Eurasian Journal of Veterinary Sciences

www.eurasianjvetsci.org

RESEARCH ARTICLE

Comparison of growth curves with non-linear models in Japanese quails of different plumage color

Serdar Guler[1*], Emre Arslan[1], Muhammet Mucahit Sari[2], Orhan Cetin[1]

[1]Selcuk University, Veterinary Faculty, Department of Animal Science, Konya, Turkey
[2]Afyon Kocatepe University, Veterinary Faculty, Department of Medical Biology and Genetics, Afyonkarahisar, Turkey

Received:09.02.2022, Accepted: 17.08.2022
*vethekserdar@hotmail.com

Farklı tüy renklerindeki Japon bıldırcınlarında büyüme eğrisi özelliklerinin doğrusal olmayan modeller ile karşılaştırılması

Eurasian J Vet Sci, 2022, 38, 3, 173-179
DOI: 10.15312/EurasianJVetSci.2022.380

Öz

Amaç: Bu çalışmada kahverengi ve sarı tüy renkli Japon bıldırcınlarında büyüme eğrisi parametrelerinin tahmini ve en uyumlu modelin tespit edilmesi amaçlanmıştır.

Gereç ve Yöntem: Araştırma materyali olarak 80 adet kahverengi ve 80 adet sarı tüy renkli Japon bıldırcını kullanılmıştır. Bıldırcınlar 0, 7, 14, 21, 28, 35 ve 42 günlük yaşlarda tartılmıştır. Büyüme eğrilerini belirlemek için Gompertz, Logistic, Von Bertalanffy ve Richards modelleri kullanılmıştır.

Bulgular: Uyum iyiliği açısından Gompertz modeli kahverengi ve sarı tüy renkli Japon bıldırcınları için en iyi model olarak tespit edilmiştir. Belirleme katsayısı (R^2), düzeltilmiş belirleme katsayısı (R^2_{adj}), Akaike Bilgi Kriteri (AIC), Bayesian Bilgi kriteri (BIC) ve hata kareler ortalaması (HKO) kahverengi ve sarı tüy renkli bıldırcınlarda sırasıyla 0,9968; 0,9952; 24,8801; 24,7179 ve 25,9657; 0,9975; 0,9963; 22,9149; 22,7527 ve 19,6099 olarak tespit edilmiştir. Modele ait β_0, β_1 veβ_2 parametreleri kahverengi ve sarı tüy renkli bıldırcınlar için sırasıyla 234,89; 3,630; 0,072 & 236,58; 3,516 ve 0,069 bulunmuştur. Bükülme noktası yaşı ve bükülme noktasındaki canlı ağırlık ise sırasıyla 17,91 gün ve 86,41 g; 18,15 gün ve 87,03 g olarak hesaplanmıştır.

Öneri: Sonuç olarak, bu çalışmada hem kahverengi hem de sarı tüy renkli Japon bıldırcınlarında Gompertz modeli en iyi model olarak belirlenmiştir. Farklı tüy renklerindeki Japon bıldırcınlarının büyüme eğrisi özelliklerinin belirlenmesinde sonraki araştırmalarda kullanılması önerilebilir. Öte yandan, Japon bıldırcınlarının bir alt türü olan Jumbo bıldırcın yetiştiriciliği, kahverengi tüy renkli Japon bıldırcınlarının yanı sıra yüksek erginleşme indeksi nedeniyle bıldırcın eti üretiminde dikkate alınmalıdır.

Anahtar kelimeler: Büyüme eğrisi, doğrusal olmayan regresyon, Japon bıldırcını, parametre tahmini, tüy rengi

Abstract

Aim: In this study, it was aimed to estimate growth curve parameters and to determine the best fit model in brown and yellow plumage-colored Japanese quails.

Materials and Methods: 80 brown and 80 yellow plumage-colored Japanese quails were used as research material. The quails were weighed 0th, 7th, 14th, 21st, 28th, 35th and 42nd days of age. Gompertz, Logistic, Von Bertalanffy and Richards models were used to determine growth curves.

