FITTING FIVE MODELS TO DESCRIBE MILK PRODUCTION CURVE FOR *KHUZESTANI* BUFFALOES OF IRAN IN DIFFERENT PARITIES AND SEASONS

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ABSTRACT

To evaluate the lactation curve of *Khuzestani* buffaloes in the south west of Iran and to determine its describing function, 89140 test day records of buffaloes, collected in 1991 to 2015, were used. In order to draw the real and predicted curves by Wood, Wilmink, Parabolic, Mixed Logarithmic and Inverse Polynomial models, the average of test-day records in 10 lactations and 4 seasons, with 14 days intervals, were used. All the functions were fitted using NLIN procedure of SAS 9.1 software. The results showed that, based on real data, the lactation curve of *Khuzestani* buffaloes became more typical from 4th and 6th lactation, as it was completed with three steps of increasing production, peak yield and decreasing phase after peak time in the 7th and 8th parities. Based on the criteria, studied functions did not have the same performance for lactation curve so that the Wood function was the best model. According to Wood function, peak of milk production increased from the first lactation and its maximum value was obtained for the 8th lactation. The time of peak yield for the studied curves were highly variable (between 79 and 90 days). In terms of estimated amount for persistency, there was not much difference among curves of different lactation, so that obtained values were very close together. In fact, we can say that lactation curves of studied buffaloes were flat, as the difference between the beginning and the end of production was very low. The results also showed that among different seasons, parabolic function had the best fitting for calving in the seasons of spring, autumn and winter and Mixed Logarithmic function was the best for calving season of summer.

Keywords: *Bubalus bubalis*, buffalo, Khuzestani buffalo, lactation curve, function, peak yield, persistency

INTRODUCTION

In dairy animals, milk production begins after calving. The diagram of milk production during lactation is called as lactation curve, which is a graphic describing of the relationship between changes in milk production in time (Santos and

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Silvestre, 2008). Lactation curve of lactating animals, have a set of features including of: increasing phase in production which is continued to peak yield, peak of production and production decline phase which is accrued after reaching the peak time and associated with the rapid fall in production after the peak yield (Santos and Silvestre, 2008).

Since the main purpose of breeding of dairy animals around the world is improving the efficiency of milk production, function describing the lactation curve can be used in estimating of genetic parameters of lactation curve characteristic and also in changing the lactation curve shape in desired direction by selection. Or we can achieve appropriate indicators to assessing the best animals and increasing their milk production, using genetic correlations between the characteristics of lactation curve and total milk yield (Taheri Dezfuli, 2017). Also, since lactation is a major phenomenon that occurs in dairy farms, estimating of animal production is very important in herd management. Being aware of the lactation curve shape can be effective in determining the pattern of milk production over the time in lactating animals and in determining the biological and economic efficiency of dairy animals in terms of feeding and management (Taheri Dezfuli, 2017).

Describing functions of the lactation curve are classified in two groups, linear and nonlinear functions. In the linear functions, the parameters are the linear functions of lactating day which can be easily calculated by linear regression techniques. Non-linear functions are not expressed as a linear functions of the parameters, so the repetition techniques are used to calculate them. Since the total range of curves are described with nonlinear functions, and also due to repetitive methods of the softwares, nonlinear methods have been used more in recent years (Soltani, 2015).

In Metry *et al.* (1994) research, the first lactation records of *Egyptian* buffalo located in the Research Institute of Animal Production in Egypt were used in order to determine lactation curves for three lactation length (between 28 to 150 days, more than 149 days, and almost 308 days as well as for all records). In this study, the highest persistency was achieved for the third group (all records). Persistency was higher for buffaloes with calving in spring and summer season in 3 groups of all records, more than 28 days and more than 149 days groups, while buffaloes with calving in summer and autumn seasons had higher persistency in almost 308 days records group. Chaudhary *et al.* (2000) analyzed lactation data of 993 *Nili Ravi* buffalos to determine the amount of milk yield during peak time and the days to reach peak yield time. In their study, the average of milk yield at peak time was 10.8 kg, which occurred on 48 days after calving as an average. Macciottaa *et al.* (2006) fitted the Wilmink function for lactation curves of 3860 *Italian* buffalos. A broad range of fitting for these animals showed a large variety in the shape of the animal's lactation curve. In addition, about 30% of the lactation curves for animals had unusual shape (were found with no peak) and it has been reported that biological and environmental factors (calving age, season of calving, herd) and especially data structure are significantly related to possibility of accruing these unusual curves.

