Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 124 No. 1 (2023) 93–100

https://doi.org/10.17170/kobra-202306128206 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

Characterisation of the lactation curve of Gyr and Sardo Negro cattle

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Abstract

The objectives were to characterise the lactation curves (LC) of tropical Gyr and Sardo Negro (SN) cattle from Mexico for the design of breeding and management programs for these breeds. A total of 3561 records of 504 lactations and 3927 records of 449 lactations were used for Gyr and SN, respectively. Three lactation lengths (LL) were evaluated, namely 240 (240 d), 270 (270 d), and 300 (300 d) days, with five non-linear models (NLM): Wood, Wiltmink, Cobby, Brody, and Sikka. Milk production was obtained at the beginning (PI; kg), daily average (PMD; kg), maximum at peak (PMX; kg), days to reach maximum production (DP), and accumulated total (PT; kg). The selection of models was made based in the Akaike and Bayesian information criteria. The NLM explained at least 88 % of the variability in the data. Brody model provided the best fit for 240 d and 270 d, and Sikka for 300 d in SN; for Gyr, Wood model showed the best fit for 240 d and 270 d, while Wiltmink had the best fit for 300 d. The means for PMD were 5.3 kg in SN and 10.2 kg in Gyr; for PMX the averages were 6.9 kg and 12.7 kg, respectively. The average of PT, within LL (240 d, 270 d, and 300 d), was 1297 kg, 1418 kg, and 1552 kg for SN, and 2653 kg, 2930 kg, and 3202 kg for Gyr, respectively. The first third of the LC presented the highest contribution (%), with average values of 37.4 in Gyr and 39.5 in SN; the second and third periods, contributed (%) 33.5 and 29.1 in Gyr, and 33.0 and 27.5 in SN, respectively. The 240 d LL, are the proposals for the design of management, feeding, and genetic improvement programs, they presented the best statistical adjustment in both breeds.

Keywords: Bos indicus, milk production, nonlinear models, persistency, tropical livestock

1 Introduction

In Mexico, tropical livestock occupies around 28 % of the national territory and is established with more than 500 thousand production units. The Mexican tropics is home to around 50 % of the national bovine inventory, contributes to the country more than 40 % of meat production and values higher than 20 % of milk production. Milk production is developed with the dual-purpose system, extensive management, feeding based on grazing, and occasionally supplemented with agro-industrial by-products; the populations are *Bos indicus* breeds and their crosses with specialised dairy breeds (Magaña textitet al., 2006; Rojo-Rubio *et al.*, 2009; González & Dávalos, 2018; Ramírez-Rivera *et al.*, 2019).

Gyr and Sardo Negro (SN) were developed as specialised breeds for milk production, adapted to the production systems of the tropical regions of Mexico. Gyr cattle are native to the Kathiawar peninsula (northwestern India); their arrival in the American continent was through Brazil, with imports dating from 1870 (Santana *et al.*, 2014), and arriving in Mexico from 1930 onwards. SN is a breed structured by Mexican breeders in the southeast of the country, where they developed it from a series of crosses alternating the two Zebu breeds Gyr and Indubrasil. The racial pattern and the pedigree of breed purity were instituted in 1978 (Domínguez-Viveros *et al.*, 2022).

Milk production is the result of synthesis, secretion, and filtration processes by specialised cells in the mammary gland. These physiological mechanisms generate a secre-

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Published online: 15 July 2023 – Received: 26 December 2023 – Accepted: 26 June 2023

tion pattern called the lactation curve (LC), subdivided into three periods, and characterised by four components: initial production, phase of progressive increase in production, maximum or peak level of production, and decreasing rate or reduction of production, called persistency (Macciotta *et al*., 2005; Macciotta *et al*., 2011). For the characteri sation and analysis of the lactation curve, non-linear models (NLM) have been used, where the regression coefficients have an interpretation associated with the components. They allow to derive other indicators, which are of importance in the definition of schemes for management, feeding and genetic improvement (Papajcsik & Bodero, 1988; Landete-Castillejos & Gallego, 2000). The objectives of this study were to characterize the LC, as well as the production levels of Gyr and SN cattle in tropical production systems of Mexico, in order to guide the design of management and breed improvement programs for these breeds.