Results: According to the goodness of fit the Gompertz model was determined the best model for both brown and yellow plumage-colored Japanese quails. Coefficient of Determination (R^2), Adjusted Coefficient of Determination (R^2_{adj}), Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC) and mean square errors (MSE) were determined 0,9968; 0,9952; 24,8801; 24,7179 and 25,9657 for brown; 0,9975; 0,9963; 22,9149; 22,7527 and 19,6099 for yellow plumage-colored quails, respectively. Parameter β_0, β_1 and β_2 of the model were found 234,89; 3,630; 0,072 & 236,58; 3,516 and 0,069, respectively. The age at point of inflection and weight at point of inflection were calculated 17,91 d and 86,41 g; 18,15 d and 87,03 g for brown and yellow plumage-colored quails, respectively.

Conclusion: In conclusion, Gompertz model was determined the best model in this study. This model can be advised to determine the growth curve traits in further researches for different plumage-colored Japanese quails. Morever, Jumbo quail breeding which is a sub-variate of Japanese quail must be considered by quail meat production due to the high maturity index besides the brown plumage-colored Japanese quails.

Keywords: Growth curve, japanese quail, non-linear regression, parameter estimate, plumage color

Introduction

Quail is a model animal for biological researches due to its ease to rearing and short generation interval (Minvielle 2004, Çimrin and Tunca 2013). On the other hand, quails are widely bred for meat and egg production all over the world (Minvielle 2004, Narinç et al 2009).

Growth which effected by genetic structure and environmental conditions can be defined as the increase in body weight and size up to adult age (Akbaş 1995, Narinç et al 2017). Because of the economic reason of detemine the optimum slaughter age, changes in body weight during growth are quiet important for both management and rearing (Narinc et al 2010, Yavuz et al 2019). Mathematical functions called growth models are used, which provides ease of application, especially in the selection of meat type animals with higher daily live weight gain and feed conversion ratio (Akbaş 1996, Narinç et al 2009, Yavuz et al 2019). Non-linear models are used for growth curve estimation because of growth generally shows a linear increase while after shows non-linear increase in the early period after birth/hatched in animals (Bilgin and Esenbuğa 2003, Bayram and Akbulut 2009). Although various growth models have been developed for years, Gompertz, Von Bertalaffy, Logistic and Richards models are widely used for fitting the growth curves and estimation of the curve parameters (Narinç et al 2017).

Shape of the growth curve is affected by genetic and environmental factors. Also related those factors, growth rate and feed consumption are changed (Narinç et al 2017). After domestication many changes were occurred in quails such as behavioural, productivity and morphological including the plumage color (Lukanov and Pavlova 2020). One of the plumage colors is yellow plumage color which determined by an outosomal dominant mutation (Minvielle et al 2007). This sub-variate of Japanese quail is also known as Italian or Jumbo quail (Avşar and Akpınar 2020, Ibrahim et al 2021) .

Previous studies on growth curve traits in quails mostly focused on the gender (Kaplan et al 2016, Gürcan and Kaplan 2017, Kaplan and Gürcan 2018, Santos et al 2018, Yavuz et al 2019). In contrast, studies on the effect of plumage color, which is origined from genetic structure, on the growth curve are limited (Yılmaz et al 2011, Anang et al 2017, Dash et al 2018, Grieser et al 2018). This study was conducted to determine growth curve traits of brown and yellow (Jumbo) plumage colored quails and to evaluate the best fit curve among the four growth models.

Material and Methods

This study was carried out at the alternative poultry unit belongs to Prof. Dr. Hümeyra Özgen Research and Application Farm in Selcuk University. Day old quail chicks were assigned to two plumage color (80 brown and 80 yellow) group. For the first three weeks the chicks were housed in a heated brooder cages (97 x 52 x 30 cm, 63cm^2/chick) and then transferred to grower cages (94 x 44 x 21 cm, 103 cm^2/chick) until 42nd days of age. The chicks were fed with a starter diet containing 22,8% CP; 3100 Kcal/kg ME; 1,3% lysin; 0,7% methionine; 0,9% Ca and 0,7% P until 21st days of age. And then until 42nd days of age they were fed with a grower diet containing 21,4% CP; 2985 Kcal/kg ME; 1,3% lysin; 0,6% methionine; 0,8% Ca and 0,6% P. Chicks were allowed access to water and food *ad libitum*. Chicks were lighted 24 hour for the first three weeks, then 23L:1D until the study finish.

Chicks were weigned 0th, 7th, 14th, 21st, 28th, 35th and 42nd days of age with a digital scale (KERN PFB 100). Growth curve parameters were estimated with Gompertz, Logistic, Von Bertalanffy and Richards models (Table 1).

