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Modeling lactation curve of Saudi camels using the linear and non-linear forms of the incomplete Gamma function

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ABSTRACT

The objectives of this study were to describe lactation curve of Saudi camels using the linear and non-linear forms of the incomplete Gamma function, to estimate lactation curve characteristics and to determine the appropriate form describing lactation curve. Records of weekly milk yield representing 9 parities were collected from 56 she-camels. Data were collected over the period 2007–2013. The results revealed that averages of total milk yield, lactation length and daily milk yield of the nine parities, ranged between 967.3 and 3107.21 kg, between 273 and 416 days and between 2.96 and 7.40 kg/day, respectively. Initial milk yield (a) estimated by the linear and non-linear forms of the nine parities ranged between 0.194 and 1.775 and between 0.155 and 1.818, respectively. The increasing rate (b) ranged between 0.754 and 1.414 and between 0.750 and 1.533, while the decreasing rate (c) ranged between −0.054 and −0.020 and between −0.059 and −0.036, respectively. Days to attain peak production, peak production and persistency, as well as persistency percentage were also estimated. It is concluded that the linear form of the incomplete Gamma function is more appropriate for describing lactation curve of camel milk yield than its non-linear counterpart.

1. Introduction

Camel milk is regarded the most popular nourishment for many Saudi people, especially those living in remote areas. The Kingdom has about 813,000 head (Ministry of Agriculture, 2006). Despite this large number, the population contributes about 4.5% of the total amount of milk produced annually from the different dairy species (FAOSTAT, 2013). This marginal level of milk production could be attributed to the effect of many factors such as feed, milking practices, physiological and health status, as well as other non-genetic factors (Almutairi et al., 2010 and Jemmali et al., 2016). Although intensive camel farming is expanding, very little improvement in milk production has been achieved. Lack of proper recording system and sound breeding programs are considered the main constraints facing the improvement process.

Mathematical modeling of lactation curve represents a valuable tool for understanding the temporal evolution of milk production. Description of lactation curves provides valuable information for designing proper breeding programs and improving management practices. Dag et al. (2005) stated that appropriate models for describing lactation curves could provide useful information in this regard. In comparison with other dairy species, information concerning camel lactation curve is rarely found in the literature, and is greatly needed (Gradiz et al., 2009; Steri, 2009; Musaad et al., 2013 and Jemmali et al., 2016).

The objectives of this study were to describe lactation curve of milk production of Saudi camels using the linear and non-linear forms of the incomplete Gamma function of Wood (1967), to estimate lactation curve characteristics of both forms and to compare the results obtained. Results obtained may provide camel researchers with a clear picture, and hence, a spur to the development of camel as a dairy animal.

2. Materials and methods

This study was conducted on records of she-camels collected from two herds. The first herd belongs to the Camel Research Center of the Experiment Station of King Faisal University, located in Al-Ahsa region of the Eastern province of Saudi Arabia (university herd), while the second is belonging to the Camel and Range

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Research Center, which is located in Al-Jouf region, northwest Saudi Arabia (center herd). Camels of the university herd were Majaheem, while those of the center herd were from different local types (Majaheem, Waddah, and Homor). Both herds were raised under intensive feeding management and were housed in open air shade pens.

The university herd is newly established and consists of seven pregnant she-camels in their first lactation. They were purchased from market. After purchasing, animals were quarantined for 30 days. Then, they were ear tagged and kept in open air pens equipped with feeders and drinkers. The center herd consists of 49 she-camels, representing 9 lactations. More details on the constitution of the latter herd can be found in Almutairi et al. (2010).

The amount of ration given to the animals of both herds was estimated based on the actual production status of each female. Concentrates were provided in equal parts in the morning and afternoon, while the forage (alfalfa or Rhodes) was provided **ad libitum**. Fresh water was also provided **ad libitum**. Salt and standard minerals were thoroughly mixed with the concentrate ration.

Females of the center herd were naturally mated in November–December to calve the following December–February. Calves were separated from their mother for 12 h each day, starting from 6 weeks age and allowed to suckle only at milking time to enhance milk release by the mother. Camels were milked twice a day at 6:00AM and 5:00PM. Milk was weighed by a balance with an accuracy of 10 g at the two milking times and summed to determine the total yield of each lactating camel over a period of 24 h.

