Mexican Creole chickens: effect of data collection periods on goodness-of-fit and parameter precision of growth models

Diego Zárate-Contreras,* Fernando González-Cerón,† Juan M. Cuca-García,* Arturo Pro-Martínez,*,[1] Gustavo Ramírez-Valverde,* Samuel E. Aggrey,‡ Omar Hernández-Mendo,* Jaime Gallegos-Sánchez,* and Eliseo Sosa-Montes†

*College of Postgraduates Campus Montecillo, Texcoco, State of Mexico CP 56230, Mexico; †Department of Animal Science, Chapingo Autonomous University, Texcoco, State of Mexico CP 56230, Mexico; and ‡Poultry Genetics and Biotechnology Laboratory, Department of Poultry Science and Institute of Bioinformatics, University of Georgia, Athens, GA 30602, USA

ABSTRACT The objective of this study was to estimate the good-of-fitness and precision of parameters of the Gompertz-Laird, Logistic, Richards, and Von Bertalanffy growth models, using different data collection periods (**DCP**). Two hundred and sixty-two Mexican Creole chicks (116 females and 146 males), were individually weighed to form the following sets of data for each sex: DCP_1 (weights recorded weekly from hatching to 63 d, and every 2 wk, from 63 to 133 d of age), DCP_2 (weights recorded weekly from hatching to 133 d of age), DCP_3 (weights recorded every third day, from hatching to 63 d, and every 14 d, from 63 to 133 d of age), and DCP_4 (weights recorded every third day, from hatching to 63 d, and weekly, from 63 to 133 d of age). Data were analyzed using the NLIN procedure of SAS (Marquardt algorithm). For all growth models, the width of confidence interval (**CI**) of each parameter, was estimated ($\alpha = 0.05$). The adjusted coefficient of determination ($\boldsymbol{AR^2}$), as well as the Akaike ($\boldsymbol{AIC}$) and Bayesian information criteria ($\boldsymbol{BIC}$) were used to select the best model. The higher the AR^2, and the lower the width of CI, as well as the AIC and BIC values, the better the model. The Gompertz-Laird model, more frequently showed the highest AR^2, and the lowest AIC and BIC values compared to the other models. Moreover, for all models, both sexes and all parameters, most confidence interval widths (all with the Gompertz-Laird model) were the lowest with DCP_3 when compared to the other sets of data. In conclusion, the Gompertz-Laird model was the best provided that the chickens are weighed every third day from hatching until 63 d of age, and every 2 wk thereafter.

Key words: growth curves, Mexican Creole chickens, nonlinear models, confidence intervals, good-of-fitness

2022 Poultry Science 101:101903
https://doi.org/10.1016/j.psj.2022.101903

INTRODUCTION

In poultry farming, the BW of birds is an economically important and heritable trait (Mata-Estrada et al., 2020), and can be improved by genetic selection (Osei-Amponsah et al., 2013). Changes in BW over time can be represented by growth curves (Aggrey, 2002; Narinç et al. 2010), based on nonlinear models (Zhao et al., 2015; Adenaike et al., 2017; Mata-Estrada et al., 2020). According to Narinç et al. (2017) the nonlinear model most used for growth curves of zootechnical interest are: Gompertz, Logistic, Richards, and Von Bertalanffy. Some parameters estimated therein are initial or hatching BW ($\boldsymbol{W_0}$), specific initial rate ($\boldsymbol{L}$), specific maturation rate ($\boldsymbol{K}$), age of maximum growth ($\boldsymbol{t_i}$), and asymptotic weight ($\boldsymbol{W_A}$). For the estimation of parameters, BW of animals is recorded at different data collection periods (**DCP**), that is, at different frequencies and durations (Aggrey, 2002; Manjula et al., 2018; Faraji-Arough et al., 2019). Aggrey (2008) demonstrated with the Gompertz model, that the precision of initial growth rate, age of maximum growth, and asymptotic weight, is affected by the DCP. Aggrey (2002) and Mata-Estrada et al. (2020) used a DCP, in which the BW of chickens was obtained every third day from hatching to 54 d of age and subsequently, every 14 d until the age of 170 d. In contrast, Faraji-Arough et al. (2019), reported in native chickens evaluated up to 203 d of age, a DCP of 7 d, from hatching to 147 d of age; subsequently, data collection was carried out every 14 d. Other researchers used longer DCP, Manjula et al. (2018), established a DCP of 14 d from hatching to 140 d of age, while Osei-Amponsah et al. (2011, 2013, 2014) reported a similar DCP from hatching to 84 d of age, followed by every 28 d until 280 d of age. Although there is already data about growth modeling of Mexican Creole chickens (Mata-Estrada et al., 2020), data on the effect of DCP on the model goodness-of-fit and the precision of the estimated parameters remains scant. Confidence intervals (**CI**) provide the precision with which a parameter is estimated, the narrower the interval, the greater the precision is (Dagnino, 2014). Additionally, the adjusted coefficient of determination ($\boldsymbol{AR^2}$), as well as the Akaike ($\boldsymbol{AIC}$) and Bayesian information criteria ($\boldsymbol{BIC}$) are goodness-of-fit criteria used to select the best model. In this case, the higher the AR^2, and the lower the AIC and BIC values, the better the fit of the model (Leeb and Pötscher, 2009). It is likely that the length and frequency of data collection period affects the precision of parameters and the fit of growth models. Therefore, in this study, the goodness-of-fit of the following nonlinear models, Gompertz-Laird, Logistic, Richards, and Von Bertalanffy and their respective parameter precision, were estimated. To achieve this objective, different data collection periods were used along the growth curve of Mexican Creole chickens.

