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NONRUMINANT NUTRITION

Growth curves of broilers fed different nutritional relationships using the Gompertz model

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ABSTRACT. The study aimed to evaluate performance and growth curves of broilers fed different nutritional relations. A total of 1,440 Cobb-500 male day-old chicks were assigned to eight treatments in a 2 x 2 x 2 factorial arrangement with six replicates of 30 birds each. The main factors were nutritional density (control and high), lysine source (HCl and sulfate), and calcium pidolate (presence and absence). Analyses were made for body weight gain (BWG), and feed conversion rate (FCR) at 21, and 42 days of age. The growth curves were adjusted by weighing a bird per plot every three days. Data for BWG were tested by ANOVA to evaluate the effects of treatments and their interactions at 5% significance, and the Gompertz model was adjusted by NLS. Birds fed a high nutritional density had higher BWG and lower FCR. Calcium pidolate and different sources of lysine did not influence the FCR of broilers, however a triple interaction was evidenced for BWG at 1 to 42 days of age. The day with maximum gain adjusted by Gompertz of all treatments was at the 32nd day of age and the maximum weight (A) was around 5.85 kg.

Keywords: calcium pidolate; *Gallus domesticus*; growth rate; lysine; nonlinear models; nutritional density.

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Introduction

The use of models to estimate the growth of broilers can provide more information besides the maximum weight gain; they are also used to evaluate the nutritional impact on different growth stages. The analysis of growth curves of animals using nonlinear models has been attractive, as they are flexible and summarize the characteristics of the species under development (Fernandes, Fernandes, Pereira, Meirelles, & Costa, 2019). Several nonlinear mathematical models have been used to describe animal growth, including birds, but according to some authors (Sakomura, Longo, Oviedo-Rondon, Boa-Viagem, & Ferraudo, 2005; Santos et al., 2005; Neme et al., 2006; Fernandes, Muniz, Pereira, Muniz, & Muianga, 2015), the Gompertz model was indicated as the one that best fits the growth rate of birds. According to Silva, Lima, Silva and Muniz (2010), an advantage of nonlinear models are the possibilities for biological interpretation of the parameters.

In agreement with Aggrey (2002), genetics, sex, and nutrition are the main factors acting in animal growth. Over the years, the improvement in nutrition was able to produce different responses on the feed efficiency of birds and shorten the period to achieve the maximum weight, changing the rate to reach maturity (K) (Eleroğlu, Yildirim, Canikli, Duman, & Bircan, 2018). In this way, evaluating the impact of different nutritional management on broiler growth allows to define the best nutritional plan for maximum performance, and it is possible to verify the impact of different ingredients and additives on bird growth. However, nutrition cannot affect the final weight of birds at maturity, being this characteristic responsive only by genetics.

Currently, poultry diets are formulated based on the ideal protein concept, with digestible lysine as the reference amino acid (Baker, 2009), however, nowadays there are different sources of this amino acid on the market, such as lysine sulfate (LS) and lysine HCl (LH). These forms differ in their ways of production, bioavailability, and purity (Smiricky-Tjardes et al., 2004) and such differences are responsible for the final cost. The use of additives is an alternative to improve bird performance in commercial production. The calcium pidolate additive represents an alternative, consisting of an organic source of calcium, with 13%

calcium ion in its composition, linked to two molecules of pidolic acid (pyrrolidone carboxylic acid) (87%) (Joshi, Desai, Ranade, & Avari, 2019). Pidolic acid is a precursor in the synthesis of arginine, as well as in the synthesis of proline at the intestinal level (Price, 2012). Arginine provides birds with an increase in growth rate due to its relationship with angiogenesis through vascularization and performance in lipid metabolism (Wu et al., 2011). In addition, arginine and proline have a complexing capacity with calcium, in such a way that they allow for greater absorption of the mineral at the blood level.

In this way, this study was developed to check the effects of two nutritional densities, different sources of lysine, and the use of calcium pidolate on performance and growth curves of broilers adjusted by the Gompertz model.

