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Original Article

Bone Growth and Quality of Meat Quails Submitted to Different Lighting Programmes

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ABSTRACT

The present study was executed to evaluate the effect of lighting programs for meat quails on their bone growth and development. A total of 1500 sexed European quails (*Coturnix coturnix coturnix*) were distributed using a completely randomized design in a 2 × 3 factorial arrangement, with two sexes and three lighting programs (natural, intermittent, and continuous) with five replicates of 50 quails. The lighting programs were applied in the period from 7 to 49 d of age. Weekly slaughterings were performed to remove the tibiotarsus and femur and subsequently determine weight, length, dry and mineral matter content. The growth and deposition curves of dry and mineral matter in the bones were obtained using the Gompertz model. There was no significant interaction between lighting programs and sex for the estimates of the Gompertz curve parameters of all variables studied. There was an effect of the lighting programs only on the time needed to reach the maximum deposition rate of the growth curve and dry and mineral matter deposition. Females showed higher weight and deposition of mineral matter at maturity, and took longer to reach the maximum deposition rate value for these variables. There was influence of the lighting programs on resistance and bone deformity of the tibiotarsus. For quails raised in the tropical region, a natural or intermittent lighting program must be used, as it does not compromise the development of bones and assures bone quality.

INTRODUCTION

In the genetic improvement of poultry for meat production, selection pressure has prioritized increasing the growth rate, thus increasing the susceptibility of these birds to problems in the skeletal system. In addition to genetics, other factors involved in broiler raising that can accelerate growth can also increase the incidence of bone problems, since bone tissue is closely related to the growth of the animal, constantly adapting during its life (Araújo *et al.*, 2012). Animal growth is characterized by increased body weight over time, represented mainly by an increase of muscle tissue. However, for this to happen, it is essential that the development of bone tissue is equivalent to the rate of muscle deposition, in order to avoid bone disorders associated with the rapid growth of broiler birds (Gonzales & Sartori, 2002).

In raising broiler birds, there is a consensus that each genotype must receive adequate nutrition and management aiming at full and healthy body development, allowing the bird to express its maximum genetic potential. In raising meat quails this is no different, and several management techniques have been evaluated with the intention of guaranteeing conditions for maximum performance. According to Abreu *et al.* (2011) and Arowolo *et al.* (2018), lighting programs are a management technique that aims to provide satisfactory environmental conditions that make it possible to optimize weight gain, feed conversion, and carcass quality, and avoid metabolic changes. Increasing the time of exposure of broilers to darkness can reduce the rate of growth and the incidence of leg problems and metabolic disorders (Brickett *et al.,* 2007). Thus, intermittent lighting programs have been shown to be better than continuous ones at reducing leg problems in broilers (Petek *et al.,* 2005). In this context, adjusting lighting programs is a management factor that can be manipulated to reduce the occurrence of bone problems in birds.

According to Gous *et al.* (1999), in the search to understand the development and growth of animals, tissues, and organs, it is possible to develop mathematical models that are capable of predicting how different environmental conditions can influence them. Thus, considering that there are few studies evaluating disorders of the skeletal system in meat quails, the present study was executed to evaluate the effects on bone growth and development of lighting programs for meat quails raised in a tropical region.

MATERIAL AND METHODS

This study was conducted in a manner that avoided unnecessary discomfort to the animals by the use of proper management and laboratory techniques, and experimental procedures were approved by the Ethics Committee on the Use of Animals - CEUA / UFC (protocol No. 56/2016), according to the ethical principles adopted by the Brazilian Council for the Control of Animal Experimentation.

The experiment was carried out in Fortaleza, Ceará, Brazil (latitude 3°43'02" S and longitude 38°32'35" W), with an experimental period was 49 days and an average duration of 12 hours and 30 minutes of natural light.

