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Research Article

Lactation Curve Modeling For Dhofari Cows Breed

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Abstract

Background and Objective: There is almost no study in the literature about the Dhofari cow breed lactation curve, as it is the main source of dairy products for large population in Sultanate of Oman and the only one of two native cattle breed in Arabia. The objective of this study was to use different mathematical nonlinear model functions to describe and predict the Dhofari cow breed. **Materials and Methods:** A total data of 1640 test day records of monthly milk production between years 2010 and 2014, from 173 dairy herds located at Salalah Livestock Research Station was analyzed using GLM method (SPSS 2010). Models (Gompertz, Von Bertalanffy, Logistic, Brody, Wood, Wilmink, Cobby and LeDu, Cappio Borlino and Dijkstra) for goodness of fit using adjusted coefficient of determination (R^2), root mean square error (RMSE), akaikes information criterion (AIC) and bayesian information criterion (BIC). **Results:** Gompertz model provided the best lactation curve than the other models due to the lower values of RMSE (4.05), AIC (38.50) and BIC (6.83) but the Dijkstra model did not fit the observed data as well as the rest. The peak yield (9.72 kg), peak time (60 days), 305 days milk (1580 kg) and persistency (90.65%) were best estimated by the Gompertz model. **Conclusion:** Gompertz model provided the best estimation for the lactation curve for the Dhofari cows.

Key words: Dhofari cow, Gompertz model, lactation curve, milk yield, nonlinear models, peak time, peak yield, persistency

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sultanate of Oman is the only Arabian Gulf country that has native cattle called the Dhofari cattle breed with approximately 208,000 dairy cows which is about 60% of the total cows in the country¹. Omani people domesticated and used Dhofari cows for milk and meat production for ages. The Dhofari cow produces an average of 7.06 L of milk per day per cow² which could be a promising high potential for milk production trait improvement. There is almost no research published in the literature about this specific breed lactation curve. The lactation curve was the graphical representation of the relationship between milk yield and lactation time³. It is vital to find out and study the lactation curve of certain cow breed as this would depict different management, breeding and feeding problems of that breed⁴ and the lactation stage⁵. It was important to study and describe it as it will summarize the information needed for milk production, making management decisions, feeding and health monitoring⁶. It was also important as it will allow estimating the peak yield, peak time and 305-sum of production⁷ and milk fat and protein content⁸. Modeling the lactation curve is also useful in the genetic analysis of test-day records for the effect of lactation stage and persistency⁹ and to model the covariance between test-day records in a random regression analysis and the effect of number of lactations on the curve¹⁰. Lactation curve can be affected by dry period omission¹¹. Most researchers who studied the lactation curve used one to four non-linear models such as Woods, Wilmlink and Brody to describe the lactation curve of cows and compare between them to find the best fit. Others have used different non-linear models such as Gompertz, Von Bertalanffy, Logistic, Chobby and LeDu, Cappio Borlino and Dijkstra for that purpose. These were the famous well known non-linear models used in the literature by researchers to find out and graph the lactation curve of cows. However, the objective of study was to use all these famous well known models in order to widen and enrich the possibility and option to find the best and closest among them for the description of the Dhofari cow lactation curve.

MATERIALS AND METHODS

Data collection and experimental procedure: Data of 1640 test-days record from 173 Dhofari cows at Salalah Livestock Research Station in the South region of the Sultanate of Oman during the years 2010 and 2014 were collected. Cows were milked twice per day in the morning and evening, from the 5th day of parturition till the end of the lactation period at

305 days. Cows were hand milked and milk quantity was recorded by weighing each record plus the milk consumed by their relative calves. They were fed commercial concentrate (crude protein, 2.5% crude fat, 7% crude fiber, 5% ash, 0.9% calcium, 0.5% phosphorus and 11.5 MJ/Kg ME energy) according to their weight and milk production based on NRC nutrient requirements tables¹². They were also given Rhodes grass hay (*Chloris gayana*), water and mineral blocks as *ad libitum*. All cows were vaccinated against national endemic diseases and possessed good health conditions, strong ability to bear the hot temperature (30-40°C) during the summer and high humidity (80-90%) during the rainy monsoon season (July-August).

