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COMPARATIVE ANALYSIS OF THE EQUATIONS USED IN MODELING INDIVIDUAL LACTATION CURVES IN ANATOLIAN WATER BUFFALO (*Bubalus bubalis*)

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Abstract: In this study, the equations used in modeling the individual lactation curves of Anatolian Water Buffalo were comparatively examined and the most suitable model or models were tried to be determined. For this purpose, individuals with 8, 9 and 10 lactation records were selected among 8057 Anatolian Water Buffalo and a total of 1591 individual lactation curves were modeled. Guo-Salve, Grossman, Cappio-Borlino, Parabolic Exponential, Cobby and Le Du, Logarithmic Quadratic, Wilmink, Logarithmic Linear, Quadratic, Inverse Polynomial and Wood equations were used in the study. When comparing the models, coefficient of determination, mean squared error, Durbin-Watson autocorrelation test, the Akaike Information Criterion were considered. Among the models used in the study, the Cobby and Le Du, Wood and Logarithmic Quadratic models gave the best results, as opposed to the Guo-Salve model.

Keywords: Anatolian water buffalo, Individual lactation, Modeling, *Bubalus bubalis*

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1. Introduction

Modeling studies have been used extensively in both ovine, bovine and poultry farming throughout history. While few models and equations were used in the initial periods, there has been a noticeable increase in the number of models and equations used over time, especially in parallel with the developments in the fields of computers and software. This is true for small cattle (Bayazıt et al., 2022; Tahtalı et al., 2020), cattle (Şahin and Efe, 2010; Cankaya et al., 2014) and poultry (Yavuz et al., 2019; Yalçınöz and Şahin, 2020; Tolun et al., 2023) has led to many studies on the use of many models in breeding and the selection of the best models.

In addition to the amount of milk obtained during a lactation, both in ovine and bovine livestock, researchers have been intensely interested in the structure of the lactation curve. The most important reason for this is the determination of genetically high productive individuals and their use in breeding studies. For this purpose, it is extremely difficult to determine the individuals with the best or the worst yield in the models made on the average of the herd. Because, in the models made on the average of the herd, the individuals with the best or the worst efficiency are camouflaged in the herd and it is very difficult to select these individuals (Yavuz et al., 2019; Gök et al., 2021). Considering that your influence on the individuals selected by selection or the individuals selected in breeding studies emerges after many years, it becomes clear how important the selection and selection processes are. From this point of view, it becomes clear how important it is to model individual lactation curves with correct equations. Establishment of individual lactation curves seems to be extremely difficult in terms of time and labor compared to the herd average at the initial stage. However, this difficulty seems to be extremely insignificant when it is considered that the results of the breeding studies emerge after a very long time.

The buffaloes in Türkiye are in the Mediterranean buffalo subgroup, which is in the river buffalo group (Şahin et al., 2019). This native animal breed is referred to as the Anatolian Water Buffalo. Considering that buffalo breeding is generally in the form of small family businesses in Türkiye as well as around the world, it clearly reveals how difficult and valuable the breeding studies are compared to the breeding of other species. First of all, in the study of these models, the lactation yields and milk content of Anatolian Water Buffalo were determined (Ağyar et al., 2020; Ağyar, 2021). For this reason, each of the studies on buffalo breeding and breeding is very valuable. This makes it more important to model the limited number of lactation data with correct models and not to waste the given data. Herd management studies are carried out in different geographies on buffalo populations with limited data sets (Sing and Gopal, 1982; Catillo et al., 2002; Aziz et al., 2006).

For this purpose, in this study, as many models as possible were included in the research and the model evaluation phase was examined from a statistical point of view. In addition, considering that Buffalo breeding is carried out in different geographies and has different care and feeding conditions, it is aimed to propose more than one model.

2. Materials and Methods

2.1. Materials

Animal material of the study comprises of Anatolian Water Buffalo were selected among 8057 lactation records in Muş province (39°29' and 38°29' N 41°06' and 41°47' E) between 2012 and 2022. Among these 8057 Anatolian Water Buffaloes, 1591 of which have individual lactation data of 8, 9 and 10 lactations were selected.

