Comparison of nine growth curve models to describe growth of partridges (Alectoris chukar)

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ABSTRACT

In this study, nine non-linear growth curve models were used to determine the goodness of fit by the body weight measurements of the total number of 178 partridges (Alectoris chukar), 93 females, and 85 males, respectively. The $R^2$ (coefficient of determination) values for the total partridges, females and males in Brody, Gompertz, Logistic, von Bertalanffy, asymptote regression, exponential, Monomolecular, Richards and Weibull-type were 0.985, 0.980 and 0.984, 0.997 and 0.998, 0.996 and 0.999, 0.995 and 0.996, 0.985 and 0.980 and 0.984, 0.891 and 0.892, 0.985 and 0.980 and 0.984, 0.997, 0.999 and 0.997, 0.999 and 0.999, respectively. The $R^2$ values for Gompertz, Logistic, von Bertalanffy, Richards and Weibull-type were $>0.99$, while the exponential ($<0.90$) had the lowest. What’s more, the Gompertz, Logistic, Richards and Weibull-type models best described the data because of lower MSE (mean square error), AIC (Akaike’s information criteria) and BIC (Schwarz Bayesian information criterion), higher adj. $R^2$ (Adjusted coefficient of determination) and (the correlation coefficient between measured body weight and estimated body weight) and there was not an autocorrelation between the residual values. As a result, based on goodness of fit criteria; $R^2$, adj.$R^2$, MSE, r, AIC, BIC values, the Weibull-type model best described live weight data of the Partridges (Alectoris chukar).

Implications

In livestock and poultry, the fitting and analysis of growth curves of parameters is the basic work for breeding and production. In this study, we determine the best model to describe live weight data of the partridges. The growth curve parameters determination, effectively, describe issues such as growth, livestock performance, and optimum slaughter age, as well as preparing an appropriate feeding process and selection. Via fitting and analysis of growth curves of parameters, Weibull-type model was determined to be the best model to describe live weight data of the partridges. It will facilitate to judge and analyze the standards of feeding, management, and epidemic prevention in partridges, and to compare and test the genetic quality of different genders.

Introduction

Partridges (Alectoris chukar), belong to the phasianidae family and phasianidae subfamily group in taxonomy (Cetin and Kirikci 2000). The partridges include seven closely related inter-fertile species, distribute in Eurasia, China and southern Arabia (Johnsgard 1988). In China, the common partridges in the market are Alectoris chukar selected and bred by American scientists. Partridges are characterized with fast growth performance, high prolificacy and superior meat quality, accordingly, they are best used for commercial production. The domestication and the post-selection on growth traits provide an excellent source of protein for humans (Queiroz et al. 2004).

Growth is one of the well-known features in biological creatures. The evolution of body weight during growth is of particular importance in both breeding and management. In livestock and poultry, the fitting and analysis of growth curves of parameters is the basic work for breeding and production, and is also one of the main methods for studying the growth and development. The growth curve parameters determination, effectively, describe issues such as growth, livestock performance, and optimum slaughter age, as well as preparing an appropriate feeding process and selection (Sariyel et al. 2017). There are many mathematical models that describe the growth curve of livestock and poultry, and quite a few different models applied to fit the growth curve in other poultry including duck and Japanese quail and forth on (Maruyama et al. 1999; Raji et al. 2014). Growth curves illustrating these changes allow the data to be summarized by a few number of parameters known as growth curve parameters (Firat et al. 2016). It could also be expected that the conversion of the collected data into actual breeding practices increase the productivity of partridges breeding (Sariyel et al. 2017). Although there are a number of reports on the growth curve model of partridge, there is conflicting reports on the appropriate model for describing growth in the partridge. Therefore, sound and comprehensive models were used in this study to fit the growth curve of partridge on the basis of previous studies.

Material and methods

The study was carried out at Wenzhou Yongzheng Agricultural cooperation company (Wenzhou,). A total of 93 female and 85
Table 1. Growth curve models and the age at point of inflection and weight at point of inflection in partridge (Alectoris chukar).

| Model         | Function                                         | Ti  | Yi    |
|---------------|--------------------------------------------------|-----|-------|
| Brody         | \( Y_t = A(1 - Be^{-Kt}) \)                      | –   | –     |
| Gompertz      | \( Y_t = Ae^{-(R_t - A/K)} \)                     | Ln(B)/K | A/e |
| Logistic      | \( Y_t = A(1 + Be^{-Kt}) \) – Ln(1/B)/K          | A(0.5) | –   |
| von Bertalanffy| \( Y_t = A(1 - Be^{-Kt})^3 \)                    | Ln(B)/K | 8A/27|
| Asymptotic regression | \( Y_t = A - BK \)                             | –   | –     |
| Exponential   | \( Y_t = Ae^{Kt} \)                              | –   | –     |
| Monomolecular | \( Y_t = A(1 - e^{-(B - Kt)}) \)                  | –   | –     |
| Richards      | \( Y_t = A + e^{[B-(Kt)](1/n)} (-1/K Ln(B/Bi) \) | A/√n + 1| –   |

\( A = \) the asymptotic weight or maximum growth response (g); \( B = \) the biological constant; \( K = \) the growth rate; \( n = \) the shape parameter; \( t = \) the age in days; \( Ti = \) the age at point of inflection; \( Yi = \) the body weight (g) at age (t); \( Yi = \) weight at point of inflection.

