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MODELING OF SOME EGG CHARACTERISTICS IN HENNA PARTRIDGES

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Abstract: In this study, the distributions of egg count (daily and cumulative), width, length and weight values of chukar partridges obtained in two different egg production seasons were statistically modeled. For this purpose, in modeling cumulative egg production curves; Logistic, Gompertz, Gamma, Schunute, Brody, Richard, Negative Exponential, Von Bertalanffy, Cubic Piecewise and Cubic models were used, and in evaluating daily egg production curves; Gompertz, Logistic, Richard, McNally, Gamma, Cubic Piecewise, Quadratic, Quadratic Piecewise and Modified Compartmental models were used. In modeling egg width values; Gompertz, Gamma, Cubic Piecewise and Cubic models were used, in modeling length values; Logistic, Gamma, Cubic Piecewise and Cubic models were used, and in modeling weight values; McNally, Gamma, Cubic Piecewise and Cubic models were used. In all modeling studies, as comparison and evaluation criteria; Error Mean Square, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion were taken into consideration. As a result of the study; Gamma was determined as the most suitable model for modeling cumulative egg yields and length values, McNally for modeling daily egg yields and weight values, and Gompertz and Gamma models for modeling egg width values.

Keywords: *Alectoris chukar*, Egg production, Modeling, Curve

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1. Introduction

People have been trying to raise and produce poultry for many years, primarily for their meat and eggs, and secondarily for their singing and beautiful appearance. In this area, domesticated poultry or those whose domestication efforts are ongoing include; primarily chickens *(Gallus gallus domesticus)* and pheasants, which are taxonomically members of the *Galliformes (*Chickens*)* order, quails, partridges, turkeys and francolins, which are members of the *Phasianidae (*Phasians*)* family, and geese and ducks, which are members of the *Anatidae (*Ducks*)* family of the *Anseriformes* (Geese*)* order (Çetin et al., 1997). Other poultry, other than chickens, are also known as alternative poultry. Partridges have an important place among alternative poultry due to their meat, eggs, and beautiful singing and appearance. Partridges, whose homeland is Central Asia, are known to have spread to the southern parts of Europe, North Africa, Middle Eastern countries and Southern China. In some European countries (such as France, Spain, Hungary, Czechia and Slovakia), in the years when pheasants and partridges were raised for investment purposes and hunted in private hunting grounds, the same practice was started in private hunting grounds in Çatalca and Nazilli in Türkiye with imported partridges (Çetin et al., 1997). Partridges, which have adapted many regions of our country, are not seen in the dense forests of the Black Sea coast, which receives excessive rainfall, and in the flat plains of the Marmara, Aegean and Mediterranean regions (Kantarlı, 2018). Although there are many domesticated and wild partridges in the world, it is known that the most common breeds in Türkiye are the Chukar Partridge *(Alectoris chukar),* Stone Partridge *(Alectoris graeca),* Freckle Partridge *(Perdix perdix)* and Sand (Desert) Partridge *(Ammoperdix gri-seogularis)* (Kiziroğlu, 1983). In terms of the general characteristics of partridges; they are medium-sized birds that can be described as game or ornamental birds with their structures larger than quails, relatively smaller than chickens and smaller than pheasants. They are birds that live in groups in their natural habitats, mostly in mountainous or forested areas, and attract attention with their beautiful songs and are loved (Kantarlı, 2018).

In the physical characteristics of partridges; males have an average live weight of 550-650 gr, females 500-550 gr, and their average body measurements are known as; height 33 cm, wing gap 52 cm, wing length 15 cm and tail length 13 cm. (Kantarlı, 2018).

When partridges are examined phenotypically; brown, white and gray tones are predominant in their feathers. They do not make long flights due to their short and oval wing structures. They prefer to walk more, which explains their muscular leg structure. In addition, the short beaks of partridges make it easier to take small foods (seeds, small plant parts, small insects, ticks, stink bugs, etc.). When looking at chukar partridges, their beaks, eye area, feet and legs are red. They have orange feathers on the lower part of their abdomen, orange feathers with black stripes on their wings and ash grey feathers on the remaining areas. The black band line specific to chukar partridges starts from the bottom of their necks and passes through the ears and eyes on both sides and joins on the beak.

Like other partridge species, it is known that the average egg yield of partridges reared on the ground is 38.40, while it is 11.20 for those reared in cages, and the average egg yield of 1-year-old adult partridges is 34.16, while it is 45.65 for 2-year-old adult partridges (Çetin et al., 1997; Çetin et al., 2002). As in all poultry, seasonal egg production in partridges is a direct indicator of the population growth rate. It is known that breed, temperature, age of sexual maturity, feeding method and other environmental factors directly affect egg production. Especially in breeding studies related to poultry, criteria such as age of use in breeding, breeding life, commercial life for species are of great importance for producers and breeders. Non-linear growth models are used to determine these criteria that emerge as a result of breeding studies. These models belonging to yield curves can also be explained statistically. The main purpose of the models is to be able to present significant statistical inferences in determining the criteria that are the target of breeding studies (Tolun et al., 2023). It is known that by presenting the correct models, the probability of selecting individuals with high genetic capacity will increase for the flock, the decision-making process in selection will decrease, and the degree of accuracy in selection will increase (Tolun et al., 2023).

In this study, it is aimed to examine the egg yields of some egg characteristics (width, length and egg weight) of 1.5-year-old broodstock partridges (during two production periods) with non-linear mathematical models and to reveal the model or models that best explain the relevant production values in partridges.

2. Materials and Methods

The data set in this study was obtained from breeding chukar partridges reared under intensive conditions at the Kahramanmaraş Kapıçam Chukar Partridge Production Station of the General Directorate of Nature Conservation and National Parks, XV. Regional Directorate (Malatya), Ministry of Agriculture and Forestry of the Republic of Türkiye. Since the productive period at the production station starts in mid-December on average and continues until mid-May of the following year (maximum 20 weeks), measurements were made in two different periods (Period I; December 2021 - May 2022 for 13 weeks, Period II; December 2023 - May 2024 for 11 weeks). In the measurements; 22 pens were created and 24 males and 36 females were placed in each pen. A total of 81-day egg yields were obtained from 22 pens consisting of 792 female individuals during the egg production season, and during the research, the partridges raised as breeders were provided with 20% crude protein and 2900 Kcal energy egg feed, feed and water requirements ad libitum, and 18 hours of lighting was used in the pens. For this purpose, the statistical equations and evaluation criteria used in the literature for the model comparison criteria of cumulative and daily egg yield, width, length and weight curves on the partridge data set were calculated using the SAS statistical package program and a detailed examination of the evaluation criteria of the models was performed. In the modeling of cumulative egg yield curves; Logistic, Gompertz, Gamma, Schunute, Brody, Richard, Negative Exponential, Von Bertalanffy, Cubic Piecewise and Cubic models were used. The equations used in the modeling of cumulative egg yields are given in Table 1 (Ahmadu et al., 2017; Yalçınöz and Şahin; 2020; Yavuz et al., 2023).

