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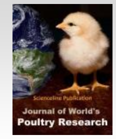

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Model Estimation for LongitudinalBone Growth Based on Age in Male and Female Commercial Broiler Chickens

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ABSTRACT

Longitudinal bone growth is essential to support rapid body growth in commercial broiler chickens. The present study aimed to determine which simple mathematic model is best suitable for explaining the absolute and the relative bone growth in length (expressed as a ratio of bone length to body weight) as a function of age in male and female commercial broiler chickens over the first 35 days of age. A total of 1,800 broiler chickens (900 males and 900 females) of Cobb 500, Ross 308, and Arbor Acres raised in standard commercial broiler houses were randomly selected for this study. Body weight and the lengths of backbones, third toe, shank bone, and keel bone were individually measured in all chickens at 1, 7, 14, 21, 28, and 35 days of age. Regression analysis (with 4 simple mathematical models including linear, logarithmic, inverse, and exponential) was used to find a suitable model for estimating the absolute and the relative bone growth in length. In addition, an adjusted R^2 was used to assess the model fitting. The results indicated that the absolute bone growth in length linearly increased with age. The adjusted R^2 values for the linear model were 0.973, 0.937, 0.950, and 0.974 for the lengths of the backbones, third toe, shank bone, and keel bone, respectively. However, the relative bone growth in length logarithmically decreased with age. The adjusted R^2 values of the logarithmic model were 0.971, 0.952, 0.957, and 0.905 for the relative length of the backbones, third toe, shank bone, and keel bone, respectively.The present investigation suggests thata linear model is a suitable model for estimating the absolute bone growth in length, but a logarithmic model is a proper model for estimating the relative bone growth in length of commercial broiler chickens.

Key words: Age, Bone growth, Broiler chickens, Mathematical model, Regression

INTRODUCTION

The meat of broiler chickens is a popular and cheap protein source for humans worldwide. To serve a huge demand with affordable cost for consumers, fast-growing strains of commercial broiler chickens are necessary. At present, commercial broiler chickens can reach a market size of 2.2 kg within 35 days of age (Tallentire et al., 2018). The percentages of breast plus leg muscles of these chickens accounts for more than 40% of whole eviscerated carcasses (Kokoszyński and Bernacki, 2008; Sarsenbek et al., 2013). However, due to a very rapid growth rate, fast-growing commercial broiler chickens face several problems or disorders, especially in bone and leg (Cook, 2000; Knowles et al., 2008; Granquist et al., 2019). The skeletonis an important structure that supports the whole body; therefore, bone growth is a key physiological process to ensure a proper supporting system for the whole body of animals. Bone growth has many aspects, such as circumferential growth, weight growth, volume growth, bone mineralization, chemical composition, and structural organization (Rose et al., 1996; Kerschnitzki et al., 2016; Pratt and Cooper, 2018; Sanchez-Rodriguez et al., 2019). Bone growth in length (or longitudinal bone growth) is an important factor that supports the rapid expansion of the body of broiler chickens. Several studies have indicated that absolute rate of longitudinal bone growth is positively associated with the age or weight of broiler chickens (Applegate and Lilburn, 2002; Biesiada-Drzaga et al., 2012; Han et al., 2015; Mabelebele et al., 2017). However, one study indicated that relative bone growth in length, expressed as a ratio of bone length to body weight, was negatively associated with body weight gain in broiler chickens (Shim et al., 2012). This ratio is a useful variable to assess the rate of bone length compared to the rate of body weight gain as a function of age. To better understand the bone growth in length as a function of age in broiler chickens, the objective of this study was to determine which simple mathematical model is suitable for explaining the absolute and the relative bone growth in length in male and female commercial broiler chickens over the first 35 days of the rearing period.

MATERIALS AND METHODS

Ethical approval

The study was approved by the Institutional Animal Care and Use Committee of Khon Kaen University, Khon Kaen, Thailand (ACUC KKU license No. 27/2559).