2.2. Methods

2.2.1. Equations used in modeling

In this study, 11 different models, including Guo-Salve, Parabolic Exponantial, Grossman, Cappio-Borlino, Cobby and Le Du, Logarithmic Linear, Quadratic, Logarithmic Quadratic, Wilmink, Inverse Polynomial, Wood were used to model individual lactation curves of Anatolian Water Buffalo. Gauss-Newton algorithm was used for parameter estimation. Curve plots and model parameter estimations were made in the SAS 9.1 package program. Expansions and equations of these models (1-11) are as follows:

Wood (equation 1):

$$Y_t = at^b.\, e^{-(ct)} \quad (1)$$

Inverse Polynomial (equation 2):

$$Y_t = t/(a + bt + ct^2) \quad (2)$$

Wilmink (equation 3):

$$Y_t = a + bt + ce^{-0{,}05t} \quad (3)$$

Logarithmic Linear (equation 4):

$$Y_t = a + bt + ct^2 + d.\log(t^2) \quad (4)$$

Quadratic (equation 5):

$$Y_t = a + bt + ct^2 \quad (5)$$

Logarithmic Quadratic (equation 6):

$$Y_t = a + bt + c.\log(t) \quad (6)$$

Cobby ve Le Du (equation 7):

$$Y_t = a - bt - a.\, e^{-ct} \quad (7)$$

Cappio-Borlino (equation 8):

$$Y_t = at^{bex(-ct)} \quad (8)$$

Grossman (equation 9):

$$Y_t = at^b.\, e^{-cn}(1 + u.\, sin(x) + v.\, co(x)) \quad (9)$$

Parabolic Exponantial (equation 10):

$$Y_t = ae(bt - ct^2) \quad (10)$$

Guo-Salve (equation 11):

$$Y_t = a + bt^{0.5} + c\ln(t) \quad (11)$$

Is in the form. Here, Yt: T. milk yield per day, a: Initial milk yields in Cobby and Le Du, Parabolic Exponential, Cappio-Borlino, Wood, Wilmink, Guo-Salve and Grossman models, b and c: slope parameters in Cobby and Le Du, Parabolic Exponential, Cappio-Borlino, Wood, Wilmink, Guo-Salve and Grossman models, x: The day on which the daily yield is calculated in radians in the Grossman model, u and v: the year coefficient in the Grossman model, a, b, c: regression coefficients in Inverse Polynomial, Logarithmic Linear, logarithmic Quadratic and Quadratic models, e: 2.7182 in Cobby and Le Du, Wood, Wilmink, Grossman and Parabolic Exponential models, means.

2.2.2. Model comparison criteria

In this study, in the modeling of individual lactation curves, the coefficient of determination in determining how well the Wood, Quadratic, Inverse Polynomial, Wilmink, Logarithmic Linear, Logarithmic Quadratic, Cobby and Le Du, Cappio-Borlino, Parabolic Exponential, Grossman, and Guo-Salve equations fit the point distribution, coefficient of determination, mean squared error, Durbin-Watson autocorrelation test, Akaike Information Criterion were taken into account (Şahin et al., 2011; Cankaya et al., 2014).

Coefficient of determination (R^2)

R^2 value takes values in the range of 0≤R2≤1. In addition, R^2 shows the extent to which all variations in the data can be expressed by the model suitable for the point distribution. High values in this range mean that the model fits the point distribution well. Calculation equation of the coefficient of determination; equation 12.

$$R^2 = 1 - (SSE/SSG) \quad (12)$$

Here, SSE is error sum of squares and SSG is grand sum of squares.

Error mean squares

One parameter that shows that the model is suitable is that the Mean Squared Error is low. This parameter, used to compare models, is calculated like PLA, equations 13.

$$MSE = SSE/(n - p) \quad (13)$$

In the equation, p is the number of parameters in the model and n is the number of observation pairs.

Akaike Information Criteria (AIC)

The Akaike Information Criterion value is the criterion used to select the statistically most appropriate one among the obtained equations in the calculations, the model with the smallest AIC value is considered the most suitable model. Equation for determining the AIC value (equation 14).

$$AIC = n \times \ln(SSE/n) + 2k \quad (14)$$

In the equation, n is the number of observation pairs, SSE is error sum of squares, ln is log10 base, and k is the number of parameters in the model.