2 Materials and methods

The analysed database was provided by the dairy control of the Mexican Association of Zebu Breeders (AMCC, 2015). For Gyr, 3561 monthly measurements of 504 lactations of 256 cows from three herds were analysed. In SN, 3927 monthly measurements of 449 lactations of 403 cows from three herds were the basis for the evaluation. The herds (six in all) were in the states of Veracruz and Tabasco. Monthly measurements generate a distribution of productive data in the interval from one to 315 days in lactation. To define and analyse the lactation curve (LC), three lactations lengths (LL) were evaluated, namely 240 (240 d), 270 (270 d) and 300 (300 d) days, using five NLM (Cobuci *et al*., 2000; Cunha *et al*., 2010; Luna-Palomera *et al*., 2021; Ferro *et al*., 2022):

1. Wood (WOD): γt = β1*(tβ2)*(exp (-β3*t))
2. Wiltmink (WIL): γt = β1 + β2*t + β3*(exp(-0.05*t))
3. Cobby (COB); γt = β1-β2*t-β1*(exp(-β3*t))
4. Brody (BRO): γt = β1*(exp (-β2*t)) – β1*(exp(-β3*t))
5. Sikka (SIK): γt = β1*(exp ((β2*t) - (β3*t2)))

Where: γt = corresponds to milk production (kg) on day t; β1, β2, and β3 = regression coefficients that make up each model. Analyses were conducted with the NLIN procedure of SAS statistical analysis program version 9.0 (SAS, 2005). The selection of the model with the best fit was made based on the coefficient of determination (R2), the Akaike information criterion (AIC), and the Bayesian (BIC) information criterion (Motulsky & Christopoulos, 2003; Piccardi *et al*., 2017). To validate the prediction capacity the mean prediction error (MPE), the mean absolute prediction error (MAPE), the variance of the prediction error (VEP), the Durbin-Watson (DW) statistic, and the concordance and correlation coefficient (CCC) were analysed (Palacios-Espinosa *et al*., 2016a; Luna-Palomera *et al*., 2021; Ferro *et al*., 2022). The CCC takes values from zero to one and jointly measures the accuracy and precision of a model (Lin, 1989; Khan *et al*., 2012). In addition, the linear relationship between the estimated daily production (pde) and the observed daily production (pdo) was analysed, from the correlation between both (γ).The regression analysis was based on the model: pdo = β0 + βi*pde; where, β0 is the intercept and βi is the slope or rate of change of pdo, for each unit of change in pde, with estimates in the interval from zero to one.

To characterize the LC, the following productive variables were evaluated: initial production (PI; kg), total accumulated (PT; kg), maximum at the peak of lactation (PMX; kg), daily average (PMD; kg); and days to reach maximum production (DP; days). In addition, persistence was estimated by four methods (Sölkner & Fuchs, 1987; Penchev & Peeva, 2013; Kaushal *et al*., 2016):

1. Percentage contribution for period. The LL was divided into three periods (P1, P2, P3) of equal number of days (LL / 3), and the contribution per period was defined with respect to PT: AP1 = (production in P1 / PT)*100; AP2 = (production in P2 / PT)*100; AP3 = (production in P3 / PT)*100
2. Level of production through periods: P2:1 = (production in P2 / production in P1)*100; P3:1 = (production in P3 / production in P1)*100; P3:2 = (production in P3 / production in P2)*100
3. Ratio of the maximum production (PMX) with respect to the average daily production (PMD) in the second and third periods of lactation (P2 and P3): PE1 = (PMX / PMD in P2)*100; PE2 = (PMX / PMD in P3)*100
4. Ratio of the total production (PT) with respect to the average daily production (PMX) for the respective length of lactation (LL; days): PN = (PT / (PMX * LL))*100

3 Results

Tables 1, 2, and 3 present the statistics for the selection and adjustment of the NLM for 240 d, 270 d and 300 d, respectively, separately for each breed. The NLM explained (R2) around 88 % of the variability in SN and 92 % in Gyr.