Nonlinear models: The used nine nonlinear model functions of Gompertz, Von Bertalanffy, Logistic, Brody, Wood, Wilmlink, Chobby and LeDu, Cappio Borlino and Dijkstra to estimate the Dhofari cow lactation curve with their relative equations are presented in Table 1.

Peak yield and peak time were assumed to be the maximum milk production test-day reached at that day time respectively. The predicted 305 days milk yield was achieved for every model using the following Eq.¹³:

$$305TY = \sum_{t=5}^{305} y(t)$$

where, 305TY denotes predicted 305 days milk yield and $y(t)$ represents milk yield at day t (5, ..., 305) estimated by corresponding lactation models.

The persistency (P) was calculated using the following Eq.¹⁴:

$$\left[1 - \frac{(\text{Milk K gearlier test} - \text{Milk K glater test}) \times \frac{30 \text{ days}}{\text{Days between tests}}}{\text{Milk K gearlier test}} \right] \times 100$$

Table 1: Non-linear models and their equations used to describe the lactation curve of dhofari cows

Models	Equations
Gompertz	$Y_t = ab \cdot \exp(b(1 - \exp(-ct)/c - ct))$
Von Bertalanffy	$Y_t = a \cdot (1 - b \cdot \exp(-kt))^3$
Logistic	$Y_t = a / (1 + b \cdot \exp(-ct))$
Brody	$Y_t = a(1 - b \cdot \exp(-ct))$
Wood	$Y_t = a \cdot \exp(-b \cdot \exp(-ct))$
Wilmlink	$Y_t = a - b \cdot \exp(-0.05t) - ct$
Cobby and Le Du	$Y_t = a - b \cdot t - a \cdot \exp(-ct)$
Cappio Borlino	$Y_t = at^b \cdot \exp(-c \cdot t)$
Dijkstra	$Y_t = a \cdot \exp(b/c) \cdot (1 - \exp(-c \cdot t)) - 1 \cdot t$

Y_t : Milk yield at (t) time, a: Initial yield, b: Increasing slope of yield, c: Decreasing slope of yield, t: Time

Statistical analysis: All data of each cow daily milk production during the lactation period was analyzed using the SPSS¹⁵ to find the least square means and standard errors. Bivariate correlation¹⁵ using the Pearson as a correlation ($p < 0.05$) coefficient was used between the observed milk production and the results of the estimated milk production by the used nonlinear models used in this research.

The nine nonlinear model functions of Gompertz, Von Bertalanffy, Logistic, Brody, Wood, Wilink, Chobby and LeDu, Cappio Borlino and Dijkstra were fitted to the milk production-days in milk data using the nonlinear regression procedure (NLR) option in SPSS¹⁵. Assessment of goodness of fit between the 9 models used was done using adjusted coefficient of determination (R^2), root mean square error (RMSE), akaikes information criterion (AIC) and Bayesian information criterion (BIC). The R^2 adjusted was calculated using the following Eq:

$$R^2_{adj} = 1 - \left[\frac{(n-1)}{(n-p)} \right] (1 - R^2)$$

where, R^2 is the coefficient of the determination.

$$R^2 = 1 - \frac{RSS}{TSS}$$

RSS is the residual sum of squares, TSS is total sum of squares, n is the number of observations and p is the number of parameters in the model equation. The R^2 is between 0-1 and the closer the value to 1 the better the fit of the model.

The RMSE is a sort of general standard deviation and was calculated by using the following Eq.¹⁶:

$$RMSE = \frac{RSS}{\sqrt{n-p-1}}$$

where, RSS is the residual sum of squares, n is the number of observations and p is the number of parameters of the model used. The model with the best fit is the one with the lowest RMSE value.