MATERIALS AND METHODS

All animal experiments were performed in accordance with the guide for care and use of experimental animals approved by the General Academic Council of the Colegio de Postgraduados (COLPOS, 2016). This study was conducted at the experimental chicken house of the Colegio de Postgraduados, Campus Montecillo, located in Texcoco, State of Mexico, at 19° 27′ 47″ north latitude, 98° 54′ 27″ west longitude and 2,247 m altitude. A total of 30 hens and 30 roosters, Mexican Creole breeders, from an experimental population with pedigree, were used under random mating to produce 286 chicks (Mata-Estrada et al., 2020). The breeding was carried out by artificial insemination with 1:1 sex ratio. The chicks obtained were fed a corn-soybean non pelleted diet containing 21.5% CP and 2,900 kcal ME/kg, during the entire experimental period. Feed and water were offered ad libitum. From hatching to 42 d of age, the birds were housed in electric brooders with 5 levels; each level with 2 spaces of 0.4 m × 1.2 m (0.48 m^2), and 10 birds per space for each sex (0.048 m^2 per bird). Thereafter, birds were housed in pens of 1 m × 1.5 m (1.5 m^2), and 10 birds per pen per sex (0.15 m^2 per bird). Wood shavings of about 20 mm size, were used as bedding material. Birds were kept under natural light program. At hatching, chicks were kept at a temperature of 32°C, which decreased by 1°C per week until reaching 26°C. The temperature control in electric brooders was implemented with a thermostat that controlled the operation of electrical resistances. The temperature in the poultry house was regulated by adjusting side curtains. The experimental chicks were identified by sex and weighed individually. From hatching to 63 d of age, the birds were weighed individually every third day and seventh day. Subsequently, the individual weight records were obtained weekly until 133 d of age (Table 1). Hereafter, four sets with different DCP were formed: DCP_1 (weights recorded weekly from hatching to 63 d, and every 2 wk, from 63 to 133 d of age), DCP_2 (weights recorded weekly from hatching to 133 d of age), DCP_3 (weights recorded every third day, from hatching to 63 d, and every 14 d, from 63 to 133 d of age), and DCP_4 (weights recorded every third day, from hatching to 63 d, and weekly, from 63 to 133 d of age).

Growth Models

From each set of data, the parameters of the following nonlinear growth models were estimated: Gompertz-Laird, Logistic, Richards, and Von Bertalanffy. The following goodness-of-fit criteria were also estimated for the models: AR^2), AIC, and BIC.

Gompertz-Laird Model

The following model describes the Gompertz-Laird growth curve:

$$W_t = W_0 \, exp\left[(L/K)(1 - exp(-Kt))\right]$$

where W_t is the BW of the chickens at time t; W_0 is the initial BW (hatching weight, g), exp is the exponential function ($exp(1) = e^1 = 2.71828183$), L is the specific initial growth rate [(g d^{-1}) $g^{-1} = d^{-1}$], K is the specific maturation growth rate [(g d^{-1}) $g^{-1} = d^{-1}$] (Laird et al., 1965; Aggrey, 2002). Age at maximum growth or at the inflexion point (t_i, d) and asymptotic weight (W_A, g) were estimated as follows:

$$t_i = \left(\frac{1}{K}\right) ln\left(\frac{L}{K}\right) \text{ and } W_A = W_0 \, exp\left(\frac{L}{K}\right)$$

Logistic Model

The following equation describes the logistic growth model:

$$W_t = W_A / \lfloor 1 + \ exp(-K(t - t_i)) \rfloor$$

where W_t is the BW at time t, W_A is the asymptotic weight or weight at maturity, K is the specific maximum growth rate [(g d^{-1}) $g^{-1} = d^{-1}$], t_i is the age at the inflection point (Robertson, 1923; Aggrey, 2002).