Table1. Model expressions and parameters of the growth curves

Growth models	Equations	IPT	IPW
Gompertz (Winsor 1932)	$Y_t = \beta_0 e^{-\beta_1 e^{(-\beta_2 t)}}$	$\ln(\beta_1)/\beta_2$	β_0/e
Logistic (Nelder 1961)	$Y_t = \beta_0(1+\beta_1 e^{(-\beta_2 t)})^{-1}$	$-\ln(1/\beta_1)/\beta_2$	$\beta_0/2$
Von Bertalanffy (Von Bertalanffy 1957)	$Y_t = \beta_0(1-\beta_1 e^{(-\beta_2 t)})^3$	$\ln(3\beta_1)/\beta_2$	$8\beta_0/27$
Richards (Richards 1959)	$Y_t = \beta_0/(1+\beta_1 e^{(-B_2 t)})^{(1/\beta_3)}$	$(-1/\beta_2)\times\ln(\beta_3/\beta_1)$	$\beta_0/\sqrt[\beta_3]{\beta_3+1}$

Y_t: Predicted live weigth at day t (g), t: Age (day), β_0: Asymptotic weight (mature) (g), β_1: Scale parameter related to initial weigth, β_2: Maturity rate, β_3: Inflection parameter of the Richards' model, IPT: Age at point of inflection (day), IPW: Weight at point of inflection (g), e: natural logarithm base.

Statistical analyses

The parameters of the models were estimated with non-linear regression analyse (Levenberg-Marquardt iteration 1E-8) in SPSS version 22,0. For goodness of fit R2, R2adj, AIC, BIC and MSE were used (Table 2) (Akaike 1974, Schwarz 1978). Then age and weight at point of inflection values were calculated.

Table 2. Goodness of fit statistics

Goodnes of fit criteria	Formula of criteria
R^2	1-(SSE/SST)
R^2_{adj}	R^2 –[((k-1)/(n-k))(1- R^2)]
AIC	n×ln(SSE/n)+2k
BIC	n×ln(SSE/n)+k×ln(n)
MSE	SSE/(n-k)

R^2: Coefficient of determination, R^2_{adj}: Adjusted coefficient of determination, AIC: Akaike's Information Criterion, BIC: Schwarz Bayesian Information Criterion, SSE: Sum of square errors, SST: Total sum of squares, MSE: Mean square of errors, n: The number of observations, k= The number of parameters in the model

Results

Growth curve parameters of the models and point of inflection values are presented in Table 3. Parameter β_0 which defines the predicted asymptotic weights were ranged from 205,16 to 266,35 g for yellow and 206,46 to 261,01 g for brown plumage colored quails. The parameter β_0 were estimated more higher for brown and yellow (261,01 g and 266,35 g, respectively) plumage colored quails in Von Bertalanffy model while more lower in Logistic model (206,46 g and 205,16 g; respectively). The parameter β_1 which related to initial weight was ranged 0,768 to 16,006 for brown and 0,001 to 14,941 for yellow plumage colored quails. Parameter β_2 is the maturity index and it was ranged 0,052 to 0,132 for brown and 0,049 to 0,128 for yellow plumage colored quails. Maturity index had higher values for brown and yellow plumage colored quails in Logistic model (0,132 and 0,128) while lower values in Von Bertalanffy model (0,052 and 0,049).

Weight at point of inflection was calculated higher both brown and yellow plumage colored quails in Logistic model (103,23 g; 102,58 g) and lower in Von Bertalanffy model (77,34 g; 78,92 g). Age at point of inflection, similar to weight at point of inflection was calculated higher for both group in Logistic model (21,03 d; 21,05 d), lower in Von Bertalanffy model (16,18 d; 16,58 d). Growth curves of brown (Figure 1) and yellow (Figure 2) plumage colored quails are also given below.

Table 3. Parameter estimates of the growth curves

Growth models	β_0	β_1	β_2	β_3	IPT (d)	IPW (g)
Brown						
Gompertz	234,89	3,630	0,072	-	17,91	86,41
Logistic	206,46	16,006	0,132	-	21,03	103,23
Von Bertalanffy	261,01	0,768	0,052	-	16,18	77,34
Richards	218,71	2,579	0,096	0,3999	19,40	94,31
Yellow						
Gompertz	236,58	3,516	0,069	-	18,15	87,03
Logistic	205,16	14,941	0,128	-	21,05	102,58
Von Bertalanffy	266,35	0,750	0,049	-	16,58	78,92
Richards	236,57	0,001	0,069	0,0003	18,15	87,04