Animals and housing

The present study was conducted in six broiler houses (three each) from two commercial broiler farms located in Buriram Province, Northeastern Thailand on June 2018 (Latitude: 14° 36' 21.31" N, Longitude: 103° 07' 14.92" E). The year-round outside temperature was approximately 27 °C, and the relative humidity was approximately 75%. Both farms used a tunnel ventilated house with dimensions of 14 × 2.8 × 120 m (width x height x length), resulting in a 1,680 m^2 rearing area. Each house was equipped with a cooling pad on both lateral sides near the front end and 10 large exhaust fans at the rear end. Each house was equipped with four rows of automatic feeding pans, totaling 644 pans, and five rows of the drinkers, totaling 2,366 heads. The stock density was 11-12.5 heads per square meter, resulting in 18,000 to 21,000 birds per house. Each house was considered for both sexes but with a single breed. Chickens were reared in floor pens. The floor was made from concrete cement and covered with a 5 cm thick layer of new rice husk for each growing cycle. Diet, feeding, vaccination, husbandry, and care of the broiler chickens were under standard conditions depending on the age of chickens recomme-nded by the broiler breeder companies. Briefly, feed and water were provided *ad libitum* throughout the rearing cycle. Starter, grower, and finisher feed were used for chickens at aged 1-21 days, 22-32 days, and 33 days until the end of the rearing period, respectively. All chickens were vaccinated against Newcastle disease and infectious bronchitis according to a routine vaccination program. In addition, the chickens were regularly inspected for health status by a veterinarian. The flocks and the farms had no history of disease outbreaks. The temperature in the poultry house was controlled by using a heater or tunnel ventilation system depending on the age of chickens to provide the optimal conditions for birds according to the guidelines for commercial broilers.

Study design, sampling, and outcome measurements

This observational study was designed based on three chick characteristics as follows: age with six levels (1, 7, 14, 21, 28, and 35 days of age), sex with two categories(male and female), and breed with three types (Cobb 500, Ross 308, and Arbor Acres). Therefore, 36 subgroups were included and 50 healthy broiler chickens were randomly selected from the flocks for each subgroup. This resulted in a total sample of 1,800 broiler chickens. All samples were randomly selected from the flocks around the middle of the commercial broiler house (approximately 60 meters from the front end of the house). All measurements were made non-invasively on living animals. For a selected chicken, the body weight was measured with a digital weight scale. Moreover, the length of the backbones, a third toe, a shank bone (a tarsometatarsus), and a keel bone was measured with a Vernier caliper. All variables were measured in living birds using two people (one held the bird gently and another one made the measurement). After birds were measured, they were returned to their flocks. The total length of the backbones (including thoracic, lumbosacral, and caudal vertebrae) was measured from the junction of the last cervical vertebra to the distal end of the last caudal vertebra. The third toe was measured from the proximal end (metatarso-digital joint) to the tip of the claw. The shank bone was measured from the proximal end to the distal end. The keel bone was measured from the proximal end to the distal end. The original measurement scale was in grams for body weight and in millimeters for the bones length.

Statistical analysis

All data from each variable were verified and checked for normality. The mean and standard deviation from each variable for males and females at six different ages (1, 7, 14, 21, 28, and 35 days) of broiler chickens were calculated. A mean difference of each variable was compared using an independent sample t-test. The relative bone growth in length was calculated as a ratio of bone length to body weight. To avoid many decimals and for ease of interpretation, this ratio was expressed in cm/kg. Regression analysis with four mathematical models was used to estimate the absolute and relative bone growth in length as a function of age in broiler chickens. These mathematical models included linear, logarithmic, inverse, and exponential models. The mathematical equation for each model was as follows.

Linear model: $Y = b0 + (b1 * t)$.

*Logarithmic model: Y = b0 + (b1 * log (t)).*

Inverse model: *Y = b0 + (b1 / t).*

Exponential model: *Y = b0 * (e** (b1 * t)).*

(*Y* stands for the dependent variable; *b0* for the intercept; *b1* for the slope; *e* for an irrational constant (approximately equal to 2.718); and *t* for the independent variable (age of chickens)). A p-value of <0.05 was considered statistically significant. SPSS version 17 (SPSS Inc, Chicago, IL) was used for all statistical analysis.

RESULTS

The mean and standard deviation of the body weight of male and female broiler chickens at 1, 7, 14, 21, 28, and 35 days of age is shown in table 1. The difference in mean body weight was significantly higher in males than in females starting from days 7 through 35. The effect sizes of the mean differences were 4.9 g at 7 days to 260 g at 35 days of age.

Comparison of the absolute and the relative bone growth in length between the studied male and female broiler chickens for the backbones, the third toe, the shank bone, and the keel bone are presented in tables 2-5. At 28 and 35 days of age, the absolute length of the backbones was significantly greater in males than in females; however, the relative length was significantly smaller in males compared to females at 7, 14, 21, 28, and 35 days of age (Table 2). The absolute length of the third toe was significantly greater in males than in females at 21, 28, and 35 days of age; however, the relative length was significantly smaller in males than in females at 7, 14, 21, 28, and 35 days of age (Table 3). The absolute length of the shank bone was significantly greater in males than in females at 14, 28, and 35 days of age; however, the relative length was significantly smaller in males than in females at 7, 21, 28, and 35 days of age (Table 4). The absolute length of the keel bone was significantly greater in males than in females at 14, 21, 28, and 35 days of age; however, the relative length was significantly smaller in males than in females at 7, 14, 21, 28, and 35 days of age (Table 5).

