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Determination of the Best Lactation Curve Model and Lactation Curve Parameters using Different Nonlinear Models for Anatolian Buffaloes

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ABSTRACT

The present investigation was conducted to determine the lactation curve parameters and to choose the best model that defines the lactation curve. Data were composed of 4897 test day milk yield (TDMY) records from Anatolian buffaloes calved during 2014-2017 raised under different farm conditions in Amasya Province, Turkey. Five different lactation curve models such as Wood (WOD), Cobby and Le Du (CLD), Exponential (EXP), Parabolic Exponential (PEXP) and Quadratic (QUA) models were used. The adjusted multiple coefficient of determination (R^2_{adj}) and the residual standard deviation (RSD) were evaluated as parameters to detect the best fitted lactation curve model. The results revealed that WOD model described the highest R^2_{adj} (0.98) and with the lowest RSD (0.065), besides the highest R^2_{adj} (0.97) and the lowest RSD (0.087) were also observed in CLD model. To conclude, WOD and CLD models were detected to be the most suitable models defining the lactation curve of Anatolian buffaloes. As a result, using the parameters detected via WOD and CLD models in breeding studies will contribute significantly to the researches in this direction in these herds.

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INTRODUCTION

Milk is an important product in dairy farms (Hussain *et al*., 2018). Daily milk yield during the lactation period follows a curvilinear pattern, therefore a fitted model is necessary for this curve. Lactation curve can provide a valuable knowledge about dairy production (Shinde and Jadhav, 2017). The lactation curve is a graphical representation of milk yield and gives information about the prediction of total milk yield from a single or several test days in the early lactation period. Dairy producer makes better decisions early according to management based on production with such a knowledge (Nasri *et al*., 2008).

Mathematical models can serve several purposes in herd nutritional management, genetic breeding programs, decision-making on the milk production systems and culling programs to improve animal production (Shinde and Jadhav, 2017). The term lactation curve, which is a graphic representation of the milk yield, enriches characterization of production in the course of lactation, and provides estimation about peak yield and lactation persistency. The knowledge of the lactation curve shape is important for more accurate predictions to study and manage the diary industry. Mathematical modeling of lactation curve by suitable functions widely has been used in the dairy cattle. These functions can also represent a management tool in breeding and selection decisions for buffaloes (Ghavi Hossein-Zadeh, 2016).

Various mathematical models have been developed to describe the lactation curve shape in buffaloes (Wood, 1967; Ali and Schaeffer, 1987; Wilmink, 1987; Guo and Swalve, 1995; Dijkstra *et al*., 1997). However, the model of best fit has been still elusive due to the influence of various environmental factors. There has been rare information on lactation curve of buffaloes, particularly so in case of Anatolian buffaloes, where different functions were described, and the models of best fit differed (Sahoo *et al*., 2015).

In this study, lactation curve parameters were determined and by comparing the models used in defining lactation curves the best mathematical models was detected defining the lactation curve of Anatolian buffaloes.

MATERIALS AND METHODS

The test day milk yield (TDMY) records obtained from buffaloes farms in Amasya province where Anatolian buffaloes were kept in. Their cows calved from 2014 to 2017 under different conditions. Amasya province is located in the Mid-Black Sea Region of Turkey with 34°

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57' 06"-36° 31'53" East longitudes, and 41° 04' 54"-40° 16' 16" North latitudes. The province has a climate with a transition feature between a Mid Black Sea maritime climates. Long-term average annual temperature varies from 2.7 to 24.1 °C and average relative humidity was 52.5 to 69.4% (MARA, 2015). Buffaloes were kept and fed indoors during the winter and grazed outside from April to December (Kul *et al*., 2018).

TDMY records were collected during the morning and evening milking once a month in individual farms. The TDMY data known first five or more control yields of buffaloes to define the lactation curves, were obtained. Records of buffaloes with fewer than five test-day records were excluded from the analysis (Torshizi *et al*., 2011; Şahin *et al*., 2015). The records pertaining to cull in the middle of lactation, abortion, still-birth or any other pathological causes affecting the lactation yield of the buffaloes were considered as abnormalities and were removed from the dataset. The calving ages were divided into eight sub-groups from three to ten. Then, TDMY records were grouped according to age groups.

Final datasheet comprised of 4897 TDMY records, which consisted of TDMY records of 733 third, 846 fourth, 732 fifth, 757 sixth, 612 seventh, 480 eighth, 354 ninth and 383 tenth year of calving age.

As seen in Table I, five different models were used to estimate the lactation curve parameters.

Table I. Models used to describe the lactation curve.