Table 1. Equations used in modeling cumulative egg yields

Models Names	Equalities
Logistic	$Y_t = \beta_0(1+\beta_1\exp(-\beta_2 t))^{-1}$
Gompertz	$Y_t = \beta_0\exp(-\beta_1\exp(-\beta_2 t))$
Gamma	$Y_t = {\beta_0}^{\beta_1}(e^{-\beta_2 t})$
Schunute	$Y_t = Z_2 * Z_3$ $Z_1 = {\beta_4}^{(\beta_2)} - {\beta_3}^{(\beta_2)}$, $Z_2 = {\beta_3}^{(\beta_2 + Z_1)}$, $Z_3 = (1-e(-\beta_1(X-X_1)/(1-e(-\beta_1(X_2-X_1))^{(1/\beta_2)}$
Brody	$Y_t = \beta_0(1-\beta_1\exp(-\beta_2 t))$
Richard	$Y_t = \beta_0(1+\beta_1\exp(-\beta_2 t))^{\beta_3}$
NegativeExponential	$Y_t = \beta_0 - (\beta_0 e^{-\beta_2 t})$
Von Bertalanffy	$Y_t = \beta_0(1-\beta_1\exp(-\beta_2 t))^3$
Cubic Piecewise	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + \beta_4(t-a)^3$
Cubic	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3$

In modeling daily egg yields; Gompertz, Logistic, Richard, McNally, Gamma, Cubic Piecewise, Quadratic, Quadratic Piecewise and Modified Compartmental models were used. The equations used in modeling daily egg yields are given in Table 2 (Ahmadu et al., 2017; Yalçınöz and Şahin; 2020; Yavuz et al., 2023).

In modeling egg width values; Gompertz, Gamma, Cubic Piecewise and Cubic models were used. The equations used in modeling egg width values are given in Table 3 (Ahmadu et al., 2017; Yalçınöz and Şahin; 2020; Yavuz et al., 2023).

Logistic, Gamma, Cubic Piecewise and Cubic models were used in modeling egg size values. The equations used in modeling egg size values are given in Table 4 (Ahmadu et al., 2017; Yalçınöz and Şahin; 2020; Yavuz et al., 2023).

Table 2. Equations used in modeling daily egg yields

Models Names	Equalities
Gompertz	$Y_t = \beta_0 exp(-\beta_1 exp(-\beta_2 t))$
Logistic	$Y_t = \beta_0(1+\beta_1 exp(-\beta_2 t))^{-1}$
Richard	$Y_t = \beta_0(1+\beta_1 exp(-\beta_2 t))^{\beta_3}$
McNally	$Y_t = \beta_0 t^{\beta_1} exp(-\beta_2 t + \beta_3 t^{1/2})$
Gamma	$Y_t = \beta_0 t^{\beta_1} exp(-\beta_2 t)$
Cubic Piecewise	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + \beta_4 (t-a)^3$
Quadratic	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2$
Quadratic Piecewise	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 (t-a)^2$
Modified Compartmental	$Y_t = \beta_0 exp(-\beta_1 t)/(1 + exp((-\beta_3(t-\beta_4))$

Table 3. Equations used in modeling egg width values

Models Names	Equalities
Gompertz	$Y_t = \beta_0 exp(-\beta_1 exp(-\beta_2 t))$
Gamma	$Y_t = {\beta_0}^{\beta_1} exp(-\beta_2 t)$
Cubic Piecewise	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + \beta_4 (t -$
Cubic	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3$

Table 4. Equations used in modeling egg size values

Models Names	Equalities
Logistic	$Y_t = \beta_0(1+\beta_1 exp(-\beta_2 t))^{-1}$
Gamma	$Y_t = {\beta_0}^{\beta_1} exp(-\beta_2 t)$
Cubic Piecewise	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + \beta_4 (t-a)^3$
Cubic	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3$

In modeling egg weight values; McNally, Gamma, Cubic Piecewise and Cubic models were used. The equations used in modeling egg weight values are given in Table 5 (Ahmadu et al., 2017; Yalçınöz and Şahin; 2020; Yavuz et al., 2023).

Table 5. Equations used in modeling egg weight values

Models Names	Equalities
McNally	$Y_t = \beta_0 t^{\beta_1} exp(-\beta 2t + \beta 3t^{1/2})$
Gamma	$Y_t = {\beta_0}^{\beta_1} exp(-\beta_2 t)$
Cubic Piecewise	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + \beta_4 (t-a)^3$
Cubic	$Y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3$

In the model comparison criteria; Mean Square Error, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion were used. Model comparison criteria are given in Table 6.

Table 6. Model comparison criteria

Criteria	Equation
Mean Square Error	MSE = ESS/EDF
Coefficient of Determination	$R^2 = 1 - (MSE/SST)$
Adjusted Coefficient of Determination	$\bar{R}^2 = 1-(1-R^2)(n-1/(n-p-1))$
Accuracy Factor	$AF = 10^{\sum_{i=1}^{n}\lvert\log(\hat{Y}_i/Y_i)\rvert/n}$
Bias Factor	$BF = 10^{\sum_{i=1}^{n}\log(\hat{Y}_i/Y_i)/n}$
Durbin-Watson Value	$DW = \frac{\sum_{i=2}^{n}(e_1-e_2)^2}{\sum_{i=1}^{n} e_1^2}$
Akaike Information Criterion	$\mathrm{AIC} = \mathrm{nxln}\left(\frac{\mathrm{MSE}}{\mathrm{n}}\right) + 2\mathrm{k}$
Corrected Akaike Information Criterion	$\mathrm{CAIC} = \mathrm{AIC} + \left(\frac{2\mathrm{p}(\mathrm{p}+1)}{\mathrm{n}-\mathrm{p}-1}\right)$
Bayesian Information Criterion	$BIC = nxln\left(\frac{MSE}{n}\right) + kln(n)$

3. Results and Discussion

In this study, the distributions of the number of eggs (daily and cumulative), width, length and weight values obtained from breeding chukar partridges reared under intensive conditions in Kahramanmaraş Kapıçam Chukar Partridge Production Station of the Republic of Türkiye Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks, XV. Regional Directorate (Malatya), were statistically modeled in two different egg production seasons. In modeling the cumulative egg production curves; Logistic, Gompertz, Gamma, Schunute, Brody, Richard, Negative Exponential, Von Bertalanffy, Cubic Piecewise and Cubic models were used and the Gamma model was determined as the best-fitting model. In evaluation of daily egg production curves; Gompertz, Logistic, Richard, McNally, Gamma, Cubic Piecewise, Quadratic, Quadratic Piecewise and Modified Compartmental models were used and the McNally model was determined as the best-fitting model. In modeling the egg width values; Gompertz, Gamma, Cubic Piecewise and Cubic models were used and it was determined that Gompertz and Gamma models, which have very close fit criterion values, provided better fit than the other two models. Logistic, Gamma, Cubic Piecewise and Cubic models were used in modeling egg length values and as in cumulative egg yields, Gamma model was determined as the most suitable model. McNally, Gamma, Cubic Piecewise and Cubic models were used in modeling egg weight values and similar to daily egg yields, McNally model was determined as the most suitable model. While obtaining these results in all modeling studies, in addition to model fit and comparison criteria commonly used in the literature (Mean Square Error, Corrected Coefficient of Determination, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion), Accuracy Factor, Bias Factor and Durbin-Watson test were also taken into consideration. Especially here, Durbin-Watson test is extremely important. Because if a model with a high Coefficient of Determination and a low Mean Square Error has a negative or positive autocorrelation, then it cannot be said that this model is a good fit. On the other hand, when the literature is examined, there are many studies on modeling egg production in poultry (Congleton et al., 1981; McMillan et al., 1986; Cason and Britton, 1988; Ersoz and Alpan 1994; Narinç et al., 2007; Balcıoğlu et al., 2009; Narinç et al., 2009; Pis 2012; Narinç et al., 2013; Narinç and Aksoy 2014; Kaplan et al., 2015; Eleroğlu et al., 2016; Türker et al., 2017; Wen et al., 2019; İzgi et al., 2020; Karadavut et al., 2022). However, in the literature searches; No modeling study has been found regarding egg width, length and weight, and it has also been determined that there are very few studies on egg production on partridges. The scarcity of studies in this field can be thought to be related to the fact that partridge production in our country is largely carried out by the state and that it is not in commercial demand as much as chicken, quail and goose.