Table 1: *Fitting of non-linear models in the analysis of the lactation curve at 240 days*

Parameters	*WOD*	*WIL*	*COB*	*BRO*	*SIK*
		Sardo Negro			
β1	6.6601	6.7591	6.8831	7.0643	7.1487
β2	0.0145	-0.0112	0.0121	0.00228	-0.00298
β3	0.00235	0.1914	0.4409	0.4033	-3.9E-6
AIC	5369.9	5380.4	5365.4	5350.2	5364.9
BIC	5388.6	5399.1	5384.1	5368.9	5383.5
R^2	88.19	88.16	88.21	88.25	88.21
MPE	-17.1	-17.5	-17.0	-17.2	-17.3
MAPE	36.6	36.9	36.7	36.5	36.7
VEP	4.22	4.23	4.22	4.20	4.71
DW	0.90	0.91	0.92	0.90	0.91
γ	0.34	0.34	0.35	0.35	0.34
βi	0.98	1.00	0.99	0.98	0.99
CCC	0.21	0.21	0.20	0.22	0.20
		Gyr			
β1	11.2397	13.4155	13.0498	13.1753	12.8117
β2	0.0508	-0.0184	0.0162	0.00147	-0.00089
β3	0.00207	-1.5729	0.6316	0.5874	2.292E-6
AIC	7538.5	7540.7	7550.8	7551.3	7553.4
BIC	7556.7	7558.8	7569.0	7569.5	7571.6
R^2	92.16	92.15	92.13	92.13	92.12
MPE	-11.1	-11.1	-11.2	-11.1	-11.3
MAPE	27.9	27.9	28.0	28.0	28.1
VEP	10.7	10.7	10.8	10.8	10.9
DW	1.03	1.02	1.01	1.03	1.01
γ	0.32	0.32	0.31	0.31	0.31
βi	0.99	1.00	0.99	0.98	0.99
CCC	0.18	0.16	0.17	0.18	0.16

Models: Wood (WOD), Wiltmink (WIL), Cobby (COB), Brody (BRO), Sikka (SIK). $\beta1$, $\beta2$, and $\beta3$, regression coefficients that make up the models. AIC, Akaike information criterion. BIC, Bayesian information criterion. R^2, coefficient of determination. MPE, mean prediction error. MAPE, absolute mean prediction error. VEP, the variance of the prediction error. DW, Durbin-Watson statistic. γ, the correlation coefficient between estimated daily production (pde) and the observed daily production (pdo). βi, the slope of regression analysis between pdo and pde (all $p < 0.01$). CCC, coefficient of agreement, and correlation.

Table 2: *Fitting of non-linear models in the analysis of the lactation curve at 270 days*

Parameters	*WOD*	*WIL*	*COB*	*BRO*	*SIK*
		Sardo Negro			
β1	6.8494	6.6537	6.8153	7.0079	7.1789
β2	0.00272	-0.0103	0.0113	0.00217	-0.00313
β3	0.00210	0.3881	0.4577	0.4150	-4.75E-6
AIC	5492.6	5505.4	5493.8	5473.5	5479.8
BIC	5511.4	5524.2	5512.6	5492.3	5498.5
R^2	88.21	88.18	88.21	88.27	88.25
MPE	-14.3	-17.1	-17.0	-16.9	-17.2
MAPE	35.7	36.7	36.5	36.4	36.5
VEP	4.18	4.15	4.16	4.14	4.95
DW	0.92	0.92	0.91	0.91	0.90
γ	0.35	0.34	0.35	0.35	0.35
βi	0.97	0.99	0.99	0.97	1.00
CCC	0.22	0.21	0.22	0.23	0.22
		Gyr			
β1	11.4551	13.2694	12.9905	13.1397	12.8941
β2	0.0427	-0.0171	0.0155	0.00143	-0.00111
β3	0.00190	-1.3197	0.6575	0.5999	1.069E-6
AIC	8063.4	8066.6	8074.1	8073.1	8077.1
BIC	8081.8	8085.0	8092.5	8091.5	8095.5
R^2	92.10	92.09	92.07	92.07	92.06
MPE	-11.1	-11.1	-11.2	-11.2	-11.3
MAPE	28.0	28.2	28.1	28.3	28.1
VEP	10.7	10.7	10.7	10.8	10.8
DW	1.05	1.05	1.04	1.03	1.04
γ	0.34	0.33	0.33	0.33	0.33
βi	0.99	0.99	0.99	0.99	1.00
CCC	0.21	0.19	0.20	0.20	0.19