Model		Functional form
Wood	WOD	Y_t: $at^b \exp(-ct)$
Cobby and Le Du	CLD	Y_t: $a - bt - a \exp(-ct)$
Exponential	EXP	Y_t: $a \exp(-ct)$
Parabolic Exponential	PEXP	Y_t: $a \exp(-bt+ct^2)$
Quadratic	QUA	Y_t: $a+bt+ct^2$

In the models, Yt = average daily yield in the t^{th} test day of lactation (kg); t = length of time since calving; e is the base of the natural logarithms (Ln); exp is exponential function; a is approximates the initial milk yield after calving; b is the increasing slope parameter up to lactation peak yield, and c is the decreasing slope parameter of lactation curve.

The models were tested for goodness of fit using adjusted coefficient of determination (R^2_{adj}), residual standard deviation (RSD).

R^2_{adj} was calculated using the following formula:

$$R^2_{adj} = 1 - [(n-1) / (n-p)] \times (1-R^2)$$

Where: R^2 is the multiple coefficient of determination, [R^2 =1−(RSS/TSS)]; RSS is the residual sum of squares, TSS is the total sum of squares, n is the number of observations and p is the number of parameters in the model (Cankaya *et al*., 2011; Ghavi Hossein-Zadeh, 2014).

$$RSD = \sqrt{RSS} / \sqrt{(n-p)}$$

Where; RSS is the residual sum of squares, n is the number of observations and p is the number of parameters in the model (Cankaya *et al*., 2011; Ghavi Hossein-Zadeh, 2014).

In this study, the most suitable model was identified on the basis of the highest R^2_{adj} and RSD. Modelling processing and its estimation were performed by using the Statistica 5.0. V (1995).

RESULTS AND DISCUSSION

The estimated functions of all studied calving ages are reported in Table II. Criteria such as R^2_{adj} and RSD were used to evaluate and compare the goodness of fit of these models (Dezfuli and Babaei, 2018). In this study, the WOD and CLD models had higher R^2_{adj} and lower RSD value compared to EXP, PEXP and QUA models (Table II). Results of present study indicated that WOD and CLD models were more appropriate models for explaining the properties of milk yield in all calving ages. Although R^2_{adj} value for PEXP model was high (0.94), RSD value (0.141) was higher than WOD and CLD models. The R^2_{adj} and RSD values for WOD and CLD models were determined as 0.98 and 0.065; 0.97 and 0.087, respectively. Nearly same R^2_{adj} value for WOD (Catillo *et al*., 2002; Gantner *et al*., 2010; Torshizi *et al*., 2011) and CLD (Soysal *et al*., 2016) models were determined in different buffalo breeds. In this study, R^2_{adj} values for WOD and CLD models were higher than those of Şahin *et al*. (2014) who determined as 0.932 and 0.931, respectively.

Table II. Mean values (a, b and c), standard errors, R^2_{adj} and RSD of lactation parameters for different lactation curves for all calving ages.

Models	a	s_x	b	s_x	c	s_x	R^2_{adj}	RSD
WOD	5.18	0.145	0.88	0.073	0.36	0.023	0.98	0.065
CLD	6.86	0.367	0.63	0.058	0.99	0.110	0.97	0.087
EXP	5.14	0.089			0.069	0.032	0.61	0.313
PEXP	3.26	0.349	-0.22	0.060	-0.04	0.007	0.94	0.141
QUA	3.66	0.0581	0.50	0.296	-0.09	0.032	0.88	0.208

R^2_{adj}: Adjusted multiple coefficient of determination, RSD: Residual standard deviation.

The results of the current study are in agreement with those of Aziz *et al*. (2006) and Abdel-Salam *et al*. (2011)

reported WOD model provided the best fit of lactation curve. Also, in the study by Barbosa *et al*. (2007) on Murrah, Mediterranean and Jafarabadi in Brazil, WOD model has been reported as an appropriate model among Linear (LIN), QUA, Logarithmic (LOG), EXP, Inverse Polynomial (IPOL) and Incomplete Gamma Functions (IGF). In accordance with this finding, Soysal *et al*. (2016) concluded that WOD model was determined the highest R^2_{adj} than Wilmink (WIL) and CLD models. Wood (1967) stressed that WOD model has been used in most lactation curve model studies because of including the main traits of lactation curves with only three parameters allowed the calculation of some key measurements, such as average and maximum production and day to maximum production.