Population of *Khuzestani* buffaloes in the south west of Iran (Khuzestan province) is over 83700 heads which are distributed in 20 cities of the province (Anonymous, 2016). In all cities, buffalo is bred primarily for milk production, so that about 40% of the province's dairy products are produced by buffaloes (Anonymous, 2008). Therefore, the objective of this study is investigating the lactation curve and determining its describing function for mentioned buffaloes in the south west of Iran using 5 common functions. The results about the shape of lactation curve can be used in making management and breeding decisions as well as in feeding programs.

MATERIALS AND METHODS

In this study, a total 89140 monthly test-day milk records from different parities of buffaloes located in 526 herds in Khuzestan province, collected from 1991 to 2015 by Deputy of improving livestock production of Khuzestan, were used. The dataset was compiled and edited by Excel software. Buffaloes having less than 4 consecutive records or did not have the specified recording time were excluded from the analysis. Lactation days were considered from the fifth day of lactation and the test-day records after 210 days of lactation were removed from the dataset (the estimated average length of lactation for *Khuzestani* buffaloes by Taheri Dezfuli *et al.*, 2012). Then, milk records from buffaloes were classified based on parity number. After that, the actual lactation curves for buffalo cows in each group were drawn using the average of records, with an interval of 14 days. Curves were plotted for each group by Excel software. Then, the curve function of buffalo production records were set. First lactation records were used in classification records to investigate the effect of season. Then, for the first calving buffaloes the actual and the predicted lactation curves were plotted by the functions during different seasons (Table 1 and Table 2).

Statistical models

Five different models were tested for fitting the lactation curve of the *Khuzestani* buffaloes including of incomplete gamma Wood function, Wilmink, inverse polynomial, parabolic and mixed

Table 1. Descriptive statistics of different lactation periods for milk production (kg).

Lactation	1	2	3	4	5	6	7	8	9	>10
Number of records	6411	6586	6690	7193	14536	6374	5264	4472	3113	5470
Mean	8.18	8.27	8.34	8.46	8.65	8.68	8.81	9.06	9	8.78
SD	2.90	2.90	3	3.03	3	3.5	2.96	3.03	2.94	2.90

Table 2. Descriptive statistics of different seasons for milk production (kg).

Season	Number of Records	Mean	S.D
Spring	164	7.80	2.42
Summer	233	7.42	2.68
Autumn	4244	7.90	2.93
Winter	1770	8.65	2.58

logarithmic as the following:

1. Incomplete Gamma Wood function (Wood, 1967):

$$y_t = at^b e^{ct} \quad \text{(WD)}$$

Where, a is a scaling factor associated with the level of production (initial production rate), b is a factor related to the increasing slope of the curve, c is related to a decline slope and t is days in milk.

2. Wilmink function (Wilmink, 1987):

$$y_t = a + bt + ce^{-0.05t} \quad \text{(WIL)}$$

Where, the parameters a, b, and c are related to the level of production, the increase of production before the peak, and the subsequent decrease, respectively.

3. Inverse Polynomial function (Nelder, 1966):

$$y_t = 1/(a + bt^{-1} + ct) \quad \text{(IP)}$$

Where, a is a parameter related to the increasing intensity of production until peak time, b is the parameter associated with the average slope of the curve, c is the parameter related to the decreasing intensity of production after peak time and t is days in milk.

4. Mixed Logarithmic function (Guo and Swalve, 1955):

$$y_t = a + bt^{-0.5} + c\ln(t) \quad \text{(ML)}$$

Where, a is a parameter associated with the level of production (initial production rate), b is a parameter related to the increasing slope of the curve, c is a decline slope and t is days in milk.

5. Parabolic function (Sikka, 1950):

$$y_t = 1/(a + bt^{-1} + ct) \quad \text{(Para)}$$

Where, a is a parameter associated with the level of production (initial production rate), b is a parameter related to the increasing slope of the curve, c is a decline slope and t is days in milk. y_t in all equations is milk yield in day t of lactation.

All functions were fitted using NLIN procedure of SAS 9.1 software and obtained parameters were used to predict production values from any of the functions.

Peak Time Value (PT) was calculated through equaling the first partial derivative of each function to zero, Peak yield value (PY) was obtained by setting peak time value in each model, and Persistency (P) was calculated from the following equation:

$$P(\%) = 1 - \frac{(\text{peak yield - the last record value})\times(30/210)\times 100}{(\text{peak yield})}$$

Criteria for comparing models

Criteria such as adjusted coefficient of determination (R^2_{adj}), residual standard deviation (RSD), Akaike Information Criteria (AIC) and the correlation coefficient between actual and estimated values (r) were used to evaluate and to compare the goodness of fit of these models.

Adjusted coefficient of determination (R^2_{adj}):

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

Where, R^2 is the multiple coefficient of determination, n is the number of observations and p is the number of parameters in the model. In this test, R^2_{Adj} does corrections for a number of different parameters in the model.

