

Lactation curves in some selected breeds of cows in Niger state, Nigeria

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Target Audience: Milk processors, Researchers, Dairy farmers, Government policy makers

Abstract

The aim of this study was to characterize and compare the lactation curves in some selected breeds of cattle in Niger State, Nigeria. The data for the study was obtained from three genotypes (Bunaji; n=350; Sokoto-Gudali; n=220 and Simmental; n=202) from the years 2014 to 2021 domiciled at Maizube® Farm. Lactation curves were namely the logistics, Gompertz, Woods, Wilmlink and Cobby and Ledu were fitted on actual daily milk yield records. Estimators of the lactation parameters for each model were computed for each cow by AI-REML algorithm. A lactation curve was fitted in MATHPLOT using days in milk as a numerical variable. The adjustment criteria considered to compare models were persistency, adjusted R^2 coefficient of determination and model selection criterion. The initial milk yield was predicted to be 4.37, 4.39, 4.95, 4.2 and 4.4kg for Logistic, Gompertz, Wood, Wilmlink and Cobby and Ledu models in Simmental cows. Wood model (7.95kg/day) had the best scale factor for average milk yield followed by Logistic and Gompertz models (7.78kg/day) in Bunaji cows which was better than Wilmlink (6.14kg/day) and Cobby and Ledu (6.93 kg/day) in Simmental cows. Gompertz model predicted the highest peak milk yield, followed by Logistic (8.04kg) and Wood (7.79kg) for Simmental and Sokoto Gudali cows. More research on the topic is required to reach significant recommendations.

Keywords: Lactation curves; mathematical models, selected breeds of cattle

Description of Problem

In the tropics, the generation of hybrid animals aims to optimize the best production characteristics of each group; on one hand, the adaptation to the tropical conditions of Zebu cattle and, on the other hand, the high production of specialized European breeds for beef and milk (1).

The lactation curve is one of the main tools to understand and evaluate the physiology of milk production, the genetic potential for milk production in a herd or breed and to establish better management strategies (2, 3). Lactation curve can be defined as a mathematical expression of a biological process. Lactation curves are

useful for forecasting total production for the remainder of the lactation from partial records, for planning herd management using a reliable prediction tool and for selecting animals considering the relationships among the different phases of the lactation period (4). However, it is advisable to find for each production circumstance the mathematical function better describing the lactation pattern (1).

To describe milk yield behaviour through lactation in domestic animals, various mathematical models have been proposed. Mathematical models for describing a lactation curve include: negative exponentials, incomplete gamma, and

polynomials all of which can estimate the milk yield average at a given time (5). The shape of the lactation curve provides valuable information which is essential to evaluate the biological and economic efficiency of the animal or herd and is useful for genetic evaluation, health monitoring, feed management decisions and planning purposes (6). Also, knowing when to expect an animal to reach peak yield, would affect the feeding strategy followed, allowing economic management of feed to extent that would satisfy the animal's requirement during various stages of lactation, reduce cost, and possibly maintaining peak yield for as long as possible (7). A lot of mathematical models as Wood, Wilmink, Cobby and Ledu, and Gompertz were used to describe the lactation curve of cows (8). Since the choice of appropriate mathematical function to describe the fixed and random effects is the key element in fitting random regression model. The correct choice of these functions to estimates genetic parameters leads to more accurate estimates (8). The choice of the function influences number of parameters and order of the estimated (co) variance components matrix (9). The objective of this study was to characterize and compare the lactation curves in some selected breeds of cattle in Niger State, Nigeria.

Materials and methods

Study location, experimental animals and management

This study on indigenous and exotic cattle was carried out in Maizube® farms, Niger State, Nigeria. The farm is located in the tropical climate of Nigeria, with pronounced wet and dry seasons and steady

high temperatures. Its geographical coordinates are 9° 1' north, 5° 9' East at an altitude of 305m above sea level. The rainy season with duration of about 218 days, starts in April and ends in October (10).

Experimental Animals

Dual purpose Simmental cattle (n=202) and indigenous cattle namely white Fulani (n=350) and Sokoto Gudali (n=220) which had pedigree information were used for this study belonged to the first lactation dairy cows from year 2014 to 2021. The age of cows in the first lactation was from 12 to 108 months. Farm records showed that the Simmental cows were initially imported from Switzerland as pregnant heifers and subsequent service in the studied herd was by artificial insemination using imported frozen purebred bull semen with a restriction to avoid full-sib and sire-daughter inseminations.