Durbin-Watson autocorrelation test (DW)

It is a test to test whether the error terms of the estimated model are correlated. The DW value range is 0 to 4. Obtaining a value around 2 as a result of the calculation made with this test is a strong indicator that there is no autocorrelation. Because if the DW value is exactly 2, it is accepted that there is no autocorrelation. Equation for determining the DW value (equation 15).

$$DW = \frac{\sum_{t=2}^{n}(e_1 - e_2)^2}{\sum_{t=1}^{n} e_1^2} \quad (15)$$

Here, t is time and e_i is error term.

SAS 9.1 statistical package program was used to obtain the parameter estimates and lactation curves of the models. NLIN procedure and Gauss-Newton algorithm were used to obtain the parameters.

3. Results

In the study, individual lactation records of 8057 Anatolian Water Buffalo were taken into account. Among these records, those with less than 8 and more than 10 lactation records were excluded from the evaluation. At the same time, individuals whose lactation curve was outside the known distribution were excluded from the modeling. Considering all these, modeling studies were conducted on 548 individuals with 10 lactation records, 618 individuals with 9 lactation records, and 425 individuals with 8 lactation records. In total, lactation records of 1591 individuals were included in the modeling. Coefficient of determination, mean error squares, Durbin-Watson autocorrelation values and Akaike Information values Criterion belonging to all models and obtained are presented in Table 1, Table 2 and Table 3 (with plus and minus standard errors).

As seen in Table 1, the mean square error of the Wood, coefficient of determination, Quadratic, Logarithmic Quadratic and Cobby and Le Du models, Akaike Information criterion and Durbin-Watson values gave the best results in individuals with 10 lactation records. When Durbin-Watson values are examined in Cappio-Barlino, Parabolic Exponantial and Grossman models, it is seen that there is an autocorrelation problem.

In Table 2, it is seen that the Wood, Logarithmic Quadratic, and Cobby and Le Du models give the best results in individuals with 9 lactation records, when the mean squared error, coefficient of determination, Durbin-Watson values and Akaike Information criterion values are taken into account. Although the coefficient of determination is high in the Parabolic Exponential model, when Durbin-Watson values are examined, it is seen that there is an autocorrelation problem.

Table 1. Coefficient of determination, mean error squares, Durbin-Watson autocorrelation values and Akaike information values for individual lactation curves of Anatolian Water Buffalo with 10 lactation records (n=548).

Models	Milk Control (10)			
	HKO	R^2	AIC	DW
Wood	0.018±0.03	0.9983±0.05	-7.126±0.5	2.07±0.4
Wilmink	0.028±0.07	0.9752±0.17	3.638±0.1	2.33±0.3
Quadratic	0.032±0.06	0.9903±0.27	-9.697±0.3	1.91±0.4
Inverse Polynomial	0.134±0.03	0.9849±0.06	-5.323±0.3	2.11±0.4
Logarithmic Linear	0.027±0.07	0.9765±0.15	2.725±3.1	1.76±0.2
Logarithmic Quadratic	0.026±0.05	0.9941±0.47	-5.154±2.7	1.67±0.7
Cobby and Le Du	0.037±0.03	0.9972±0.09	-1.214±2.1	1.84±0.4
Cappio-Barlino	0.161±0.12	0.9927±0.19	6.249±3.7	3.91±0.2
Parabolic Exponantial	0.019±0.05	0.9994±0.04	10.341±3.2	3.05±0.1
Guo-Salve	0.184±0.32	0.8178±0.41	-0.577±3.1	2.98±0.1
Grossman	0.091±0.07	0.9994±0.49	-8.131±2.4	3.98±0.4

Table 2. Mean error squares, coefficient of determination, Akaike information criterion and Durbin-Watson autocorrelation values for individual lactation curves of Anatolian Water Buffalo with 9 lactation records (n=618).