A total of 1,500 meat quails (*Coturnix coturnix coturnix*), sexed (750 males and 750 females), were distributed using a completely randomised design in a 2 x 3 factorial arrangement (2 sexes and 3 lighting programs), with five replicates of 50 quails. The treatments consisted of lighting programs: natural, intermittent, and continuous.

The natural lighting program consisted of 12 hours and 30 minutes of natural light and 11 hours and 30 minutes of dark. The intermittent lighting program consisted of 18 hours of light and six hours of dark, with the light period composed of 12 hours and 30 minutes of natural light and five hours and 30 minutes of artificial light, alternating lighting periods of one hour and six minutes and periods of darkness of one hour and 12 minutes. In the continuous lighting program, quails were subjected to 23 hours of constant light, 12 hours and 30 minutes of which being natural light, 10 hours and 30 minutes of artificial light, and one hour of dark.

The experimental shed was subdivided into 3 parts according to the treatments. Partitions were made of 150-micron thick black tarps and placed in a pulley system, which allowed the curtains to be closed and opened to provide the correct amount of light for each program without interfering with the lighting of the other treatments.

Independent lighting systems were installed in the 3 parts of the shed and controlled by timers. White lamps (7W) were used to provide a lighting level of 15 lux at the quails' height (Aguiar *et al.*, 2017). The verification of the level of lighting was carried out using an electronic light meter (MINIPA-MLM 1020, São Paulo, Brazil) in the range of zero to 20000 lux. To elaborate the growth and deposition component curves for the bones, quails were euthanised at 7, 14, 21, 28, 35, 42, and 49 days of age. At each age, two quails per plot were selected, based on the mean weight, and after fasting for 6 h, they were stunned by electronarcosis, slaughtered, plucked, and eviscerated. Subsequently, the thigh and drumstick were removed, identified, and frozen at -20 °C, thus remaining until the moment of boning.

To carry out boning, pieces were initially defrosted in a domestic refrigerator (temperature of 4 °C for 12 hours) and left on benches until the material reached room temperature. Subsequently, the pieces were immersed in boiling water for 10 minutes and then deboned with a scalpel.

After boning, the length and diameter of the right tibiotarsus and femur were measured by a digital calliper, and the weight was determined on a precision scale (0.01 g). Bone density (mg/mm) was calculated using the Seedor index, obtained by dividing the weight (mg) by the length (mm) of the evaluated bone (Seedor *et al.*, 1991).

After weighing, the bones were placed in a forced ventilation oven at 55 ºC for 72 hours to determine the pre-dry matter. Then, bones were ground in a ball mill and submitted to determination of dry matter and mineral matter according to the methodologies described by the AOAC (1990).

Bone quality was assessed for the left tibiotarsus and femur of quails slaughtered at 49 days of age, where the resistance and deformity were determined in the bone *in natura* with the aid of a Testo/Ronald Triaxial mechanical press (Ronald Top Ltda., Brazil) with a 150-kg capacity. The bones were placed horizontally on a wooden support and a force applied to the centre of each bone. The maximum amount of force applied to the bone before breaking was considered to be the breaking resistance (kgf/cm^2), and the amount of force at the time the bone broke was considered to be the deformity (mm).

To describe the growth and deposition of components in bone, the Gompertz model was used, according to the equation:

$$y = A \exp(-B \exp(-kt))$$

where: y: average weight at age t; A: asymptotic weight; B: integration constant; k: maturity rate, exp: the base of the natural logarithm.

At the end of the experimental period, when the quails were 49 days old, the experimental units were weighed and the average weight of the quails in each treatment was calculated.