Material and methods

The Ethics Committee on Animal Experimentation approved all procedures for Research on protocol number 027/2019 by the Federal University of Lavras. The experiment was carried out in Lavras, state of Minas Gerais, Brazil, located at 21° 14′43″ S and 44° 59′59″ W.

A total of 1,440 one-day-old Cobb-500 chicks, from 40- to 46-week-old Cobb 500 broiler breeders, were placed in a conventional facility and reared on pens with litter (wood shavings). Birds were randomly assigned to eight dietary treatments, with six replicates (2.0 m x 1.5 m, 10 birds m^{-2}) and 30 birds each, in a 2 x 2 x 2 factorial design (nutritional densities x sources of lysine x presence or absence of calcium pidolate). All pens were equipped with semi-automatic tube feeders and automatic bell drinkers, with ad libitum supply of water and feed. The room temperature was controlled according to Cobb Guidelines (2018), using an automatic wood heater and fans. Mean temperature in the first week was 32.1 ± 1.3°C, in the second week, 30.0 ± 1.0°C and from day 14 of age to the end, 27.8 ± 1.0°C. The relative humidity was constant throughout the study, with a mean of 60%. The lighting programs were 24 hours of light until day 14 of age, and after, birds received six hours of dark to the end.

Diets were based on maize and soybean meal formulated according to Rostagno et al. (2017) for each period. The nutritional composition of the diets is listed in Tables 1 and 2, for 1-21 days and 22-42 days of age, respectively. All treatments were formulated to meet or exceed the requirement of all nutrients according to the phase. The inclusion of different types of lysine sources and the additive calcium pidolate was carried out in substitution to inert material. The calcium pidolate was offered only in the first phase (1-21 days of age) of the experiment.

BWG and FCR were measured at 21, and 42 days of age. For BWG, broilers from each pen were weighted and subtracted by their initial body weight. For FCR, feed intake was divided per BWG corrected for mortality, which was evaluated every day according to Sakomura and Rostagno (2016). A bird per plot (48 birds in total) was selected on the first day, according to average weight (± 5%), identified (banded), and weighed every three days until d 42 of age. At the end, each bird was weighted 14 times, and a total of 672 individual weights was used to fit the Gompertz model.

Broiler growth was analyzed using the non-linear Gompertz model (Gompertz, 1825). Data parameterization was performed according to Fernandes et al. (2015), being indicated as the most suitable for this model and given by:

$$\mathrm{Y_i} = \mathrm{A}\exp\{-\exp(-\mathrm{B} * (\mathrm{X} - \mathrm{t_i})\} + u_i$$

where, Yi is the estimated value of chicken weight, in grams, in the i-th observation; A is the maximum horizontal asymptote, that is, the maximum weight that these birds can reach; B is interpreted as the abscissa inflection point, from which growth slows down (Dmax). u_i corresponds to the random error, which is assumed to be independent and identically distributed following a normal distribution with zero mean and constant variance, that is, $u_i \sim N(0, \sigma^2)$.

The model parameters for describing the growth curves were estimated, as suggested by Mischan and Pinho (2014), using the least squares method. Estimates of these parameters were obtained using the Gauss-Newton iterative method implemented in the nls function of the R software (R Core Team, 2016). Significance of parameters was checked by t-test at the 5% level. Initially, it was considered that all assumptions about errors were met. Based on the error vector of this adjustment, analysis of residuals was made based on statistical tests. The statistical tests of Shapiro-Wilk (SW), Durbin-Watson (DW) and Breusch-Pagan (BP) were applied to verify normality, independence and residual homoscedasticity respectively, at the level of 5% significance. To assess the goodness-of-fit of the model, the coefficient of determination $\left(R^2 = \frac{SQR}{SQT}\right)$, was adopted, where SQR is the sum of squares of the residuals and SQT is the sum of total squares. Then, the first derivative of the Gompertz model was used to obtain K, the rate to reach maturity.

$$Y = AK\exp(-\exp(B - X)))\exp\ (K\,(B - X));$$

Table 1. Dietary composition used in the treatments (control nutritional density (C), high nutritional density (H), lysine HCl (LH), lysine sulfate (LS), absence of calcium pidolate (A) and presence of calcium pidolate (P)) at 1 to 21 days of age of broilers.