Regression analysis of linear, logarithmic, inverse, and exponential models for estimating the association between the absolute bone growth in length and the age of the broiler chickens are shown in table 6. The regression coefficient of the absolute bone length as a function of age was significant for all models and for all the studied bones (p<0.001) (Table 6). However, the adjusted R^2 was the greatest for the linear model for all bone types (0.973, 0.937, 0.950, and 0.974 for backbones, third toe, the shank bone, and the keel bone; respectively) (Table 6). Visually, a linear model was a better model than a logarithmic model in fitting the data for the absolute bone growth in length in the broiler chickens (Figure 1A-4A). In the linear model, a regression coefficient for age was positively maximal for the keel bone (3.46) and positively minimal for the third toe (1.13) (Table 6).

Regression analysis with four different models (linear, logarithmic, inverse, and exponential models) for estimating the association between the relative bone growth in length and age of broiler chickens are presented in table 7. The regression coefficient of the relative bone length as a function of age was significant for all the models and for all the bones (p<0.001) (Table 7). However, the adjusted R^2 was the greatest for the logarithmic model for most bone types (0.971 for backbones, 0.952 for the third toe, 0.957 for the shank bone, and 0.905 for the keel bone) (Table 7). Visually, the logarithmic model was a better model than the linear model in fitting the data for the relative bone growth in length in the broiler chickens (Figure 1B-4B). In the logarithmic model, a regression coefficient for age was negatively maximal for the keel bone (-31.28) and negatively minimal for the third toe (-13.44) (Table 7).

Table 1. Body weight of broiler chickens at different ages

Age of chickens (day) \ Body weight (g)	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	p-value
1	43.6 ± 2.5	44.0 ± 2.7	-0.4 (-1.0, 0.2)	0.181
7	180.9 ± 11.6	176.0 ± 15.4	4.9 (1.8, 8.0)	0.002
14	479.5 ± 15.7	462.0 ± 12.8	17.5 (14.3, 20.8)	<0.001
21	959.6 ± 15.1	902.2 ± 16.1	57.3 (53.8, 60.9)	<0.001
28	1575.8 ± 28.6	1435.3 ± 30.7	140.5 (133.7, 147.2)	<0.001
35	2282.6 ± 43.8	2022.8 ± 55.2	259.8 (248.5, 271.2)	<0.001

CI: confidence interval, MD: mean difference, SD: standard deviation

Table 2. The absolute length and relative length (expressed as a ratio of bone length to body weight) of backbones in male and female broiler chickens at different ages

Age (days)	Absolute length of backbones (mm)				Relative length of backbones (cm/kg)			
	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	p-value	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	p-value
1	50.8 ± 2.4	50.0 ± 2.0	0.8 (0.3, 1.3)	0.001	116.9 ± 7.8	114.0 ± 7.9	2.9 (1.1, 4.6)	0.002
7	79.6 ± 4.8	80.6 ± 3.6	-1.0 (-2.0, 0.0)	0.042	44.2 ± 3.6	46.2 ± 4.7	-2.0 (-2.9, -1.1)	<0.001
14	100.0 ± 9.1	103.9 ± 5.4	-3.8 (-5.5, -2.1)	<0.001	20.9 ± 1.9	22.5 ± 1.3	-1.6 (-2.0, -1.3)	<0.001
21	118.6 ± 3.8	119.9 ± 5.7	-1.3 (-2.4, -0.2)	0.021	12.4 ± 0.4	13.3 ± 0.6	-0.9 (-1.0, -0.8)	<0.001
28	146.4 ± 5.8	143.2 ± 4.2	3.2 (2.0, 4.3)	<0.001	9.3 ± 0.4	10.0 ± 0.4	-0.7 (-0.8, -0.6)	<0.001
35	169.6 ± 7.5	165.2 ± 5.8	4.4 (2.9, 6.0)	<0.001	7.4 ± 0.4	8.2 ± 0.3	-0.7 (-0.8, -0.7)	<0.001

CI: confidence interval, MD: mean difference, SD: standard deviation

Table 3. The absolute length and the relative length (expressed as a ratio of bone length to body weight) of the third toe in male and female broiler chickens at different ages