Residual Standard Error (RSD):

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

Where, RSS is the residual sum of squares, n is the number of observations and p is the number of parameters in the model.

Akaike Information Criterion (AIC):

$$AIC = -2\log L + 2P$$

In this equation, log L were calculated through log (SSR/n) and P is the number of estimated parameters.

The correlation coefficient between actual and estimated values (r).

RESULTS AND DISCUSSION

Buffalo lactation curve in first to 10th lactation periods

The estimated functions of the studied lactation curves (first to 10th parities) with comparable criteria are reported in Table 3. Based on these indicators, the largest R^2_{adj} and correlation between the real and estimated data and the lowest RSD and AIC show the appropriate model. Among studied models, Wood function was the most appropriate model for explaining properties of milk yield in all lactation periods.

As be shown in Table 3 and based on the criteria of the fitted functions, studied models did not have similar performance in fitting different lactation curves of buffaloes. So that, the studied functions had more perfect fitting from the first lactation to the 5th lactation, and the best describing performance were obtained for 5th, 4th and 3rd lactations, respectively. Fitted curves for 5th lactation using Wood, Wilmink, mixed logarithmic, inverse polynomial and parabolic functions had the lowest AIC, RSD and the largest R^2_{adj} and correlation coefficient between the real and estimated data as -25.71, -25.78, -25.78, -22.45, -25.78 and 0.10, 0.10, 0.10, 0.12, 0.27 and 0.95, 0.95 , 0.95, 0.93, 0.67 and 0.98, 0.98, 0.98, 0.97, 0.85, respectively. Based on the results, Wood function had the best fit for all lactation periods among the studied functions. The mixed logarithmic, Wilmink and inverse polynomial functions were the next functions after Wood model in ranking. On the contrary of these four functions, parabolic model showed the best fitting for the first to three lactations.

The average curves of the studied lactations based on appropriate model (Wood) are shown in Figure 1. Lactation curve of buffaloes has gradually taken a more typical shape from 4th to 6th lactations, comparing the standard pattern of lactation curve. So that, it has been completed in 7th and 8th lactations with three remarkable stages of increasing slope of production, peak time and decreasing slope of production until the end of the lactation curve. In general, the lactation curve of buffaloes in different parities showed that these animals did not have very high peak yield while they had high persistency after the peak time. This high level of persistency is due to the less decline

Table 3. The expected equations of the studied traits in different lactations using the relevant five models.

Lactation	Function	Model	R^2_{adj}	RSD	AIC	$r_{y,\bar{y}}$
First	Wood	$y = 4.67t^{0.169}e^{-0.00186t}$	0.87	0.13	-22.03	0.95
	Wilmink	$y = 8.82\text{-}3.38e^{-0.05t}\text{-}0.0043t$	0.77	0.18	-17.5	0.89
	Mixed log	$y = 2.01\text{-}0.63t^{0.5}+2.8\ \ln(t)$	0.81	0.16	-19.24	0.92
	Inverse polynomial	$y = 1/(0.11+0.48t^{-1}+0.000082t)$	0.73	0.19	-16.80	0.88
	Parabolic	$y = 7.15\ e^{(0.0030t\text{-}0.000013\text{^}2)}$	0.84	0.15	-20.16	0.93
Second	Wood	$y = 4.28t^{0.203}e^{-0.0024t}$	0.85	0.17	-18.28	0.94
	Wilmink	$y = 9.18\text{-}4.148e^{-0.05t}\text{-}0.0064t$	0.75	0.22	-14.90	0.75
	Mixed log	$y = 3.03\text{-}0.48t^{0.5}+2.22\ \ln(t)$	0.80	0.20	-16.27	0.91
	Inverse polynomial	$y = 1/(0.10+0.58t^{-1}+0.000116t)$	0.74	0.23	-14.32	0.88
	Parabolic	$y = 7.15e^{(0.00344t\text{-}0.000015t\text{^}2)}$	0.81	0.20	-16.58	0.92
Third	Wood	$y = 4.098t^{0.2237}e^{-0.00274t}$	0.92	0.15	-20.55	0.96
	Wilmink	$y = 9.47\text{-}4.627e^{-0.05t}\text{-}0.0082t$	0.82	0.21	-15.70	0.92
	Mixed log	$y = 1.41\text{-}0.74t^{0.5}+3.2\ \ln(t)$	0.86	0.18	-17.57	0.94
	Inverse polynomial	$y = 1/(0.095+0.63t^{-1}+0.000142t)$	0.81	0.22	-14.87	0.91
	Parabolic	$y = 7.22e^{(0.00365t\text{-}0.000017t\text{^}2)}$	0.86	0.19	-17.21	0.94
Forth	Wood	$y = 3.66t^{0.2641}e^{-0.00328t}$	0.94	0.14	-21.4	0.98
	Wilmink	$y = 9.85\text{-}5.615e^{-0.05t}\text{-}0.0102t$	0.88	0.20	-16.56	0.95
	Mixed log	$y = 0.1\text{-}0.91t^{0.5}+3.87\ \ln(t)$	0.91	0.16	-19.19	0.97
	Inverse polynomial	$y = 1/(0.088+0.77t^{-1}+0.000174t)$	0.87	0.21	-15.88	0.94
	Parabolic	$y = 7.20e^{(0.0041t\text{-}0.000019t\text{^}2)}$	0.81	0.25	-13.33	0.92
Fifth	Wood	$y = 4.52t^{0.2074}e^{-0.00264t}$	0.95	0.10	-25.71	0.98
	Wilmink	$y = 9.86\text{-}4.689e^{-0.05t}\text{-}0.0089t$	0.95	0.10	-25.78	0.98
	Mixed log	$y = 1.82\text{-}0.76t^{0.5}+3.2\ \ln(t)$	0.95	0.10	-25.78	0.98
	Inverse polynomial	$y = 1/(0.092+0.589t^{-1}+0.000143t)$	0.93	0.12	-22.45	0.97
	Parabolic	$y = 7.75e^{(0.0029t\text{-}0.000014t\text{^}2)}$	0.67	0.27	-12.33	0.85