As a result, the fact that the egg yield of chukar partridges is confined to a certain time interval makes all kinds of scientific data obtained from egg yields much more important. For example, if the ration content is adjusted accordingly during the peak egg yield period, it will mean that the hatchability will be high and therefore it will have maximum hatchability. On the other hand, when the models of individual egg yields can be used in selection and selection, and when the effect on breeding studies is considered, the importance of choosing the right model becomes even clearer. For this reason, including as many models as possible in modeling studies on egg yields obtained from chukar partridges, and considering all aspects of model comparison and evaluation criteria will greatly contribute to the determination of the right model or models.

In the data set obtained from breeding chukar partridges raised under intensive conditions at Kahramanmaraş Kapıçam Chukar Partridge Production Station of the General Directorate of Nature Conservation and National Parks of the Republic of Türkiye Ministry of Agriculture and Forestry (Malatya), since the productive period starts in mid-December on average and continues until mid-May of the following year (maximum 20 weeks), measurements were made in two different periods (I. Period; December 2021-May 2022 for 13 weeks, II. Period; December 2023-May 2024 for 11 weeks). For the cumulative egg yields of the Ist and IInd periods, obtained from 10 different models over the averages of 22 compartments; The values of Mean Square Error, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion are given in Table 7 and Table 8, and the curves obtained for the cumulative egg yields of the Ist and IInd periods are given in Figure 1 and Figure 2.

Table 7. Comparison criteria for cumulative egg yields in the first period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Logistic	1567.932	0.9982	1.21	1.10	0.01	672.48	672.50	680.02
Gompertz	558.227	0.9993	1.15	1.12	0.04	578.50	578.52	586.04
Gamma	12.460	0.9999	1.02	1.00	0.11	232.50	232.52	240.03
Schunute	1349.954	0.9985	1.04	1.04	0.09	661.82	661.84	674.38
Brody	281.557	0.9988	1.13	0.92	0.07	516.22	516.24	523.75
Richard	8.963	0.9999	1.03	0.98	0.14	203.48	203.50	213.53
N. Exponential	984.270	0.9989	1.15	1.13	0.04	629.14	629.16	634.16
Von Bertalanffy	192.352	0.9997	1.10	1.08	0.12	481.55	481.57	489.08
Cubic Piecewise	9.337	0.9999	1.01	1.00	0.19	208.15	208.17	220.71
Cubic	51.207	0.9998	1.06	0.97	0.11	362.07	362.09	372.12

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

Table 8. Comparison criteria for cumulative egg yields in the second period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Logistic	1835.3	0.9894	1.26	1.12	0.01	686.81	686.82	694.34
Gompertz	608.7	0.9990	1.18	1.14	0.05	586.38	586.40	593.92
Gamma	34.6	0.9999	1.04	1.03	0.08	325.54	325.55	333.07
Schunute	3512.9	0.9942	1.13	0.99	0.04	748.85	748.87	761.41
Brody	12048.5	0.9308	1.23	0.92	0.05	858.05	858.06	865.58
Richard	4386.1	0.9928	1.14	0.88	0.04	767.05	767.07	777.10
N. Exponential	279.7	0.9995	1.12	1.11	0.02	514.63	514.64	519.66
Von Bertalanffy	302.0	0.9995	1.14	1.11	0.16	522.61	522.62	530.14
Cubic Piecewise	4.2	0.9999	1.01	1.00	0.37	135.15	135.16	147.70
Cubic	33.9	0.9998	1.06	0.97	0.12	324.44	324.45	334.48

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

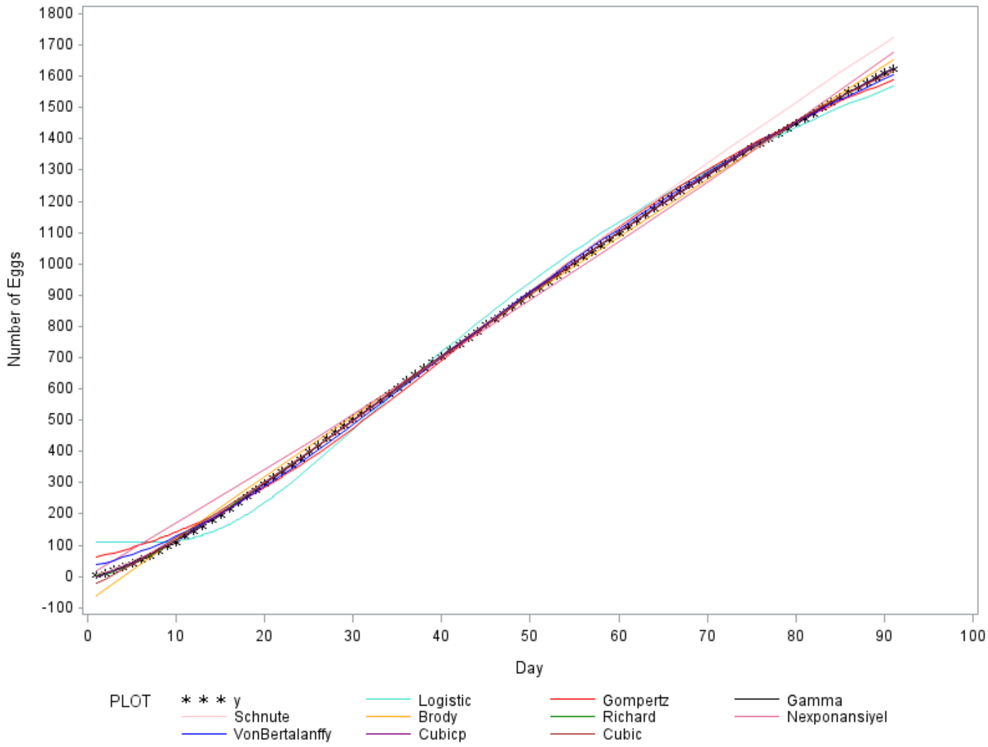

Figure 1. Curves obtained for cumulative egg yields in the 1st period.