Data were submitted to analysis of variance by the PROC ANOVA procedure of the SAS, version 9.2, to test if there were significant differences between the lighting programs and between the sexes, as well as the presence or absence of interaction between these factors. Differences between treatments were tested using the Tukey test at 5% probability. The proposed statistical model was as follows:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk}$$

in which y_{ijk} = value observed in the sex i (i = 1, 2), lighting programs j (j = 1, 2, 3), and repetition k (k = 1, 2, 3, 4, 5); μ = overall mean of the experiment; α_i = fixed effect of the sex i (i = 1, 2); β_j = fixed effect of the lighting programs j (j = 1, 2, 3); $(\alpha\beta)_{ij}$ = fixed effect of the interaction between sex i (i = 1, 2) and lighting programs j (j = 1, 2, 3); and ε_{ijk} = random error in the sex i (i = 1, 2), lighting programs j (j = 1, 2, 3), and repetition k (k = 1, 2, 3, 4, 5).

RESULTS

The average weight results of the quails at 49 days of age showed there was a significant interaction between lighting programs and sex (Table 1).

Table 1 – Live body weight of male and female meat quails submitted to different lighting programs at 49 days.

Sex (S)	Lighting programs (LP)			Mean	SEM	ANOVA		
	Natural	Intermittent	Continuous			LP	S	LP x S
Male	236.68^{x,b}	240.46^{x,b}	243.59^{x,b}	240.24	8.44	**	**	**
Female	253.11^{y,a}	269.38^{x,a}	299.78^{x,a}	274.09				
Mean	244.90	254.92	271.69					

SEM: Standard error of the mean; *$p\leq0.05$; **$p\leq0.01$. Means followed by different letters (x, y) in the line and (a,b) in the column differ by the Tukey test at 5% probability.

According to these results, the average male weight did not vary significantly between the lighting programs, but females submitted to natural light had significantly lower weight in relation to those that received continuous and intermittent light, which did not differ among each other. Regarding the effect of sex, females were heavier than males regardless of the lighting program, and quails submitted to natural lighting were significantly less heavy than those subjected to continuous and intermittent light, the values of which did not differ.

For tibiotarsus and femur weight (Table 2), no significant interaction between lighting programs and the sex of quails was found for the estimated parameters: weight at maturity (Wm), maturity rate (k), and age of maximum growth (t).

There was no significant difference related to the lighting programs on the tibiotarsus and femur for the parameters Pm and k. However, there was a significant difference for the age of maximum growth, indicating that quails receiving the continuous lighting program had a more precocious growth of the tibiotarsus and femur.

Regarding the difference between sexes, it was observed that females had greater weight at maturity for the tibiotarsus and femur in relation to males, consequently taking longer to reach the maximum growth rate, although only for the tibiotarsus was the value of t* significantly higher for females.

There was no significant interaction between the lighting programs and sex for the estimated tibiotarsus and femur length parameters (Table 3): length to maturity (Lm), maturity rate (k), and age to reach maximum growth rate (t). These parameters were also not significantly influenced by the lighting programs. Among the sexes, it was observed that the estimated length at maturity of the tibiotarsus was statistically higher in females compared to males, but

Table 2 - Estimate of parameters of the Gompertz equation for the weight of the tibiotarsus and femur of male and female meat quails submitted to different lighting programs.

Lighting programs (LP)	Parameters of the Gompertz equation								
	Wm[1] (g)			k[2]			t[3] (days)		
	Male	Female	Mean	Male	Female	Mean	Male	Female	Mean
Tibiotarsus									
Natural	1.06	1.15	1.10	0.12	0.12	0.12	14.84	15.68	15.26[a]
Intermittent	1.01	1.14	1.08	0.14	0.14	0.14	14.64	16.50	15.58[a]
Continuous	1,01	1.08	1.04	0.15	0.15	0.15	12.21	12.58	12.40[b]
Mean	1.03[y]	1.12[x]		0.13	0.13		13.90[y]	14.92[x]	
p-value									
LP		0.0886			0.1128			< 0.0001	
Sex (S)		0.0001			0.9744			0.0109	
LP x S		0.4937			0.9968			0.2660	
SEM		0.2548			0.0057			0.1889	
Femur									
Natural	0.85	0.93	0.89	0.11	0.09	0.10	15.79	16.49	16.14[a]
Intermittent	0.92	0.93	0.93	0.08	0.09	0.09	18.02	17.70	17.90[a]
Continuous	0.81	0.96	0.89	0.10	0.09	0.10	14.10	15.81	14.96[b]
Mean	0.86[y]	0.94[x]		0.10	0.09		16.00	16.67	
p-value									
LP		0.3411			0.1204			0.0003	
Sex (S)		0.0042			0.1734			0.1945	
LP x S		0.0792			0.1883			0.2481	
SEM		0.0129			0.0028			0.2548	