These results were opposed to those of Dijkstra *et al*. (1997) who found that Dijkstra (DIJK) model fitted better than WOD model. A different result was reported by Gürcan *et al*. (2011) who found that Logarithmic Quadratic (LQUA) model is the most fitted model for defining lactation curve compared to QUA, Logaritmic Linear (LLIN), Linear Hyperbolic (LHYP) and WIL models. On contrary to these results, in a study conducted on Murrah buffaloes (Fraga *et al*., 2003), WOD, Multiple Regression (MREG), LQUA and LHYP models were compared, and it was determined that the LQUA function was the best model. Also, some researches (Sherchand *et al*., 1995; Landete-Castillejos and Gallego, 2000) determined that QUA model was the fitted model to estimate the lactation curves. Şahin *et al*. (2014) reported that LQUA and QUA models were the best fitted better model models due to the highest R^2_{adj} and the lowest RSD. One of the main differences between this and previous studies is the frequency of measurement (Nasri *et al*., 2008).

The estimated functions of the studied lactation curves (the third to the tenth age groups) with comparable criteria are reported in Table III. According to the results, although lower R^2_{adj} were determined for WOD, CLD, EXP and QUA models in the third and fourth age groups, it was found to be the higher R^2_{adj} in fifth to tenth age groups. On the contrary of these four functions, PEXP model showed the worst fitting for the third calving age. The RSD was the highest for only WOD and CLD models in third and fourth age groups, but do not differ for EXP, PEXP and QUA values in all age groups. So that, the studied models were do not fitting from the third to the fourth age groups and the best describing performance were obtained for elder age groups. Based on the results, fitted curves from fifth to tenth age groups using WOD and CLD models had largest R^2_{adj} and lowest RSD. The shape of the lactation curve was influenced by age groups. Ghavi Hossein-Zadeh (2016) reported that the DIJK model provided the best fit of milk yield for the first three parities of buffaloes due to the lower RSD. In Italy, Catillo *et al*. (2002) examined the lactation records by using WOD, Reverse Polynomial (RPOL), Exponential Log (ELOG), Polynomial Regression (PREG) model in buffaloes, and reported that the adaptation of all mathematical functions with the lactation curve was very high. Differences between the lactation curve characteristics of buffaloes with different age groups were likely to the differences between goodness of fit of the models for the different calving ages. Also, the difference between fit of models may occur due to the variations in mathematical functions of the models (Ghavi Hossein-Zadeh, 2016). Graphical presentation of observed and predicted TDMY for the five models are illustrated in Figure 1.

Various lactation curve parameters (a, b and c) were calculated to fit into the five models (WOD, CLD, EXP, PEXP and QUA) to obtain the prediction for milk yield (Table III). Where, a is the initial milk yield after calving, b is the ascending slope parameter up to the peak yield, and c is the descending slope parameter (Şahin *et al*., 2015). Among the studied functions, based on the results, CLD and WOD had the highest a, b and c values. The results revealed that a, b and c values for the WOD and CLD models steadily increased until eight calving age and determined the highest in eighth lactations compared to early lactations. As expected, the younger calving ages of buffaloes had lower milk yield than elder calving ages of buffaloes. This might be explained by the fact that the increasing milk yield in milk secretary tissue increased with age, reaching its maximum value at physiological maturity. Also, Ghavi Hossein-Zadeh (2016) stressed that buffaloes could be selected based on their peak yield, because buffaloes with high daily milk yield at peak can produce more total milk yield over the lactation. Nasri *et al*. (2008) reported that the goodness of fit for cows of parities 2 and 3 were similar. Scott *et al*. (1996) pointed out that there was not any difference among lactation curves of multiparous cows. This result is in contrast to Dijkstra *et al*. (1997) who stressed that greater persistency was determined for cows in their first parity compared to later parities. In this study, values related to the parameter determined by different age groups were found to be different from previous studies. This may be due to the fact that the TDMY of the buffaloes used in the researches are different and the inspection intervals are different.

The parameters a, b and c were generally compatible with the previous literature. This indicates that the lactation curves of the Anatolian buffaloes are typical.

In this study, the number of runs of sign tended to increase with all equations as calving age increased, which means the equations were able to fit lactation records of elder buffaloes better than younger buffaloes (Nasri *et al*., 2008). Shokrollahi and Hasanpur (2014) stressed that milk production increased until the middle age and decreased afterward. According to Dijkstra *et al*. (1997), this is due to underdeveloped udder and hence lower alveoli activity at younger age. Differences between the characteristics of the lactation curve of younger and elder buffaloes are likely to be responsible for the difference between goodness of fit of the equations for the different ages (Nasri *et al*., 2008). Because younger buffaloes are more persistent, their lactation curves are flatter than those of elder buffaloes (Wood, 1967).