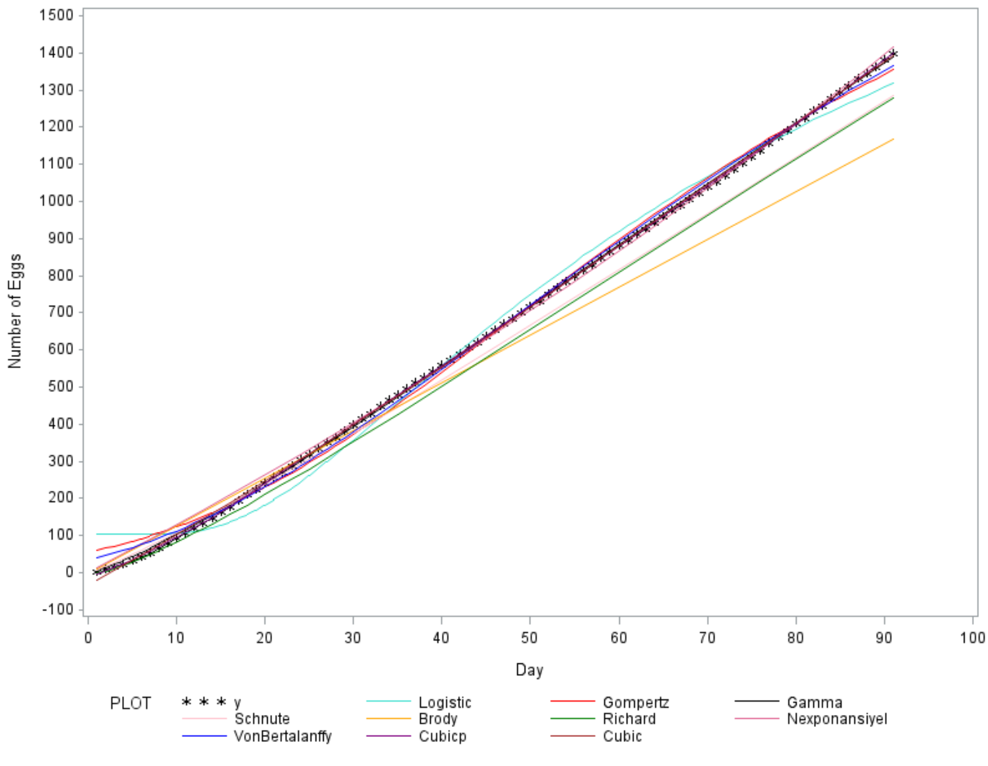

Figure 2. Curves obtained for cumulative egg yields in the 2nd period.

When the comparison criteria for cumulative egg yields of the first period are examined in Table 7; it is seen that the best results in terms of Error Squares Mean Squares were obtained from Gamma, Richard and Cubic Partial models, in terms of Corrected Determination Coefficients, all models produced values of 0.99 and above, and in terms of Accuracy and Bias Factors, it was determined that Gamma, Richard and Cubic Partial models were the closest to 1 compared to other models. In terms of Durbin-Watson Autocorrelation values, all models tend to have positive autocorrelation. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, the values obtained from Gamma Richard and Cubic Partial models were the smallest values compared to other models. The curves obtained for cumulative egg yields of the first period are as in Figure 1.

When the comparison criteria for cumulative egg yields of the 2nd period are examined in Table 8; it is seen that the best results in terms of Error Squares Mean Squares were obtained from Gamma, Cubic Piecewise and Cubic models, in terms of Corrected Determination Coefficients, all models except Logistic and Brody produced values of 0.99 and above, and in terms of Accuracy and Bias Factors, it was determined that Gamma, Cubic Piecewise and Cubic models were the closest to 1 compared to other models. In terms of Durbin-Watson Autocorrelation values, all models tend to have positive autocorrelation. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, the values obtained from Gamma, Cubic Piecewise and Cubic models were the smallest values compared to other models. The curves obtained for cumulative egg yields of the 2nd period are as in Figure 2.

For the daily egg yields of the 1st and 2nd periods, the values of Mean Square Error, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion obtained from nine different models on the averages of 22 compartments are given in Table 9 and Table 10, and the curves obtained for the daily egg yields of the 1st and 2nd periods are given in Figure 3 and Figure 4.

When the comparison criteria for daily egg yields of the First Period are examined in Table 9; it is seen that the best results in terms of Error Squares Mean Squares were obtained from McNally, Cubic Partial, Quadratic Partial and Modified Compartmental models, in terms of Adjusted Determination Coefficients; it is seen that all models except McNally and Modified Compartmental produced values below 0.99, and in terms of Accuracy and Bias Factors, it was determined that Richard, McNally, Quadratic Partial and Modified Compartmental models were the closest to 1 compared to other models. In terms of Durbin-Watson Autocorrelation values; all models except McNally, Cubic Partial, Quadratic Partial and Modified Compartmental models tend to have positive autocorrelation. In terms of Akaike Information Criterion, Adjusted Akaike Information Criterion and Bayesian Information Criterion, the values obtained from McNally, Cubic Piecewise, Quadratic Piecewise and Modified Compartmental models were the smallest values compared to other models. The curves obtained for the first period daily egg yields are as in Figure 3.

Table 9. Comparison criteria for daily egg yields in 1st period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Gompertz	3.55	0.9896	1.21	1.09	0.02	118.42	118.43	125.95
Logistic	3.51	0.9897	1.15	1.11	0.56	117.25	117.26	124.78
Richard	3.69	0.9892	1.01	1.00	0.55	123.84	123.85	133.88
McNally	1.07	0.9969	1.01	1.00	1.74	10.37	10.38	20.41
Gamma	17.13	0.9500	1.13	0.91	0.12	261.32	261.33	268.85
Cubic Piecewise	0.98	0.9100	1.07	0.96	1.86	3.79	3.81	16.35
Quadratic	3.72	0.6529	1.14	1.12	0.51	122.68	122.69	130.21
Quadratic Piecewise	1.16	0.8931	1.01	1.03	1.55	27.49	27.51	37.53
Modified Compartmental	1.17	0.9966	1.02	1.00	1.56	20.38	20.40	32.94

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

Table 10. Comparison criteria for daily egg yields in the second period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Gompertz	1.13	0.9954	1.00	1.00	0.08	14.03	14.05	21.57
Logistic	1.15	0.9953	1.00	1.00	1.88	15.49	15.50	23.02
Richard	1.14	0.9953	1.00	1.00	1.92	16.58	16.60	26.63
McNally	0.94	0.9962	1.00	1.00	2.41	-2.04	-2.02	8.00
Gamma	7.38	0.9697	1.20	0.80	0.33	184.78	184.79	192.31
Cubic Piecewise	3.29	0.5398	1.00	1.00	2.38	113.25	113.26	125.80
Quadratic	6.04	0.1263	1.10	1.00	0.70	164.63	183.94	167.14
Quadratic Piecewise	1.30	0.9947	1.00	1.00	1.47	27.54	27.561	37.59
Modified Compartmental	9.40	0.9619	1.00	0.90	2.37	209.84	209.85	222.39

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

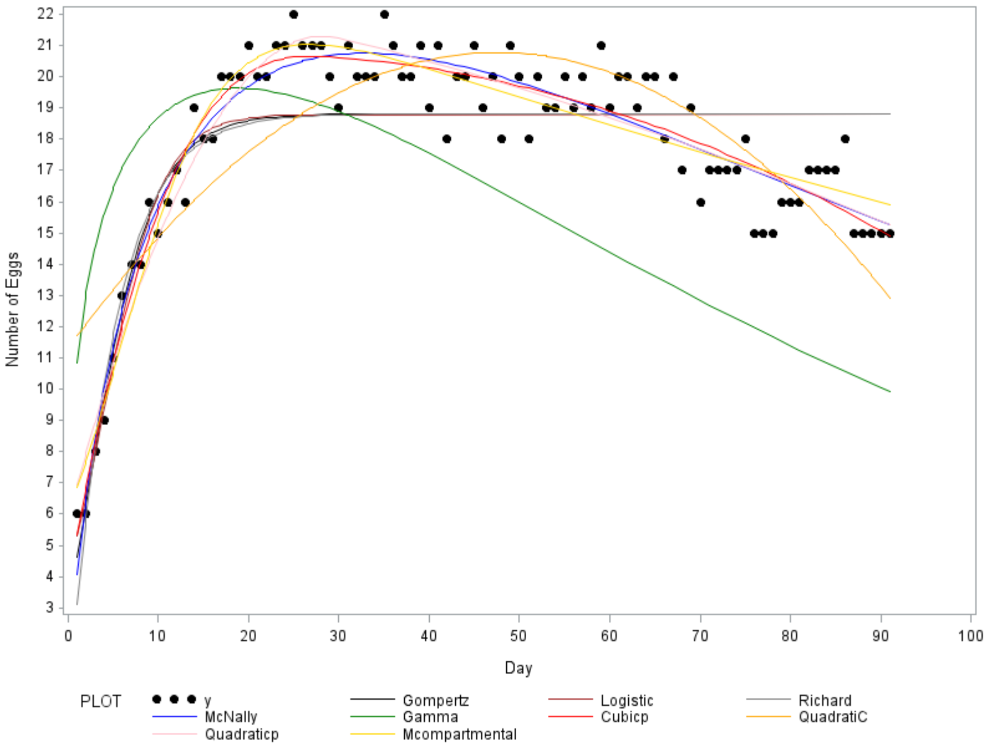

Figure 3. Curves obtained for daily egg yields in the 1st period.