Age (days)	Absolute length of the third toe (mm)				Relative length of the third toe (cm/kg)			
	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	p-value	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	p-value
1	21.4 ± 2.2	21.5 ± 1.7	-0.1 (-0.5, 0.4)	0.814	49.3 ± 6.5	49.0 ± 5.8	0.3 (-1.1, 1.7)	0.667
7	32.4 ± 1.5	32.6 ± 1.4	-0.1 (-0.5, 0.2)	0.444	18.0 ± 1.7	18.7 ± 2.3	-0.7 (-1.1, -0.2)	0.005
14	41.5 ± 3.1	41.1 ± 2.2	0.4 (-0.3, 1.0)	0.248	8.7 ± 0.7	8.9 ± 0.5	-0.3 (-0.4, -0.1)	0.001
21	46.2 ± 1.6	45.8 ± 1.7	0.4 (0.0, 0.8)	0.033	4.8 ± 0.2	5.1 ± 0.2	-0.3 (-0.3, -0.2)	<0.001
28	56.3 ± 3.3	54.3 ± 3.2	2.0 (1.2, 2.7)	<0.001	3.6 ± 0.2	3.8 ± 0.3	-0.2 (-0.3, -0.2)	<0.001
35	62.7 ± 5.0	59.4 ± 4.1	3.3 (2.3, 4.3)	<0.001	2.7 ± 0.2	2.9 ± 0.2	-0.2 (-0.2, -0.1)	<0.001

CI: confidence interval, MD: mean difference, SD: standard deviation

Table 4. The absolute length and relative length (expressed as a ratio of bone length to body weight) of the shank bone in male and female broiler chickens at different ages

Age (days)	Absolute length of the shank bone (mm)				Relative length of the shank bone (cm/kg)			
	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	P-value	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	P-value
1	29.1 ± 2.0	29.0 ± 1.4	0.1 (-0.3, 0.5)	0.576	66.8 ± 5.3	66.0 ± 4.3	0.9 (-0.2, 1.9)	0.127
7	39.1 ± 1.7	39.1 ± 1.4	0.0 (-0.3, 0.4)	0.970	21.7 ± 1.8	22.4 ± 2.4	-0.7 (-1.2, -0.2)	0.005
14	54.2 ± 3.5	52.5 ± 2.4	1.7 (1.0, 2.4)	<0.001	11.3 ± 0.8	11.4 ± 0.6	-0.1 (-0.2, 0.1)	0.478
21	63.1 ± 8.2	61.9 ± 8.1	1.2 (-0.7, 3.0)	0.214	6.6 ± 0.8	6.9 ± 0.9	-0.3 (-0.5, -0.1)	0.003
28	79.0 ± 3.8	76.3 ± 3.5	2.8 (2.0, 3.6)	<0.001	5.0 ± 0.2	5.3 ± 0.2	-0.3 (-0.3, -0.2)	<0.001
35	89.8 ± 4.0	84.3 ± 3.8	5.5 (4.7, 6.4)	<0.001	3.9 ± 0.2	4.2 ± 0.2	-0.2 (-0.3, -0.2)	<0.001

CI: confidence interval, MD: mean difference, SD: standard deviation

Table 5. The absolute length and the relative length (expressed as a ratio of bone length to body weight) of keel bone in male and female broiler chickens at different ages

Age (days)	Absolute length of the keel bone (mm)				Relative length of the keel bone (cm/kg)			
	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	P-value	Male Mean ± SD	Female Mean ± SD	MD (95% CI)	p-value
1	23.3 ± 4.4	23.6 ± 4.6	-0.4 (-1.4 0.7)	0.500	53.7 ± 11.7	54.2 ± 12.8	-0.5 (-3.3, 2.3)	0.729
7	52.4 ± 2.7	52.4 ± 3.4	0.0 (-0.7, 0.7)	0.911	29.1 ± 2.8	30.1 ± 4.0	-1.0 (-1.8, -0.2)	0.013
14	79.7 ± 3.7	78.2 ± 4.0	1.5 (0.6, 2.4)	0.001	16.6 ± 0.0	16.9 ± 1.0	-0.3 (-0.5, -0.1)	0.007
21	105.1 ± 3.7	102.9 ± 3.7	2.1 (1.3, 3.0)	<0.001	11.0 ± 0.4	11.4 ± 0.5	-0.5 (-0.6, -0.4)	<0.001
28	127.9 ± 5.2	123.4 ± 4.9	4.5 (3.3, 5.6)	<0.001	8.1 ± 0.3	8.6 ± 0.3	-0.5 (-0.6, -0.4)	<0.001
35	143.9 ± 5.2	138.2 ± 6.2	5.7 (4.4, 7.0)	<0.001	6.3 ± 0.2	6.8 ± 0.3	-0.5 (-0.6, -0.5)	<0.001