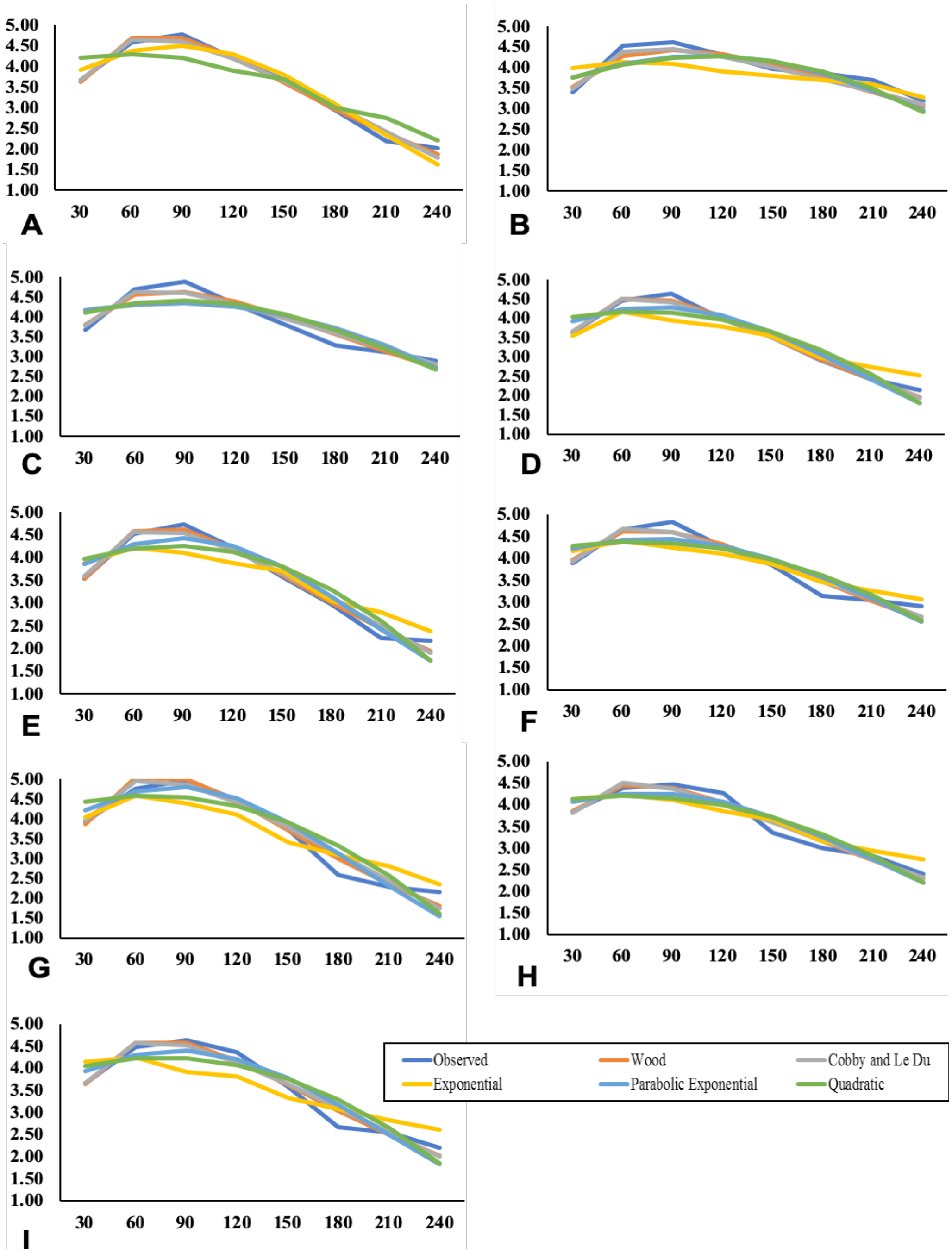

Fig. 1. Lactation curves; A, all calving stages; B, third calving stage; C, fourth calving stage; D, fifth calving stage; E, sixth calving stage; F, seventh calving stage; G, eight calving stage; H, ninth calving stage; I, tenth calving stage.

Table III. Mean values (a, b and c), standard errors, R^2_{adj} and RSD of lactation parameters for different calving ages from three to ten.