AIC values were calculated using the following Eq.¹⁷:

$$AIC = n \times \ln(RSS) + 2P$$

A smaller number value of AIC means a better fit for a model used.

Also, BIC values were calculated as follows Eq.¹⁶:

$$BIC = n \ln \left(\frac{RSS}{n} \right) + p \ln(n)$$

Smaller number values of BIC indicates a better fit when comparing models.

RESULTS AND DISCUSSION

The overall observed least squares means (Table 2) of Dhofari cow daily milk production per head was higher by 25% (6.64 ± 0.11 kg) than found by others¹⁸. Dhofari cow's average peak yield was 9.72 ± 0.35 kg at day 60 (Table 2) which was higher by 60% than the native Ethiopian cattle¹⁹. Estimated parameters of the different 9 nonlinear model functions to describe the lactation curve are shown in Table 3. Analysis revealed that Gompertz model was the closest to the observed data and got the best fit based on RMSE (4.05), AIC(38.5) and BIC(6.83) lowest numerical values in comparison to the other nonlinear model functions (Table 4), it was also found to be the second best model in Holstein cows¹⁶. The adjusted R^2 for the Wood model was similar in value to that of the Gompertz, but provided higher values for the rest of the

Table 2: Least square means and standard error of the observed milk yield of the dhofari cow during the lactation period

Days in milk (days)	Mean (kg)	Standard error	Lower bound	Upper bound
5	7.97	0.26	7.46	8.48
20	8.16	0.27	7.62	8.69
30	8.40	0.28	7.85	8.94
60	9.72	0.35	9.03	10.4
90	9.32	0.42	8.49	10.2
120	5.11	0.23	4.66	5.56
150	4.73	0.24	4.25	5.21
180	4.58	0.24	4.10	5.07
210	2.69	0.20	2.30	3.08
240	1.66	0.27	1.13	2.19
270	3.91	0.58	2.72	5.11
300	1.50	0.25	1.00	1.80
305	0.50	0.05	0.20	0.80
Total	6.64	0.11	6.43	6.86

quality of prediction methods (RMSE, AIC and BIC) (Table 4) as found in Chinese Holstein²⁰. The Dijkstra model gave the highest numerical values of RMSE, AIC and BIC, which indicated its weakness in giving credited representation of the estimated lactation curve (Table 4) as also found in Holstein cows²¹. The models were widely used in literature to describe both growth (Von Bertalanffy, Gompertz and Logistic) and lactation (Wilmlink, Chobby and LeDu, Cappio Borlino, Dijkstra and Brody) curves. However, this research showed that the Gompertz model, which was widely used for estimating the growth curve, could also be used to estimate the lactation curve and give better goodness of fit in comparison to other

Table 3: Dhofari cows estimated lactation curve parameters (mean $\pm$ standard error) by 9 different non-linear models

Models	Parameters		
	A	B	C
Gompertz	358.70 $\pm$ 26.05	0.021 $\pm$ 0.006	0.012 $\pm$ 0.002
Von Bertalanffy	13.26 $\pm$ 7.21	0.117 $\pm$ 0.14	0.005 $\pm$ 0.004
Logistic	9.66 $\pm$ 1.70	0.08 $\pm$ 0.11	0.015 $\pm$ 0.006
Brody	37.40 $\pm$ 11.20	0.753 $\pm$ 0.20	0.001 $\pm$ 0.003
Wood	3.58 $\pm$ 1.46	0.488 $\pm$ 0.153	0.017 $\pm$ 0.003
Wilmlink	10.40 $\pm$ 0.92	3.22 $\pm$ 2.09	0.032 $\pm$ 0.004
Cobby and Le Du	9.78 $\pm$ 0.75	0.029 $\pm$ 0.004	0.35 $\pm$ 0.17
Cappio Borlino	4.76 $\pm$ 1.43	0.28 $\pm$ 0.10	0.009 $\pm$ 0.002
Dijkstra	9.91 $\pm$ 2.56	0.002 $\pm$ 0.031	0.038 $\pm$ 6.40

