Growth Characteristics of Pearl Gray Guinea Fowl as Predicted by the Richards, Gompertz, and Logistic Models

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ABSTRACT This study was undertaken to describe the growth pattern of the pearl gray Guinea fowl. Using BW data from hatch to 22 wk, 3 nonlinear mathematical functions (Richards, Gompertz, and logistic) were used to estimate growth patterns of the pearl gray guinea fowl. The logistic and Gompertz models are a special case of the Richards model, which has a variable point of inflection defined by the shape or growth trajectory parameter, *m*. The shape parameter *m* was 1.08 and 0.98 in males and females, respectively, suggesting that the growth pattern of the pearl gray female guinea fowl is Gompertz. The pearl gray guinea fowl exhibited sexual dimorphism for their growth characteristics. From the Gompertz model, the asymptotic BW, growth rate, and age at maximum growth were 1.62 kg, 0.22 kg/wk, and 6.65 wk in males, respectively, and 1.70 kg, 0.19 kg/wk, and 6.70 wk in females, respectively. The ages at maximum growth were 6.65, 6.47, and 8.12 wk for the Richards, Gompertz, and logistic models, respectively. The pearl gray guinea fowl females have a higher asymptotic BW compared with the males. The average asymptotic BW of about 1.57 kg for both sexes predicted by the logistic model was below the average predicted BW from the Richards (1.66 kg) and Gompertz (1.67 kg) models, respectively, at 22 wk of age. The inverse relationship between the asymptotic weight and both relative growth and age at maximum growth of the pearl gray guinea fowl is similar to that of chickens, quail, and ducks. Success in studying the growth characteristics of guinea fowl will contribute to the efforts of genetically improving this least-studied avian species.

Key words: guinea fowl, growth pattern, Gompertz, logistic, Richards

INTRODUCTION

Commercialization of the guinea fowl has gained momentum in many countries, including the United States, France, and Belgium. In order for this to be successful, efficient ways of producing guinea fowl must be sought. Feeding accounts for about 60 to 80% of the total cost of poultry production (Pym, 1990); thus, designing birds that are highly efficient in utilizing feed for growth will profit the guinea fowl industry (Fedkiw et al., 1992). However, turning guinea fowl production into a profitable enterprise will require understanding of their growth characteristics and patterns. The growth patterns will allow the design of nutritional or feeding regimens for the guinea fowl for efficient use of feed and profitability. The pearl gray guinea fowl is a dominant variety that is raised for meat in addition to its higher egg production characteristics. The pearl gray variety of the guinea fowl also has a leaner carcass than the French variety. Unlike

chicken eggs, consumption of guinea fowl eggs is not popular, and thus most guinea fowl are raised for meat and served in restaurants around the world, especially as substitutes for game birds. In the United States, there is increasing expansion in guinea fowl breeding and grow out enterprises because of increasing demand for guinea fowl meat. A recent survey (Nahashon et al., 2004) pointed to an increase in interest to raise guinea fowl in the United States. However, the greatest challenge is the establishment of optimum nutrient requirements for the guinea fowl and the design of feeding schemes that will maximize growth and minimize the cost of production (Nahashon et al., 2005). To do so effectively, the growth patterns for the different guinea fowl varieties must be understood. The general importance of mathematical models of growth and their use in poultry was emphasized in earlier reports (Anthony et al., 1991; Knížetová et al., 1991; Aggrey, 2002). These models are useful because they summarize time series data into a few parameters to enable an objective comparison of the growth efficiencies. When these functions are expressed graphically, irregular fluctuations in weight caused by random environmental effects are usually eliminated. The application of mathematical growth models in combination with feed