R^2_{adj} = adjusted determination coefficient, RSD = residual standard deviation,

AIC = Akaike index and r = correlation coefficient between actual and estimated milk yield values.

Table 3. Continue of the expected equations of the studied traits in different lactations using the relevant three models. (Continue)

Lactation	Function	Model	R^2_{adj}	RSD	AIC	$r_{y,\bar{y}}$
Sixth	Wood	$y = 4.4351t^{0.2055}e^{-0.00237t}$	0.84	0.19	-17.11	0.93
	Wilmink	$y = 9.63\text{-}4.522e^{-0.05t}\text{-}0.0066t$	0.81	0.21	-15.71	0.92
	Mixed log	y = 1.94-0.67+2.98 ln (t)	0.82	0.20	-16.23	0.92
	Inverse polynomial	$y = 1/(0.095\ 0.582t^{-1}+0.000112t)$	0.78	0.23	-14.80	0.90
	Parabolic	$y = 7.54\ e^{(0.0032t\text{-}0.000014t\text{^}2)}$	0.65	0.29	-11.61	0.83
Seventh	Wood	$y = 4.33t^{0.224}e^{-0.00279t}$	0.89	0.17	-18.5	0.95
	Wilmink	$y = 10.05\text{-}5.061e^{-0.05t}\text{-}0.009t$	0.87	0.18	-17.27	0.94
	Mixed log	$y = 1.35\text{-}0.81t^{0.5}+3.44$ ln (t)	0.89	0.17	-18.05	0.95
	Inverse polynomial	$y = 1/(0.0893+0.63t^{-1}+0.000144t)$	0.86	0.20	-16.45	0.94
	Parabolic	$y = 7.75e^{(0.00323t\text{-}0.000015t\text{^}2)}$	0.65	0.32	-10.43	0.84
Eighth	Wood	$y = 4.27t^{0.229}e^{-0.00257t}$	0.85	0.19	-17.23	0.95
	Wilmink	$y = 10.11\text{-}5.32e^{-0.05t}\text{-}0.0072t$	0.88	0.19	-17.06	0.94
	Mixed log	$y = 1.16\text{-}0.76t^{0.5}+3.45$ ln (t)	0.88	0.18	-17.26	0.95
	Inverse polynomial	$y = 1/(0.089+0.646t^{-1}+0.000116t)$	0.86	0.20	-16.11	0.94
	Parabolic	$y = 7.74e^{(0.00349t\text{-}0.000015t\text{^}2)}$	0.61	0.34	-9.40	0.82
Ninth	Wood	$y = 4.3008t^{0.2308}e^{-0.00283t}$	0.86	0.21	-16.03	0.94
	Wilmink	y = 10.25-5.33e^(-0.05t)-0.0092t	0.85	0.21	-15.32	0.93
	Mixed log	+3.6 ln (t)	0.86	0.21	-15.84	0.94
	Inverse polynomial	$y = 1/(0.0872+0.641t^{-1}+0.000142t)$	0.84	0.23	-14.67	0.93
	Parabolic	$y = 7.84e^{(0.00336t\text{-}0.000016t\text{^}2)}$	0.63	0.35	-9.23	0.82
>Tenth	Wood	$y = 4.78t^{0.1904}e^{-0.00233t}$	0.73	0.25	-13.20	0.87
	Wilmink	$y = 9.84\text{-}4.52e^{-0.05t}\text{-}0.0077t$	0.79	0.23	-14.75	0.90
	Mixed log	$y = 2.2\text{-}0.70t^{0.5}+3$ ln (t)	0.78	0.23	-14.35	0.90
	Inverse polynomial	$y = 1/(0.093+0.557t^{-1}+0.000124t)$	0.79	0.22	-14.80	0.91
	Parabolic	$y = 7.92e^{(0.00252t\text{-}0.000012t\text{^}2)}$	0.42	0.38	-7.93	0.70