Models: see table 1 for model description.

Table 3: *Fitting of non-linear models in the analysis of the lactation curve at 300 days*

Parameters	*WOD*	*WIL*	*COB*	*BRO*	*SIK*
		Sardo Negro			
β1	7.0345	6.5550	6.7494	6.9542	7.2039
β2	-0.00827	-0.00939	0.0105	0.00207	-0.00325
β3	0.00187	0.5749	0.4753	0.4267	-5.33E-6
AIC	5573.7	5589.4	5582.4	5556.4	5551.1
BIC	5592.5	5608.2	5601.2	5575.2	5569.9
R^2	88.23	88.18	88.20	88.28	88.30
MPE	-15.7	-17.2	-17.1	-16.8	-17.00
MAPE	35.2	36.6	36.5	36.3	36.3
VEP	4.13	4.14	4.14	4.11	4.10
DW	0.93	0.92	0.93	0.92	0.91
γ	0.34	0.34	0.35	0.35	0.36
βi	0.98	0.99	0.99	1.01	1.00
CCC	0.22	0.21	0.21	0.23	0.23
		Gyr			
β1	11.6704	13.1332	12.9217	13.0899	12.9757
β2	0.0350	-0.0159	0.0148	0.00139	-0.00132
β3	0.00174	-1.0791	0.6914	0.6187	9.509E-8
AIC	8355.1	8360.1	8365.1	8361.6	8366.2
BIC	8373.6	8378.6	8383.7	8380.1	8384.8
R^2	92.15	92.14	92.12	92.13	92.12
MPE	-11.0	-11.01	-11.3	-10.9	-11.5
MAPE	27.8	27.8	27.6	27.9	28.0
VEP	10.4	10.3	10.5	10.4	10.6
DW	1.07	1.06	1.07	1.06	1.05
γ	0.35	0.35	0.34	0.35	0.34
βi	0.99	0.99	0.99	0.98	1.01
CCC	0.22	0.20	0.20	0.21	0.21

Models: see table 1 for model description.

The AIC results indicate that the best fit model was BRO for 240 d and 270 d, and SIK for 300 d in SN; for Gyr, WOD was the best fit model for 240 d and 270 d, and WIL for 300 d. The AIC-based and BIC-based order selection of NLM for LL within SN and Gyr was 240 d, followed 270 d and 300 d. For the MPE, all models tend to underestimate the predictions since they presented negative sign results. MAPE and VEP did not present substantial differences across NLM and LL. The mean values of MAPE and VEP for SN were 36.4 and 4.25, and for Gyr 28.0 and 10.6, respectively.