Models	Milk Control (9)			
	HKO	R^2	AIC	DW
Wood	0.23±0.12	0.9952±0.05	-21.146±1.5	2.16±0.2
Wilmink	2.19±0.95	0.8121±0.09	3.448±0.1	2.33±0.3
Quadratic	2.33±0.72	0.7995±1.28	0.807±2.3	2.46±0.1
Inverse Polynomial	0.8±0.81	0.8889±0.17	-5.813±0.3	0.97±0.9
Logarithmic Linear	0.92±0.89	0.9203±0.54	2.815±3.1	2.95±0.2
Logarithmic Quadratic	0.38±0.41	0.9724±0.21	-20.453±1.1	1.90±0.7
Cobby and Le Du	0.76±0.17	0.9896±0.27	-12.312±1.2	1.63±0.4
Cappio-Barlino	3.98±0.78	0.9335±1.85	-16.301±3.1	1.90±0.2
Parabolic Exponantial	1.04±0.33	0.9855±0.99	11.315±4.2	3.64±0.1
Guo-Salve	4.67±1.59	0.5322±2.97	-0.558±3.1	2.97±0.1
Grossman	6.47±2.55	0.9227±2.41	-8.144±2.6	2.98±0.4

Table 3. Mean error squares, coefficient of determination, Durbin-Watson values and Akaike Information criterion values for individual lactation curves of Anatolian Water Buffalo with 8 lactation records (n=425).

Models	Milk Control (8)			
	HKO	R^2	AIC	DW
Wood	1.08±1.25	0.9815±0.09	-31.106±1.2	2.41±0.2
Wilmink	3.55±2.45	0.6745±1.47	3.538±0.1	2.37±0.3
Quadratic	3.66±2.78	0.6711±2.01	0.877±2.3	2.49±0.1
Inverse Polynomial	0.30±1.45	0.9954±0.08	5.823±0.3	0.54±0.4
Logarithmic Linear	2.15±3.11	0.8027±1.25	2.875±3.1	1.73±0.2
Logarithmic Quadratic	0.84±3.78	0.9880±0.47	-21.443±2.4	1.66±0.7
Cobby and Le Du	1.90±4.56	0.9705±1.92	-12.234±1.1	1.84±0.1
Cappio-Barlino	4.14±3.89	0.9231±2.33	-16.301±3.1	1.90±0.2
Parabolic Exponantial	2.69±4.15	0.9585±3.02	11.335±4.2	2.61±0.1
Guo-Salve	4.70±15.6	0.4825±11.4	-0.568±3.1	2.96±0.1
Grossman	6.89±2.56	0.9151±4.09	-8.137±2.6	2.91±0.4

When Table 3 is examined, it is seen that Wood, Logarithmic Quadratic and Cobby and Le Du models give the best results in individuals with 8 lactation records, considering the mean squared error, coefficient of determination, Durbin-Watson values and Akaike Information criterion values.
Figures 1, 2 and 3, lactation curves for Wood, Inverse Polynomial, Cobby and Le Du, Logarithmic Linear, Grossman, Wilmink, Logarithmic Quadratic, Quadratic, Cappio-Borlino, Parabolic Exponential and Guo-Salve models are given.
The lactation curves obtained for 8, 9 and 10 lactation records of Wood, Logarithmic Quadratic and Cobby and Le Du models, which were determined as the best model, are given in Figure 4, Figure 5 and Figure 6.