R^2_{adj} = adjusted determination coefficient, RSD = residual standard deviation,
AIC = Akaike index and r = correlation coefficient between actual and estimated milk yield values.

which occurred in milk production after peak yield. It has been reported that buffaloes with flatter lactation curve, have higher persistency than the buffaloes that show a sharp decline after the peak production (Anwar *et al.*, 2009). For estimated curves in the first lactation, peak yield occurred in longer time after calving and so it showed a short persistency. In curves fitted by appropriate function for second and third lactations, peak yield occurred within a shorter time after calving continued to show better persistency. The 4^{th}, 5^{th}, 6^{th} and 7^{th} fitted curves had similar trend but the curve fitted for the 5^{th} lactation period was more consistent with the actual curve (Figure 1).

Hassanpour *et al.* (2012) studied 9 nonlinear functions in fitting lactation curve of Iranian *Holstein* cows and reported that the functions of Wood, Dijkstra and Rook had the largest and Legendre polynomials function had the lowest corrected coefficient of determination in fitting the lactation curves. Fathi Nasri *et al.* (2008) in the study of growth curves in describing lactation curve of dairy cows, introduced Gompertz function as one of the describing functions of lactation curve. Roshan *et al.* (2012) also reported Gompertz function as an appropriate function for estimating lactation curves parameters for the first lactation *Holstein* cows of Mashhad. However, Abdul-Salam *et al.* (2011) in the study of Wood, Wilmink and Geo and Swallows models for predicting lactation curves of *Egyptian* buffaloes, and Soltani (2015) in investigating the lactation curve of first lactation buffaloes in Khuzestan reported Wood function as the best model that corresponded with our results. Also, in the study by Barbosa *et al.* (2007) on the lactation curve of buffaloes of Brazil consists of three breeds of *Murrah*, *Mediterranean* and *Jafar Abadi*, incomplete gamma Wood function has been reported as an appropriate model among linear, quadratic, logarithmic, exponential quadratic, inverse polynomial and incomplete gamma functions.

After fitting the proposed proper function (Wood function) for individual animals at different lactation periods, it was observed that the lactation curve of 50% of buffalo cows were not in typical shape. Dimauro *et al.* (2005), studied the fitness of Wood, Wilmink, polynomial regression, Ali and Schaeffer and fourth grade Legendre polynomials models to obtain the individual and mean lactation curves for Italian buffaloes. In these analysis, individual curves showed the wide range of fitness that it seems this wide range was related to random variations in the shape of the lactation curves more than the used model. Macciottaa *et al.* (2006), also studied the lactation curve of Italian buffaloes using the Wilmink function and reported a wide range of fitness for this species which showed a large variety for the shape of the lactation curve of animals. These researchers have reported that improper and with low efficiency recording system as one of the most likely causes of atypical curves. The lack of normal and typical lactation curves for 50% of the buffalo cows may be related to traditional system of buffalo breeding and some of inaccuracies in milk recording in this province.

The values of scaling factors associated with the milk peak yield (ym), time of peak yield (tm) and persistency (s) are also present in Table 4, based on appropriate model.

Based on the obtained values, as can be seen in Table 4, the peak yield has increased from first lactation to 8^{th} lactation and the largest peak yield was obtained for 8^{th} lactation curve (9.52 kg). But the changes of peak yield was not more among studied parities and was in the range of 8.46 kg in first lactation to 9.52 kg in 8^{th} lactation with the difference of approximately one kilogram which confirmed having mild peak yield of *Khuzestani* buffaloes. The low value and mild peak of milk yield can be associated to nutritional deficiencies and the lack of suitable and balanced diet in buffalo herds of the province, as due to the lack of the favorable nutritional conditions, buffaloes could not express their genetic potential. Seahin *et al.* (2015) in the study of 5 lactation periods of *Anatolian* buffaloes reported the increasing of peak yield from 7.33 to 9.17 in the 5th lactation. Dimauro *et al.* (2005) also reported the peak value of production for the *Italian* buffaloes in different lactation periods as 10.9 kg using Wood function, 11.3 kg using Wilmink function, 11.5 kg using Scheffer polynomial and 11 kg using fourth grade Legendre polynomial which is more than the estimated peak yield value for *Khuzestani* buffaloes.