consumption data is important in bioeconomical studies because, according to Pasternak and Shalev (1983), the cumulative feed consumption up to slaughter weight is dependent on both growth rate and the shape of the growth curve. Brody (1945) suggested that the asymptotic or mature weight, rate of attainment of mature weight, and the standardized age at which an animal attained the inflection point of the curve were quantities that could be manipulated by geneticists. Sigmoid, logistic, and polynomial models have been fitted to growth curves of chickens (Grossman and Bohren, 1982). The Gompertz model (Gompertz, 1925) as modified by Laird et al. (1965) has been cited as the model of choice for chicken data because of its overall fit and the biological meaning of the model parameters (Ricklefs, 1985; Mignon-Grasteau et al., 1999). Aggrey (2002) recently compared 3 nonlinear (Richards, logistic, and Gompertz) and spline linear regression models for describing chicken growth curves. The spline model predicted the hatching weight better than the Gompertz model; however, the spline model had the poorest fit to the data compared with the 3 nonlinear models. Information on the growth characteristics of the guinea fowl is scanty. It would be useful to study the growth pattern of guinea fowl to provide the basis for improvement. The objective of this study was to describe the growth pattern of the pearl gray guinea fowl using the 3 nonlinear mathematical models: Richards, logistic, and Gompertz. The information realized from this study will be used to design feeding regimens for the pearl gray guinea fowl raised for meat consumption.

MATERIALS AND METHODS

Animals

A total of 118, 1-d-old random-bred pearl gray guinea keets were obtained from Ideal Poultry Breeding Farms (Cameron, TX). Birds were weighed individually and randomly assigned to electrically heated, thermostatically controlled battery brooders (Petersime Electric Brooding Units, Petersime Incubator Co., Gettysburg, OH) equipped with raised wire floors from hatch to 4 wk of age. The battery cages measured $99 \times 66 \times 26$ cm, and each housed about 20 birds. At 1-d-old, the brooder temperature was maintained at 32.2°C for the first wk and was reduced gradually by 2.8°C every wk until 23.9°C, and at this point on no artificial heating was provided to the birds. At 5 wk of age the keets were transferred into growing batteries that were not supplied with supplemental heating. However, constant room temperature was maintained at 21.1°C. The growing batteries measured $163 \times 69 \times 33$ cm and housed 15 birds from 5 to 8 wk of age. Ventilation within the growing cages was maintained by thermostatically controlled exhaust fans. Birds were then transferred to 3 floor pens measuring $452 \times 274 \times 213$ cm (50 birds/pen), where they were raised from 9 to 22 wk of age. The birds received 23 h constant lighting from hatch to 22 wk of age. All birds were fed

Table 1. Composition of experimental diets

Wk of age	0–4	5–8	9–22
ME, kcal/kg	3,000	3,100	3,100
CP, %	24	21	18
Ingredient		%	
Corn, yellow #2 (8% CP)	44.93	49.35	67.75
Soybean meal (48% CP)	42.70	37.30	22.60
Alfalfa meal (17% CP)	1.00	1.00	1.00
Meat and bone meal (50% CP)	3.00	3.00	3.00
Poultry blended fat	5.80	6.70	3.10
Dicalcium phosphate (18% P, 22% Ca)	0.90	1.00	1.10
Limestone flour (38.8% Ca)	0.90	0.90	0.75
Salt	0.37	0.37	0.37
Vitamin-mineral premix[1]	0.25	0.25	0.25
DL-methionine (98%)[2]	0.15	0.13	0.08
Calculated level			
Metabolizable energy (kcal/kg of diet)	3,000	3,100	3,100
Crude protein, %	24	21	18
Calcium, %	1.0	1.00	0.95
P, total	0.72	0.72	0.70
Available P, %	0.48	0.48	0.47
Methionine, %	0.53	0.48	0.37
Methionine + cystine, %	0.92	0.85	0.68
Lysine, %	1.46	1.31	0.92

[1]Provided per kilogram of diet: retinyl acetate, 3,500 IU; cholecalciferol, 1,000 ICU; DL-α-tocopheryl acetate, 4.5 IU; menadione sodium bisulfite complex, 2.8 mg; vitamin B_{12}, 5.0 mg; riboflavin, 2.5 mg; pantothenic acid, 4.0 mg; niacin, 15.0 mg; choline, 172 mg; folic acid, 230 mg; ethoxyquin, 56.7 mg; manganese, 65 mg; iodine, 1 mg; iron, 54.8 mg; copper, 6 mg; zinc, 55 mg; selenium, 0.3 mg.