A, Band C parameters that define the scale and shape of the lactation curve

Table 4: Comparison between the goodness of fit for the 9 estimated lactation curves using R²adj, RMSE, AIC and BIC criteria

Models	Quality of prediction method			
	R ² adj.	RMSE	AIC	BIC
Gompertz	0.90	4.05	38.5	6.83
Von bertalanffy	0.85	6.14	43.9	12.2
Logistic	0.86	5.54	42.5	10.9
Brody	0.84	6.42	44.5	12.8
Wood	0.91	6.04	43.7	12.0
Wilmlink	0.87	5.23	41.8	10.1
Cobby and Le Du	0.86	5.76	43.0	11.4
Cappio borlino	0.88	4.83	40.7	9.09
Dijkstra	0.79	8.62	48.3	16.6

R²adj: Adjusted coefficient of determination, RMSE: Root mean square error, AIC: Akaike's information criteria, BIC: Bayesian information criteria

lactation curve models used in the literature. Among the widely used nonlinear models to estimate lactation curve, the Cappio Borlino model would be the second best choice to estimate the Dhofari cow breed due to its low RMSE (4.83), AIC (40.74) and BIC (9.09), (Table 4). The correlation between the observed data and the estimated results showed that the first and second model of choice to best represent the real observed lactation curve of the Dhofari cows could be the Gompertz and the Cappio Borlino (Table 5). The Cappio Borlino model was also found to be the second best model to describe the lactation curve by others²² after Wood model as it was simply a modification of it. Evaluation of the lactation features of PY (9.72) kg, PT (60) day, MY (1580) kg and P (90.65)% by Gompertz model showed more accurate estimation than the other used models (Table 6) as found by others¹⁶. Von Bertalanffy, Logistic, Brody, Wood, Wilmlink, Chobby and LeDu, Cappio Borlino and Dijkstra models showed variations of their lactations features estimated as found by others²³⁻²⁵. The Cappio Borlino model was the second accurate estimation of 305-MY (1585) kg, but under-estimated the PT (30) day (Table 6), as it was also found by others²⁴. The Dijkstra model was the worst to predict the lactation features of PY (9.01) kg, PT (20) day, MY (1524) kg and P (91.96)% due to higher values of RMSE, AIC and BIC (Table 6). Predicted lactation curves plots by different nonlinear model function were presented in Fig. 1 with the best fit was for the Gompertz and worst for Dijkstra. Most models except the Gompertz under-estimated the PY and 305-total yield which showed the positive relationship between the PY and TY (Fig. 1). In addition, this would suggest that cows with high PY would give high TY. Therefore, it could be more practical to select dairy cows according to their PYs as found by others²⁵. The results analyzed by this study showed high potentiality for the Dhofari cows towards genetic improvement for milk production. This study would give insight for further studies and reliable reference. It would be recommended to conduct a genetic improvement program aimed for this indigenous breed.

Table 5: Correlations between the observed milk yield and the different non-linear model used to estimate the lactation curve of Dhofari cows

	Observed MP	Gompertz	Von Bertalanffy	Logistic	Brody	Cobby	Wilmlink	Cappio	Dijkstra	Wood
Observed MP	1	0.949**	0.921	0.929	0.917	0.926	0.933	0.938**	0.888	0.899
Gompertz		1	0.980	0.988	0.974	0.986	0.991	0.989	0.936	0.951
Von Bertalanffy			1	0.998	1.000	0.992	0.989	0.968	0.974	0.929
Logistic				1	0.996	0.992	0.990	0.975	0.970	0.934
Brody					1	0.991	0.986	0.964	0.975	0.928
Cobby						1	0.996	0.987	0.958	0.967
Wilmlink							1	0.983	0.937	0.952
Cappio								1	0.940	0.988
Dijkstra									1	0.918
Woods										1