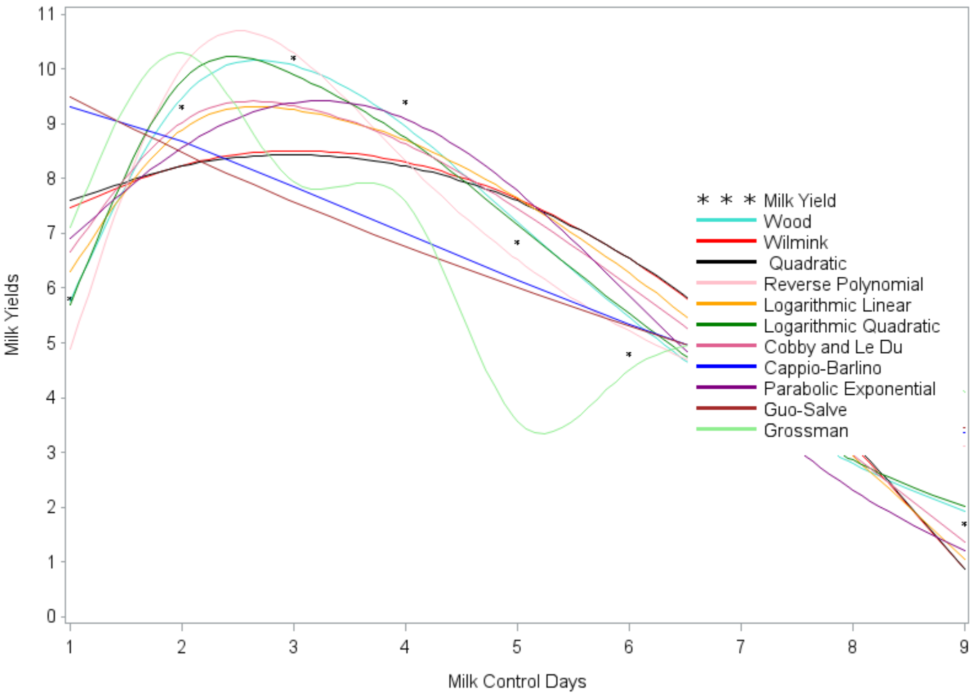

Figure 1. Lactation curves for 10 lactation records of 11 different models.

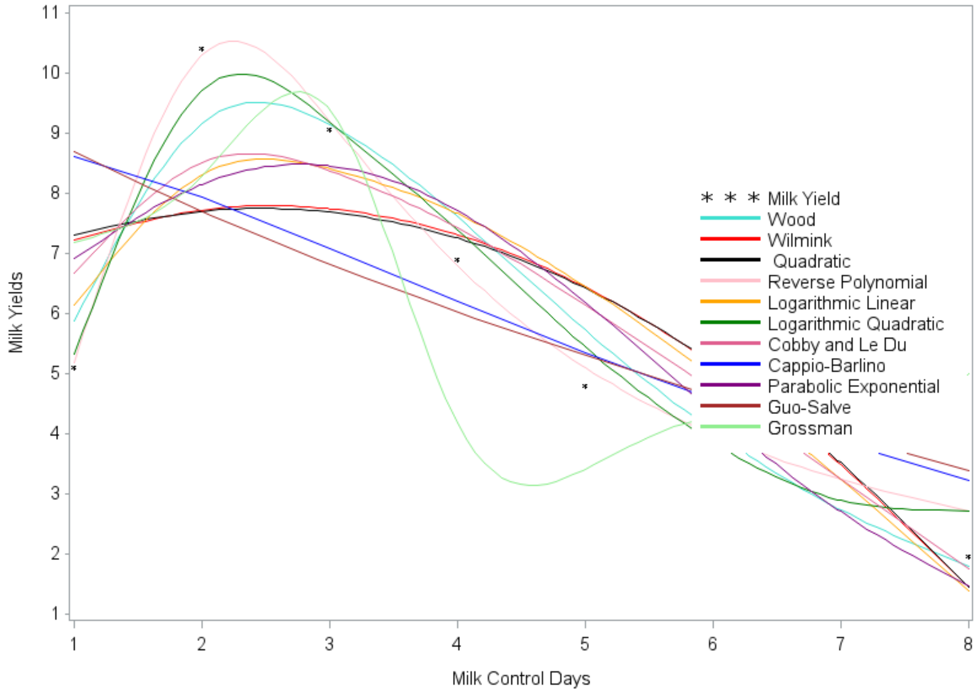

Figure 2. Lactation curves for 9 lactation records of 11 different models.