[1]Wm (g) - weight to maturity; [2]k (per day) - maturity rate. [3]t (days) - time to reach maximum growth rate; Means followed by different letters (x,y) in the line and (a,b) in the column differ by the Tukey test at 5% probability.

Table 3 – Estimate of parameters of the Gompertz equation for the length of the tibiotarsus and femur of male and female meat quails submitted to different lighting programs.

Lighting programs (LP)	Parameters of the Gompertz equation								
	Lm[1] (mm)			k[2]			t[3] (days)		
	Male	Female	Mean	Male	Female	Mean	Male	Female	Mean
Tibiotarsus									
Natural	56.18	57.46	56.82	0.11	0.11	0.11	15.51	15.63	15.58
Intermittent	57.47	57.82	57.65	0.10	0.10	0.10	15.43	15.37	15.40
Continuous	56.30	58.45	57.38	0.11	0.11	0.11	15.68	15.71	15.70
Mean	56.66[y]	57.91[x]		0.11	0.10		15.54	15.57	
p-value									
LP		0.4835			0.1198			0.3685	
Sex (S)		0.0342			0.4092			0.8510	
LP x S		0.4376			0.9140			0.9062	
SEM		1.5295			0.0124			1.2895	
Femur									
Natural	46.24	47.75	46.99	0.11	0.11	0.11	16.08	16.19	16.14
Intermittent	46.49	46.60	46.55	0.10	0.11	0.11	15.74	15.92	15.84
Continuous	46.24	48.93	47.59	0.11	0.10	0.11	15.91	16.05	15.99
Mean	46.32	47.76		0.11	0.11		15.91	16.05	
p-value									
LP		0.5040			0.7620			0.4811	
Sex (S)		0.0559			0.3285			0.4948	
LP x S		0.3526			0.5463			0.9913	
SEM		0.3634			0.0029			0.2741	

[1]Lm (mm) - length to maturity; [2]k (per day) - maturity rate. [3]t (days) - time to reach maximum growth rate; Means followed by different letters (x,y) in the line differ by the Tukey test at 5% probability.

the values of the k and t parameters for this bone did not differ between the sexes. When the parameters were estimated for the femur, there was no significant difference between sexes for Lm, k, and t.

When evaluating the estimated values of the Gompertz parameters for the amount of dry matter in the tibiotarsus and femur (Table 4), it was observed that there was no significant interaction between lighting programs and sex for all parameters: dry matter weight from bone to maturity (Wm), maturity rate (k), and age to reach maximum deposition rate (t). Additionally, there was no significant effect between sexes. However, the lighting program significantly influenced the age needed to reach the maximum deposition of dry matter in both bones.

Table 4 – Estimate of parameters of the Gompertz equation for the dry matter of the tibiotarsus and femur of male and female meat quails submitted to different lighting programs.