[2]Eli Lilly, Indianapolis, IN.

corn-soy-based diets containing 24% CP and 3,000 kcal of ME/kg of diet at hatch to 4 wk of age, 21% CP and 3,100 kcal of ME/kg of diet from 5 to 8 wk of age, and 18% CP and 3,100 kcal of ME/kg of diet from 9 to 22 wk of age (Table 1). The diets were fed in mash form and were provided for ad libitum consumption. Body weights were measured weekly from hatch to 22 wk, and mortality was recorded as it occurred.

Growth Models

Richards Model. To estimate the expected BW at a specific age, a 4-parameter growth curve modified from Richards (1959) growth function (Sugden et al., 1981) was fitted to BW data collected. The growth curve was of the following form:

$$W_t = W_A[1 - (1 - m)\exp[-K(t - ti)/m^{m/(1-m)}]]^{1/(1-m)},$$

in which W_t is the weight of bird at time t, W_A is the asymptotic (mature) body weight, K is the maximum relative growth (per wk), ti is the age at maximum rate of growth (wk), and m is a shape parameter, with the property that $m^{1/(1-m)}$ is relative weight at ti.

Gompertz-Laird Model. The Laird form of the Gompertz equation (Laird et al., 1965) was fit to the data. The following equation describes the Gompertz-Laird growth curve:

$$W_t = W_0 \exp[(L/K)(1 - \exp\text{-}Kt)],$$

Table 2. Means and standard deviation for body weight at different ages in a random-bred pearl gray guinea fowl population

Age (wk)	Body weight (g)	
	Male (n = 63)	Female (n = 55)
0	25.67 ± 1.79	25.27 ± 2.48
1	60.39 ± 8.47	61.01 ± 8.72
2	121.73 ± 14.87	124.09 ± 14.26
3	212.66 ± 24.03	213.78 ± 27.85
4	323.37 ± 29.84	323.06 ± 34.06
5	440.83 ± 42.73	445.80 ± 44.98
6	527.30 ± 48.79	529.87 ± 46.24
7	630.01 ± 69.12	618.10 ± 64.72
8	787.05 ± 77.59	771.39 ± 81.93
9	913.27 ± 82.05	901.42 ± 87.46
10	1,016.28 ± 88.92	1,004.91 ± 92.55
11	1,112.17 ± 97.41	1,097.06 ± 107.47
12	1,203.18 ± 116.15	1,118.50 ± 127.28
13	1,263.83 ± 130.04	1,239.77 ± 140.81
14	1,333.09 ± 131.97	1,315.83 ± 142.73
15	1,416.68 ± 133.07	1,405.19 ± 149.46
16	1,439.53 ± 133.66	1,436.98 ± 152.78
17	1,478.69 ± 132.02	1,508.59 ± 145.31
18	1,498.83 ± 132.39	1,549.29 ± 142.96
19	1,516.01 ± 135.28	1,570.92 ± 146.42
20	1,522.02 ± 136.71	1,586.39 ± 142.18
21	1,532.88 ± 134.59	1,594.90 ± 140.78
22	1,591.70 ± 193.90	1,562.37 ± 141.17

in which W_t is the weight of bird at time t, W_0 is the initial body (hatch) weight, L is the instantaneous growth rate (per wk), K is the rate of exponential decay of the initial specific growth rate, L, which measures the rate of decline in the growth rate. The parameters derived for the inflection point, ti, the body weight at the inflection point and the asymptotic body, W_A are

$$ti = (1/K)\log(L/K)$$
$$Wi = W_0 \exp((L/K)^{-1})$$
$$W_A = W_0 \exp(L/K).$$

Logistic Model. The following equation describes the logistic (Robertson, 1923) growth model:

$$W_t = W_A/[1 + \exp\text{-}K(t - ti)],$$

in which W_t is the body weight at time t, W_A is the asymptotic body weight, K is the exponential growth rate, and ti is the age at the inflection point. Differences between sex and growth curve parameters among prediction models were evaluated by the t-test (SAS Institute, 1999).