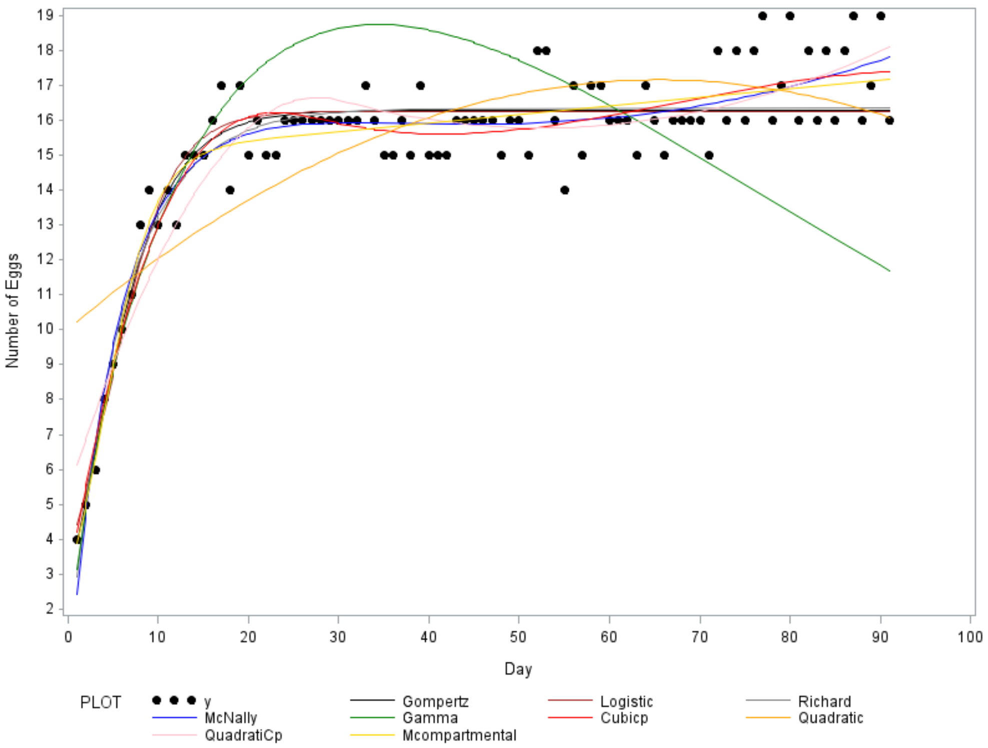

Figure 4. Curves obtained for daily egg yields in the 2nd period.

When the comparison criteria for daily egg yields of the 2nd period are examined in Table 10; it is seen that the best results in terms of Error Squares Error Mean Squares were obtained from Gompertz, Logistic, Richard, McNally and Quadratic Piecewise models, in terms of Corrected Determination Coefficients; it is seen that all models except Cubic Piecewise and Quadratic produced values above 0.96, and in terms of Accuracy and Bias Factors, it was determined that all models except Gamma and Modified Compartmental had the closest values to 1. In terms of Durbin-Watson Autocorrelation values; there is no problem of positive autocorrelation in all models except Gompertz, Gamma and Quadratic models. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, the values obtained from the McNally model were the smallest values compared to other models. The curves obtained for daily egg yields of the 2nd period are as in Figure 4.

For the egg width values of the first and second periods, the values of the mean square error, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion obtained from 4 different models on the averages of 22 compartments are given in Table 11 and Table 12, the arithmetic mean and standard errors are given in Table 13, and the curves obtained for the egg width values of the first and second periods are given in Figure 5 and Figure 6.

Table 11. Comparison criteria for the egg width values of the first period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Gompertz	0.0130	0.999	1.00	1.00	2.54	-53.67	-53.50	-51.97
Gamma	0.0129	0.999	1.00	1.00	2.67	-53.97	-53.80	-52.27
Cubic Piecewise	0.0148	0.55	1.00	1.00	2.93	-51.13	-50.88	-48.30
Cubic	0.0134	0.53	1.00	1.00	2.91	-52.80	-52.60	-50.54

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

Table 12. Comparison criteria for egg width values in the second period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Gompertz	0.0265	0.999	1.00	1.00	2.11	-37.54	-37.33	-36.35
Gamma	0.0182	0.999	1.00	1.00	2.68	-41.54	-41.32	-40.34
Cubic Piecewise	0.0172	0.721	1.00	1.00	3.02	-39.60	-39.27	-37.61
Cubic	0.0175	0.717	1.00	1.00	3.02	-41.42	-41.16	-39.83

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

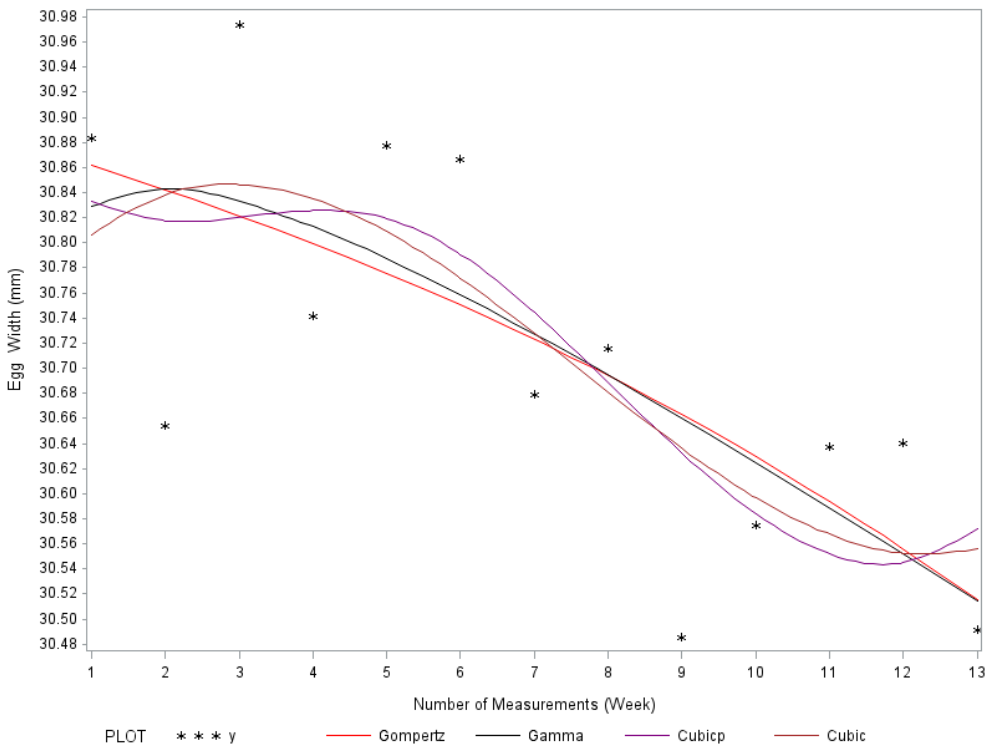

Figure 5. Curves obtained for egg width values in the first period.