Peak time value for different lactation periods was obtained from the 79th day of lactation (5th parity) to the 90th day of lactation (8th parity). However, all of 10 lactation curves had the same persistency (98%). The estimated value for persistency of lactation curves also show that curves of lactation periods did not have much difference in terms of this parameter. The persistency of 98% means that milk yield per month is as much as 98% of the previous month and this high level of persistency occurs as a result of the mild peak yield. In fact, the lactation curve for these buffaloes is flat as the difference between the beginning and the end of production was very low. Atashi *et al.* (2007) reported that cows with more flat curves compared to cows with less persistency require less concentrates to produce the same volume of milk in the lactation. Thus the possibility of feeding them according to the changes in milk production is possible that it also reduce the incidence of metabolic and reproduction disorders and complications after calving. So, farmers usually prefer cows with high persistency and more flat curve. This parameter have been reported for buffaloes in Cuba according to two different methods as 82% for buffaloes with 100 days in milk and 44% for buffaloes with 200 days in milk. The persistency value have been also reported for *Bulgarian Murrah* buffaloes as 89.23% (Penchev and Peeva, 2013). Also, in the study of Zakariyya *et al.* (1995) the persistency for *Nili Ravi* buffaloes was estimated as 91.31% and in the range of 80.3 to 99.96 %. Das *et al.* (2007) in the study of buffalo lactation curve in India have been reported persistency parameter as 97% using the first lactation records and 97.40% using all lactations which is close to result of present study.

Lactation curve for first lactation buffaloes in different seasons

The estimated functions of the studied lactation curves in 4 different seasons with comparable criteria are reported in Table 5. Based on the criteria, the largest R^2_{adj} and correlation values and the lowest RSD indicator and AIC shows the appropriate model.

Based on the results for different seasons and different functions (Table 5), the adjusted determination coefficients were obtained from 0.41 to 0.92. The results of the other indices relatively coincided with the R^2_{adj} changes for the studied functions. Based on all the criteria used in comparing models, in general, the parabolic model among the five examined functions had the most suitable fitting for the lactation curve in different seasons. In the study of 11 models for the lactation curve of the first lactation period *Khuzestani* buffaloes, according to the AICc criteria and the adjusted determination coefficient it has been reported Diphasic function was as appropriate for milk production, which is different with results obtained in this study (Bahmani *et al*., 2012).

Also, in the study of Wood, Wilmink and mixed logarithmic models for data on Egyptian buffalos (Abdul-Salam *et al*., 2011) the Wood function were reported as the most appropriate function. In the study of linear, quadratic, logarithmic, second order logarithmic, incomplete gamma and inverse polynomials for *Brazilian* buffaloes including three breeds of *Murrah*, *Mediterranean* and *Jafar-Abadi*, the incomplete Gamma function was also better fitted for lactation curves (Barbosa *et al*., 2007). In general, researchers have presented different functions for describing the lactation curve of buffaloes in Khuzestan province (Bahmani *et al.*, 2012; Soltani, 2015), but the curves tended to have a rapid increasing phase in a few weeks after calving, and then reducing phase to dry period of buffaloes, and most of the curves did not have high peak yield. Among the examined functions, the Wood model showed this trend well.

In the study of different models in each season, it was observed that the parabolic model had the largest values of R^2_{adj} and correlation coefficient and the lowest values of RSD and AIC in the spring, autumn and winter seasons for the five studied functions. But for the summer season, the two logarithmic and Wood functions was the most appropriate models, respectively. Contrary to our results in the study of functions for fitting the lactation curve of *Simmental* cows during different seasons, polynomial function has been reported more appropriate than Wood and Parabolic functions (Korkmaz *et al.*, 2011).

Figure 2 shows the best fitted functions on lactation curves in four studied seasons. Comparing the lactation curves in different seasons, as shown in Figure 2, the lactation curve for buffaloes calved in winter was in higher level than other seasons, which is surely related to the availability of appropriate forage and better feeding on calving time and starting the lactation. The level of production for other three seasons were almost in line with each other but for the calvings in the summer, the decline production after peak time was occurred earlier due to intense summer heat. Generally, by observing the lactation curve of first lactation in different seasons, it can be said that these buffaloes do not have high production rates, while the continuation of milk production or persistency is high. This means that production declines after a peak with a lower slope. High persistency in buffaloes with a flat curve has also been reported by Anwar *et al.* (2009). Since buffaloes are bred in *Khuzestan* province traditionally and in open conditions, breeding season seems to be more influential on milk production than that in closed systems.

