growth in ethanol production may limit the access of poultry farmers to corn.

It is noteworthy that in order to include glycerin as an ingredient in diets for broilers, one should know its composition in terms of metabolizable and/or digestible energy, and chlorine, sodium and potassium contents so that corrections can be made in diet formulation, because many studies evaluating inclusion of glycerin do not always have this correction and eventually exceed the requirement by increasing the inclusion, which results in losses in the performance of these birds.

Heat Production

The data relating to heat production (HP) in the phases from 1-7, 8-21, 22-34 and 35-42 days are shown in Table 7. A decreasing linear effect (P≤0.05) (HP = 233.23 = 3.4708GL, R^2 = 0.6599) was observed in heat production in the period of 1-7 days of age as the level of glycerin included in the diet was increased: as the glycerin level was elevated, bird heat production decreased by 3.4708 kcal/kg$^{0.75}$/day.

In this phase, birds fed diets containing higher levels of glycerin met their energy requirements through the energy contained in glycerin, because the metabolizable energy value of the glycerin (3.585 kcal/kg) used in the diet formulation was the same for all phases. However, when the inclusion level is increased, there is higher energy availability from glycerin, which may have reduced the heat production, considering that some authors report that the metabolizable energy of glycerin is higher in the initial phases of birds (Dozier et al., 2008). Thus, glycerin inclusion levels up to 12.5% in broiler diets reduces heat production, which may be associated with a lower heat increment from this ingredient, considering that the glycerol is absorbed passively by the intestinal cells (Dozier et al., 2008), which probably generates a lower expenditure of energy in the digestion and metabolism processes.

Longo *et al.* (2006) found consistent results, obtaining heat production with a linear response in an experiment using different temperatures and different levels of feed supply for broilers of 7-56 days of age.

Table 6. Mean values of weight gain (WG), feed intake (FI) and feed conversion (FC) of broilers of 35 to 42 days of age fed diets containing different glycerin levels (GL).

Glycerin (%)	Variable		
	WG (g)	FI (g)	FC
0.0	361.31 ± 32.33	838.53 ± 35.69	2.33 ± 0.11
2.5	382.31 ± 7.95	840.97 ± 34.20	2.20 ± 0.13
5.0	394.50 ± 27.42	814.63 ± 54.48	2.08 ± 0.37
7.5	375.50 ± 7.06	888.34 ± 21.59	2.37 ± 0.05
10.0	378.81 ± 72.82	886.81 ± 32.65	2.26 ± 0.21
12.5	396.56 ± 29.11	883.72 ± 19.09	2.23 ± 0.06
Probability (ANOVA)	0.0953	0.1232	0.8462
Regression	NS	NS	NS
CV (%)	6.56	6.76	8.86

NS = not significant; CV = coefficient of variation.

Table 7. Average heat production (HP) by broilers fed diets containing different glycerin levels (GL) in different rearing phases.

Glycerin (%)	Heat production (kcal/kg$^{0.75}$/day)			
	1–7	8–21	22–34	35–42
0.0	225 ± 20.27	181 ± 8.68	243 ± 16.86	200 ± 5.59
2.5	234 ± 9.76	165 ± 23.94	248 ± 13.95	132 ± 16.69
5.0	206 ± 24.83	181 ± 10.87	297 ± 5.97	211 ± 18.20
7.5	227 ± 20.70	172 ± 26.36	277 ± 10.93	142 ± 5.27
10.0	192 ± 23.89	170 ± 12.71	273 ± 13.14	134 ± 18.25
12.5	186 ± 17.33	169 ± 2.78	291 ± 13.75	157 ± 13.87
Probability (ANVOA)	0.0311	0.5563	0.0669	0.1289
Regression	Linear[1]	NS	NS	NS
Probability of Regression	0.0229	-	-	-
CV (%)	12.94	12.31	12.09	23.22

NS = not significant; CV = Coefficient of Variation; [1]HP = 233.23 - 3.4708GL; R^2 = 0.6599.

Freitas *et al.* (2008) observed no variation in heat production between birds fed different diets; however, they found differences in the value of energy ingested by birds, which was higher in the mash diets, because these authors checked heat production in relation to the physical characteristics of diets for broilers of 1-7 days of age. Yunianto *et al.* (1997) observed a linear decrease in heat production by broilers of 23 days of age as the temperature was increased to approximately 30ºC; the opposite was observed when the temperature was reduced. Birds in the phase 1-7 days of age (pre-starter) require a greater amount of heat because they do not have their thermoregulatory system completely formed; they also need heat to maintain their body temperature, given that the temperatures recorded during this experimental phase were lower than the comfort zone temperature. This was not different from the results obtained in the other study phases (8-21, 22-34 and 35-42 days). Thus, an increase in glycerin inclusion may not be favorable in this phase, because the birds would require a greater amount of heat. Nevertheless, no negative effect related to weight gain (Table 3) was observed in these animals in this period.

No effect of glycerin inclusion levels was observed ($P \geq 0.05$) on heat production in broilers of 8-21, 22-34 and 35-42 days of age. Thus, the supply of up to 12.5% glycerin for broilers in these periods showed these birds had heat production similar to those fed the control diet. This can be related to the feed intake (Tables 4, 5 and 6), which in these periods was also similar to that obtained with the control diet. Therefore, inclusion of glycerin in diets for broilers in these periods has no negative effect on the performance of these birds; however, considering the reduction in heat production, this does not seem to be a solution for rearing birds in hot climates, because animals require a lower heat production, especially considering the average temperatures recorded in this experimental period, which were higher than that of the comfort zone.

CONCLUSIONS

Glycerin can be included in broiler diets at up to 12.5% in the phases 1-7, 8-21, 22-34 and 35-42 days of age without affecting their performance. Inclusion of up to 12.5% glycerin causes a reduction in heat production in the phase 1-7 days of age.

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