Regarding the prediction capacity (Tables 1, 2, and 3), the results for CCC, DW, EPP, EPPA, and VEP did not show differences across the NLM or LL; the NLM the precision and accuracy levels were of low magnitude, given the results in γ and CCC. Generally, the models underestimate the true production level, given the negative sign of the EPP. The regression coefficient for pde (βi) ranged from 0.97 to 1.00 (all $p < 0.01$). The DW presented values in the interval 0.90 to 1.07, indicating minimal differences between residuals with a possible positive autocorrelation. Tables 4, 5, and 6 compare the estimates for persistency and productive variables across models and LL. The average value (kg) for PMD (through models and LL) was 5.3 for SN and 10.8 for Gyr; likewise, the mean (kg) for PMX was 6.9 in SN and 12.7 in Gyr. The average PT (kg), within LL (240 d, 270 d, and 300 d), was 1297, 1418, and 1552 for SN, as well as 2653, 2930, and 3202 for Gyr, respectively. The first third (AP1) of the LC presented the highest contribution (%), with average values of 37.4 in Gyr and 39.5 in SN; the second (AP2) and third (AP3) periods, contributed (%) 33.5 and 29.1 in Gyr, and 33.0 and 27.5 in SN, respectively. In the context of maintaining production from maximum values, the results (%) for PN (contrast of PT and PMX within LL) showed an average value of 85.3 in Gyr and 76.6 in SN, and for PE (contrast of PMX and PMD in P2 and P3) the average values (%) were 106.7 in Gyr and 109.3 in SN. Fig. 1 and 2 show the LC of the NLM, where WOD and BRO show the typical behaviour associated with a LC (PI, DP, and PMX); however, SIK in SN at 300 d presented a different or atypical behaviour, it starts with PMX (PI and DP are not observed) and shows a continuous decreasing curve.

Table 4: *Productive levels and persistency estimate in lactations at 240 days*

Parameters	*WOD*	*WIL*	*COB*	*BRO*	*SIK*
			Sardo Negro		
PI	6.6	6.9	2.4	2.3	7.1
PT	1299.9	1302.1	1289.6	1290.1	1305.1
PMX	6.74	6.93	6.70	6.82	7.13
DP	7	2	13	14	2
PMD	5.4	5.4	5.3	5.3	5.4
P2:1	84.5	85.2	87.0	85.7	82.8
P3:1	70.6	71.1	71.5	71.4	72.1
P3:2	83.5	83.4	82.2	83.3	87.1
PE1	108.9	108.2	108.8	109.2	108.7
PE2	109.2	109.8	110.7	109.2	106.1
PN	80.4	78.3	80.2	78.8	76.3
AP1	39.2	39.0	38.7	38.9	39.7
AP2	33.1	33.2	33.6	33.3	32.8
AP3	27.6	27.7	27.6	27.7	28.4
			Gyr		
PI	11.2	11.9	6.1	5.8	12.8
PT	2655.2	2656.9	2648.6	2646.0	2655.7
PMX	12.5	12.5	12.8	12.9	12.8
DP	22	26	10	10	2
PMD	11.1	11.0	11.1	11.0	11.7
P2:1	90.8	91.0	90.9	90.4	90.4
P3:1	79.0	79.1	80.3	80.4	79.4
P3:2	87.0	86.9	88.3	88.9	87.8
PE1	106.3	106.3	105.7	105.9	105.5
PE2	107.2	107.4	106.5	105.9	107.0
PN	88.0	88.5	85.8	85.2	86.4
AP1	37.0	37.0	36.8	36.9	37.0
AP2	33.6	33.7	33.5	33.4	33.5
AP3	29.3	29.3	29.6	29.7	29.4

Models: Wood (WOD), Wiltmink (WIL), Cobby (COB), Brody (BRO), Sikka (SIK). Production (kg) at the start (PI), cumulative total (PT), maximum peak (PMX), and daily average (PMD). DP, days to reach PMX. The lactations lengths (LL) were divided into three periods (P1, P2, P3) of equal number of days. Contribution for period (%), AP1 = (production in P1 / PT)*100; AP2 = (production in P2 / PT)*100; AP3 = (production in P3 / PT)*100. Level of production through periods, P2:1 = (production in P2 / production in P1)*100; P3:1 = (production in P3 / production in P1*100; P3:2 = (production in P3 / production in P2)*100. PE1 = (PMX / PMD en P2)*100; PE2 = (PMX / PMD en P3)*100. PN = (PT / (PMX* LL))*100.