CI: confidence interval, MD: mean difference, SD: standard deviation

Table 6. Regression analysis for estimating the relationship between the absolute bone growth in length and age of broiler chickens

Variables	Model equation	Adjusted R^2	Constant		Age (day)		p-value for age
			B	SE	B	SE	
Length of backbones (mm)	Linear	0.973	52.14	0.28	3.31	0.01	<0.001
	Logarithmic	0.838	38.04	0.84	30.01	0.31	<0.001
	Inverse	0.561	129.25	0.73	-84.13	1.75	<0.001
	Exponential	0.924	57.51	0.27	0.03	0.00	<0.001
Length of third toe (mm)	Linear	0.937	23.04	0.15	1.13	0.01	<0.001
	Logarithmic	0.848	17.63	0.28	10.45	0.10	<0.001
	Inverse	0.589	49.51	0.24	-29.84	0.59	<0.001
	Exponential	0.890	24.38	0.12	0.03	0.00	<0.001
Length of shank bone (mm)	Linear	0.950	27.58	0.20	1.73	0.01	<0.001
	Logarithmic	0.776	21.21	0.52	15.25	0.19	<0.001
	Inverse	0.485	67.22	0.42	-41.27	1.00	<0.001
	Exponential	0.933	30.77	0.13	0.03	0.00	<0.001
Length of keel bone (mm)	Linear	0.974	26.40	0.28	3.46	0.01	<0.001
	Logarithmic	0.868	10.37	0.79	31.92	0.29	<0.001
	Inverse	0.585	107.42	0.74	-89.76	1.78	<0.001
	Exponential	0.857	31.21	0.32	0.05	0.00	<0.001

B: unstandardized regression coefficient, SE: standard error

Table 7. Regression analysis for estimating the relationship between the relative bone growth in length (expressed as a ratio of bone length to body weight) and age of broiler chickens

Variables	Model equation	Adjusted R^2	Constant		Age (day)		p-value for age
			B	SE	B	SE	
Backbones to body weight (cm/kg)	Linear	0.679	82.79	0.92	-2.68	0.04	<0.001
	Logarithmic	0.971	111.09	0.35	-31.28	0.13	<0.001
	Inverse	0.939	12.13	0.26	105.37	0.63	<0.001
	Exponential	0.918	85.16	0.98	-0.08	0.00	<0.001
Third toe to body weight (cm/kg)	Linear	0.661	34.89	0.41	-1.15	0.02	<0.001
	Logarithmic	0.952	47.14	0.19	-13.44	0.07	<0.001
	Inverse	0.929	4.59	0.12	45.45	0.30	<0.001
	Exponential	0.923	36.10	0.42	-0.08	0.00	<0.001
Shank bone to body weight (cm/kg)	Linear	0.639	45.85	0.56	-1.50	0.03	<0.001
	Logarithmic	0.957	62.73	0.24	-17.95	0.09	<0.001
	Inverse	0.962	5.67	0.12	61.63	0.29	<0.001
	Exponential	0.902	45.56	0.59	-0.08	0.00	<0.001
Keel bone to body weight (cm/kg)	Linear	0.726	43.35	0.39	-1.26	0.02	<0.001
	Logarithmic	0.905	54.32	0.28	-13.74	0.11	<0.001
	Inverse	0.792	11.34	0.22	44.02	0.53	<0.001
	Exponential	0.942	46.21	0.35	-0.06	0.00	<0.001