	Treatments							
Ingredients (g kg^{-1})	C LH A	C LH P	C LS A	C LS P	H LH A	H LH P	H LS A	H LS P
Maize 7.88%	65.91	65.91	65.91	65.91	57.76	57.76	57.76	57.76
Soybean meal 45%	30.30	30.30	30.30	30.30	34.97	34.97	34.97	34.97
Soybean oil	0.41	0.41	0.41	0.41	3.05	3.05	3.05	3.05
Dicalcium phosphate	1.03	1.03	1.03	1.03	0.99	0.99	0.99	0.99
Salt	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Limestone	0.74	0.74	0.74	0.74	0.96	0.96	0.96	0.96
DL-methionine-99%	0.21	0.21	0.21	0.21	0.39	0.39	0.39	0.39
L-Lysine-HCl-78%	0.12	0.12	0.00	0.00	0.36	0.36	0.00	0.00
L-Lysine-SO4-70%	0.00	0.00	0.13	0.13	0.00	0.00	0.40	0.40
Pidolin PCa®, %	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03
L-Threonine-98%	0.01	0.01	0.01	0.01	0.14	0.14	0.14	0.14
L-Valine-98%	0.01	0.01	0.01	0.01	0.09	0.09	0.09	0.09
Vitamin premix[1]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Mineral premix[2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Salinomicin, 12%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride, 60%	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Bacitracin	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Phytase[3]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inert	0.50	0.47	0.50	0.47	0.50	0.47	0.50	0.47
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated nutrient content								
Metabolizable energy (kcal kg^{-1})		19.30				3,050		
Crude protein (g kg^{-1})		19.30				21.00		
Fat (g kg^{-1})		4.422				6.122		
Digestible Lysine (g kg^{-1})		1.000				1.300		
Digestible Met + Cys (g kg^{-1})		0.811				0.962		
Digestible Arginine (g kg^{-1})		1.179				1.309		
Calcium (g kg^{-1})		0.800				0.800		
Available phosphorus (g kg^{-1})		0.430				0.430		
Sodium (g kg^{-1})		0.200				0.200		

[1]Provided per kg of diet: vitamin A – 8,250 IU; vitamin D3 – 2,090 IU; vitamin E - 31 IU; vitamin B1 – 2.20 mg; vitamin B2 – 5.50 mg; vitamin B6 – 3.08 mg; vitamin B12 – 0.013 mg; niacin – 33.0 mg; pantothenic acid – 11.00 mg; vitamin K_3 - 1,65 mg; folic acid – 0.77 mg; biotin – 0.077 mg; choline chloride (60%) – 1.0 g. [2]Provided per kg of diet: Se – 0.33 mg; Mn - 77 mg; Fe - 55 mg; Zn – 71.5 mg; Cu - 11 mg; I – 1.10 mg, B - 42 mg. [3] Genophos®, activity of 10,000 FTU g^{-1}, matrix 0.13 g kg^{-1} of Ca and 0.15 g kg^{-1} of P.

Results and discussion

The evaluation of different nutritional relationships, different sources of ingredients and additives for broiler chicken production is important, since nutrition is usually responsible for high costs in broiler production, thus determining dietary plans to achieve higher performance in birds and reach the potential genetics faster can be interesting.

No interaction ($p < 0.05$) was detected between factors for BWG and FCR during the starting phase (1-21d), and for FCR at 1 to 42 days of age, thus the main effect of each factor was evaluated separately (Table 3). The use of different sources of lysine had no effect ($p > 0.05$) on BWG of the birds during the starting phase (1-21d), and it can be assumed that the use of any of the sources in the diet would result in a similar BWG. However, some authors (Jackson, 2001; Smiricky-Tjardes et al., 2004) reported that LS synthesis generates certain by-products in the fermentation process, responsible to worsen the performance of broilers, which was not observed here. Similar to the present study, Wang, You, Qiao and Wang (2007) did not observe difference in BWG of broilers when comparing both sources in the entire period evaluated relating to the similar bioefficacy between the sources.