4 Discussion

For SN, a breed developed in the Mexican tropics, this is the first study that describes the lactation curve. Atypical LC were associated with grazing cows in the tropics (Madalena *et al*., 1979; Rodríguez *et al*., 1998). Santellano-Estrada *et al*. (2011) and Cobuci *et al*. (2000) reported similar results, with atypical LC in tropical Creole dairy cattle and Guzerat

Table 5: *Productive levels and persistency estimate in lactations at 270 days*

Parameters	*WOD*	*WIL*	*COB*	*BRO*	*SIK*
			Sardo Negro		
PI	6.8	7.0	2.5	2.3	7.1
PT	1393.0	1427.2	1414.9	1416.7	1439.3
PMX	6.8	7.0	6.6	6.8	7.1
DP	2	2	14	14	2
PMD	5.1	5.3	5.2	5.2	5.3
P2:1	82.5	83.9	85.6	84.3	81.4
P3:1	68.2	69.1	69.2	69.3	71.6
P3:2	82.7	82.4	80.8	82.3	88.0
PE1	109.7	108.7	109.5	109.9	109.1
PE2	109.6	110.5	111.7	109.9	105.1
PN	86.6	87.1	84.6	83.8	84.4
AP1	39.9	39.5	39.2	39.4	39.4
AP2	32.9	33.1	33.6	33.2	32.5
AP3	27.2	27.3	27.1	27.3	28.3
			Gyr		
PI	11.4	12.0	6.2	5.9	12.9
PT	2929.9	2931.4	2926.4	2925.0	2935.4
PMX	12.5	12.4	12.8	12.9	12.9
DP	24	28	10	11	2
PMD	10.8	10.8	10.8	10.8	10.8
P2:1	89.4	89.7	89.8	89.2	88.9
P3:1	77.0	77.1	78.3	78.4	77.8
P3:2	86.2	86.0	87.2	87.9	87.4
PE1	106.9	106.8	106.3	106.5	106.2
PE2	107.7	108.1	107.2	106.5	107.1
PN	75.5	75.4	78.8	77.4	74.5
AP1	37.5	37.5	37.3	37.3	37.5
AP2	33.5	33.6	33.5	33.3	33.3
AP3	28.9	28.9	29.2	29.3	29.1

Models: See table 4 for model description.

Table 6: *Productive levels and persistency estimate in lactations at 300 days*

Parameters	*WOD*	*WIL*	*COB*	*BRO*	*SIK*
			Sardo Negro		
PI	7.0	7.1	2.5	2.5	7.2
PT	1553.8	1553.8	1539.7	1539.4	1573.5
PMX	7.0	7.1	6.6	6.7	7.2
DP	2	2	13	10	2
PMD	5.2	5.2	5.1	5.1	5.2
P2:1	82.0	83.0	84.6	83.0	80.3
P3:1	67.7	67.9	67.4	67.5	71.7
P3:2	81.7	80.8	78.8	80.4	88.5
PE1	109.9	109.1	110.1	110.6	109.3
PE2	109.7	111.1	112.6	110.6	103.8
PN	85.3	85.9	83.5	82.6	82.8
AP1	40.1	39.9	39.7	39.5	39.7
AP2	32.7	33.1	33.6	33.2	31.9
AP3	27.2	27.0	26.8	26.3	28.5
			Gyr		
PI	11.7	12.1	6.4	6.0	13.0
PT	3201.6	3201.0	3195.3	3193.6	3220.6
PMX	12.5	12.4	12.8	12.9	13.0
DP	22	26	10	11	2
PMD	10.7	10.7	10.7	10.6	10.7
P2:1	88.2	88.6	88.8	88.1	87.8
P3:1	75.5	75.5	76.5	76.7	77.2
P3:2	84.7	84.3	85.2	86.1	87.0
PE1	107.5	107.3	106.9	107.0	106.5
PE2	108.1	108.6	108.0	107.0	106.4
PN	73.8	73.0	77.7	76.1	73.0
AP1	37.9	37.9	37.7	37.8	37.7
AP2	33.4	33.5	33.5	33.3	33.1
AP3	28.6	28.6	28.8	29.0	29.1

Models: See table 4 for model description.