Table 4. Goodnes of fit criterias of the models

Growth models	R^2	R^2_{adj}	AIC	BIC	MSE
Brown					
Gompertz	0,9968	0,9952	24,8801	24,7179	25,9657
Logistic	0,9967	0,9950	25,2094	25,0471	27,2163
Von Bertalanffy	0,9954	0,9930	27,4921	27,3298	37,7094
Richards	0,9972	0,9945	25,7861	25,5697	29,6115
Yellow					
Gompertz	0,9975	0,9963	22,9149	22,7527	19,6099
Logistic	0,9940	0,9910	29,1063	28,9440	47,4900
Von Bertalanffy	0,9973	0,9960	23,4976	23,3354	21,3122
Richards	0,9975	0,9951	24,9157	24,6994	26,1495

Table 5. Means of observed and predicted live weights of the models

Observed		Gompertz		Logistic		Von Bertalanffy		Richards	
Age (d)	Weight (g)	P	D	P	D	P	D	P	D
Brown									
Hatched	8,21	6,23	1,98	12,14	-3,93	3,25	4,96	9,02	-0,81
7	25,31	26,21	-0,90	28,05	-2,74	26,19	-0,88	26,78	-1,47
14	64,67	62,43	2,24	58,52	6,15	64,35	0,32	60,51	4,16
21	101,90	105,47	-3,57	102,99	-1,09	105,84	-3,94	104,65	-2,75
28	143,05	144,80	-1,75	147,55	-4,50	143,37	-0,32	146,14	-3,09
35	183,07	175,35	7,72	178,19	4,88	174,18	8,89	176,59	6,48
42	192,53	196,86	-4,34	194,22	-1,69	198,07	-5,54	195,65	-3,13
Yellow									
Hatched	8,07	7,03	1,04	12,87	-4,80	4,16	3,91	7,03	1,04
7	25,13	27,14	-2,01	28,98	-3,85	27,21	-2,08	27,14	-2,01
14	63,14	62,37	0,77	59,05	4,09	64,07	-0,93	62,37	0,77
21	104,10	104,09	0,01	102,22	1,88	104,28	-0,18	104,09	0,01
28	146,51	142,70	3,81	145,52	0,99	141,25	5,26	142,7	3,81
35	166,42	173,29	-6,87	175,83	-9,41	172,21	-5,79	173,29	-6,87
42	198,62	195,31	3,31	192,12	6,50	196,73	1,89	195,31	3,31

P: Means of predicted live weigths (g), D: Difference between means of observed and predicted live weights (g)