Richards Model

The following equation describes the Richards growth model:

$$W_t = W_A \left\lfloor 1 - (1 - m) \, exp\left[-K(t - t_i)/m^{m/(1-m)}\right] \right\rfloor^{1/(1-m)}$$

where W_t is the BW of the chickens at time t, W_A is the asymptotic weight or mature weight, K is the specific growth rate at t_i, with respect W_A [(g d^{-1}) $g^{-1} = d^{-1}$], t_i is the age at the maximum growth rate or at the inflexion point (d), and m is a parameter of shape, with the property that $m^{1/(1-m)}$ is the ratio of weight at t_i to W_A (Richards, 1959; Aggrey, 2002).

Von Bertalanffy Model

The following equation describes the Von Bertalanffy growth model:

$$W_t = W_A\left(1 - B * exp^{(-K*t)}\right)^3$$

where W_t is the BW of the chickens at time t, W_A is the asymptotic weight or mature weight, K is the specific maximum growth rate [(g d^{-1}) g^{-1} = d^{-1}] and B is an integration constant. Age at maximum growth rate or age at the inflexion point (t_i) and BW at the inflection point age (W_I), are estimated as follows: $t_i = ln\ (3B)/K$ and $W_I = W_A$*8/27 (Bertalanffy, 1957; Goshu and Koya, 2013).

Statistical Analysis

Data were analyzed using the PROC NLIN procedure (Marquardt algorithm) version 9.3 (SAS Institute Inc., 2011). Three goodness-of-fit criteria were used to select the best model: 1) Adjusted coefficient of determination, AR^2 = 1-{[(n-1)(1-R^2)]/(1-q)}; 2) Akaike information criterion, $AIC = n^*ln(SSE/n) + 2q$; and 3) Bayesian information criterion, $BIC = n^*ln(SSE/n) + q^*ln(n)$. Where, R^2 is the determination coefficient of each data set, q is the number of model parameters, n is the number of observations, SSE is the square sum of the error, and ln is the natural logarithm function. Likewise, for some parameters of each growth model, their confidence intervals (**CI**) with $\alpha = 0.05$ were obtained using the profile-likelihood program (Royston, 2007).

RESULTS

Body Weights of Male and Female Mexican Creole Chickens

The observed initial weights of males and females were very similar (37.23 ± 3.95 and 36.19 ± 3.52 g, respectively), the corresponding estimated hatching weights were (W_0) 33.42 and 33.14 g. Either according to standard deviation or width of CI, the group of females showed more precision than that of males. Only the Gompertz-Laird model use W_0 as a parameter. The observed BW of Creole chickens was higher in males than in females, a trend that was observed from hatching to 133 d of age. At the end of the observation period (Table 1), the weight of females represented 69% (1,571.06 ± 242.16) of the weight of males (2,276.34 ± 364.55). The asymptotic weights (W_A) of females ranged from 63 to 64% (Tables 2 and 3) with respect those of males and showed more precision, either according to the CI or the standard deviation. These values were lower than those observed at the end of the experimental period (69%, Table 1) and differed little between them (1%).

Goodness-of-Fit Criteria and Parameters of the Growth Models

The Gompertz-Laird model showed more frequently, a better goodness-of-fit than the others. In 10 of 12 (3 criteria × 4 models) values of females, this model showed the highest AR^2 and the lowest values of AIC and BIC (Table 3). Also, in the group of males, all 12 values of AR^2, AIC, and BIC were the best using the Gompertz-Laird model (Table 2).

Values of the Gompertz-Laird Model Parameters

The DCP$_3$ set of males had the lowest specific initial growth rate (L, 0.098200 d^{-1}), however, the specific growth rate at maturation was also low (K, 0.021971 d^{-1}). The DCP$_3$ set of females also showed low values of L and K: 0.095772 and 0.023833 d^{-1}, respectively.