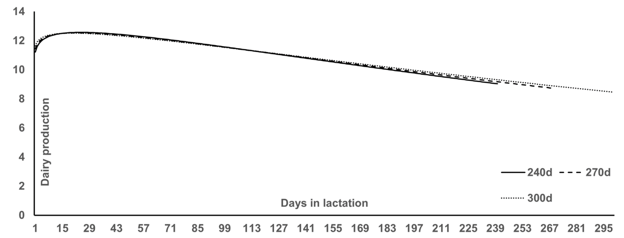

Fig. 1: *Lactation curves for Gyr cows based on the Wood model at 240 (240 d), 270 (270 d), and 300 (300 d) days in lactation*

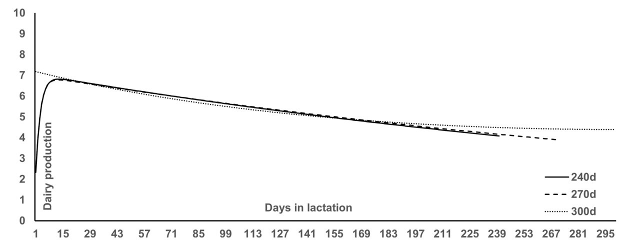

Fig. 2: *Lactation curves for Sardo Negro cows based on the Brody model at 240 (240 d) and 270 (270 d) days in lactation, and based on the Sikka model at 300 (300 d) days in lactation*

cows, respectively. Brody and Wood's model for 240 d represented the best fit model for SN and Gyr in Mexico, respectively. In tropical livestock, Wood's model has been reported for LC in Siboney (Palacios-Espinosa *et al.*, 2016a), Brown Swiss (Rodríguez *et al.*, 1998; García-Muñiz *et al.*, 2008), Gyr (Huamán *et al.*, 2018) cows, or *Bos indicus* breeds and their crosses with Holstein (Osorio-Arce & Segura-Correa, 2005; Gradiz *et al.*, 2009; Cunha *et al.*, 2010; Ribeiro *et al.*, 2010). Wood's model can present four behaviours of LC, depending on the combination of signs in $\beta 2$ and $\beta 3$ (Macciotta *et al.*, 2005); given the results in Gyr, for 240 d and 270 d the LC was continuously increasing, for 300 d the LC was classified as inverted standard. The Brody model in SN can be described as a model with two exponential phases, at the beginning an exponential function that represents the increase in production up to the maximum peak, followed by another descending exponential function to adapt to the decreasing phase of the lactation pattern in dairy cattle.

Milk production is characterised by cycles, defined by the calving interval, LL, gestation, and a dry period followed by the next calving. The LL has significance in the profitability of the herd (Dekkers *et al.*, 1998; Magaña *et al.*, 2006), in the productive and reproductive life of the female (Bello *et al.*, 2012; Lehmann *et al.*, 2016), in the definition of criteria and objectives of selection, and in the estimation of genetic parameters and the response to selection (Baldi *et al.*, 2011). In the present study, the LL of best fit in the two populations evaluated was 240 d, followed by 270 d and 300 d; however, to consider LL in management and genetic improvement programs, the sources of variation attributable to the environment and genotype must be explored (Vaccaro *et al.*, 1999; Verneque *et al.*, 2000; Teyer *et al.*, 2003).