B: unstandardized regression coefficient, SE: standard error

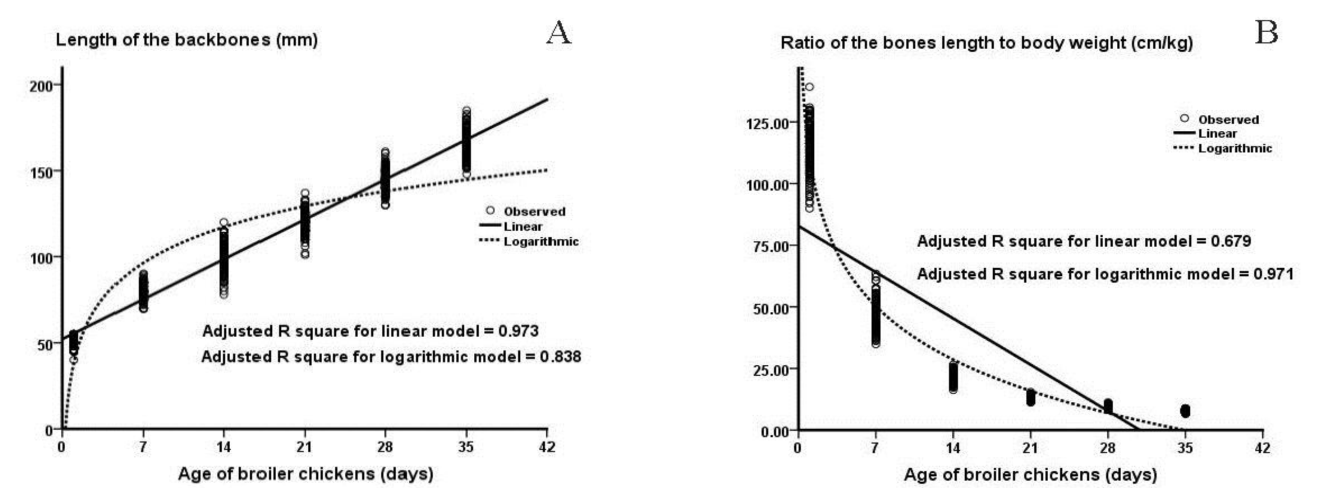

Figure 1. Regression analysis using linear and logarithmic models for the absolute (**A**) and the relative (**B**) bone growth in length (expressed as a ratio of bone length to body weight) of the backbones in the broiler chickens during 35 days rearing period.

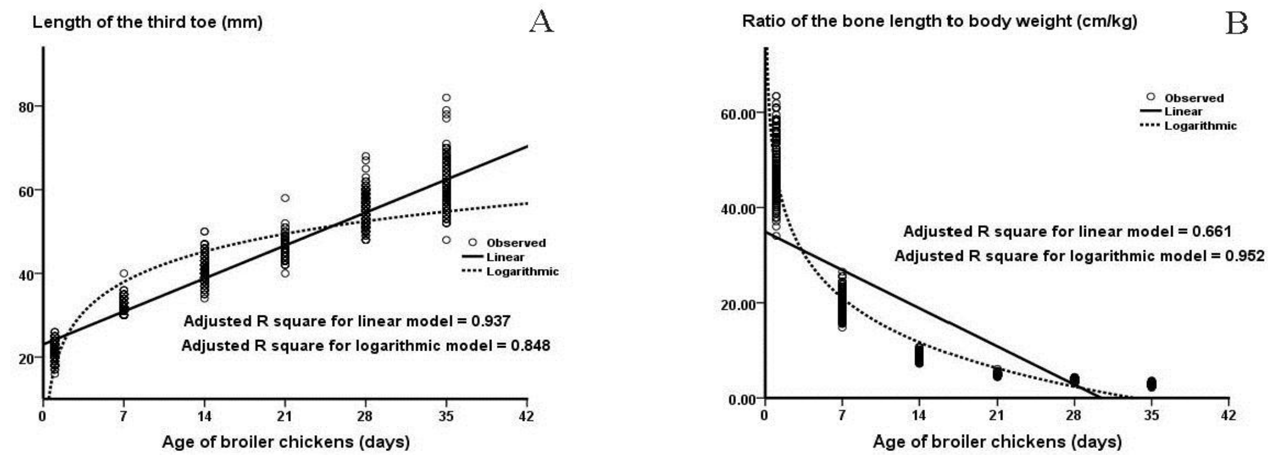

Figure 2. Regression analysis using linear and logarithmic models for the absolute (**A**) and the relative (**B**) bone growth in length (expressed as a ratio of bone length to body weight) of the third toe in the broiler chickens during 35 days rearing period.