Table 2. Dietary composition used in the treatments (Control nutritional density (C), high nutritional density (H), lysine HCl (LH), lysine sulfate (LS)) at 22 to 42 days of age of broilers.

	Treatments			
Ingredients (g kg^{-1})	C*LH	C*LS	H*LH	H*LS
Maize 7.88%	68.266	68.266	60.581	60.581
Soybean meal 45,0%	27.314	27.314	30.668	30.668
Soybean oil	1.120	1.120	4.987	4.987
Dicalcium phosphate	0.895	0.895	0.879	0.879
Salt	0.456	0.456	0.456	0.456
Limestone	0.787	0.787	0.783	0.783
DL-methionine-99%	0.190	0.190	0.398	0.398
L-Lysine-HCl-78%	0.141	0.000	0.433	0.000
L-Lysine-SO_4-70%	0.000	0.157	0.000	0.482
L-Threonine-98%	0.005	0.005	0.005	0.172
L-Valine-98%	0.005	0.005	0.005	0.169
Vitamin premix[1]	0.100	0.100	0.100	0.100
Mineral premix [2]	0.100	0.100	0.100	0.100
Salinomicin, 12%	0.050	0.050	0.050	0.050
Choline-Chloride, 60%	0.040	0.040	0.040	0.040
Phytase[3]	0.025	0.025	0.025	0.025
Inert	0.500	0.500	0.500	0.500
	100.00	100.00	100.00	100.00
Calculated nutrient content				
Metabolizable energy (kcal kg^{-1})	3,050	3,050	3,200	3,200
Crude protein (g kg^{-1})	18.30	18.30	19.20	19.20
Fat (g kg^{-1})	3.500	3.500	6.601	6.601
Digestible lysine (g kg^{-1})	0.95	0.95	1.250	1.250
Digestible Met + Cys (g kg^{-1})	0.703	0.703	0.925	0.925
Calcium (g kg^{-1})	0.700	0.700	0.700	0.700
Available phosphorus (g kg^{-1})	0.400	0.400	0.400	0.400
Sodium (g kg^{-1})	0.200	0.200	0.200	0.200

[1]Provided per kg of diet: vitamin A – 8,250 IU; vitamin D3 – 2,090 IU; vitamin E - 31 IU; vitamin B1 – 2.20 mg; vitamin B2 – 5.50 mg; vitamin B6 – 3.08 mg; vitamin B12 – 0.013 mg; nicotinic acid - 33,0 mg; pantothenic acid - 11,0 mg; vitamin K3 – 1.65 mg; folic acid – 0.770 mg; biotin – 0.077 mg; choline chloride (60%) – 1.0 g. [2]Provided per kg of diet: Se – 0.330 mg; Mn - 77 mg; Fe - 55 mg; Zn – 71.5 mg; Cu - 11 mg; I – 1.10 mg, B - 42 mg. [3]Genophos®, activity of 10,000 FTU g^{-1}, matrix 0.13 g kg^{-1} of Ca and 0.15 g kg^{-1} of P.

Table 3. Body weight gain (BWG) (kg), feed conversion rate (FCR) (kg kg^{-1}) of broilers at 1-21, and 1-42 days of age in different nutritional relationships.