Albuquerque *et al.* (1999) reported a lactation length of 232 to 334 days with PT from 1172 to 3991 kg for the first three lactations of Gyr cows. Similar observations were made for Gyr by Teyer *et al.* (2003), who reported PT from 1501 to 2991 kg with a LL from 211 to 318 days, by Verneque *et al.* (2000), who reported a PT of 942 kg, 1462 kg, 1899 kg and 2339 kg, respectively for a LL of 90, 150, 210, and 305 days and by Rebouças *et al.*, (2008), who showed an average PT of 3814 kg and 2747 kg in two production systems, with a LL of 305 days based on the Michaelis Menten model. Similar values of 3180 to 3667 kg were obtained for Gyr cows by Ferro *et al.* (2022). On the contrary, Magaña *et al.*, (2006) reported a lactation length from 244 to 311 days, PMD from 2.8 to 6.5 kg and lower PT that ranged from 749 to 1589 kg. In cross-bred cows, Zebu (Gyr, Guzerat, and Nelore) with Holstein, for LC defined with WOD model, the PT ranged from 1469 to 3267 kg from 228 to 315 days (Ribeiro *et al.*, 2010). Another study of Huamán *et al.* (2018) compared the LC of Gyr and F1 cows (Gyr x Holstein) based on the WOD model, obtained estimates for PT and PMX of 1032 kg in 305 days and 4.28 kg compared to 4031 kg in 305 days and 17.2 kg, respectively. Finally, dos Santos *et al.* (2019a) and dos Santos *et al.* (2019b) evaluated the PT in Gyr cows compared to crosses between the Gyr with varying degree of Holstein blood. They observed a PT in the range of 3737 to 5441 kg. In contrast to other populations, models, and LL, Cobuci *et al.* (2000), in Guzerat cows, reported an average PT of 2359 kg in 290 days, and Pino *et al.* (2009) published a PT of 1744 kg in 244 days in dual-purpose cows. Furthermore, Palacios-Espinosa *et al.* (2016a) reported an average PT and PMX of 1659 kg in 240 days and 7.8 kg, respectively, for Siboney cows using NLM. In the present study, the differences in production levels can be associated with: Gyr is a specialised breed with selection criteria and objectives associated with the lactation curve; SN as a synthetic breed was derived from the cross between Gyr and Indubrasil, in dual-purpose production systems and feeding based on grazing.

Persistency represents the ability to maintain production through periods, or after maximum values (Grossman *et al.*, 1999). It is an important selection criterion in genetic improvement schemes (Cole & Null, 2009) and is important for other variables of economic interest that are associated with reproduction, nutrition, and health (Dekkers *et al.*, 1998). In the present study, the ability to maintain production in P2 (P2:1) and P3 (P3:1) compared to P1 was higher in Gyr than in SN cows (89.5 % and 77.9 % vs. 83.7 % and 69.7 %, respectively); similarly, the production in P3, as a percentage of P2 (P3:2), was 86.7 % in Gyr and 83.0 % in SN. Higher values were estimated for of P2:1, P3:1, and P3:2 of Gyr cows and crosses of varying degrees with Holstein, namely 76.7 to 102.9 % (dos Santos *et al.*, 2019a) and 87.9 % to 120.5 % (dos Santos *et al.*, 2019b), respectively. Furthermore, Kaushal *et al.* (2016) reported higher PE estimates of 126.3 to 285.0 % in Sahiwal cows. In contrast, Jiang *et al.* (2020) reported estimates in the range of 54 to 91 % for P2:1 and P3:1 in Holstein-Friesian and Jersey cows and their crosses in grazing-based production systems. Similarly, lower values were obtained for F1 Gyr x Holstein cows (42.6 to 59.7 %) by Motta *et al.* (2012) and for Gyr cows (46.0 to 122.0 %) by Ferro *et al.* (2022).

5 Conclusion

Lactations of 240 days are proposed for the design of appropriate management, feeding, and genetic improvement programs for Gyr and SN in tropical Mexico, since they presented the best statistical adjustment in both breeds. All Gyr cow lactation curves, defined by Wood's model, presented a typical behaviour. The lactation curve of SN cows presented a typical behaviour in lactations at 240 and 270 days; however, in lactations at 300 days, the observed behaviour changed, presenting an atypical lactation curve.

Acknowledgements

To the Mexican Association of Zebu Breeders for providing the database analysed,

Conflict of interest

The author declares that they have no conflict of interest.

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