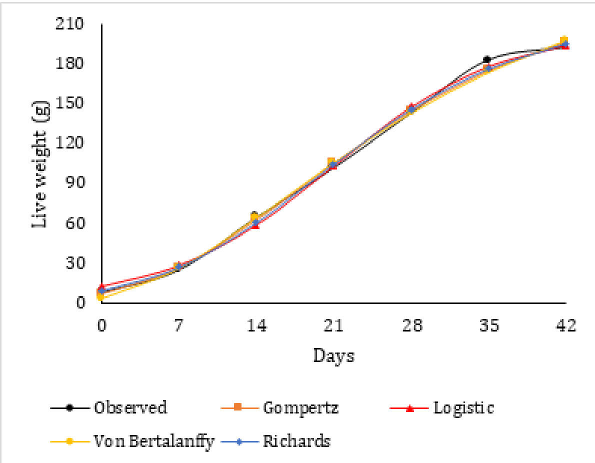

Figure 1. Growth curves of brown plumage-colored quails

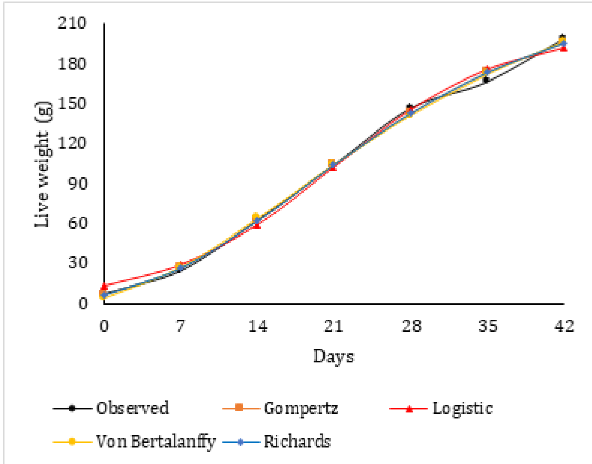

Figure 2. Growth curves of yellow plumage-colored quails

Goodness of fit criteria of the models are presented in Table 4. Also, observed and estimated live weights of the quails are given in Table 5. All models had high R^2 values ranged 0,9940 to 0,9975. Although all models had high R^2 and R^2_{adj}, Gompertz model had lower AIC (24,8801; 22.91,49), BIC (24,7179; 22,7527) and MSE (25,9657; 19,6099) values for both brown and yellow plumage colored quails. Because of those values Gompertz model was determined the best fit growth model for the groups in this study.

Discussion

In the current study, Gompertz model was determined the best fit growth curve model. Similarly, Narinc et al (2010) (R^2: 0,99998; AIC: -2,010; BIC: -2,172) determined the Gompertz model is the best fit for Japanese quails. Also, Anang et al (2017) determined Gompertz model (R^2: 0,9988 for black, R^2: 0,9991 for brown) is the best fit for black and brown plumage colored Padjadjaran quails. In constrat, in some studies Weibull model (R^2: 0,999; MSE: 318,54; AIC: 4717,067) (Raji et al 2014); Von Bertalanffy model (R^2: 0,98; MSE: 49,731; AIC: 100,47) (Adedeji et al 2017); Janoschek model (R^2: 0,9976; AIC: 34,15; BIC: 35,74) (Gürcan and Kaplan 2017); Richards model (for females and males R^2: 99,98 & 99,97; AIC: -1034,12 & -1044,97; BIC: -1018,94 & -1029,19) (Kaplan and Gürcan 2018); cubic spline model (for females and males; MSE: 92,50; 35,391 & AIC: -19,21 & -35.04) (Yavuz et al 2019) were determined as the best model for Japanese quails. Among the four growth model, Richards model did not fit the datas for both group because it had convergence problem in parameter estimation similar to findings of Kheirabadi and Rashidi (2019).

According to Gompertz model, parameter β_0 was estimated 234,89 for brown and 236,58 for yellow plumage colored quails. Similar to current study results, Narinc et al (2014) found 233,12 and Uckardes and Narinç (2014) found the parameter β_0 as 242,10. In constrat, with same model Anang et al (2017) were determined that parameter 164.47 for black, 213,43 for brown; Grieser et al (2018) 167,5 for yellow; 179,6 for red plumage colored quails. On the other hand, Santos et al (2018) found the parameter β_0 for meat and laying type Japanese quails as 305 and 159, respectively. Wide variation of the β_0 parameter in studies may be due to asymptote weight is related to genetic structure and the environmental conditions (Raji et al 2014, Bashiru et al 2019).

The parameter β_1 of Gompertz model was found 3,630 for brown and 3,516 for yellow plumage colored quails. The findings were higher than Narinc et al (2010) (3,31), but aggree with findings of Narinç et al (2009) (3,66). The parameter β_1 is the constant related to the initial weight but has no biological meaning (Kaplan and Gürcan 2018). That means this parameter can be found more different for each study.

The parameter β_2 is the maturity index that defines which animal has early which animal is late maturing. A low maturity index indicates that the animal is late maturing while high maturity index early maturing (Adedeji et al 2017). According to Gompertz model results this paramater found 0,072 for brown and 0,069 for yellow plumage colored quails. This results similar to (0,06572) Beiki et al (2013). Although the indexes are close in the current study, brown plumage colored quails are early maturing than yellows can be said.

In the study, age at point of inflection (IPT) was calculated 17,91 day for brown; 18,15 day for yellow plumage colored Japanese quails. Approximately to this results of the study, Kızılkaya et al (2005) found the IPT 17,05 day; Beiki et al (2013) 19,74 day; Adedeji et al (2017) 22,15 day for Japanese quails. On the other hand, weight at point of inflection was calculated 86,41 g for brown and 87,03 g for yellow plumage colored quails. This value is higher than Adedeji et al (2017) (57,17 g) and Gurcan et al (2012) (68,96 g). Similar to current study Alkan et al (2009) found 82,3 g; Kızılkaya et al (2005) found 82,96 g. Point of inflection is a key factor to determine where the growth rate is maximum. After the inflection point growth rate is begins to decline (Adedeji et al 2017). The diffecences between studies for point of inflections may be originated from genetic and environmental factors.