Milk yield characterization

The following variables were used to characterize the milk yield of the experimental animals.

- a. Initial yield (kg): This is milk yield at day 7 postpartum
- b. Peak yield (kg): This is the highest test day yield during the lactation period
- c. Peak day (d): This is the day of highest milk yield within the lactation period
- d. Last test day yield (kg): This is the last test day yield before production dropped to below 2 litres per day (end of lactation).
- e. Lactation length (days): This is the number of days from the beginning to end of lactation.

Table 1: Growth Models

Model	Functions	Ti	Yi
Gompertz	$Y_t = ae^{-bexp-Kt}$	$\ln(b)/K$	a/e -----(26)
Logistic	$Y_t = \frac{a}{(1 + be^{-Kt})}$	$-\ln(1/b)/K$	$a(0.5)$ ----- (27)

Ln=parameter; a=growth rate; b=inflexion point; k=lower asymptote; e=upper asymptote; Ti = The age at point of inflexion; Yi =Weight at point of inflection

Table 2: Milk yield characteristics of exotic and indigenous cows

Traits	Simmental				
	Logistic	Gompertz	Wood	Wilmink	Cobby and Ledu
Initial yield (kg)	4.37	4.39	4.95	4.2	4.4
Days at Peak yield (d)	150.6	151	150.5	150	150
Peak yield (kg)	8.04	8.05	7.79	7.7	7.4
Last day yield(kg)	7.52	7.51	7.23	7.6	7.2
Bunaji					
Initial yield (kg)	0.5	0.4	0.4	0.4	0.5
Days at Peak yield (d)	150	150	150	150	150
Peak yield (kg)	2.4	2.3	2.3	2.3	2.3
Last day yield (kg)	2.17	2.16	2.15	2.15	2.15
Sokoto Gudali					
Initial yield	0.71	0.71	0.77	0.69	0.74
Days at Peak yield (d)	120	180	90	120	90
Peak yield (kg)	2.94	2.95	2.95	3.1	3.3
Last day yield (kg)	2.94	2.95	2.95	2.7	2.95

Fitting of lactation curve models to milk yield pattern

Five lactation models (Wood, Wilmink, Gompertz, Logistic and Cobby and LeDu) were constructed from the milk yield data.

Total milk yield (TMY) was estimated as:

$$TMY = \sum_{t=1}^{350} Y_t$$

Where, t is the days of lactation

Y_t = average milk yield on day t of lactation

$$\text{Peak day} = \frac{b}{c}$$

$$\text{Peak yield} = a \left(\frac{b}{c} \right)^b e^{-b}$$

a = scaling factor, b = increasing slope of yield or rate of increase to peak yield, c = decreasing slope of yield or rate of decline after peak yield

$$\text{Persistence (S)} = -(b+1)\ln c$$

Wood Model

Woods (11) incomplete gamma function method is an empirical model where

$$Y = at^b e^{-ct}$$

Wilmink Model

The Wilmink (12) model is a modification of the model by Cobby and Le Du (13)

$$Y = a + bt + ce^{-kt}$$

where a = production level, b = related to milk production before lactation peak, c = correlated to the peak day, d = decrease in production after the lactation peak

Cobby and Ledu Model

The Cobby and Le Du (13) model

$$Y = a - bt - ae^{-ct}$$

Where;

Y = milk yield, a = production level, b = related to milk production before lactation peak,

c = correlated to the peak day, t = time, e = is the exponential, k = parameter assumes a fixed value derived from a preliminary analysis and is associated with the time at peak yield.

Statistical analysis

Model describing the ANOVA was given as; $Y_{ijk} = \mu + \alpha_i + \delta_j + e_{ijk}$,

where Y_{ijk} = observed measure, μ = the overall mean, α_i = i^{th} fixed effect of genotype, δ_j = j^{th} covariate effect of days in milk and e_{ijk} = residual random error (the error terms are assumed to be randomly, independently, and normally distributed with a mean of zero and a common variance)

Means, SD were computed by ANOVA, using GLM (General Linear Procedure) in (14). The means that were significant was compared using Tukey's-Kramer tests.