The age at maximum growth for the sexes were similar among the four sets of DCP (t_i, 68.03 to 68.24 d, males, t_i, 58.03 to 58.59 d, females, Tables 2 and 3). Also, the asymptotic weight of males ranged from 2,910.29 to 2,923.83 g and that of females ranged from 1,832.13 to 1,848.56 g (Tables 2 and 3). That is, the age at maximum growth as well as the asymptotic weight had low variation among the DCP sets of the Gompertz model.

Precision of the Gompertz-Laird Model Parameters

The precision of parameters is considered higher, as long as the confidence interval is small. With males and females, all Gompertz-Laird model parameters (W_0, L, and K) obtained with DCP$_3$ showed smaller CI, than the other DCP sets (Tables 2 and 3). The W_0 of females, were more precise than that of males, however L and K showed a lesser precision (Tables 2 and 3).

DISCUSSION

Modeling growth characteristics of poultry is important for both management and genetic improvement. The precision of the prediction equation is essential in choosing the appropriate model for the data collected. It is common practice to collect growth data on the Mexican Creole chickens at different time periods. Thus, the effect of DCP on the precision of models predicting their growth becomes important and worth investigating.

Goodness-of-Fit Criteria and Parameters of the Growth Models

In general, the Gompertz-Laird model showed the best goodness-of-fit as judged by the AR^2, AIC, and BIC. These values were also better in males than in females. Selvaggi et al. (2015) indicated that the goodness-of-fit of a specific model depends, among other factors, on sampling methods, genotype, and sex of the birds. Likewise, based on 622 reports carried out from 1970 to 2016 (Narinç, 2017) reported that the nonlinear models more frequently used to obtain chickens' growth curves were: Gompertz-Laird: (38.26%), Logistic: (29.75%), Richards: (17.52%), and Von Bertalanffy: (14.47%). The results were however different from that reported by Mata-Estrada et al. (2020), who found that the Von Bertalanffy model followed by that of Gompertz-Laird, best described the growth curve of Mexican Creole chickens. Other reports on indigenous chickens (Norris et al., 2007; Zhao et al., 2015; Adenaike et al., 2017), broilers (Topal and Bolukbasi, 2008; Koushandeh et al., 2019), guinea fowl (Nahashon et al., 2006), and quail (Rossi et al., 2017) reported that the Gompertz-Laird function, better fit the growth curves compared to the other models.

Values of the Gompertz-Laird Model Parameters

The high value of L (initial specific growth rate) and low of K (specific maturation growth rate), shown by the male data (0.098200 and 0.021971 d^{-1}, respectively) compared to the corresponding values of females (0.095772 and 0.023833 d^{-1}, respectively), indicate that males grew faster than females (higher value of L) and decrease slower than females (lower value of K). The initial specific growth rate (L, d^{-1}) is affected by sex (Jaap, 1970), with males recording higher values (Mignon-Grasteau, 1999). Mata-Estrada et al. (2020) found the same trend but with lower values: males (0.0765 d^{-1}) and females (0.0751 d^{-1}). Similarly, Mignon-Grasteau (1999) reported a similar pattern with very close values for males (0.1001 d^{-1}) and females (0.0979 d^{-1}) while Aggrey (2002) reported lower data (0.0908 d^{-1}; 0.0804 d^{-1}, respectively).

The same trend for K using Mexican Creole chickens was reported by Mata-Estrada et al. (2020), the values of males (0.0195 d^{-1}) were higher than those of females (0.0210 d^{-1}). On the contrary, using Athens-Canadian chickens, Aggrey (2002) showed an opposite trend of K: males 0.0224 d^{-1}, females 0.0216 d^{-1}. Therefore, the data presented by Mata-Estrada et al. (2020) is in concordance with data from the current study with Mexican Creole chickens.

The initial weight (W_0) estimated by the Gompertz model for males and females (33.42 and 33.14 g, respectively) was 3.81 and 3.05 g lower than the observed values with the chickens of the current study (37.23 and 36.19 g, respectively); however, Mata-Estrada et al. (2020) obtained higher values (53.5 and 51.1 g, respectively). In another study with random mating unimproved chicken population, Aggrey (2002) also estimated higher values of hatching weights for males and females (44.6 and 47.5 g, respectively).