After delivery, calves of the university herd were allowed to suckle their dams up to weaning. They were weaned at approximately 6 months. During weaning period, milk production was determined by weigh to weigh technique, where calves were weighted before and after suckling their dams and the difference in both weights were considered the amount of milk suckled by them. After weaning, she-camels were hand milked once daily, after introducing calves to their mothers to stimulate milk let down. Milk yield was collected from three teats, while the fourth one was left for the calf. One third of the amount of milk produced from the three teats was added to compensate for the amount consumed by the calf.

2.1. Data collection

Parity and daily milk yield were collected on lactating camels of the center herd during the years 2007, 2008, 2009, 2010, and 2011, while daily milk yield of camels of the university herd was collected during the year 2013. Test day records were collected on 82 lactations of 56 she-camels from both herds. The records represent 9 parities with different lactation periods ranging from 56 up to 78 test days. Parities longer than 56 test days were truncated. Data for which the first milk recording had occurred between 7 and 72 days were only used for the analysis. After editing, number of records left for analysis was 575.

2.2. Statistical analysis:

Descriptive statistics of total milk yield, lactation length and average daily milk yield were calculated by the means procedure (PROC MEANS) of SAS (2000).

The linear and non-linear forms of the incomplete gamma function were used to describe lactation curve, according to the following equation (Wood, 1967);

$$Y_t = a^t b e^{-ct}$$

where Y_t is the milk production at time t, a is the parameter that represents a scale factor or milk production at the beginning of lactation, b is a parameter determining the slope of the increasing part of the function, c is a parameter determining the slope of the decreasing part of the function and t is number of days after calving, while e is the base of the natural logarithm. The constants of the linear form were derived by solving the above equation after transformation on the log scale, according to the following formula:

$$\ln(Y_t) = \ln(a) + b\ln(t) - ct$$

Data were analyzed by the linear form using the regression procedure (PROC REG) of SAS package (SAS, 2000), while the non-linear form was fitted using the iterative non-linear procedure (PROC NLIN) in SAS (2000), following the computational strategy of Marquardt (Marquardt, 1963) to search for the 'best fit' solution. The method was chosen because of the high correlation between the parameters of Wood's model (Gantner et al., 2010). The "best fit" curve was obtained when there was a less than 10^{-6} difference between the error sums of squares in successive iterations. Analysis was performed on data of each parity separately.

2.3. Lactation curve characteristics:

The shape of lactation curve depends on the initial milk yield, peak yield, and persistency. Thus, several characteristics were estimated, including the following (Wood, 1967):

- Peak yield (PY) = $a(b/c)^b e^{-b}$
- Time at peak yield (T) = b/c, it is the days to attain peak yield.
- Persistency (P) = $-(b+1)^*\ln(c)$. This measure was used due to the instability attributed to small values of "c" parameter (Rekaya et al., 2000). It covers the entire period of lactation and is independent of time. Higher value of this measure is favorable.
- Persistency percentage was calculated by the following formula:

$$PP = \left[1 - \frac{y_m - y_{56}}{y_m}\right] \times 100$$

where PP is the percent persistency, y_m is milk yield at peak, and y_{56} is milk yield on week 56.

2.4. Model comparison:

Both forms of the Wood function were compared based on the following criteria:

1.) **Root mean square error (RMSE):** It is a function of the sum of squared errors (SSE), number of observations n, and the number of independent variables including the intercept.
2.) **Akaike information criterion (AIC):** It is a function of the number of observations n, the SSE, and the number of independent variables including the intercept (Akaike, 1973).
3.) **Bayesian Information Criterion (BIC):** It is a Bayesian modification of the AIC criterion (Schwarz, 1978).

Model with the smallest values of RMSE, AIC and BIC is declared the best model describing lactation curve.

- **Durbin-Watson statistic (D-W):** It is a measure of first-order autocorrelation of residuals. It is used to compare the goodness-of-fit for both forms of the incomplete gamma. If the value of D-W test is equal to 2, that indicates no autocorrelation among the errors, while if it is less than 2, there is evidence of positive serial correlation. Here, we were interested in testing the hypothesis of zero autocorrelation against the alternative of positive first-order autocorrelation. So, the D-W values were compared to the tabulated value at $P < 0.05$, with number of observations (n) and