Results

Lactation models for milk yield characteristics of exotic and indigenous cows

Table 2; shows the lactation models for milk yield characteristics of exotic and indigenous cows. The initial milk yield was predicted to be 4.37, 4.39, 4.95, 4.2 and 4.4kg for Logistic, Gompertz, Wood, Wilmink and Cobby and Ledu models in Simmental cows. Gompertz model predicted the highest peak milk yield (8.05kg/day), followed by Logistic (8.04kg/day) and Wood (7.79kg/day) for Simmental cows. The days to peak yield predicted by all the models ranged from 150 to 151 days. The last day milk yield was lowest in Wood model prediction as compared to the estimates by the two growth models (Gompertz and Logistic) and two 4 traits lactation curves (Wilmink and Cobby and Ledu).

In Bunaji cows, the initial milk yield was predicted to be less than 1kg/day with the days to peak yield estimated at 135 days by all the models. Logistic models had the best peak yield (2.4kg/day) while the growth and 4 traits lactation models recorded the least yield (2.3kg/day). The last day milk yield ranged from 2.15 to 2.17kg. The peak milk yield was estimated at 150 days.

The initial milk yield in Sokoto Gudali was predicted to be higher than Bunaji cows though there were variations in days to peak yield (90 to 120 days). Cobby and Ledu models had the best peak yield (3.3kg/day), followed by Wilmink (3.1kg/day), Gompertz (2.95kg/day), Wood (2.95kg/day) and Logistic (2.94kg/day). The last day milk yield ranged from 2.7 to 2.95kg.

Table 3: Estimates for curve traits by different models in Exotic and Indigenous cows

Traits	Wood	Logistic	Gompertz	Wilmink	Cobby and Ledu
Simmental					
$a \pm s_a$	7.95±2.105	7.78±0.13	7.78±0.14	6.14±0.76	6.93±0.09
$b \pm s_b$	0.02±0.038	0.05±0.001	0.05±0.013	-0.24±0.12	0.05±0.013
$c \pm s_c$	-0.587±0.05	-0.387±0.38	-0.23±0.01	-0.40±0.17	-0.23±0.01
$d \pm s_d$				-0.13±0.11	-0.23±0.01
Adj R ²	0.77	0.91	0.89	0.67	0.70
RSD	0.32	0.37	0.38	0.46	0.42
S	7.80	7.78	7.77	8.10	7.86
Bunaji					
$a \pm s_a$	2.52±0.75	2.68±0.43	2.57±0.22	2.23±0.18	2.14±0.12
$b \pm s_b$	0.022±0.067	0.05±0.008	0.03±0.007	-0.14±0.02	0.26±0.05
$c \pm s_c$	-0.125±0.001	-0.295±0.065	-0.296±0.09	-0.19±0.17	-0.08±0.06
$d \pm s_d$				-0.12±0.14	-0.19±0.08
Adj R ²	0.93	0.97	0.96	0.88	0.76
RSD	0.32	0.16	0.20	0.34	0.39
S	2.86	2.93	2.91	2.20	2.13
Sokoto Gudali					
$a \pm s_a$	2.64±3.29	1.81±0.20	2.03±0.31	2.52±0.67	2.48±0.82
$b \pm s_b$	0.42±0.07	0.07±0.013	0.05±0.01	-0.85±0.18	0.43±0.25
$c \pm s_c$	-0.295±0.08	-0.295±0.06	-0.295±0.08	-0.36±0.12	-0.23±0.18
$d \pm s_d$				-0.09±0.05	-0.13±0.04
Adj R ²	0.96	0.96	0.94	0.83	0.78
RSD	0.20	0.17	0.19	0.22	0.18
S	2.95	2.95	2.94	2.67	2.82

S-persistency; Adj R²-Adjusted coefficient of determination; RSD-Residual standard deviation; $a \pm s_a$ -scaling factor with its standard error; $b \pm s_b$ -inclining slope to peak production; $c \pm s_c$ -declining slope after peak production.