Conclusion

In conclusion, Gompertz model had best fit both brown and yellow plumage colored Japanese quails with higher R^2, R^2_{adj} and lower AIC, BIC and MSE values. Therefore this model can be used for growth curve traits of the Japanese quails. On the other hand, Jumbo quail breeding which is a sub-variate of Japanese quail must be considered by quail meat production due to the high maturity index besides the brown plumage-colored Japanese quails.

Acknowledgement

This study was presented as an oral presentation at the 8th International KOP Regional Development Symposium and was published as a summary text in the congress book.

Conflict of Interest

The authors did not report any conflict of interest or financial support.

Funding

During this study, any pharmaceutical company which has a direct connection with the research subject, a company that provides and / or manufactures medical instruments, equipment and materials or any commercial company may have a negative impact on the decision to be made during the evaluation process of the study or no moral support.

References

Adedeji OA, Omolara AM, Osamede OH, Emmanuel SA, 2017. Analysis of growth models of Japanese quails (*Coturnix Coturnix Japonica*) in Nigeria. Thai J Agric Sci, 50(3-4), 155-65.

Akaike H, 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19(6), 716-23.

Akbaş Y, 1995. Büyüme eğrisi modellerinin karşılaştırılması. Hayvansal Üretim, 36(1), 73-81.

Akbaş Y, 1996. Büyüme eğrisi parametreleri ve ıslah kriteri olarak kullanımı olanakları. Ege Üniv Ziraat Fak Derg, 33(1), 241-8.

Alkan S, Mendes M, Karabag K, Balcioglu MS, 2009. Effect of short-term divergent selection for 5-week body weight on growth characteristics of Japanese quail. Arch Geflügelk, 73, 124-31.

Anang A, Indrijani H, Sujana E, 2017. Mathematical model of growth of two purelines of Padjadjaran female quail aged 0 to 6 weeks. J Indones Trop Anim Agric, 42(2), 66.

Avşar AA, Akpınar GÇ, 2020. Sarı tüy rengindeki (*Coturnix japonica*) bıldırcınlarda farklı yaş ve depolama sürelerinin yumurta kalite özellikleri üzerine etkisi. MKU Tar Bil Derg, 25(2), 198-210.

Bashiru HA, Oseni SO, Omadime LA, 2019. Evaluation of four classical non-linear models to describe the growth curve of funaab-alpha chickens. Animal Health and Production, 67, 323-32.

Bayram B, Akbulut Ö, 2009. Esmer ve siyah alaca sığırlarda büyüme eğrilerinin doğrusal ve doğrusal olmayan modellerle analizi. Hayvansal Üretim, 50(2).

Beiki H, Pakdel A, Moradi-Shahrbabak M, Mehrban H, 2013. Evaluation of growth functions on Japanese quail lines. J Poult Sci, 50(1), 20-7.

Bilgin ÖC, Esenbuğa N, 2003. Doğrusal olmayan büyüme modellerinde parametre tahmini. Hayvansal Üretim, 44(2), 81-90.

Çimrin Tl, Tunca Rİ, 2013. The effects of different methods on yield performances of Japanase quails (*Coturnix Coturnix Japonica*). FBED, 3(2), 103-12.

Dash SK, Naik S, Dubey PP, Malhotra P, et al., 2018. Effect of plumage colour and estimation of variance components of bi-weekly growth traits in Japanese quail (*Coturnix Coturnix Japonica*). Indian J Anim Sci, 88(10), 1193-6.

Grieser DdO, Marcato SM, Furlan AC, Zancanela V, et al., 2018. Estimation of growth parameters of body weight and body nutrient deposition in males and females of meat-and laying-type quail using the Gompertz model. Rev Bras de Zootec, 47.

Gurcan EK, Cobanoglu O, Genc S, 2012. Determination of body weight-age relationship by non-linear models in Japanese quail. J Anim Vet Adv, 11(3), 314-7.

Gürcan EK, Kaplan S, 2017. Flexible alternatives to models widely used for describing growth in Japanese quail. JAPS, 27(1), 48-56.

Ibrahim NS, El-Sayed MA, Assi HAM, Enab A, et al., 2021. Genetic and physiological variation in two strains of Japanese quail. J Genet Eng Biotechnol, 19(1), 1-12.

Kaplan S, Gürcan EK, 2018. Comparison of growth curves using non-linear regression function in Japanese quail. J Appl Anim Res, 46(1), 112-7.