Lighting programs (LP)	Parameters of the Gompertz equation								
	Wm[1] (g)			k[2]			t[3] (days)		
	Male	Female	Mean	Male	Female	Mean	Male	Female	Mean
Tibiotarsus									
Natural	0.87	0.91	0.89	0.11	0.12	0.12	16.45	16.67	16.56^{a}
Intermittent	0.83	0.87	0.85	0.14	0.15	0.14	15.45	16.58	16.02^{a}
Continuous	0.86	0.84	0.85	0.12	0.14	0.13	14.43	13.92	14.17^{b}
Mean	0.85	0.87		0.12	0.14		15.45	15.73	
p-value									
LP		0.0736			0.1519			< 0.0001	
Sex (S)		0.2370			0.1667			0.4092	
LP x S		0.2885			0.8512			0.1478	
SEM		0.0086			0.0055			0.6733	
Femur									
Natural	0.72	0.77	0.75	0.09	0.09	0.09	18.07	18.41	18.24^{a}
Intermittent	0.73	0.66	0.70	0.09	0.11	0.10	17.87	16.42	17.15^{ab}
Continuous	0.70	0.71	0.71	0.10	0.11	0.10	15.99	15.92	15.96^{b}
Mean	0.72	0.71		0.10	0.10		17.31	16.92	
p-value									
LP		0.2030			0.2018			0.9416	
Sex (S)		0.9416			0.2001			0.1493	
LP x S		0.1493			0.1785			0.2030	
SEM		0.0121			0.0031			0.2895	

[1]Wm (g) - weight to maturity; [2]k (per day) - maturity rate. [3]t (days) - time to reach the maximum deposition rate; Means followed by different letters (a,b) in the column differ by the Tukey test at 5% probability.

According to these results, quails submitted to the continuous lighting program had less time to reach the maximum deposition of dry matter in the tibiotarsus and femur in relation to quails submitted to the natural and intermittent light programs, which did not differ between them.

In the estimates of the amount of mineral material in the tibiotarsus and femur (Table 5), it was observed that there was no significant interaction between lighting programs and sex for all parameters (weight of ash in bone to maturity (Wm), maturity rate (k), and age to reach maximum deposition (t)). However, there was a significant effect of sex on the Wm and t parameters of the tibiotarsus, and on the Pm, k, and t parameters of the femur. The lighting program, in turn, significantly affected the age to maximum deposition of mineral matter in the tibiotarsus and femur, and the rate of deposition in the femur.

The tibiotarsus and femur of the females presented greater weight of mineral material at maturity and required more time to reach the point of maximum deposition. Females also showed a lower growth rate, although there was only a significant difference for the femur.

Regarding the effect of lighting programs, the quails submitted to continuous light required less time to reach the maximum rate of ash deposition in the tibiotarsus and femur in relation to quails submitted to the programs of continuous or intermittent light, which did not differ among each other.

Table 6 shows the average values of bone growth parameters for quails at 49 days of age. According to the statistical analysis, there was no effect of interaction between lighting program and sex for the weight, length, and diameter of the tibiotarsus and femur. There was also no significant effect of the lighting programs on these variables, but there was a

Table 5 – Estimate of parameters of the Gompertz equation for the mineral matter of the tibiotarsus and femur of male and female meat quails submitted to different lighting programs.

Lighting programs (LP)	Parameters of the Gompertz equation								
	Wm¹ (g)			k²			t³ (days)		
	Male	Female	Mean	Male	Female	Mean	Male	Female	Mean
Tibiotarsus									
Natural	0.52	0.60	0.56	0.13	0.12	0.13	14.40	15.49	14.95[a]
Intermittent	0.50	0.64	0.57	0.16	0.13	0.15	14.25	17.51	15.89[a]
Continuous	0.50	0.61	0.55	0.16	0.14	0.15	11.73	13.45	12.59[b]
Mean	0.50[y]	0.62[x]		0.15	0.13		13.46[y]	15.49[x]	
p-value									
LP		0.7692			0.3151			< 0.0001	
Sex (S)		< 0.0001			0.0725			< 0.0001	
LP x S		0.3018			0.7833			0.1249	
SEM		0.0092			0.0063			0.2174	
Femur									
Natural	0.42	0.57	0.49	0.08	0.07	0.08[a]	17.14	21.13	19.14[a]
Intermittent	0.50	0.67	0.59	0.07	0.05	0.06[b]	20.67	19.36	20.01[a]
Continuous	0.40	0.67	0.52	0.07	0.05	0.07[ab]	15.05	20.11	17.58[b]
Mean	0.44[y]	0.67[x]		0.07[x]	0.06[y]		17.62[y]	24.63[x]	
p-value									
LP		0.1038			0.0091			0.0165	
Sex (S)		0.0002			0.0028			0.0008	
LP x S		0.5023			0.8125			0.5088	
SEM		0.0269			0.0026			0.8967	