Mignon-Grasteau (1999) and Aggrey (2002) showed that asymptotic weight (W_A, g) was higher in males compared to females. The values of t_i and W_A in this study were: 68.15 d and 2917.79 g (males) and 58.36 d and 1843.23 g (females); Mata-Estrada et al. (2020), reported that for males and females, t_i was higher (69.80 and 60.80 d) and W_A lower (2683.1 and 1839.1 g) than the values obtained in the present study. The data of males showed greater values of t_i and W_A than those of females. This indicates that the growth rate of females begins to decrease faster than that of males (higher t_i), and therefore they reach a lower final weight, a lower asymptotic weight (W_A).

Precision of the Gompertz-Laird Model Parameters

For all the models evaluated, those with smaller CI also had the highest precision. In the current study, there were 13 parameter estimates per sex, out of which 8 and 7 parameters for males and females (62, and 54%), respectively had small CI in the DCP_3 data set. In the DCP_4 data set, 38% of male and 46% of female parameter estimates had smaller CI. It appears that in general, DCP_3 resulted in more precision outcomes than DCP_4.

For the data to which the Gompertz-Laird model were applied, the CI for both sexes for all parameters of DCP_3 regarding W_0, L, and K were smaller than all the other DCP sets.

When the Gompertz-Laird model was applied to data from both sexes, the CI for all parameters (W_0, L, and K) for the DCP_3 set was smaller when compared with other DCP sets.

Aggrey (2008) suggested that the accuracy of data collection and the precision of the estimated parameters should be considered prior to choosing a particular growth model. Also, because the L and K parameters are related to the maximum and asymptotic weight of the Gompertz-Laird model, the precision of these estimates has to be high if they were to be used in a genetic improvement program (Grossman and Bohren, 1985; Barbato, 1991; Manjula et al., 2018; Faraji-Arough et al., 2019).

In conclusion, based on the higher adjusted R^2, Akaike and Bayesian information criteria, the Gompertz-Laird model showed the best goodness-of-fit, for growth data of the Mexican Creole chicken. Judging from the CI values, it is recommended that the chickens be weighed every third day from hatching to 63 d and subsequently every 14 d until 133 d of age.

ACKNOWLEDGMENTS

D. Z.-C. expresses his gratitude to the National Council of Science and Technology (CONACyT) for the scholarship granted to carry out his Doctorate in Science studies.

DISCLOSURES

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the study reported.

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Received December 11, 2021.

Accepted March 26, 2022.

[1]Corresponding author: aproma@colpos.mx

Table 1. Means and standard deviations of BW of Mexican Creole chickens from hatching to 133 d of age.

	BW (g)	
Age (d)	Male (n = 146)[1]	Female (n = 116)[1]
0	37.23 ± 3.95	36.19 ± 3.52
3	45.86 ± 7.01	43.13 ± 5.88
6	55.08 ± 10.56	51.66 ± 8.30
7	59.18 ± 12.20	55.15 ± 9.04
9	69.56 ± 15.11	65.43 ± 11.67
12	88.37 ± 19.11	82.11 ± 15.59
14	103.72 ± 23.02	95.56 ± 19.28
15	113.79 ± 24.96	105.18 ± 21.03
18	140.88 ± 30.44	129.50 ± 26.95
21	172.03 ± 37.52	156.06 ± 33.55
24	209.42 ± 44.11	189.82 ± 39.60
27	250.36 ± 52.73	225.11 ± 48.26
28	265.02 ± 56.36	236.61 ± 50.80
30	293.37 ± 62.07	260.92 ± 55.39
33	339.29 ± 69.78	299.98 ± 63.97
35	377.25 ± 78.60	329.70 ± 71.25
36	397.67 ± 81.93	345.47 ± 73.84
39	450.76 ± 90.13	389.62 ± 82.20
42	503.55 ± 101.37	429.09 ± 88.89
45	551.08 ± 108.13	466.91 ± 92.29
48	609.41 ± 115.05	507.14 ± 97.30
49	628.51 ± 120.92	519.90 ± 100.68
51	671.94 ± 127.91	553.42 ± 103.93
54	740.25 ± 138.56	604.97 ± 109.32
56	781.01 ± 144.29	634.10 ± 112.63
57	812.53 ± 148.12	655.53 ± 116.16
60	874.73 ± 156.82	702.84 ± 118.97
63	941.87 ± 169.53	747.63 ± 125.40
70	1,104.06 ± 196.15	865.06 ± 134.75
77	1,269.57 ± 217.27	973.09 ± 146.80
84	1,440.31 ± 242.77	1,081.42 ± 164.33
91	1,599.97 ± 267.16	1,169.98 ± 170.47
98	1,753.15 ± 292.47	1,255.14 ± 179.65
105	1,889.15 ± 302.86	1,322.52 ± 189.79
112	1,999.15 ± 314.54	1,383.25 ± 198.66
119	2,113.48 ± 333.62	1,440.18 ± 207.69
126	2,205.58 ± 346.65	1,503.31 ± 222.58
133	2,276.34 ± 364.55	1,571.06 ± 242.16