Estimates of curve traits for lactation models of exotic and indigenous cows

Table 3 shows the variation in estimates of curve traits by different models in exotic and indigenous cows. Wood model (7.95kg/day) had the best scale factor a for average milk yield followed by Logistic and Gompertz models (7.78kg/day, respectively) which is better than Wilmink (6.14kg/day) and Cobby and Ledu (6.93 kg/day) in Simmental cows (Figure 1). The b trait which represents the growth rate or the inclining slope to peak production was larger

in both Logistic and Gompertz models (0.05kg/day, respectively) than wood model (0.02kg/day). Milk yield was predicted to decline slower in Gompertz (-0.23kg/day) followed by Logistic (-0.387kg/day) and Wood models (-0.587kg/day). Wood model recorded high lactation persistency (7.80) as compared to Logistic (7.78) and Gompertz (7.77) models. The adjusted coefficient of determination was best in Logistic (0.97), followed by Gompertz (0.89) and Wood (0.77) models in reconstructing the lactation curve of Simmental cows. In Bunaji cows

(Figure 2), the model persistency ranged from 2.86 in wood to 2.93 in Logistic model. Wood, Gompertz and Logistic models had high prediction accuracy above 90% (93-97%) to reconstruct the lactation curve. Logistic model recorded the highest scale factor a for milk production (2.68kg/day) while wood model recorded the least (2.52kg/day). In Sokoto Gudali cows (Figure

3), the scale factor for milk production ranged from 1.81kg/day in Logistic to 2.64kg/day in wood model. Persistency for milk production was similar in Wood and Logistic models and higher than Gompertz by 0.34%. Wood, Gompertz and Logistic models had the best prediction accuracy than Wilmlink and Cobby and Ledu in fitting the lactation curve.