[1]Wm (g) - weight to maturity; [2]k (per day) - maturity rate. [3]t (days) - time to reach the maximum deposition rate; Means followed by different letters (x,y) in the line and (a,b) in the column differ by the Tukey test at 5% probability.

Table 6 – Growth parameters of the tibiotarsus and femur of male and female meat quails at 49 days of age submitted to different lighting programs.

Parameters	Sex (S)	Lighting programs (LP)			Mean	SEM	ANOVA		
		Natural	Intermittent	Continuous			LP	S	LP x S
Tibiotarsus									
Weight (g)	Male	0.99	1.01	1.01	1.00	0.0197	NS	NS	NS
	Female	1.05	1.09	1.08	1.07				
	Mean	1.02	1.06	1.04					
Length (mm)	Male	54.01	55.93	55.82	55.15	0.4610	NS	NS	NS
	Female	55.22	56.02	57.99	56.44				
	Mean	54.62	55.98	56.91					
Diameter (mm)	Male	3.57	3.43	3.27	3.42	0.0565	NS	NS	NS
	Female	3.49	3.47	3.46	3.47				
	Mean	3.53	3.45	3.36					
Femur									
Weight (g)	Male	0.81	0.79	0.81	0.80[b]	0,0186	NS	*	NS
	Female	0.87	0.91	0.92	0.90[a]				
	Mean	0.84	0.84	0.87					
Length (mm)	Male	44.63	44.78	45.66	44.98	0,4430	NS	NS	NS
	Female	45.94	44.93	48.44	46.54				
	Mean	45.29	44.85	47.20					
Diameter (mm)	Male	3.64	3.59	3.59	3.61	0,0424	NS	NS	NS
	Female	3.75	3.51	3.77	3.69				
	Mean	3.69	3.56	3.68					

SEM: Standard error of the mean; *$p \leq 0.05$; **$p \leq 0.01$; NS - not significant; Means followed by different letters (a,b) in the column differ by the Tukey test at 5% probability.

significant difference between the sexes in the weight of the femur, with females displaying a heavier femur as compared to the males.

Although the growth parameters estimated by the Gompertz equation indicate a significant influence of the lighting programs on the growth of quail bones, this effect was not verified in the evaluation of the weight, length, and diameter of the bones of quails slaughtered at 49 days of age. However, the absence of effects of the lighting programs on the measured variables may be associated with the fact that, at the evaluated age, all quails had already completed bone growth, causing there to be no significant difference. This fact can be confirmed if we consider that the weight and length determined at 49 days are similar to the weights and lengths at maturity, as estimated by the Gompertz equation for the tibiotarsus and femur. The absence of a significant difference in weight, length, and diameter of the tibiotarsus, and length and diameter of the femur between males and females slaughtered at 49 days can also be associated with the justification reported for the absence of effect between lighting programs.

According to the results of the bone quality variables (Seedor Index, tibiotarsus and femur deformity, and resistance - Table 7), there was no interaction effect between the lighting programs and sex. These parameters were also not significantly influenced by the sex of the quails. Among lighting programs, it was observed that the Seedor index did not differ significantly for either the tibiotarsus or the femur; however, bone resistance and deformity were significantly influenced by the lighting program for the tibiotarsus, albeit without significant difference for the femur.

According to these results, quails submitted to the continuous lighting program presented tibiotarsus bones with less resistance and deformity in comparison to the quails submitted to the programs of natural and intermittent light, which did not differ among themselves.