Calving Age	Models	a	s_x	b	s_x	c	s_x	R^2_{adj}	RSD
Three	WOD	4.23	0.29	0.53	0.17	0.18	0.05	0.86	0.166
	CLD	5.54	0.52	0.30	0.09	1.16	0.26	0.81	0.150
	EXP	4.37	0.03	-	-	0.43	0.02	0.23	0.241
	PEXP	3.34	0.49	-0.14	0.08	-0.02	0.001	0.64	0.212
	QUA	3.28	0.56	0.055	0.28	-0.07	0.03	0.65	0.200
Four	WOD	4.74	0.261	0.57	0.137	0.22	0.041	0.89	0.136
	CLD	5.94	0.416	0.39	0.069	1.21	0.211	0.91	0.122
	EXP	4.80	0.050	-	-	0.049	0.022	0.48	0.245
	PEXP	3.75	0.565	-0.11	0.080	-0.02	0.099	0.93	0.216
	QUA	3.90	0.655	0.032	0.334	-0.06	0.036	0.68	0.240
Five	WOD	4.98	0.165	0.75	0.086	0.31	0.027	0.98	0.076
	CLD	6.22	0.341	0.53	0.056	1.13	0.144	0.97	0.094
	EXP	4.94	0.084	-	-	0.058	0.027	0.64	0.267
	PEXP	3.43	0.421	-0.17	0.068	-0.03	0.008	0.91	0.161
	QUA	3.77	0.578	0.034	0.295	-0.07	0.032	0.85	0.207
Six	WOD	5.00	0.163	0.87	0.084	0.34	0.026	0.96	0.074
	CLD	6.70	0.420	0.60	0.066	0.98	0.127	0.97	0.099
	EXP	4.98	0.663	-	-	0.08	0.031	0.57	0.309
	PEXP	3.22	0.406	-0.22	0.070	-0.04	0.008	0.91	0.164
	QUA	3.57	0.624	0.050	0.316	-0.09	0.034	0.85	0.223
Seven	WOD	4.93	0.214	0.53	0.109	0.22	0.033	0.94	0.110
	CLD	5.93	0.332	0.41	0.056	1.31	0.197	0.94	0.105
	EXP	4.93	0.449	-	-	0.06	0.020	0.61	0.221
	PEXP	3.89	0.480	0.10	0.067	0.02	0.008	0.83	0.178
	QUA	4.09	0.560	0.025	0.285	-0.06	0.031	0.79	0.205
Eight	WOD	5.70	0.357	0.94	0.164	0.39	0.052	0.95	0.155
	CLD	7.31	0.779	0.70	0.124	1.01	0.229	0.93	0.178
	EXP	4.57	0.817	-	-	0.10	0.036	0.60	0.366
	PEXP	3.49	0.579	-0.23	0.094	-0.04	0.012	0.89	0.230
	QUA	4.10	0.861	0.042	0.439	-0.09	0.048	0.81	0.308
Nine	WOD	4.88	0.186	0.55	0.097	0.24	0.030	0.96	0.087
	CLD	5.77	0.306	0.43	0.052	1.34	0.194	0.95	0.097
	EXP	4.88	0.443	-	-	0.07	0.021	0.83	0.211
	PEXP	3.73	0.390	-0.11	0.657	-0.02	0.007	0.90	0.143
	QUA	3.96	0.472	0.024	0.240	-0.06	0.026	0.86	0.169
Ten	WOD	5.01	0.227	0.78	0.116	0.32	0.036	0.96	0.106
	CLD	6.45	0.478	0.56	0.077	1.06	0.175	0.95	0.123
	EXP	4.99	0.617	-	-	0.08	0.029	0.60	0.288
	PEXP	3.37	0.446	-0.19	0.073	-0.03	0.009	0.90	0.175
	QUA	3.78	0.627	0.041	0.320	-0.08	0.035	0.84	0.225

R^2_{adj}: Adjusted multiple coefficient of determination, RSD: Residual standard deviation.

CONCLUSION

A lot of factors could be considered when selecting the best fit model to describe the lactation curve of buffaloes. Various models have been used to study lactation in dairy buffaloes, although each models had having advantages and disadvantages. While the key factor is the accuracy of the fit of the model, the possibility of calculating the curve characteristics and the interpretation of the curve's parameters are also as important. Of the five functions investigated in the present study, based on R^2_{adj} and RSD, it can be stated that the WOD and CLD models can be preferred for the lactation curve to production program of Anatolian buffaloes. Also, results showed that there were differences between age groups, so the equations fitted data from elder cows better than younger buffaloes. As a result, it can be evidently declared that the WOD and CLD models can be used as an alternative for prediction of the best fitted lactation curve for early animal evaluation and the reduction of the generation interval in breeding programs of Anatolian buffaloes.

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Statement of conflict of interest

The authors declare no conflict of interest.

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