Kaplan S, Narinc D, Gurcan EK, 2016. Genetic parameter estimates of weekly body weight and Richard's growth curve in Japanese quail. Eur Poult Sci, 80.

Kheirabadi K, Rashidi A, 2019. Modelling and genetic evaluation of Markhoz goat growth curve parameters. Small Rumin Res, 170, 43-50.

Kızılkaya KKZ, Balcıoğlu MS, Yolcu HI, Karabağ K, 2005. The application of exponential method in the analysis of growth curve for Japanese quail. Arch für Geflugelkunde, 69(5), 193-8.

Lukanov H, Pavlova I, 2020. Domestication changes in Japanese quail (*Coturnix japonica*): a review. Worlds Poult Sci J, 76(4), 787-801.

Minvielle F, 2004. The future of Japanese quail for research and production. Worlds Poult Sci J, 60(4), 500-7.

Minvielle F, Gourichon D, Ito S, Inoue-Murayama M, et al., 2007. Effects of the dominant lethal yellow mutation on reproduction, growth, feed consumption, body temperature, and body composition of the Japanese quail. Poult Sci, 86(8), 1646-50.

Narinc D, Karaman E, Aksoy T, Firat MZ, 2014. Genetic parameter estimates of growth curve and reproduction traits in Japanese quail. Poult Sci, 93(1), 24-30.

Narinc D, Karaman E, Firat MZ, Aksoy T, 2010. Comparison of non-linear growth models to describe the growth in Japanese quail. J Anim Vet Adv, 9(14), 1961-6.

Narinç D, Aksoy T, Karaman E, Karabağ K, 2009. Japon bıldırcınlarında yüksek canlı ağırlık yönünde uygulanan seleksiyonun büyüme parametreleri üzerine etkisi. Akdeniz Univ Ziraat Fak Derg, 22(2), 149-56.

Narinç D, Narinç NÖ, Aygün A, 2017. Growth curve analyses in poultry science. Poult Sci J, 73(2), 395-408.

Nelder JA, 1961. The fitting of a generalization of the logistic curve. Biometrics, 17(1), 89-110.

Raji AO, Mbap ST, Aliyu J, 2014. Comparison of different models to describe growth of the Japanese quail (*Coturnix Japonica*). TJS, 12(2), 183.

Richards FJ, 1959. A flexible growth function for empirical use. J Exp Bot, 10(2), 290-301.

Santos HB, Vieira DA, Souza LP, Santos AL, et al., 2018. Application of non-linear mixed models for modelling the quail growth curve for meat and laying. J Agric Sci, 156(10), 1216-21.

Schwarz G, 1978. Estimating the dimension of a model. Ann Stat, 6(2), 461-4.

Uckardes F, Narinç D, 2014. An application of modified logistic and gompertz growth models in Japanese quail. Indian J Anim Sci, 84(8), 903-7.

Von Bertalanffy L, 1957. Quantitative laws in metabolism and growth. Q Rev Biol, 32(3), 217-31.

Winsor CP, 1932. The Gompertz curve as a growth curve. PNAS, 18(1), 1-8.

Yavuz E, Önem AB, Fahrettin K, Çanga D, et al., 2019. Modeling of individual growth curves in japanese quails. BSJ Eng Sci, 2(1), 11-5.

Yılmaz A, Tepeli C, Çağlayan T, 2011. External and internal egg quality characteristics in Japanese quails of different plumage color lines. J Food Agric Environ, 9(2), 375-9.

Author Contributions

Motivation / Concept: Serdar Güler, Orhan Çetin
Design: Serdar Güler
Control/Supervision: Orhan Çetin, Serdar Güler, Emre Arslan, Muhammet Mücahit Sarı
Data Collection and / or Processing: Serdar Güler, Emre Arslan, Muhammet Mücahit Sarı
Analysis and / or Interpretation: Serdar Güler
Literature Review: Serdar Güler
Writing the Article: Serdar Güler
Critical Review: Orhan Çetin

Ethical Approval

Selcuk University Experimental Research and Application Center, Animal Experiments Ethics Committee 03.06.2021, 2021/75 Number Ethics Committee Decision.

CITE THIS ARTICLE: *Güler S, Arslan E, Sarı MM, Çetin O, 2022. Comparison of growth curves with non-linear models in Japanese quails of different plumage color. Eurasian J Vet Sci, 38, 3, 173-179.*