Factors		BWG 1-21 21d	FCR 1-21	BWG 1-42	FCR 1-42
Sources of lysine	Lysine HCl	0.995	1.33	3.13	1.72
	Lysine SO_4	0.992	1.33	3.14	1.65
P-value		0.787	0.979	0.535	0.130
Calcium pidolate	Presence	0.994	1.33	3.13	1.71
	Absence	0.993	1.33	3.13	1.66
P-value		0.930	0.916	0.708	0.270
Nutritional density	High	1.028 a	1.28 a	3.22 a	1.61 a
	Control	0.958 b	1.39 b	3.04 b	1.77 b
P-value		0.000	0.000	0.000	0.000
Factorial interaction					
L(1) X CP(2)		0.769	0.692	0.503	0.420
L X ND(3)		0.717	0.642	0.049	0.700
CP X ND		0.925	0.745	0.345	0.310
L X CP X ND		0.149	0.671	0.000	0.340
SE(4) (%)		0.015	0.015	0.019	0.010

Means followed by different letters are significantly different by F-test at 5% significance; *Significant at 5% probability. [1]Sources of lysine,[2]CP – calcium pidolate, [3]ND - Nutritional density, [4] Coefficient of variation.

The use of the calcium pidolate additive did not change ($p > 0.05$) the BWG and the FCR of the birds. Calcium pidolate contains pidolic acid, which is a precursor for the synthesis of arginine and proline at the intestinal level. These amino acids are essential for complexation with calcium, so that higher concentrations thereof in the intestine allow for greater absorption of calcium into the blood and are responsible for better collagen formation (Joshi et al., 2019). It was expected that the addition would allow for a reduction in the frequency of muscular and skeletal disorders, preventing birds from feeling pain that would change weight gain, reducing the growth rate of birds (Bizeray, Faure, & Leterrier, 2004).

Birds given a diet of high nutritional density presented higher ($p < 0.05$) BWG and lower FCR throughout the experiment. Carvalho Filho et al. (2014) evaluated the influence of different nutritional plans, and different energy: crude protein relations (ME: PB) on broiler performance, and reported greater average daily weight gain in birds fed high nutritional density (ME:PB 145.58) compared to the control group (ME:PB 143.06). This corroborates our results, in which the energy: protein ratio was kept constant (ME:PB 166.6) and the diet with high nutritional density resulted in greater BWG compared to the recommended diet. These probably occurred because birds on high nutritional plans had higher input of nutrients for growth compared to the control group, proved by the lower FCR.

A three-factor interaction for BWG was evaluated at 1 to 42 days of age (Table 4). Birds on diets with high nutritional density, containing calcium pidolate and LS, had a better BWG compared to birds receiving LH and calcium pidolate and the birds that did not receive calcium pidolate with LS. This response was never evidenced in another study and was not expected, probably because there is some relationship between LS and calcium pidolate.

Table 4. Interaction between factors for body weight gain (BWG) (kg) at 1 to 42 days of age.

	High density				Control density				p value	SEM
	Absence of calcium pidolate		Presence of calcium pidolate		Absence of calcium pidolate		Presence of calcium pidolate			
	Lysine HCl	Lysine SO_4	Lysine HCl	Lysine SO_4	Lysine HCl	Lysine SO_4	Lysine HCl	Lysine SO_4		
BWG	3.24 ab	3.19 b	3.17 b	3.29 a	3.07 cd	2.99 d	3.08 c	3.02 cd	0.000	0.019

Means with different letters are significantly different by Tukey's test at 5% probability.

After fitting the Gompertz model for the different treatments, considering that all assumptions about the error vector were met, that is, the residuals are independent and identically distributed following a normal distribution with zero mean and constant variance. Residual analysis was performed using the SW, BP and DW tests, which evidenced no assumptions were violated at 5% significance. Except for the high nutritional plan, in which the DW test was significant, indicating that residuals were not independent; in this way, it was adjusted by the generalized least squares method, incorporating a first-order regressive parameter (ϕ). According to Muniz, Nascimento and Fernandes (2017) and Fernandes et al. (2019), this is necessary to model the autocorrelation and incorporate it into the model, obtaining adjustments that produce more accurate predictions, and allow analysis of series measured in a few observations, ensuring greater precision in the estimates and better quality in the adjustment.

Table 5 shows the parameters estimated and the respective standard error (SE) values, based on the fit of the Gompertz model.