Table 2. Growth curve parameters in different models for partridges.

| Model          | Group    | Growth curve parameters |
|----------------|----------|-------------------------|
|                | A        | B           | K         | N       | Ti     | Yi     |
| Brody          | Total    | 1459.482   | 1.004     | 0.020   | –      | –      |
|                | Female   | 1014.711   | 1.009     | 0.030   | –      | –      |
|                | Male     | 1997.984   | 1.005     | 0.015   | –      | –      |
| Gompertz       | Total    | 469.991    | 3.670     | 0.189   | 6.9    | 172.9  |
|                | Female   | 440.566    | 3.835     | 0.207   | 6.5    | 162.1  |
|                | Male     | 512.641    | 3.851     | 0.189   | 7.1    | 188.6  |
| Logistic       | Total    | 420.619    | 16.012    | 0.338   | 8.2    | 210.3  |
|                | Female   | 402.653    | 17.101    | 0.361   | 7.9    | 201.3  |
|                | Male     | 457.393    | 17.732    | 0.341   | 8.4    | 228.7  |
| von Bertalanffy| Total    | 513.057    | 0.777     | 0.138   | 6.1    | 152.0  |
|                | Female   | 471.510    | 0.809     | 0.156   | 5.7    | 139.7  |
|                | Male     | 561.250    | 0.803     | 0.137   | 6.4    | 166.3  |
| Asymptote regression | Total    | 1459.475   | 1465.852  | 0.980   | –      | –      |
|                | Female   | 1014.730   | 1023.398  | 0.970   | –      | –      |
|                | Male     | 1997.994   | 2007.255  | 0.985   | –      | –      |
| Exponential    | Total    | 83.593     | –         | 0.096   | –      | –      |
|                | Female   | 85.815     | –         | 0.093   | –      | –      |
|                | Male     | 87.060     | –         | 0.098   | –      | –      |
| Monomolecular  | Total    | 1459.483   | 0.020     | 0.220   | –      | –      |
|                | Female   | 1014.697   | 0.030     | 0.282   | –      | –      |
|                | Male     | 1998.078   | 0.015     | 0.305   | –      | –      |
| Richards       | Total    | 448.222    | 0.487     | 0.233   | 0.295  | 2.2    | 415.7  |
|                | Female   | 409.048    | 2.087     | 0.318   | 0.723  | 3.3    | 276.0  |
|                | Male     | 475.203    | 1.469     | 0.268   | 0.520  | 3.9    | 382.2  |
| Weibull-type   | Total    | 441.273    | 422.122   | 0.012   | 1.873  | –      | –      |
|                | Female   | 406.002    | 383.682   | 0.009   | 2.076  | –      | –      |
|                | Male     | 469.733    | 447.745   | 0.009   | 2.016  | –      | –      |

A, B, K: model parameters (A = Asymptotic weight; B = The biological constant; K = The growth rate; n = Shape parameter; Yi = Weight at inflection point; Ti = Age at inflection point.)
terms and if the calculated DW is between dL and dU, the test is inconclusive (Cetin et al. 2007).

Results and discussion

The growth curves of both sexes of chukar partridges appeared very similar to general sigmoid shape of typical growth curve. The growth patterns of male and female were different (Soner Balcioglu et al. 2009), therefore, data set was analyzed for each gender and population. Estimated growth curve parameters of total partridges, females and males for the nine growth models utilized were presented in Table 2. Asymptotic weight is directly related with genotypic and environmental effects (Sariyel et al. 2017). The asymptotic weight parameter represents the maximum growth response for animals (Narinc, Karaman et al. 2010). Different growth models used in this study had different estimated asymptotic weight parameters. As shown in Table 2, the parameter A, which is represented the asymptotic weight or maximum growth response in total partridges, females and males, had higher value among the three models of Brody (1459.482, 1014.711 and 1997.984), Asymptote regression (1459.475, 1014.730 and 1997.994) and Monomolecular (1459.483, 1023.398 and 1997.994) followed by von Bertalanffy (513.057, 471.510 and 561.250), Gompertz (469.991, 440.566 and 512.641), Richards (441.273, 406.002 and 469.733), Weibull-type (441.273, 406.002 and 469.733), Logistic (420.619, 402.653 and 457.393). while the least values were recorded by the Exponential (83.593, 85.815 and 87.060). In the current study, the estimated value of parameter A determined for female and male partridges in the von Bertalanffy model is consistent with the value reported by Soner Balcioglu et al. (2009) and is slightly smaller than the value reported by Sariyel et al. (2017). In the Brody model, the value obtained for female and male partridges is significantly larger than that reported by Sariyel et al. (2017). While the value belonging to the parameter A determined for female and male partridges in the Gompertz, Logistic and Richards model are lower than the values reported by Cetin et al. (2007), Soner Balcioglu et al. (2009), and Sariyel et al. (2017).