MP: Milk production. **Significant high positive correlation at 0.01

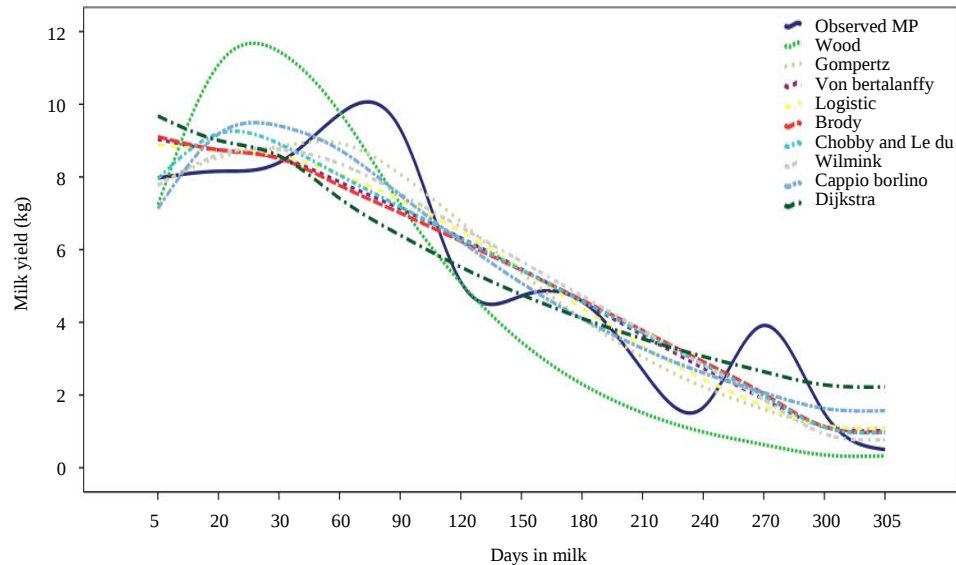


Fig. 1: Estimated lactation curves by Gompertz, Von Bertalanffy, Logistic, Brody, Wood, Wilmlink and Chobby and LeDu, Cappio Borlino and Dijkstra models compared to the observed actual yield curve during the lactation period for the Dhofari cow breed

Table 6: Peak yield (PY), peak time (PT), total yield (305TY) and persistency percentage estimated by the 9 used non-linear models

Models	Trait			
	PT (days)	PY (kg)	305TY (kg)	Persistency (%)
Gompertz	60	9.72	1580	90.7
Von Bertalanffy	5	9.04	1617	91.5
Logistic	5	8.9	1559	91.1
Brody	5	9.11	5006	91.5
Wood	30	11.3	1319	88.5
Wilmlink	30	8.76	1585	91.5
Cobby and Le Du	20	9.19	1585	91.5
Cappio Borlino	30	9.41	1585	91.4
Dijkstra	20	9.01	1524	91.9

PT: Peak time in days, PY: Peak yield (kg). 305TY: Total yield during 305 days of lactation (kg)

CONCLUSION

In this study, 9 different non-linear models were used in order to widen and enrich the possibility and option to find the best and closest among them for the description of the Dhofari cow lactation curve. The Gompertz model which is a growth model and a non-conventional to be used for prediction of the lactation curve gave the best fit $R^2 = 0.90$, $RMSE = 4.05$, $AIC = 38.5$ and $BIC = 6.83$, compared to the others. The Dhofari cow peak yield, peak time, 305-total milk production and persistency were 9.72 kg, 60 days, 1580 kg and 90.65%, respectively. The novel items in this study were to include and use growth models to predict the lactation curve which in fact proved to possess greater ability to give most accurate estimation among all models used.

SIGNIFICANCE STATEMENT

This study will help the researcher to have a reliable scientific base to start a long or short term genetic improvement programs for this indigenous cattle breed in Arabia that previous researchers were not able to explore.

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