Table 5. Estimated parameters of the Gompertz model(1) with the respective standard error (SE) to describe the growth of Cobb 500® broilers in different nutritional relationships.

Gompertz Parameters[5]	Treatments					
	Control density	High density	Lysine HCl	Lysine sulfate	Absence of calcium pidolate	Presence of calcium pidolate
A, g	5,611 (322.1)	5,937 (346.1)	6,001 (322.1)	5,838 (346.1)	5,828 (353.8)	5,741 (301.5)
B, d[(2)]	32.05 (1.198)	32.17 (1.190)	32.67 (1.280)	32.69 (1.210)	32.69 (1.259)	31.82 (1.085)
K (growth rate) d^{-1}	0.050 (0.002)	0.052 (0.002)	0.049 (0.002)	0.050 (0.002)	0.050 (0.002)	0.051 (0.002)
ϕ	-	0.3581	-	-	-	-
Statistical assumptions						
SW[(2)]	ns	ns	ns	ns	ns	ns
DW[(3)]	ns	*	ns	ns	ns	ns
BW[(4)]	ns	ns	ns	ns	ns	ns
R^2	0.99	0.99	0.99	0.99	0.99	0.99

[(1)]Gompertz model: $Y_i = A\exp\{-\exp(-B*(X - t_i))\}$; [(2)]Shapiro-Wilk test for normality of data at 5% significance; [(3)]Durbin-Watson test for independence of errors at 5% significance; [(4)]Breusch-Pagan test for homoscedasticity of residuals at 5% significance; *Significant at 5% probability. [(5)]Parameters: A represents the maximum horizontal asymptote, that is, the maximum weight these birds can reach; B is interpreted as the abscissa inflection point, from which growth slows down; k is the growth rate and ϕ is the first-order autoregressive parameter.

As can be seen, weight at maturity (A) was very similar between treatments, ranging from 5.6 kg to 6.0 kg. This is probably because different diets could only influence the growth rate of animals (K) but not the weight at maturity (Eleroğlu et al., 2018). The parameter A (5.825 kg) determined in the present study differed from obtained by Vargas et al. (2020), who evaluated the growth of Cobb 500 male broilers using the Gompertz model and obtained a maximum weight of 8.416 kg. The difference in these results is because in the present study the weight of birds was measured only until 42 days of age, while Vargas et al. (2020) weighed the broilers until 112 days of age, modifying the Gompertz parameters. However, Demuner et al. (2017) found similar results, with an A value of 5.831kg when evaluated the growth of Cobb 500 male broilers until 56 days of age.

The growth rate parameter (k) varied from 0.049 to 0.052 between treatments, in such a way, that the high nutritional density allowed for a higher growth rate of the birds, possibly for providing better nutritional support to the birds and favoring greater weight gain. Demuner et al. (2017) observed results similar to the present study, with an estimated value for the parameter of 0.047.

The inflection point of the curve, determined by parameter B, was around 32 days of age for all factors, corroborating the results found by Nogueira et al. (2019), who reported that the Dmax for male Cobb birds was on the 31 day of age. Was possible to verify that the effect of the diet does not influence the Dmax (Table 6) of the birds, and it can be assumed that it is a parameter more related to genotype of the birds.

Table 6. Estimated day of maximum weight gain (Dmax), mean weight on the first day and maximum weight gain determined in Dmax, maximum growth rates (approximate standard error).

Treatments	Dmax	Weight at d1 (g)	Maximum growth rates (g day^{-1})
High nutritional density	32.17 (1.20)	44.63	112.63
Control nutritional density	32.05 (1.19)	46.39	104.02
Lysine HCl	32.67 (1.28)	45.98	109.14
Lysine SO_4	32.69 (1.21)	45.04	107.81
Presence of calcium pidolate	31.82 (1.08)	45.45	107.98
Absence of calcium pidolate	32.69 (1.26)	45.57	108.18

Figure 1 illustrates the growth rate of birds receiving different nutritional densities, sources of lysine, and the presence of calcium pidolate estimated by the Gompertz model. According to this figure, until the 21 days of age, growth was similar regardless of the diets. Birds on diets containing high nutritional density showed a higher growth rate (8.27%) compared to birds receiving diets with control density. Regardless of the source of lysine in the diet, the growth rate was maintained and remained constant until the 40 days of age. It seems like birds fed diets containing LH had a higher growth rate (1.23%) compared to those on diets containing LS (but not compared statistically). The growth rate of birds fed diets with or without calcium pidolate until 21 days of age remained constant until the 22 days of age of birds.