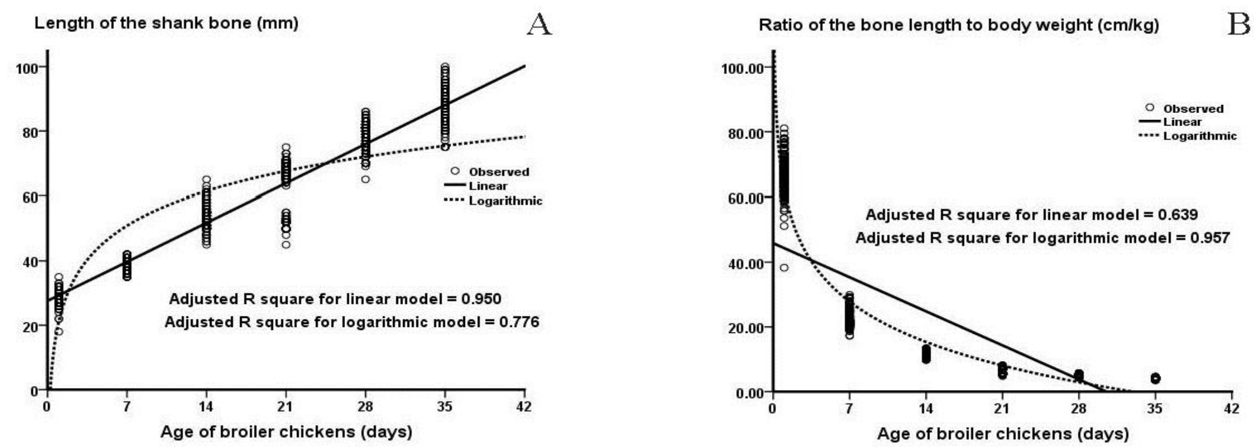

Figure 3. Regression analysis using linear and logarithmic models for the absolute (**A**) and the relative (**B**) bone growth in length (expressed as a ratio of bone length to body weight) of the shank bone in the broiler chickens during 35 days rearing period.

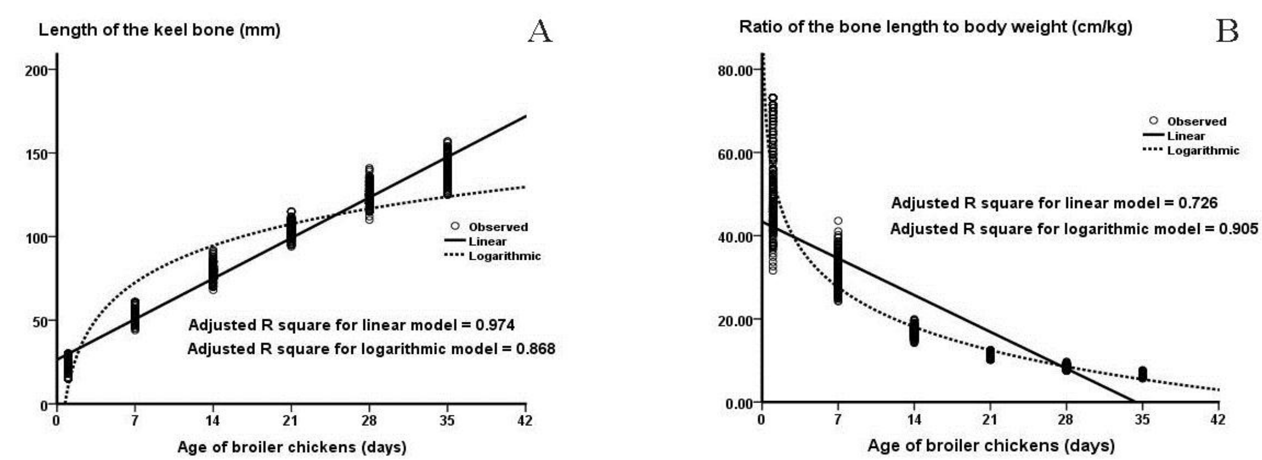

Figure 4. Regression analysis using linear and logarithmic models for the absolute (**A**) and the relative (**B**) bone growth in length (expressed as a ratio of bone length to body weight) of the keel bone in the broiler chickens during 35 days rearing period.

DISCUSSION

This study indicated that a different mathematical model was acceptable for explaining the absolute and relative bone growth in length as a function of age in commercial broiler chickens. A linear model is more suitable for explaining the absolute bone growth in length in commercial broilers because an adjusted R^2 value (indicating model fitting) of the linear model was higher than that of the other models. The adjusted R^2 values for the linear model of the absolute bone growth in length ranged from 0.937 for the third toe and to 0.974 for the keel bone, which were higher than those of the other models for all of the studied bones (Table 6). This result means that the age of the chickens can explain approximately 93.7% and 97.4% of the variability in bone growth in length for the third toe and the keel bone, respectively. However, it appeared that a logarithmic model is more suitable for explaining the relative bone growth in length in commercial broiler chickens. Adjusted R^2 values for assessing a logarithmic model fitting of the relative bone growth in length ranged from 0.905 for the keel bone to 0.971 for the backbones, which was higher than those of the other models for most of the studied bones (Table 7). This finding indicates that the age of the chickens can explain approximately 90.5% and 97.1% of the variability in bone growth in length for the keel bone and the backbones, respectively.