When the comparison criteria for the egg width values of the first period are examined in Table 11; the best results in terms of Error Squares and Error Mean Squares were obtained from the Gompertz and Gamma models, and in terms of Corrected Determination Coefficients; it was seen that the Gompertz and Gamma models produced values above 0.99, and in terms of Accuracy and Bias Factors, it was determined that all models had the closest values to the value of 1. In terms of Durbin-Watson Autocorrelation values; it was found to be close to the value of 2 in the Gompertz and Gamma models, while it was closer to the negative autocorrelation region in the Cubic Piecewise and Cubic models.

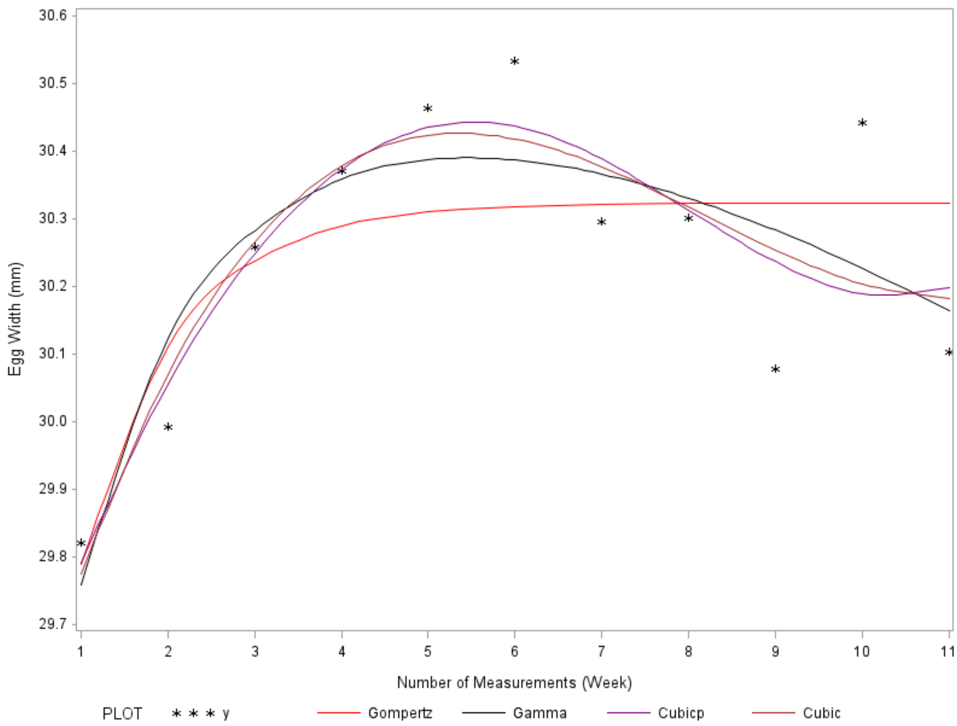

Figure 6. Curves obtained for egg width values in the second period.

In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, values very close to each other were obtained in all models. The curves obtained for the egg width values of the first period are as in Figure 5.

When the comparison criteria for the egg width values of the second period are examined in Table 12; it is seen that the best results in terms of Error Squares and Error Mean Squares were obtained from the Cubic Piecewise and Cubic models, and in terms of Corrected Determination Coefficients; it is seen that the Gompertz and Gamma models produced values above 0.99, and in terms of Accuracy and Bias Factors, it was determined that all models were closest to the value of 1. In terms of Durbin-Watson Autocorrelation values; it was found to be close to the value of two in the Gompertz and Gamma models, while it was closer to the negative autocorrelation region in the Cubic Piecewise and Cubic models. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, values very close to each other were obtained in all models. The curves obtained for the egg width values of the second period are as in Figure 6.

For the egg length values of the I. and II. periods, the values of Mean Square Error, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion obtained from 4 different models on the averages of 22 compartments are given in Table 14 and Table 15, the arithmetic mean and standard errors in Table 16, and the curves obtained for the egg length values of the 1st and the 2nd periods are given in Figure 7 and Figure 8.

Table 13. Arithmetic means and standard errors for egg width values of the first and the second periods

Measurements (Week)	Period I	Period II
1	29.48 ± 0.128	29.82 ± 0.078
2	30.65 ± 0.073	29.99 ± 0.078
3	30.97 ± 0.074	30.26 ± 0.123
4	30.74 ± 0.083	30.37 ± 0.069
5	30.88 ± 0.073	30.46 ± 0.066
6	30.87 ± 0.074	30.53 ± 0.076
7	30.68 ± 0.069	30.30 ± 0.069
8	30.72 ± 0.073	30.30 ± 0.068
9	30.49 ± 0.077	30.08 ± 0.065
10	30.58 ± 0.082	30.44 ± 0.071
11	30.64 ± 0.086	30.10 ± 0.076
12	30.64 ± 0.068	-
13	30.49± 0.081	-

When the comparison criteria for the first period egg length values are examined in Table 14; it is seen that the best results in terms of Mean Square Error were obtained from the Gamma and Cubic models, in terms of Corrected Determination Coefficients; it is seen that the Gamma model produced values above 0.99, and in terms of Accuracy and Bias Factors, it was determined that all models had the closest values to 1. In terms of Durbin-Watson Autocorrelation values; it was found that the Cubic Piecewise and Cubic models were closer to the negative autocorrelation region. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, values very close to each other were obtained in all models. The curves obtained for the first period egg length values are as in Figure 7.

Table 14. Comparison criteria for egg size values in the first period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Logistic	0.073	0.002	1.00	1.00	2.785	-31.36	-31.20	-29.67
Gamma	0.071	0.999	1.00	1.00	2.909	-31.79	-31.63	-30.10
Cubic Piecewise	0.076	0.168	1.00	1.00	3.383	-29.77	-29.53	-26.94
Cubic	0.067	0.168	1.00	1.00	3.372	-31.77	-31.57	-29.51