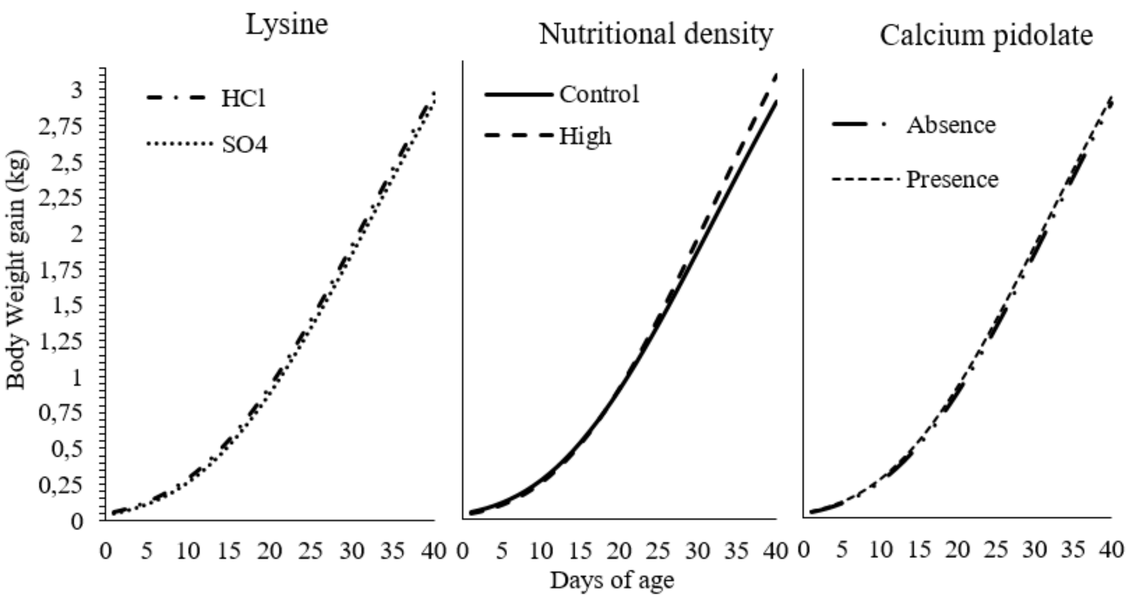

Figure 1. Growth curves of Cobb500 broilers in different nutritional relationships estimated by the Gompertz model.

As already seen in Table 3, the treatment with high nutritional density allowed for greater weight gain in birds, with a maximum gain on Dmax (GDmax) of 112.63 g, while birds in the treatment with low nutritional plan obtained the maximum gain of 104 g, that day, a gain of 8.30%. When compared to the other treatments, the GDmax was practically the same for calcium pidolate and lysine sources. Likewise, Henn, Bockor, Ribeiro, Coldebella and Kessler (2014) evaluated the growth curve of male broilers, Cobb 500, by the Gompertz model and observed a GDmax of 100.65 g, below the value determined for birds of the treatment with high nutritional density, but close to the nutritional density control treatment recommended by Rostagno et al. (2017).

Conclusion

In conclusion, nutritional factors influenced the growth rate (k) of broilers, however, they did not affect the parameters of the model that are more responsive to the lineage and sex of the birds, such as weight at maturity and Dmax. The supply of diets with high nutritional density allowed for significant higher BWG, and an increase at maximum growth rate compared to the control level. Different sources of lysine and the addition of calcium pidolate did not influence the feed conversion rate, the weight gain and growth of the birds.

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