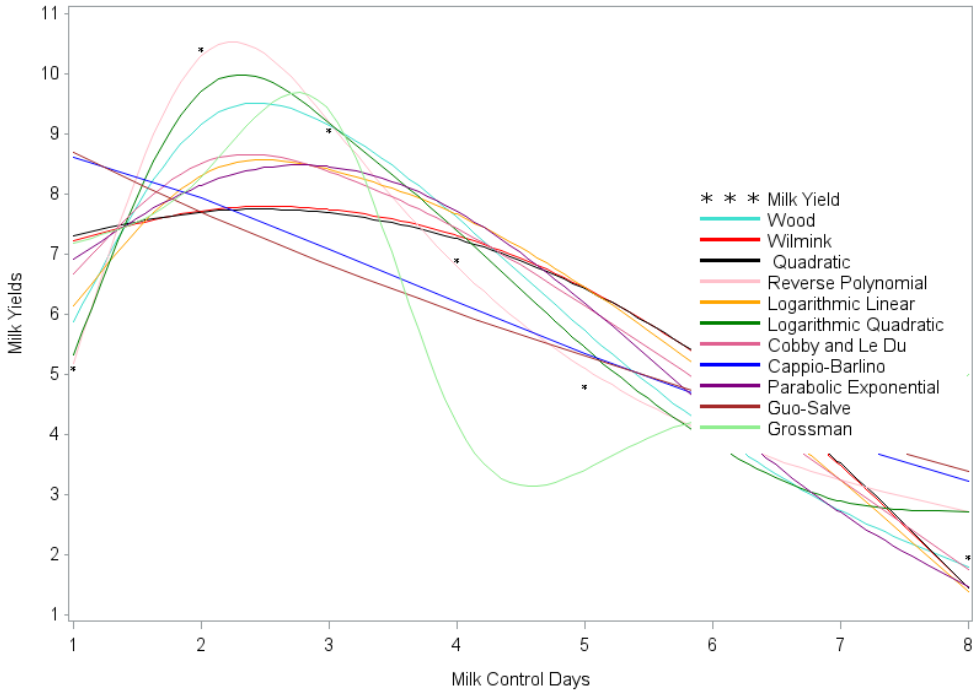

Figure 3. Lactation curves for 8 lactation records of 11 different models.

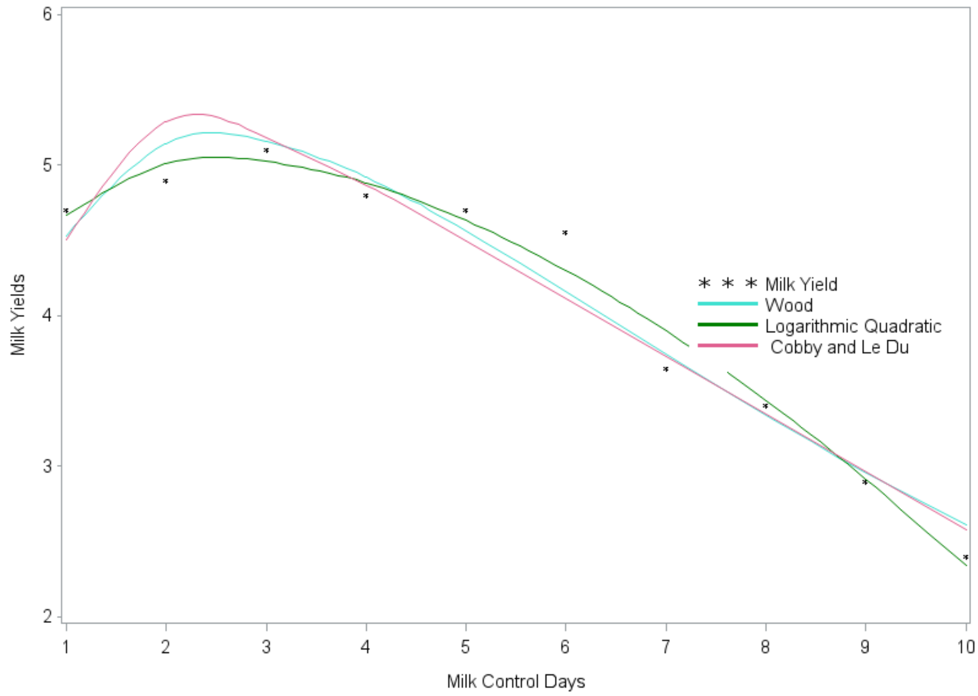

Figure 4. Lactation curves obtained for the 10 lactation records of the top 3 models.