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

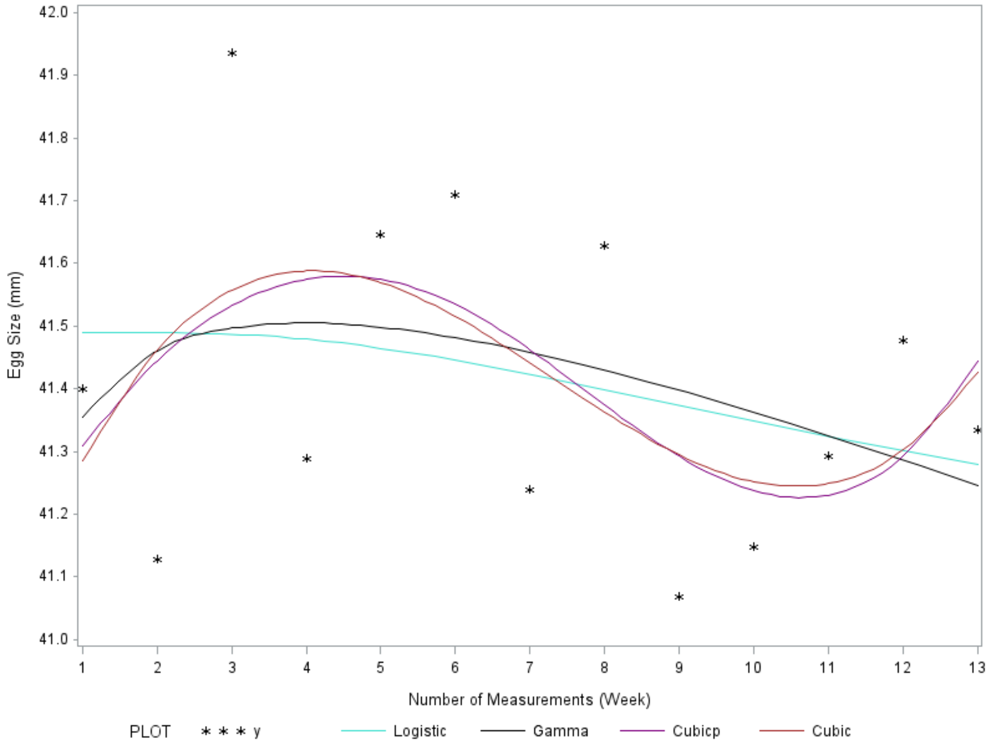

Figure 7. Curves obtained for egg length values of the first period.

Table 15. Comparison criteria for egg size values in the second period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
Logistic	0.027	0.571	1.00	1.00	3.15	-37.04	-36.83	-35.85
Gamma	0.026	0.999	1.00	1.00	3.16	-37.23	-37.02	-36.04
Cubic Piecewise	0.036	0.572	1.00	1.00	3.23	-33.07	-32.74	-31.08
Cubic	0.031	0.573	1.00	1.00	3.21	-35.07	-34.80	-33.48

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

When the comparison criteria for the egg length values of the 2nd period are examined in Table 15; it is seen that the best results in terms of Error Squares Error Mean Squares were obtained from the Logistic and Gamma models, in terms of Corrected Determination Coefficients; it is seen that the Gamma model produced values above 0.99, and in terms of Accuracy and Bias Factors, it was determined that all models had the closest values to 1. In terms of Durbin-Watson Autocorrelation values; it was determined that there was a negative autocorrelation problem in all models. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, values very close to each other were obtained in all models. The curves obtained for the egg length values of the 2nd period are as in Figure 8.

For the I. and II. period egg weight values, the values of Mean Square Error, Corrected Coefficient of Determination, Accuracy Factor, Bias Factor, Durbin-Watson, Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion obtained from 4 different models on the averages of 22 compartments are given in Table 17 and Table 18, the arithmetic mean and standard errors in Table 19, and the curves obtained for the first and the second periods egg weight values are given in Figure 9 and Figure 10.

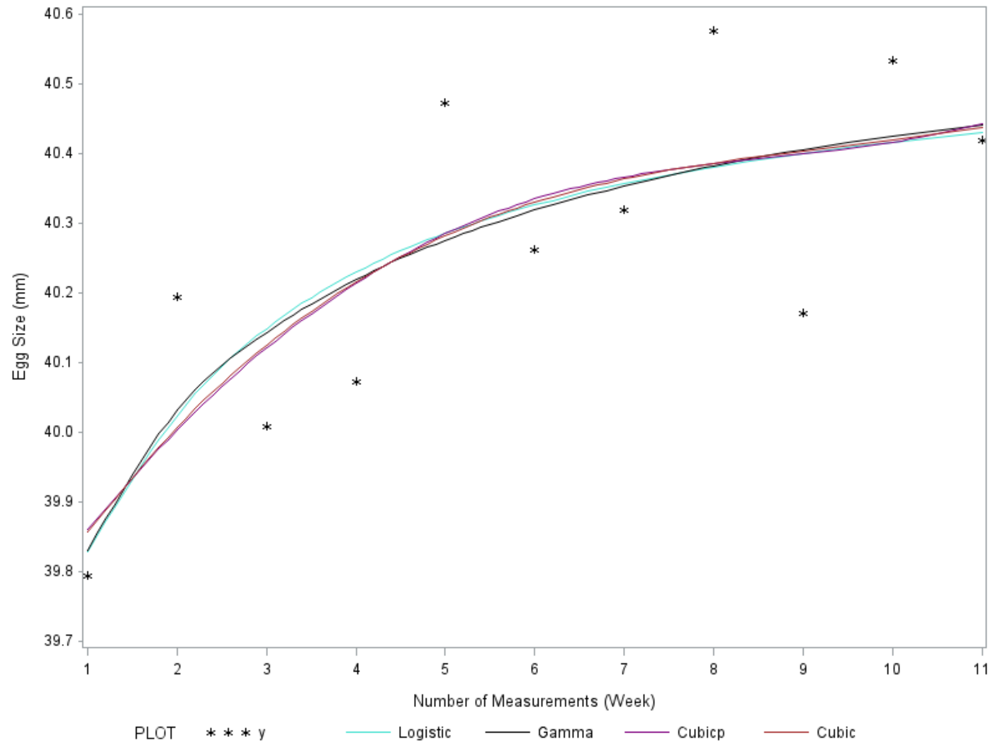

Figure 8. Curves obtained for egg length values of the second period.

Table 16. Arithmetic means and standard errors for egg length values of the first and the second periods

Measurements (Week)	Period I	Period II
1	39.19 ± 0.188	39.79 ± 0.164
2	41.13 ± 0.154	40.19 ± 0.127
3	41.94 ± 0.143	40.01 ± 0.169
4	41.29 ± 0.147	40.07 ± 0.117
5	41.65 ± 0.145	40.47 ± 0.122
6	41.71 ± 0.165	40.26 ± 0.131
7	41.24 ± 0.150	40.32 ± 0.127
8	41.63 ± 0.148	40.58 ± 0.138
9	41.07 ± 0.158	40.17 ± 0.131
10	41.15 ± 0.157	40.53 ± 0.146
11	41.29 ± 0.163	40.42 ± 0.145
12	41.48 ± 0.149	-
13	41.33 ± 0.157	-

When the comparison criteria for the first period egg weight values are examined in Table 17; it is seen that the best results in terms of Error Squares Error Mean Squares were obtained from Cubic Piecewise and Cubic models, in terms of Corrected Determination Coefficients; it is seen that values above 0.99 were produced in McNally and Gamma models, and in terms of Accuracy and Bias Factors, it was determined that all models except the Gamma model were closest to the value of 1. In terms of Durbin-Watson Autocorrelation values; it was found that the Gamma model was closer to the value of 2. In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, very close values were obtained in all models. The curves obtained for the first period egg weight values are as in Figure 9.

When the comparison criteria for the egg weight values of the 2nd period are examined in Table 18; it is seen that the best results in terms of Error Squares Error Mean Squares were obtained from the McNally and Cubic models, in terms of Corrected Determination Coefficients; it is seen that the McNally model produced values above 0.99, and in terms of Accuracy and Bias Factors, it was determined that all models except the Gamma model were closest to the value of 1. In terms of Durbin-Watson Autocorrelation Values; it was found that the McNally and Gamma models were closer to the value of 2.