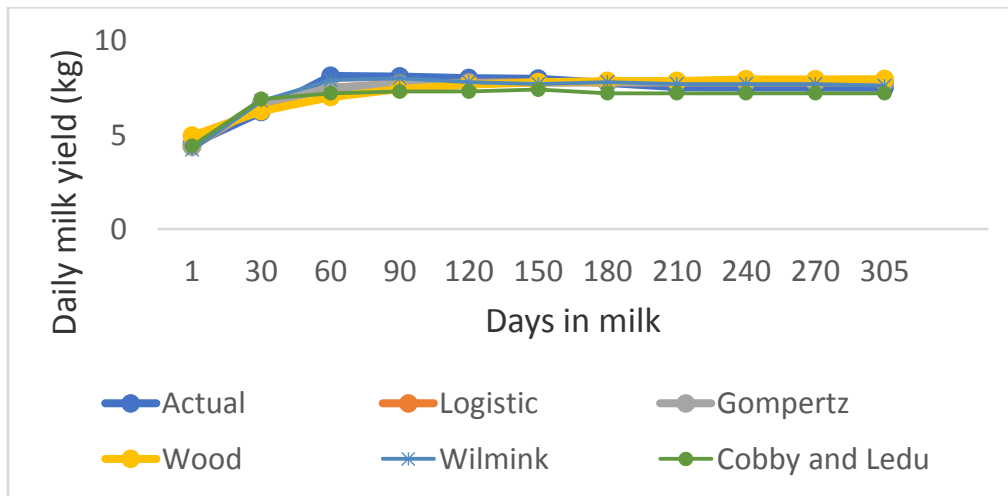


Figure 1: Lactation curves of Simmental cows in Niger State



Figure 2: Lactation curves of Bunaji cows in Niger State

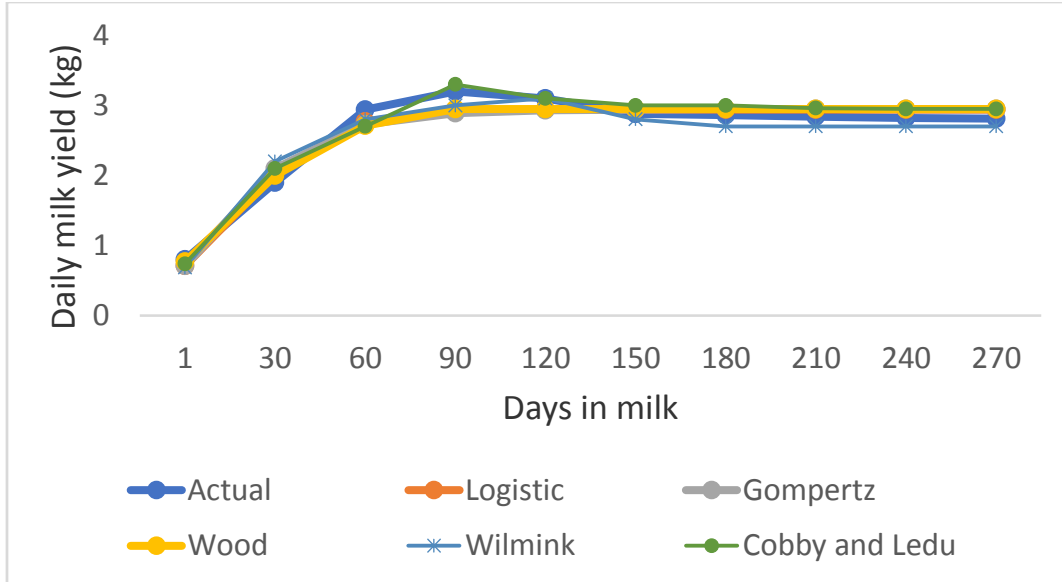


Figure 3: Lactation curves of Sokoto-Gudali cows in Niger State

Discussion

Deterministic models for reconstruction of lactation curve in exotic and indigenous cows

In this study, lactation curves were challenged by the ability of some models to mimic actual lactation records over time. Although considerable variation may have arisen due to different milking frequency, parity, low number of cows for some breed-parity interactions, and incomplete or irregular lactation records to characterize an entire lactation (0-305 days) because indigenous cows of Bunaji and Sokoto-Gudali lack the capacity to actualize 305 days lactation as reported by (4, 15). These sources of variation might have constrained some of the results and increased the difficulty of obtaining valid, convergent, and robust solutions for some models. Nonetheless, the dataset offered the opportunity for Wood, Logistic, Gompertz and Cobby and Ledu model to exhibit their flexible nature to fit convex lactation profiles (8). The moderate to good model (67-97%)

performance of the deterministic models in all the cows may be explained by the prior arbitrary exclusion of concave lactation records, as well as incomplete and irregular lactation profiles. In this research, empirical functions were compared for better fitting performance of milk production traits. The comparison results of the models are in agreement with those reported by (16, 8). Small differences were observed for estimations of coefficient of determination and coefficient of determination adjusted between different models of the lactation curves.

In general, for all models, it shows that environmental effects involved in production, are the major differences in herd or breed management. The results of this study agree with (17, 18). The results indicated that selection for increase milk production traits at a certain point during lactation has a positive effect on any other point of the curve. These results agree with results of (19). Similar genetic trends were reported by (20) using the 305 day measures

of the traits, which indicated that Simmental, Bunaji and Sokoto-Gudali cattle population can be genetically improved for milk yield.

This lends credence to the assertion by some authors (11, 21) why Wood model is flexible under high and low production systems. Wood, Wilmlink and Cobby and Ledu models were free of convergence problems as indicated by (22) in Holstein cattle in Adamawa State. Regarding the features of the different equations, all equations showed systematic deviation from actual milk yield in accordance with (23), especially at the beginning of lactation and peak yield. So, these results showed that Wilmlink, Cobby and Ledu model had some disadvantages such as standardization of production level in predicting lactation curve features and under the conditions of the present study. The interest of commercial farmers to use sperms from genetically superior bulls could be the main factor which caused these changes for tropical breeds. The tested lactation functions showed Wood model is a potential candidate for the lactation equation for Bunaji, Sokoto-Gudali and Simmental cows.

(24) state that an important point to be considered in mathematical models for describing lactation curves is the value of the coefficient of determination adjusted (70-96%) through lactation which was in tandem with this study which infer a good fit for the models. This variability is accentuated because each individual production record reflects not only the individual effect of day in lactation, but also the environmental effects (such as month and year of birth, herd management and frequency of milking) influencing milk yield of the individual cow (25).

Conclusion and Application

1. The pattern of lactation was parsimonious for milk yield and

adequately reconstructed by all the models ($\text{Adj } R^2 = 0.77\text{-}0.97$) while the growth curve for body weight was concave ($\text{Adj } R^2 = 0.93\text{-}0.99$)

2. The atypical curve suggest that the models can be incorporated into a breeding programme to make forecast for growth rate and milk production
3. Wood's model was more efficient than other models in predicting the trajectory of milk yield in Bunaji, Sokoto Gudali, and Simmental cattle, hence Wood model could be built in an index targeted towards genetic improvement of milk yield

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