The parameter B is the biological constant, indicating the ratio of live weight. The highest value for B was recorded by Asymptote regression model (1465.852, 1023.398 and 2007.255) followed by Weibull-type (422.122, 383.682 and 447.745), Logistic (16.012, 17.101 and 17.7320), Gompertz (3.670, 3.385 and 3.851), Brody (1.004, 1.009 and 1.005), Richards (0.487, 2.087 and 1.469), von Bertalanffy (0.777, 0.809 and 0.803) while the Monomolecular (0.020, 0.030 and 0.015) shown the least (Table 2). In this study, the parameter value B is larger than the values of both female and male reported by Cetin et al. (2007) in Gompertz, Logistic and Richards. Compared with the values of both female and male reported by Soner Balcioglu et al. (2009), the parameter value B is lower in Gompertz, von Bertalanffy and similar to the Logistic. The estimated value of parameter B determined for female and male partridges in the Brody, Gompertz and von Bertalanffy model is consistent with the values reported by Cetin et al. (2007). This could be due to the fact that asymptote weight parameters is directly related to genotype and environmental effects, hence different partridges genotypes fed in different environment would have different asymptote weight (Raji et al. 2014).

The parameter K is a maturing index and indicates the rate of maturity, which had the highest value in the Asymptote regression (0.980, 0.970 and 0.985) and the lowest value in
The Weibull-type (0.012, 0.009 and 0.009) (Table 2). The values of both female and male in Gompertz and Logistic model of this study are consistent with those reported by previous researches (Cetin et al. 2007; Soner Balcioglu et al. 2009; Sariyel et al. 2017). The parameter \( n \) is the shape parameter determining the position of the inflection point of the curve. In this research, only Richards (0.293, 0.723 and 0.520) and Weibull-type (1.873, 2.076 and 2.016) have the parameter \( n \).
The estimated growth curves for total partridges, females and males determined by nine different growth curve models are shown in Figures 1–3. It can be seen that four models including Gompertz, Logistic, Richards and Weibull-type present a better fit in this study. Used goodness of fit criteria; coefficients of determination ($R^2$), Adjusted coefficient of determination (adj. $R^2$), mean square error (MSE), the correlation coefficient between measured body weight and estimated body weight($r$), Akaike’s information criteria (AIC), Schwarz Bayesian information criterion (BIC) and DW to evaluate the goodness of fitting. It is known that the model with the highest $R^2$ value and the lowest MSE value explains the change in live weight depending on age in studies in which $R^2$ and MSE values are evaluated together (Keskin and Dag 2006; Sahin et al. 2014). Some researchers used the Durbin-Watson (DW) statistic, along with $R^2$ and MPE (Norris et al. 2007; Keskin et al. 2009) to evaluate whether growth curve models accord with actual values, As it can be seen in Table 3, for the model selection criteria, the $R^2$ values for the total partridges, females and males in Brody, Gompertz, Logistic, von Bertalanfny, asymptote regression, exponential, Monomolecular, Richards and Weibull-type were 0.891, 0.980 and 0.984, 0.997, 0.998 and 0.998, 0.996, 0.999 and 0.999, 0.995 and 0.996, 0.985, 0.980 and 0.984, 0.891, 0.871 and 0.892, 0.985, 0.980 and 0.984, 0.997, 0.999 and 0.999, 0.997, 0.999 and 0.999, respectively. The $R^2$ values for Gompertz, Logistic, von Bertalanfny, Richards and Weibull-type were >0.90, while the exponential (<0.90) had the lowest. The $R^2$ values obtained in this study are higher than those values reported by Keskin et al. (2007) for the Gompertz, Logistic, and Richards models, those values reported by Cetin et al. (2007) for the Gompertz, Logistic and von Bertalanfny models, those values reported by Soner Balci et al. (2009) for the Gompertz, Logistic and von Bertalanfny models. The values that Tholon et al. (2006) found for partridges (Rhynchotus rufescens) in the Gompertz model, Tholon and Queiroz (2007) obtained for tinamous (R. rufescens) in the Brody, Gompertz, Logistic, and von Bertalanfny models, and Raji et al. (2014) gained for Japanese quail (Coturnix japonica) in the asymptote regression, Gompertz, Logistic, Monomolecular, Richards and Weibull-type models are lower than the coefficient of determination obtained in this study. The Weibull-type function shows the minimum MSE(54.98 for total partridges, 12.76 for females and 21.68 for males), AIC and BIC values (209 and 221 for total partridges, 37 and 48 for females, 88 and 97 for males, respectively).