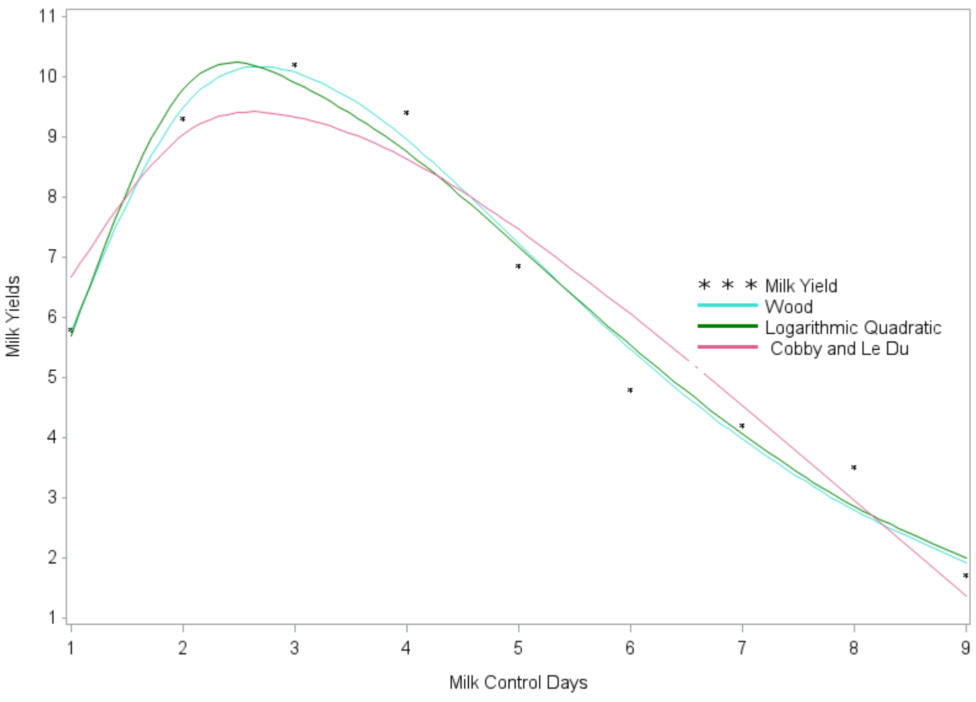

Figure 5. Lactation curves obtained for the 9 lactation records of the top 3 models.

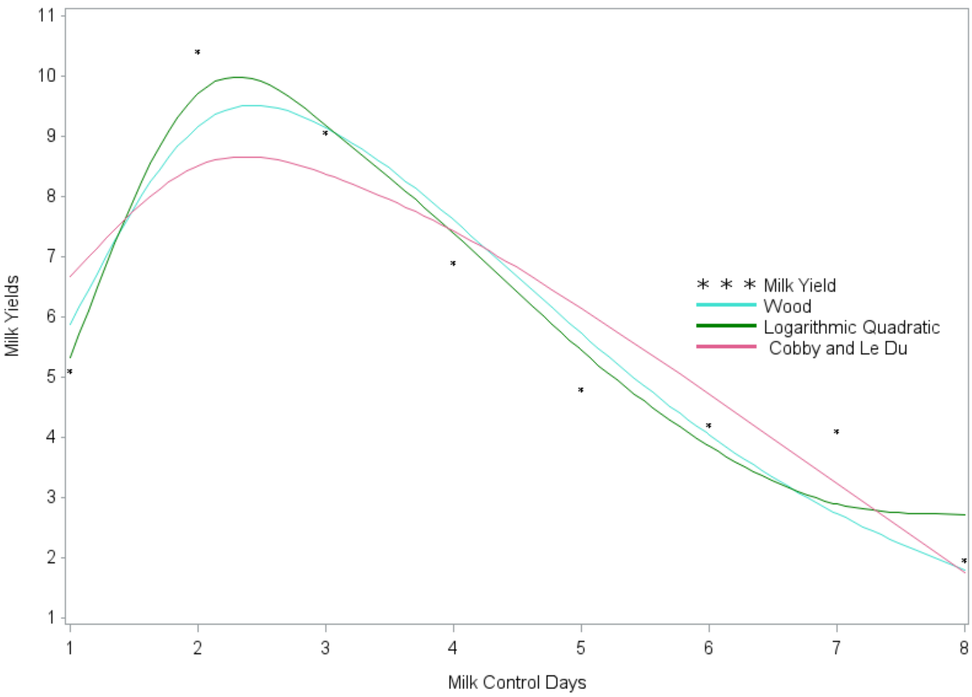

Figure 6. Lactation curves obtained for the 8 lactation records of the top 3 models.