Table 17. Comparison criteria for egg weight values in the first period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
McNally	0.093	0.999	1.01	1.00	2.67	-27.61	-27.41	-25.35
Gamma	0.104	0.999	1.01	0.99	2.15	-26.83	-26.66	-25.13
Cubic Piecewise	0.088	0.380	1.01	1.00	2.85	-26.24	-26.00	-23.42
Cubic	0.088	0.380	1.01	1.00	2.85	-28.24	-28.04	-25.98

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

Table 18. Comparison criteria for egg weight values in the second period

Models	EMS	CCD	AF	BF	DW	AIC	CAIC	BIC
McNally	0.049	0.999	1.00	1.00	2.56	-30.24	-29.97	-28.65
Gamma	0.078	0.690	1.00	0.99	1.84	-25.63	-25.42	-24.44
Cubic Piecewise	0.053	0.840	1.00	1.00	2.86	-28.91	-28.57	-26.92
Cubic	0.047	0.830	1.00	1.00	2.73	-30.57	-30.30	-28.98

MSE= mean square error, CCD= corrected coefficient of determination, AF= accuracy factor, BF= bias factor, DW= Durbin-Watson, AIC= Akaike information criterion, CAIC= corrected Akaike information criterion, BIC= Bayesian information criterion.

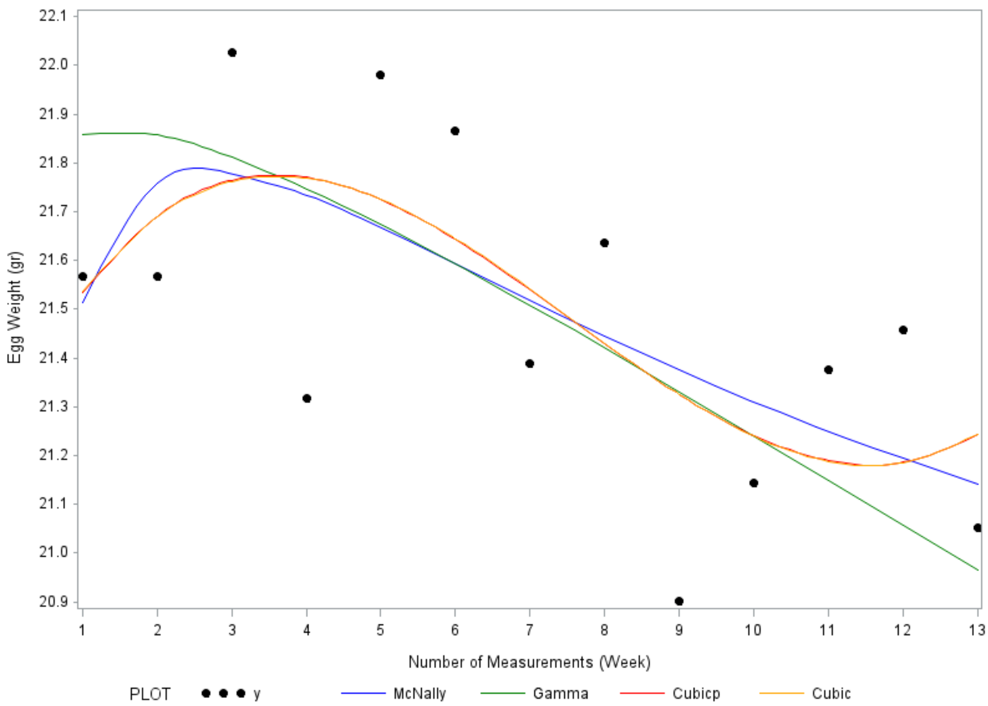

Figure 9. Curves obtained for egg weight values of the first period.

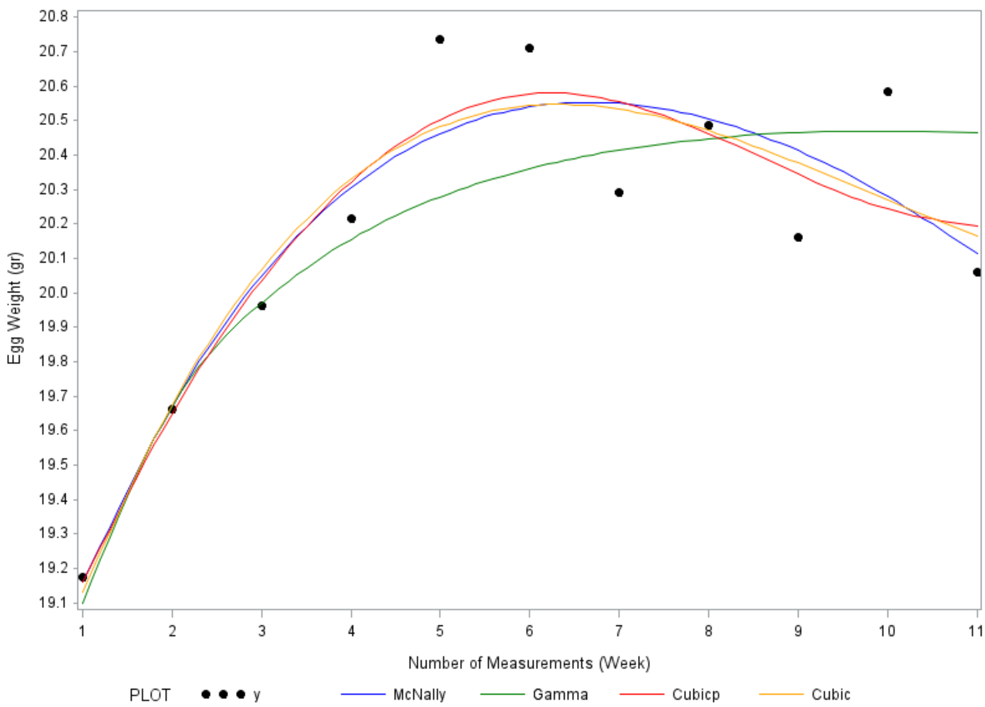

Figure 10. Curves obtained for egg weight values of the second period.

In terms of Akaike Information Criterion, Corrected Akaike Information Criterion and Bayesian Information Criterion, values very close to each other were obtained in all models. The curves obtained for the egg weight values of the 2nd period are as in Figure 10.

Table 19. Arithmetic means and standard errors for egg weight values of the first and the second periods

Measurements (Week)	Period I	Period II
1	18.46 ± 0.178	19.17 ± 0.142
2	21.57 ± 0.137	19.66 ± 0.142
3	22.03 ± 0.153	19.96 ± 0.135
4	21.32 ± 0.153	20.22 ± 0.126
5	21.98 ± 0.145	20.73 ± 0.126
6	21.87 ± 0.152	20.71 ± 0.143
7	21.39 ± 0.130	20.29 ± 0.129
8	21.64 ± 0.149	20.49 ± 0.139
9	20.90 ± 0.156	20.16 ± 0.130
10	21.14 ± 0.157	20.58 ± 0.140
11	21.38 ± 0.166	20.06 ± 0.133
12	21.46 ± 0.136	-
13	21.05 ± 0.154	-

4. Conclusion

As a result of the study; Gamma was determined as the most suitable model for modeling cumulative egg yields and length values, McNally for modeling daily egg yields and weight values, and Gompertz and Gamma models for modeling egg width values.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	T.T.	İ.G.	M.Ş.
C	50	25	25
D	40	30	30
S		100	
DCP	50	25	25
DAI	20	40	40
L	40	40	20
W	50	25	25
CR	30	35	35
SR	30	35	35
PM	30	35	35
FA	30	35	35

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. The necessary permission was taken from the Ministry of Agriculture and Forestry (Approval date: December 30, 2021; protocol number: E-21264211-288.04-3944802).

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