Table 3. Goodness-of-fit statistics ($R^2$, Adj. $R^2$, MSE, $r$, AIC, BIC and DW) in different models for partridges.

| Model                  | Group  | $R^2$ | Adj.$R^2$ | MSE   | $r$   | AIC | BIC | DW |
|------------------------|--------|-------|-----------|-------|------|-----|-----|----|
| Brody                  | Total  | 0.985 | 0.985     | 307.26| 0.9932| 513 | 523 | 0.425|
|                        | Female | 0.980 | 0.980     | 382.67| 0.9922| 352 | 359 | 0.423|
|                        | Male   | 0.984 | 0.984     | 386.29| 0.9937| 330 | 338 | 0.426|
| Gompertz               | Total  | 0.997 | 0.997     | 61.66 | 0.9988| 227 | 237 | 0.640|
|                        | Female | 0.998 | 0.998     | 45.80 | 0.9988| 154 | 162 | 0.581|
|                        | Male   | 0.997 | 0.998     | 43.59 | 0.9990| 145 | 152 | 0.690|
| Logistic               | Total  | 0.996 | 0.996     | 79.98 | 0.9992| 273 | 283 | 0.741|
|                        | Female | 0.999 | 0.999     | 15.82 | 0.9992| 55  | 63  | 0.680|
|                        | Male   | 0.999 | 0.999     | 33.67 | 0.9989| 123 | 130 | 0.779|
| von Bertalanfny        | Total  | 0.995 | 0.995     | 90.88 | 0.9979| 296 | 306 | 0.576|
|                        | Female | 0.995 | 0.995     | 95.60 | 0.9979| 223 | 230 | 0.523|
|                        | Male   | 0.996 | 0.996     | 90.82 | 0.9983| 207 | 215 | 0.626|
| Asymptote regression   | Total  | 0.985 | 0.985     | 307.26| 0.9932| 513 | 523 | 0.425|
|                        | Female | 0.980 | 0.980     | 382.67| 0.9923| 352 | 359 | 0.423|
|                        | Male   | 0.984 | 0.984     | 386.29| 0.9937| 330 | 338 | 0.426|
| Exponential            | Total  | 0.891 | 0.892     | 2189.91| 0.9441| 861 | 867 | 0.471|
|                        | Female | 0.871 | 0.872     | 2466.13| 0.9344| 523 | 528 | 0.470|
| Monomolecular          | Total  | 0.985 | 0.985     | 307.26| 0.9932| 513 | 523 | 0.425|
|                        | Female | 0.980 | 0.980     | 382.67| 0.9922| 352 | 359 | 0.423|
|                        | Male   | 0.984 | 0.984     | 386.29| 0.9937| 330 | 338 | 0.426|
| Richards               | Total  | 0.997 | 0.997     | 54.98 | 0.9992| 209 | 221 | 0.680|
|                        | Female | 0.999 | 0.999     | 12.76 | 0.9993| 37  | 48  | 0.662|
|                        | Male   | 0.999 | 0.999     | 21.68 | 0.9993| 88  | 97  | 0.751|

$R^2$ = Coefficients of determination; Adj. $R^2$ = Adjusted coefficient of determination; MSE = Mean square error; $r$ = The correlation coefficient between measured body weight and estimated body weight; AIC = Akaike’s information criteria, BIC = Schwarz Bayesian information criteria; DW = Durbin-Watson statistics.
Conculsion

In this study, nine models were used to analyze growth curve of total partridges and different sexes. Via comparing and analyzing the $R^2$, Adj.$R^2$, MSE, $r$, AIC, BIC and DW values of each model, the four models containing Gompertz, Logistic, Richards and Weibull-type were all assumed to be able to describe partridges live weight change with age. However, based on goodness of fit criteria: $R^2$, Adj.$R^2$, MSE, $r$, AIC, BIC and DW values, the Weibull-type model is in best accordance with the actual live weight data of partridges (Alectoris chukar).

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Disclosure statement

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Software and data repository resources

None of the data were deposited in an official repository. Ethics statement

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