Abbreviation: n, sample size.

[1]Only 262 Creole chickens reached the end of the study. The percentage of mortality was 8.4%.

Table 2. Parameters estimated for the Gompertz-Laird, Logistic, Richards, and Von Bertalanffy model in the growth curve of Mexican Creole chickens (Males n = 146) using different data collection periods.

Model	DCP_1 (N = 2,190)	DCP_2 (N = 2,920)	DCP_3 (N = 3,942)	DCP_4 (N = 4,672)
Gompertz				
Hatching BW (W_0, g)	32.63	32.31	33.42	33.27
CI 95%	(26.99, 38.86)	(26.35, 38.97)	(29.96, 37.07)	(29.52, 37.27)
Length of the CI	11.87	12.62	7.11	7.75
Specific initial growth rate (L, d^{-1})	0.099162	0.099441	0.098200	0.098301
CI 95%	(0.091721, 0.107393)	(0.091722, 0.108010)	(0.093575, 0.103118)	(0.093383, 0.103552)
Length of the CI	0.015672	0.016288	0.009543	0.010169
Specific maturation growth rate (K, d^{-1})	0.022081	0.022086	0.021971	0.021962
CI 95%	(0.021069, 0.023118)	(0.021080, 0.023117)	(0.021311, 0.022641)	(0.021280, 0.022656)
Length of the CI	0.002049	0.002037	0.001330	0.001376
Age of maximum growth (t_i, d)	68.03	68.13	68.15	68.24
Asymptotic weight (W_A, g)	2,910.29	2,915.63	2,917.79	2,923.83
AR^2	0.94035	0.92668	0.94584	0.94105
AIC	29,192.00	39,701.19	50,843.27	61,757.94
BIC	29,214.77	39,725.10	50,868.39	61,783.73
Logistic				
Specific maturation growth rate (K, d^{-1})	0.044261	0.043505	0.045905	0.044737
CI 95%	(0.042871, 0.045691)	(0.042146, 0.044902)	(0.044943, 0.046886)	(0.043789, 0.045703)
Length of the CI	0.002820	0.002756	0.001943	0.001914
Age of maximum growth (t_i, d)	73.97	74.58	72.24	73.30
CI 95%	(72.71, 75.29)	(73.42, 75.80)	(71.37, 73.15)	(72.43, 74.20)
Length of the CI	2.58	2.38	1.78	1.77
Asymptotic weight (W_A, g)	2,404.53	2,418.89	2,357.90	2,381.50
CI 95% (g)	(2,361.96, 2,449.77)	(2,378.00, 2,462.44)	(2,327.88, 2,389.08)	(2,351.40, 2,412.90)
Length of the CI	87.81	84.44	61.20	61.50
AR^2	0.93848	0.92523	0.94309	0.93895
AIC	29,258.99	39,758.55	51,039.07	61,921.41
BIC	29,281.76	39,782.47	51,064.19	61,947.21
Richards				
Specific maturation growth rate (K, d^{-1})	0.008462	0.008509	0.008262	0.008298
CI 95%	(0.007659, 0.009222)	(0.007719, 0.009255)	(0.007691, 0.008811)	(0.007732, 0.008842)
Length of the CI	0.001563	0.001536	0.00112	0.00111
Age of maximum growth (t_i, d)	68.55	68.90	68.23	68.47
CI 95%	(66.39, 70.67)	(66.65, 71.03)	(66.91, 69.62)	(67.05, 69.89)
Length of the CI	4.28	4.38	2.71	2.84
Asymptotic weight (W_A, g)	2,827.36	2,820.54	2,872.51	2,867.76
CI 95%	(2,668.48, 3,038.09)	(2,664.73, 3,026.38)	(2,745.50, 3,027.86)	(2,741.92, 3,021.73)
Length of the CI	369.61	361.65	282.36	279.81
Shape parameter (m)	1.08337	1.10195	1.03745	1.04998
CI 95%	(0.91558, 1.26605)	(0.92327, 1.29760)	(0.93292, 1.14735)	(0.93753, 1.16892)
Length of the CI	0.35047	0.37433	0.21443	0.23139
AR^2	0.94034	0.92668	0.94584	0.94105
AIC	29,193.09	39,701.98	50,844.79	61,759.20
BIC	29,221.55	39,731.88	50,876.19	61,791.45
Von Bertalanffy				
Specific maturation growth rate (K, d^{-1})	0.014544	0.014822	0.013858	0.014189
CI 95%	(0.013612, 0.015504)	(0.013892, 0.015780)	(0.013264, 0.014463)	(0.013567, 0.014823)
Length of the CI	0.001892	0.001888	0.001199	0.001256
Age of maximum growth (t_i, d)	66.01	65.33	68.24	67.20
Asymptotic weight (W_A, g)	3,468.60	3,431.41	3,604.64	3,549.83
CI 95%	(3,300.58, 3,661.95)	(3,273.88, 3,611.87)	(3,475.09, 3747.34)	(3,423.84, 3,688.75)
Length of the CI	361.37	337.99	272.25	264.91
Integration constant (B)	0.87061	0.87788	0.85818	0.86494
CI 95%	(0.84923, 0.89477)	(0.85410, 0.90471)	(0.84662, 0.87070)	(0.85163, 0.87938)
Length of the CI	0.04554	0.05061	0.02408	0.02775
BW at the inflection point age (W_I, g)	1,027.73	1,016.71	1,068.04	1,051.80
AR^2	0.93964	0.92607	0.94510	0.94042
AIC	29,217.61	39,725.61	50,897.21	61,807.93
BIC	29,240.38	39,749.53	50,922.33	61,833.72