RESULTS AND DISCUSSION

The Richards, Gompertz, and logistic models were used to assess growth patterns of the pearl gray guinea fowl. Means and standard deviations of BW of pearl gray guinea fowl for each sex are presented in Table 2. In general the males appeared to be heavier than females, but these differences between the sexes were not significant. As expected with time series data, the standard deviation increased with age for both sexes. The fitted parameters for 3 nonlinear models for growth are presented in Table 3. The logistic and Gompertz models are a special case of the Richards model that has a variable point of inflection defined by the shape or growth trajectory parameter, m. When the shape parameter is 2.0 or 1.0, the Richards model is equivalent to the logistic or Gompertz models, respectively. From Table 3 the shape parameter m was 1.08 and 0.98 in males and females, respectively. This implies that the growth pattern of the pearl gray female guinea fowl is Gompertz. The growth trajectory of the male as predicted by the Richards model deviates slightly from the Gompertz model. The logistic model with a fixed m value of 2.0 would either grossly over- or underpredict the model parameters compared with the Gompertz model with an m value fixed at 1.0. This is also evidenced by both the asymptotic and age at maximum growth as predicted by both the logistic and Gompertz models. The asymptotic BW predicted by the Richards model for both males and females were comparable with the predictions from the Gompertz model. The

Table 3. Estimated coefficients (±SE) and confidence limits (CL) for Richards, Gompertz, and logistic model growth parameters in a random-bred pearl gray guinea fowl population

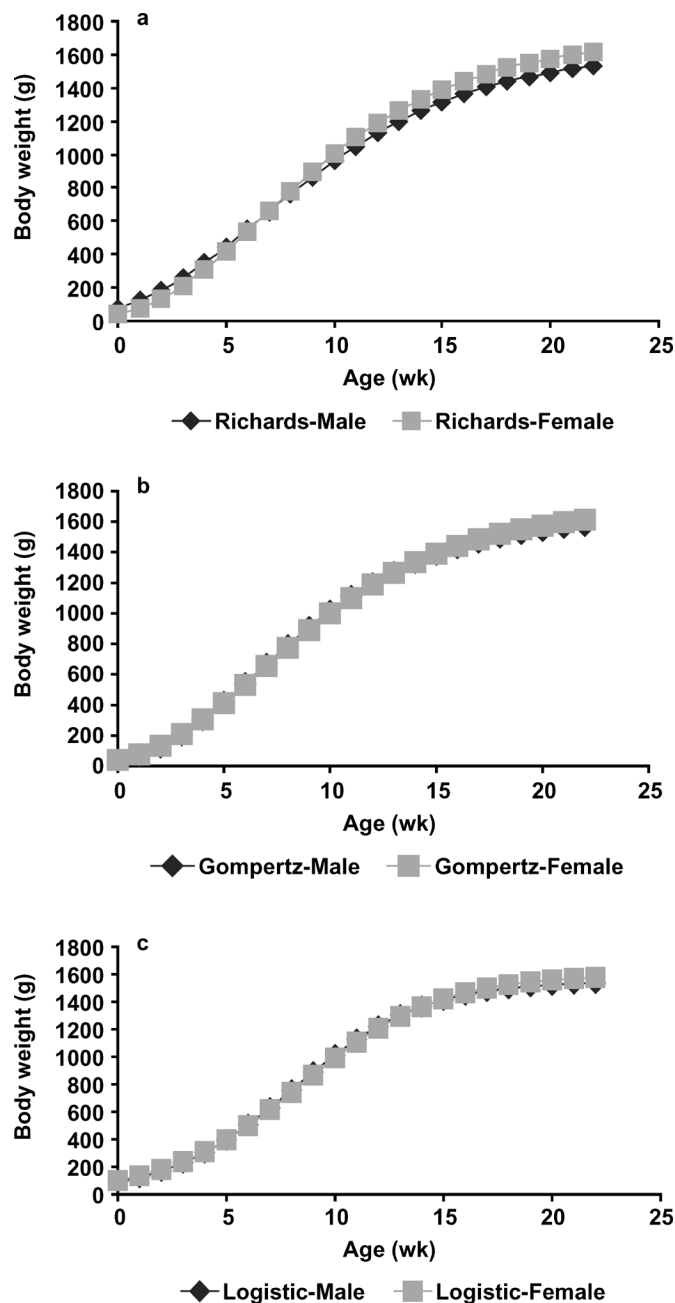| Model	Male (n = 63)		Female (n = 55)	
	Parameter	95% CL	Parameter	95% CL
Richards				
Asymptotic weight (W_A)	1,623.40 ± 13.07	1,597.80 − 1,649.00	1,700.00 ± 18.56	1,663.60 − 1,736.40
Relative growth (K)	0.22 ± 0.01	0.20 − 0.02	0.19 ± 0.01	0.17 − 0.21
Age of maximum growth (ti)	6.66 ± 0.07	6.32 − 6.99	6.70 ± 0.20	6.31 − 7.10
Shape parameter (m)	1.08 ± 0.17	0.93 − 1.22	0.98 ± 0.08	0.82 − 1.13
Gompertz				
Hatching weight (W_0)	32.13 ± 2.72	25.73 − 37.52	38.98 ± 3.34	32.42 − 45.53
Initial growth rate (L)	0.83 ± 0.03	0.77 − 0.89	0.74 ± 0.03	0.69 − 0.80
Rate of decay (K)	0.21 ± 0.00	0.20 − 0.22	0.20 ± 0.00	0.19 − 0.02
Age of maximum growth[1] (t*)	6.47 ± 0.05	6.14 − 6.88	6.75 ± 0.07	6.28 − 7.18
Asymptotic weight[1] (WA*)	1,634.21 ± 11.03	1,576.20 − 1,668.40	1,696.38 ± 15.35	1,528.30 − 1,763.10
Logistic				
Asymptotic weight (W_A)	1,550.00 ± 6.65	1,537.00 − 1563.10	1,597.20 ± 8.16	1,581.20 − 1,613.20
Exponential growth rate (K)	0.34 ± 0.01	0.33 − 0.35	0.32 ± 0.01	0.04 − 0.33
Age of maximum growth (ti)	8.13 ± 0.05	8.03 − 8.23	8.46 ± 0.06	8.34 − 8.59