DISCUSSION

According to Aguiar *et al.* (2017), male and female responses to different lighting programs can be attributed to the sexual dimorphism of these quails, as females are more precocious than males and therefore heavier at 49 days of age. However, this difference in growth may be accentuated by the exposure of quails to a greater number of hours of light: females submitted to more hours of light are thus heavier because they have greater body development, as well as greater development of the organs of the reproductive system.

To assess whether bone growth in quails could be subject to the same influence observed for body growth, the weight and length data of the tibiotarsus and femur of male and female quails submitted to different lighting programs were used to obtain estimates of the parameters of the Gompertz curve. The parameters for deposition of dry and mineral matter were also estimated.

Table 7 – Bone quality parameters of the tibiotarsus and femur of male and female meat quails at 49 days of age submitted to different lighting programs.

Parameters	Sex (S)	Lighting programs (LP)			Mean	SEM	ANOVA		
		Natural	Intermittent	Continuous			LP	S	LP x S
Tibiotarsus									
Seedor index (mg/mm)	Male	18.22	18.54	17.62	18.21	0.1966	NS	NS	NS
	Female	18.36	18.50	18.60	18.48				
	Mean	18.29	18.52	18.18					
Resistance (kgf/cm²)	Male	4.74	4.81	4.05	4.49	0.1363	*	NS	NS
	Female	4.46	4.65	3.74	4.25				
	Mean	4.60^x	4.72^x	3.89^y					
Deformity (mm)	Male	2.09	1.86	1.38	1.76	0.1028	**	NS	NS
	Female	2.00	1.88	1.14	1.66				
	Mean	2.04^x	1.87^x	1.26^y					
Femur									
Seedor index (mg/mm)	Male	18.11	18.39	17.78	18.21	0.2469	NS	NS	NS
	Female	18.68	19.47	18.62	18.48				
	Mean	18.40	18.87	18.20					
Resistance (kgf/cm²)	Male	4.11	3.68	4.02	3.94	0.0852	NS	NS	NS
	Female	3.87	4.12	3.76	3.90				
	Mean	3.99	3.88	3.89					
Deformity (mm)	Male	1.37	1.33	1.31	1.34	0.0309	NS	NS	NS
	Female	1.25	1.30	1.29	1.28				
	Mean	1.31	1.32	1.30					

SEM: Standard error of the mean; *$p \leq 0.05$; **$p \leq 0.01$; NS - not significant; Means followed by different letters (x,y) in the line differ by the Tukey test at 5% probability.

In general, the estimates of the parameters of the Gompertz curve indicated that the continuous lighting program evaluated in this research influenced growth and deposition of dry and mineral matter in the bones, making quails more precocious. Thus, it can be inferred that the influence of the greater number of hours of light accelerates the increase in body weight, as well as the growth of the tibiotarsus and femur of meat quails.

In turn, the greater weight, length, and deposition of mineral matter in bones at maturity and the greater number of days to reach maximum growth and ash deposition rate observed in the bones of females in relation to males indicate that sexual dimorphism occurs in the bone growth of meat quails, so that females take longer to complete the growth of the tibiotarsus and femur.

Reports in the literature indicate that higher ash levels in bones result in greater bone resistance and stiffness and consequently, in a lower probability of the incidence of leg problems, as the ash is related to the mineral content in the bones (Rose *et al.* 1996; Currey 1999; Williams *et al.* 2004; Reis *et al.* 2011). Given the above, it can be inferred that the continuous lighting program, which exposes quails to the greatest number of hours of light and results in a reduced time for the maximum deposition rate of mineral matter to occur in the bone, can be of benefit to quails, as weight gain is also faster in this condition. Thus, the bird will have a better formation of its bone structure, compatible with the deposition overload of other body tissues, mostly muscles, which the skeleton must support, certainly leading to less leg problems occurring due to rapid growth.