Abbreviations: AR^2, adjusted coefficient of determination; AIC, Akaike information criterion; BIC, Bayesian information criterion; CI, confidence intervals; DCP, data collection periods; n, sample size; N, total number of data.

DCP_1 (weights recorded weekly from hatching to 63 d, and every 2 wk, from 63 to 133 d of age), DCP_2 (weights recorded weekly from hatching to 133 d of age), DCP_3 (weights recorded every third day, from hatching to 63 d, and every 14 d, from 63 to 133 d of age) and DCP_4 (weights recorded every third day, from hatching to 63 d, and weekly, from 63 to 133 d of age).

The higher the AR^2, and the lower the width of CI, as well as the AIC and BIC values, the better the model was considered.

Table 3. Parameters estimated for the Gompertz-Laird, Logistic, Richards, and Von Bertalanffy model in the growth curve of Mexican Creole chickens (Females n = 116) using different data collection periods.

Model	DCP_1 (N = 1740)	DCP_2 (N = 2320)	DCP_3 (N = 3132)	DCP_4 (N = 3712)
Gompertz				
Hatching BW (W_0, g)	33.17	32.21	33.14	32.54
CI 95%	(27.86, 38.95)	(26.72, 38.23)	(29.87, 36.58)	(29.07, 36.20)
Length of the CI	11.09	11.51	6.71	7.13
Specific initial growth rate (L, d^{-1})	0.095481	0.097151	0.095772	0.096833
CI 95%	(0.088160, 0.103590)	(0.089539, 0.105606)	(0.091066, 0.100785)	(0.091847, 0.102165)
Length of the CI	0.015430	0.016067	0.009719	0.010318
Specific maturation growth rate (K, d^{-1})	0.023747	0.024039	0.023833	0.024023
CI 95%	(0.022648, 0.024877)	(0.022955, 0.025151)	(0.023102, 0.024575)	(0.023275, 0.024783)
Length of the CI	0.002229	0.002196	0.001473	0.001508
Age of maximum growth (t_i, d)	58.59	58.10	58.36	58.03
Asymptotic weight (W_A, g)	1,848.56	1,832.79	1,843.23	1,832.13
AR^2	0.94172	0.92966	0.94484	0.94204
AIC	21,810.60	29,615.12	38,126.30	46,161.31
BIC	21,832.45	29,638.12	38,150.50	46,186.19
Logistic				
Specific maturation growth rate (K, d^{-1})	0.044991	0.044373	0.047026	0.045947
CI 95%	(0.043426, 0.046606)	(0.042881, 0.045909)	(0.045923, 0.048151)	(0.044874, 0.047043)
Length of the CI	0.003180	0.003028	0.002228	0.002169
Age of maximum growth (t_i, d)	66.49	66.78	64.69	65.38
CI 95%	(65.25, 67.80)	(65.66, 67.95)	(63.85, 65.57)	(64.55, 66.24)
Length of the CI	2.55	2.3	1.72	1.69
Asymptotic weight (W_A, g)	1,594.87	1,595.84	1,564.38	1,570.85
CI 95% (g)	(1567.69, 1623.67)	(1570.92, 1622.26)	(1544.81, 1584.64)	(1552.23, 1590.22)
Length of the CI	55.98	51.34	39.83	37.99
AR^2	0.93866	0.92724	0.94095	0.93905
AIC	21,899.71	29,693.77	38,339.66	46,348.03