CONCLUSION

The comparison of the studied functions for the first to 10th lactation curves showed that these functions do not have the same performance in different parities. So that Wood (WD) model was proposed the best describing function for different lactation periods. Based on the Wood function, the milk production at peak time increased from the first lactation, and the highest amount was obtained for the 8th lactation period. However, the range of peak yield changes in these 10 studied lactations was not large which confirmed the low peak yield of *Khuzestani* buffaloes. According to the proper function, the peak yield time was obtained between 79 to 90 days of lactation which was very variable. Estimated values for persistency were also high, but did not differ significantly between different lactation periods. The results of the investigated functions in different seasons showed that the parabolic function showed a better fit for the

Table 4. The estimated peak yield, time of peak yield and persistency of different lactation periods based on the appropriate model (Wood).

Parameters	Lactation									
	1th	**2ed**	**3ed**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**>10th**
Milk peak yield (kg)	8.64	8.50	8.82	8.95	9.10	9.02	9.24	9.52	9.43	9.12
Time of peak yield (days)	89	83	83	80	79	87	80	90	82	81
Persistency	99	98	98	97	98	98	98	98	98	98

Table 5. The expected equations of the studied traits in different season using the relevant five models.

Season	Function	Model	R^2_{adj}	RSD	AIC	$r_{y,\bar{y}}$
Spring	Wood	$y = 4.31\ t^{0.20}e^{-0.003t}$	0.70	0.30	-11.04	0.86
	Wilmink	$y = 8.99\text{-}3.67t\text{-}0.01e^{-0.05t}$	0.85	0.35	-9.10	0.80
	Mixed logarithmic	$y = 1/(0.103+0.53t^{-1}+0.00017t$	0.62	0.34	-9.63	0.82
	Inverse polynomial	$y = 6.97e^{(0.003t-0.000018t\hat{}2)}$	0.52	0.38	-8.13	0.77
	Parabolic	$y = 2.28\text{-}0.70t^{0.5}+2.77\ \ln(t)$	0.84	0.22	-15.40	0.93
Summer	Wood	$y = 3.68\ t^{0.26}e^{-0.004t}$	0.81	0.36	-8.76	0.92
	Wilmink	$y = 9.46\text{-}4.85t\text{-}0.02e^{-0.05t}$	0.79	0.38	-7.97	0.90
	Mixed logarithmic	$y = 1/(0.09+0.78t^{-1}+0.00033t$	0.81	0.36	-8.70	0.91
	Inverse polynomial	$y = 7.0e^{(0.003t-0.000021t\hat{}2)}$	0.75	0.41	-7.14	0.89
	Parabolic	$y = 0.42\text{-}1.06t^{0.5}+3.91\ \ln(t)$	0.80	0.37	-8.24	0.91
Autumn	Wood	$y = 4.38\ t^{0.18}e^{-0.002t}$	0.83	0.16	-18.94	0.92
	Wilmink	$y = 8.68\text{-}3.44t\text{-}0.005e^{-0.05t}$	0.67	0.23	-14.80	0.85
	Mixed logarithmic	$y = 1/(0.108+0.51t^{-1}+0.00010t)$	0.73	0.20	-16.05	0.88
	Inverse polynomial	$y = 6.91e^{(0.003t-0.000015t\hat{}2)}$	0.63	0.24	-13.81	0.82
	Parabolic	$y = 2.67\text{-}0.53t^{0.5}+2.34\ \ln(t)$	0.88	0.13	-21.76	0.95
winter	Wood	$y = 4.41\ t^{0.20}e^{-0.002t}$	0.62	0.33	-9.73	0.82
	Wilmink	$y = 9.25\text{-}3.67t\text{-}0.004e^{-0.05t}$	0.40	0.40	-6.75	0.70
	Mixed logarithmic	$y = 1/(0.101+0.49t^{-1}+0.00007t)$	0.49	0.38	-7.93	0.75
	Inverse polynomial	$y = 7.11e^{(0.004t-0.000018t\hat{}2)}$	0.38	0.42	-6.63	0.68
	Parabolic	$y = 2.67\text{-}0.54t^{0.5}+2.51\ \ln(t)$	0.92	0.15	-20.2	0.97

R^2_{adj} = adjusted determination coefficient, RSD = residual standard deviation, AIC = Akaike index and r = correlation coefficient between actual and estimated milk yield values.