On the other hand, as females needed more time to reach the maximum rate of ash deposition in bones, associated with the fact that they showed greater body growth in relation to males, it can make them more susceptible to the incidence of leg problems, especially if a management or nutritional factor accelerates their growth. According to Pattison (1992), bone structure must increase in the same proportion as meat yield, which guarantees that quails present good mobility and consequently, good performance.

Studying the physical, chemical, and mechanical aspects of the tibiotarsus of broiler chickens, Reis (2011) observed that females tend to have denser and less porous bones, as well as a higher ash content than males. In this respect, it is worth mentioning that the sexual dimorphism between broilers and quails is different. While in broiler chickens males grow faster, and therefore are more susceptible to disorders of bone tissue that do not accompany this body growth, in quails it is the females that show greater growth.

There are few studies in the literature evaluating the effects of light programs for meat quails on bone growth, however Sagheer *et al.* (2004), in research with broilers subjected to different lighting programs, did not find differences in the weight of the femur for the different types of lighting.

According to Rath *et al.* (2000), bone is a complex tissue, and the density and resistance of bone tissue is related to the physical aspect (shape, size, and mass), architecture (orientation of collagen fibres), and material properties (matrix molecule); therefore, it is possible that there is a difference in the resistance of bones that have similar physical properties and chemical composition. This explains the fact that bone density of the tibiotarsus of the quails, measured by the Seedor index, did not vary significantly between the lighting programs, while the resistance and deformity were significantly influenced by the same variable.

In turn, the difference in results obtained between tibiotarsus and femur can be attributed to differences in growth patterns and physical properties of the bones of quails and their responses to the photoperiod. Variations between growth and bone quality, as well as different responses between bone types to the photoperiod have been reported by other researchers for laying hens (Silversides *et al.*, 2006; Hester *et al.*, 2011). Different responses by the tibiotarsus and femur of broilers to supplementation of calcium and organic acids were reported by Świątkiewicz & Arczewska-Wlosek (2012).

Considering the worse bone quality of the tibiotarsus with the increase in the number of hours of light for quails submitted to the continuous lighting program, it can be inferred that, although quails of this treatment presented an acceleration of growth, the deposition of dry and mineral matter in the bone was insufficient to guarantee better indices of resistance and deformity of the tibiotarsus. Thus, as the quails submitted to the continuous lighting program showed the greatest growth, causing the greatest body weight at 49 days of age, these birds may be more susceptible to locomotor problems related to tibiotarsus bone quality, such as tibial dyschondroplasia.

It is worth mentioning that males and females submitted to the continuous light program had worse resistance and bone deformity for the tibiotarsus (Table 7). This reinforces our expectation that more time is needed for the maximum rate of ash deposition to occur in bone; which, alongside greater body growth, can make females more susceptible to the appearance of leg problems, especially if a breeding factor accelerates their growth, as occurred for birds submitted to the continuous lighting program (Table 1). Further research must be carried out to better clarify this issue.

Although it is not yet common to report locomotor problems in current broiler quail strains, the effects of lighting programs on the quality of quail tibiotarsus ratify the observations of some researchers (Rutz *et al.,* 2014), who, in studying broiler lighting programs, concluded that the best performance and welfare of birds could be achieved with moderate photoperiods, as they allowed for an increase in hours of sleep, less physiological stress, improvement in the immune response, and possibly an improvement in bone metabolism and paw condition.

In face of the foregoing, it can be concluded that the lighting program adopted in raising meat quails influences growth and bone quality, and that a continuous lighting program with 23 hours of light influences bone growth of meat quails, contributing to the maximum growth rate and the earlier deposition of dry and mineral matter. However, this lighting program possibly causes a reduction in tibiotarsus bone deformity and resistance, worsening its quality.

For quails raised in the tropical region, a natural (12 hours of light and 30 min) or intermittent (18 hours light) lighting program must be used, as it does not compromise the development of bones and guarantees bone quality.

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DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interests with respect to the research, authorship, and/or publication of this article.

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