BIC	21,921.55	29,716.77	38,363.86	46,372.90
Richards				
Specific maturation growth rate (K, d^{-1})	0.008498	0.008738	0.008407	0.008649
CI 95%	(0.007712, 0.009242)	(0.008008, 0.009430)	(0.007829, 0.008964)	(0.008103, 0.009174)
Length of the CI	0.001530	0.001422	0.001135	0.001071
Age of maximum growth (t_i, d)	57.88	57.69	57.67	57.54
CI 95%	(55.25, 60.36)	(54.90, 60.28)	(56.12, 59.18)	(55.87, 59.14)
Length of the CI	5.12	5.38	3.06	3.27
Asymptotic weight (W_A, g)	1,884.17	1,848.38	1,896.56	1,859.71
CI 95%	(1,783.44, 2,017.10)	(1758.97, 1,964.11)	(1,816.37, 1,994.52)	(1,787.94, 1,946.43)
Length of the CI	233.66	205.14	178.15	158.49
Shape parameter (m)	0.93469	0.96712	0.91620	0.95055
CI 95%	(0.77109, 1.11268)	(0.79606, 1.15404)	(0.80808, 1.03045)	(0.83720, 1.07071)
Length of the CI	0.34159	0.35798	0.22237	0.23351
AR^2	0.94171	0.92964	0.94486	0.94203
AIC	21,812.05	29,616.99	38,126.20	46,162.64
BIC	21,839.36	29,645.74	38,156.45	46,193.74
Von Bertalanffy				
Specific maturation growth rate (K, d^{-1})	0.016540	0.017133	0.016075	0.016581
CI 95%	(0.015544, 0.017566)	(0.016142, 0.018155)	(0.015427, 0.016735)	(0.015909, 0.017266)
Length of the CI	0.002022	0.002013	0.001308	0.001357
Age of maximum growth (t_i, d)	54.43	53.23	55.40	54.27
Asymptotic weight (W_A, g)	2,097.08	2,049.99	2,136.54	2,093.24
CI 95%	(2,014.91, 2,190.08)	(1,976.78, 2,132.26)	(2,074.49, 2,204.02)	(2,035.41, 2,156.15)
Length of the CI	175.17	155.48	129.53	120.74
Integration constant (B)	0.82015	0.82981	0.81214	0.81974
CI 95%	(0.79897, 0.84389)	(0.80601, 0.85645)	(0.80006, 0.82514)	(0.80595, 0.83459)
Length of the CI	0.04492	0.05044	0.02508	0.02864
BW at the inflection point age (W_I, g)	621.36	607.40	633.05	620.22
AR^2	0.94137	0.92929	0.94449	0.94164
AIC	21,820.90	2,9627.60	38,146.14	46,186.87
BIC	21,842.75	2,9650.60	38,170.34	46,211.74

Abbreviations: n, sample size; N, total number of data; DCP, data collection periods; CI, confidence intervals; AR^2, adjusted coefficient of determination; AIC, Akaike information criterion; BIC, Bayesian information criterion.

DCP_1 (weights recorded weekly from hatching to 63 d, and every 2 wk, from 63 to 133 d of age), DCP_2 (weights recorded weekly from hatching to 133 d of age), DCP_3 (weights recorded every third day, from hatching to 63 d, and every 14 d, from 63 to 133 d of age) and DCP_4 (weights recorded every third day, from hatching to 63 d, and weekly, from 63 to 133 d of age).

The higher the AR^2, and the lower the width of CI, as well as the AIC and BIC values, the better the model was considered.