In the linear model, the absolute bone growth in length linearly increased with age for all of the studied bones. The rate for the absolute bone growth in length was the highest for the keel bone (the regression coefficient = 3.46) and was the lowest for the third toe (the regression coefficient = 1.13) (Table 6). This outcome meant that the keel bone growth in length increased from 29.9 mm at 1 day to 147.5 mm at 35 days of age, but the third toe growth in length increased from 24.2 mm at 1 day to 62.6 mm at 35 days of age. Several studies have evaluated longitudinal bone growth in broiler chickens (Applegate and Lilburn, 2002; Biesiada-Drzaga et al., 2012; Shim et al., 2012; Han et al., 2015; Mabelebele et al., 2017). The results of previous studies were similar to the obtained results in the current study. That is, the absolute bone growth in length in the broiler chickens was positively increased with age (Biesiada-Drzaga et al., 2012; Han et al., 2015) or with body weight (Applegate and Lilburn, 2002; Paxton et al., 2014; Mabelebele et al., 2017). The present study also indicated that the rate of longitudinal bone growth differed depending on the studied bones. This difference may result in bone length reaching a plateau or maturity at different ages. The statement was also supported by evidence from a previous study, conducted in broiler chickens from hatch to 43 days of age, which reported the length of the femur reached a plateau at 35 days of age, but the length of the tibia reached a plateau later than 43 days of age (Applegate and Lilburn, 2002). In addition, this finding was similar to longitudinal bone growth in other poultry species, such as ducks (Van Wyhe et al., 2012).

In a logarithmic model, the relative bone growth in length logarithmically decreased with age. It was indicated that the relative bone growth in length decreased sharply from 1 day to 14 days of age but slightly decreased from 21 days through 35 days (Figure 1B-4B). The rate of the relative bone length was negative, with the lowest rate for the backbones (regression coefficient = -31.28) and the highest rate for the third toe (regression coefficient = -13.44). Moreover, it was determined that the relative length of the backbones decreased from 109.60 cm/kg (or 1.10 mm/g) at 1 day to 69.23 cm/kg (or 0.69 mm/g) at 28 days of age, but the third toe growth in length decreased from 46.02 cm/kg (or 0.46 mm/g) at 1 day to 15.56 cm/kg (or 0.16 mm/g) at 28 days of age. The obtained results in current work were similar to those of a previous study by Shim et al. (2012), who found the relative bone growth in length decreased with body weight in both fast-growing and slow-growing broiler chickens.

The results obtained in the present article varied in overall comparisons of bone growth in length between male and female broiler chickens for all ages. However, at 28 days and 35 days of age, the absolute bone growth in length was significantly higher in males than in females for all of the studied bones. On the other hand, the relative bone growth in length was significantly lower in males than in females from 7 days through 35 days of age (Tables 2-5). The different results between the absolute and relative bone growth in length implied the importance of different rates of body weight gain between males and females (Table 1). The results from previous studies were also controversial. In one study, there was no significant difference in absolute bone length between male and female broiler chickens (Han et al., 2015). In other studies, male broiler chickens had longer tibias and femurs than female broiler chickens (Bond et al., 1991; Applegate and Lilburn, 2002).

The present study has some limitations. There are several factors that regulate bone growth and strength in poultry (Rath et al., 2000). However, the current investigation focused only on bone growth in length and ignored circumferential growth, weight, and volume of bones as well as the degree of mineralization which were studied in previous literature (Kerschnitzki et al., 2016; Pratt and Cooper, 2018; Sanchez-Rodriguez et al., 2019). These factors affect the bone strength for supporting the whole body weight. In addition, the age of broiler breeder flocks was not available in the current study. Different ages of broiler breeder may result in differences in bone length and body weight of broiler chickens. Therefore, the aforementioned limitations should be taken into account in the interpretation of bone growth in this study, which should be made carefully.

CONCLUSION

The present study demonstrated that a simple linear model is a suitable model to explain the increase in the absolute bone growth in length as a function of age; however, a logarithmic model is an acceptable model to explain the decrease in the relative longitudinal bone growth as a function of age in commercial broiler chickens.

DECLARATIONS

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Consent to publish

Not applicable

Competing interests

The authors have declared that no competing interest exists.

Author's contribution

Saijai, Damnern, and Peerapol participated in study design, data collection, data analysis, writing, and approving the final manuscript.

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