[1]Derived parameters.

Figure 1. A) Growth curves of pearl gray guinea fowl as predicted by Richards model. B) Growth curves of pearl gray guinea fowl as predicted by Gompertz model. C) Growth curves of pearl gray guinea fowl as predicted by logistic model.

phism. Unlike chicken (Aggrey, 2002; Mignon-Grasteau et al., 1999) and geese (Kniẑetová et al., 1994), in which the males have higher asymptotic BW compared with the females, the pearl gray guinea fowl females have a high asymptotic BW compared with the males. A similar pattern has been observed in quail (Aggrey and Cheng, 1994; Du Preez and Sales, 1997; Aggrey et al., 2003). The growth pattern for both sexes as predicted by the Richards, Gompertz, and the logistic models are presented in Figure 1. However, our results confirmed an inverse relationship between the asymptotic weight and both relative growth and age at maximum growth. The higher the asymptotic BW, the lower the relative growth rate and age at maximum growth. A similar observation was reported for geese, chickens, and quail (Knížetová et al., 1991; Mignon-Grasteau et al., 1999; Aggrey, 2002; Aggrey et al., 2003).

Growth curves of animals have undoubtedly displayed significant evolutionary and fitness implications in contemporary breeding programs (Famula et al., 1988). Therefore, success in studying the growth characteristics of guinea fowl will contribute to the efforts of genetically improving this little-studied avian species.

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average asymptotic BW of about 1.58 kg for both sexes predicted by the logistic model was below the average predicted BW (1.66 kg) from both the Richards and Gompertz models at 22 wk of age. This augments the fact that the logistic model least fit the data on pearl gray guinea fowl compared with the Gompertz and Richards models. The average ages at maximum growth were 6.7, 6.5, and 8.2 wk for the Richards, Gompertz, and logistic models, respectively. Unlike the Richards model that has a flexible age at maximum growth, the Gompertz and logistic models have fixed inflection points at 37 and 50% of the asymptote. The pearl gray guinea fowl exhibit sexual dimor-

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