4. Discussion

In this study, in the modeling of individual lactation curves, the fit point distribution, determination coefficient, mean square error, fit point distribution of Wood, Wilmink, Inverse Polynomial, Quadratic, Logarithmic Linear, Grossman, Cobby and Le Du, Cappio-Borlino, Logarithmic Quadratic, Parabolic Exponential and Guo-Salve equations, Durbin-Watson autocorrelation test, Akaike Information Criteria were considered. Considering the model comparison criteria, Wood, Quadratic, Logarithmic Quadratic and Cobby and Le Du models in the group with 10 lactation milk records, Wood, Logarithmic Quadratic, and Cobby and Le Du models in the group with 9 lactation milk records, and Wood in the group with 8 lactation milk records and Logarithmic Quadratic models were determined as the best models. In all groups, it was concluded that the worst model was the Guo-Salve model. In their previous study on native buffalo breeds in the Brazilian region, they stated that the Wood model was the best model and examined 8 different models. (Barbosa et al., 2007). Prasad stated in his study that the Logarithmic Quadratic model (determination coefficient = 99.4%) is the best model for modeling the lactation curves of Murrah buffaloes (Prasad, 2003). In previous studies, it was stated that the best model for modeling lactation curves in dairy cattle was the Wood model (Kaygısız, 1999; Orhan and Kaygısız, 2002). In the previous study, 8 different models were used and it was stated that the best models for modeling the lactation curves of Anatolian Water Buffalo were Logarithmic Quadratic (determination coefficient = 0.994) and Quadratic models (determination coefficient = 0.970) (Aziz et al., 2006). Kaygısız used the Wood's model to model lactation curves in Anatolian Water Buffalo in his study and determined the coefficient of determination between 0.783 and 0.498 (Kaygısız, 1999). The findings of Orhan and Kaygısız (2002), Prasad (2003), Barbosa et al., (2007), Şahin et al. (2014) are in agreement with the findings obtained in this study. The determination coefficient variation ranges obtained from their study are in harmony with this study. However, in Kaygısız (1999)'s study, the determination coefficient variation range was stated to be quite low compared to the results of this study. On the other hand, in most of these studies, the determination coefficient and mean squares of error were considered in model comparisons, Akaike Information Criterion and autocorrelation values of models were not examined.

In addition, as can be seen from the literature review, almost all of the lactation curve models in buffalo breeding were made on the average of the herd. Studies on modeling individual lactation curves in buffalo breeding were not found in the literature reviews. For this reason, we believe that this study will contribute to breeding studies in terms of modeling and statistical comparison of individual lactation curves with different models in buffalo breeding.

As a result, in this study, it was concluded that Wood, Logarithmic Quadratic, and Cobby and Le Du models can be used to model individual lactation curves of Anatolian Water Buffalo.

5. Conclusion

Industrially promising Buffalo among livestock in the world. Although milk yield (kg) is lower than cattle. The only native water buffalo breed in Türkiye is the Anatolian Water Buffalo. Since 2011, the Anatolian Water

Buffalo Breeding Project has provided data on milk yields. A 10-year data set was used. It is aimed to model selected individual lactation yields. For the first time in this study, the individual lactation yields of Anatolian Water Buffaloes were studied on 11 models. It has been tried to suggest the most suitable model for use in selection studies. The use of these equations in the individual modeling of lactation curves in Anatolian Water Buffalo will increase the degree of accuracy in selection and contribute significantly to the success of breeding studies. As a result, the success of the models used on other farm animals of the 11 models in this study on buffalo was also tested.

Author Contributions

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

	O.A.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

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 author declared that there is no conflict of interest.

Ethical Consideration

This study was carried out in accordance with the approval (approval date: June 20, 2023, protocol code: 2023/011-E-19057416-125.02.01-10312049) of Republic of Türkiye, Ministry of Agriculture and Forestry, Directorate of Muş.

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