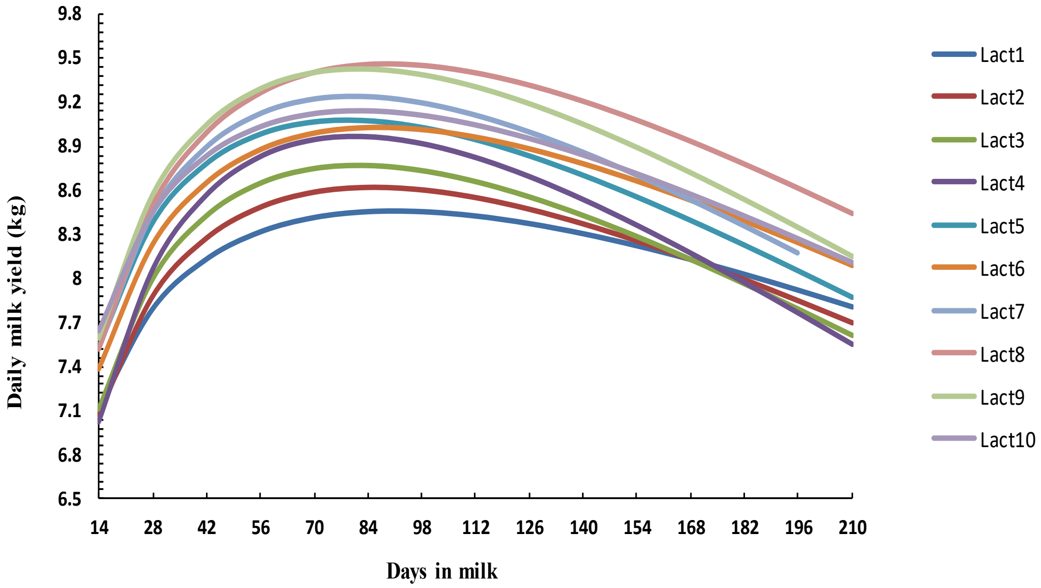

Figure 1. The estimated lactation curves of different parities using appropriate model (Wood).

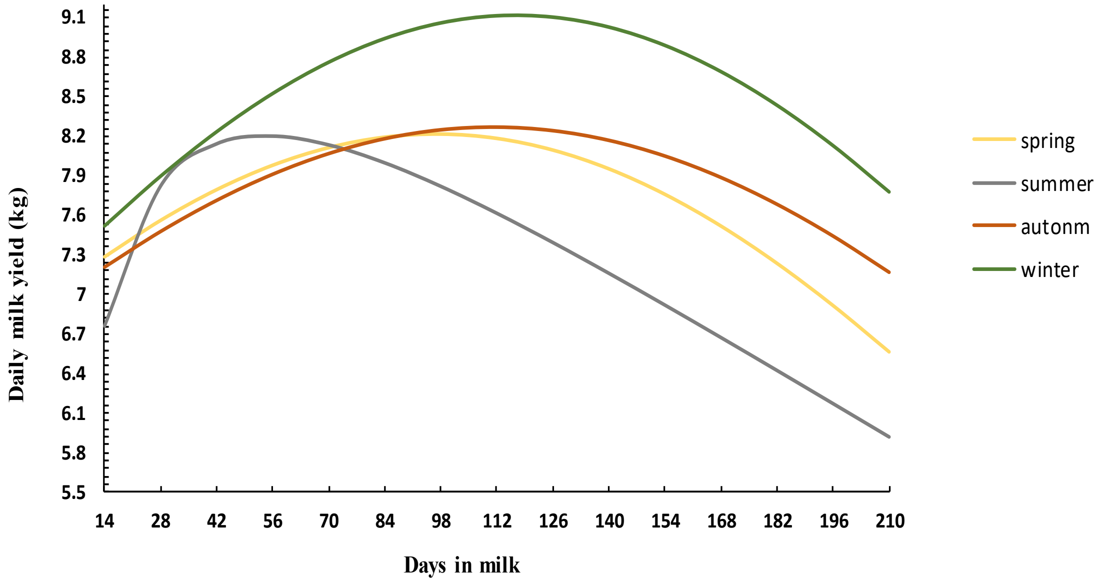

Figure 2. The estimated lactation curves of different season using appropriate models.
(Spring, Autumn and Winter = Parabolic and Summer = Mixed Logarithmic)

first lactation curve in three seasons of spring, autumn and winter and the logarithmic function was the best for the summer season. In addition, the lactation curve of buffaloes in the province are almost flat in most seasons, due to the low peak yield and high persistency. In general, our results showed that *Khuzestani* buffaloes are equal to or similar to many other breeds in the world in terms of milk production and milk yield peak. Regarding to the traditional condition of buffalo breeding in Khuzestan province and also inappropriate management, it is expected that improving the environmental conditions such as nutrition and management will provide the basis for maximizing the genetic abilities of this animal.

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