Factors Affecting The Lactation Curve Parameters of Crossbred Dairy Ewes In The Highlands of Mexico

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Abstract

Sheep milk production is incipient in Mexico with scarce knowledge on the performance of dairy ewes from different breeds. The objective was to evaluate the effect of breed (Awassi (Aw), East Friesian (EF) and other (Ot)), parity number 1, 2 and 3 or more (+3), litter size 1 and 2 or more (+2), and lambing season Spring-Summer (SS) and Autumn-Winter (AW) on day to peak milk yield (DP), peak yield (PY), persistency (P), total milk yield (TMY), 305-day milk yield (TMY305d), 150-day milk yield (TMY150d) and lactation length (LL) of crossbred dairy ewes in an intensive confined system in the central highlands of Mexico. A total of 4,312 weekly milk yield records collected from 2014 to 2015 were used to model 133 lactations using a random regression model with a 5th order orthogonal polynomial. Flock mean values of curve parameters were 42 days at DP, 1.2 kg/day at PY, -3.5 g/day of P, 190 kg TMY, 189 kg TMY305, 124 kg TMY150 and 269 days of LL. Multiparous ewes had significantly higher (P<0.05) PY and TMY than primiparous ewes. Ewes that lambed in AW had 15% higher PY and produced 14% more TMY than ewes that lambed in SS (P<0.05). Correlations among curve parameters were significant except for PY with LL, and P with TMY150d. TMY was strongly correlated with LL (0.91). It is concluded that second parity ewes lambing in AW season resulted in higher TMY. Predominantly, Awassi crossbred ewes had lower curve parameter values than predominantly East Friesian and other crossbred ewes.

Introduction

Sheep production systems are versatile sources of income in rural areas as they can produce meat, milk, or wool (Gipson and Grossman, 1990). These systems are important in several developing countries where specialised dairy sheep breeds have been introduced to enhance productivity (Pollott and Goodwine, 2004).

Dairy sheep production in México is an incipient activity. Total milk production was 56,929 t in 2019, which represented only 0.54% of world production, but represented 62% of ewe milk production in the Americas being the largest producer (FAO, 2021).

East Friesian, Laucane and Awassi are the three main specialised dairy sheep breeds that have been introduced in Mexico using crossbreeding with well-established and better adapted breeds such as Pelibuey, Kathadin, Rambouillet, Black Belly, Suffolk and Hampshire (Ochoa-Cordero et al. 2002; Angeles-Hernandez et al. 2013; Angeles-Hernandez et al. 2018; Chay-Canul et al. 2019).

There have also been some studies of the dairy potential of local *criollo* sheep landraces of Mexico that descend from the Manchega, Churra and Latxa breeds brought to Mexico by the Spanish in the XVI century; that have a yield range between 0.17 and 0.50 kg milk/ewe/day with peak yields on the first week of lactation, compared to specialized dairy sheep breeds that reach peak production during the second or third week of lactation (Peralta-Lailson et al. 2005).

Dairy sheep milk in most countries is usually used for cheese production (Morand-Fehr et al. 2007; Pirisi et al. 2007). Milk and cheese quality are affected by animal, environmental and management factors (Morand-Fehr et al. 2007; Pirisi et al. 2007; Angeles-Hernandez et al. 2018). The effect of these factors may be evaluated using models to fit lactation curves (Pollott and Gootwine, 2004). The use of models to study lactation curves is fundamental in devising breeding programmes as well as to determine production flows and weaning age of lambs (Nava-García et al. 2019).

At the farm level, the knowledge of the parameters describing the lactation curve and factors that affect these parameters are important to enable a better flock management and use of resources (Ruiz et al. 2000). For example, knowing that milk yield determines liveweight gain and age at weaning of lambs, the farmer can define feeding and management strategies to optimise both, ewe milk production and lamb performance (Morgan et al. 2006; Peniche-González et al. 2015). It is therefore important to know the dairy performance of ewes (Nava-García et al. 2019), but there are few studies on sheep milk production under Mexican conditions (Angeles-Hernandez et al. 2018; Chay-Canul et al. 2020).

The Mexican *Fundación para el Desarrollo Regional y la Competitividad (*Foundation for Regional Development and Competitivity - *FUNDECO)*, a non-government organization devoted to improving the living conditions in rural Mexico, promoted dairy sheep production through a demonstration and training farm in the central highlands of Mexico where imported dairy breeds and crosses were farmed to evaluate breeds for milk production in this region. This study evaluated the effect of breed, lactation number, litter size and lambing season on parameters of the lactation curve of dairy sheep in an intensive system in the central highlands of Mexico.

Materials And Methods

Lactation data from ewes were from the dairy sheep demonstration and training farm from FUNDECO located in the village of Río Frío in Estado de México at 19°21'09" N and 98°40'11" W; at an altitude of 3,000 m. Climate is temperate sub-humid, with rains in summer and a marked dry season from November to April, with a mean temperature of 15.1°C (mean maximum of 20°C and mean minimum of 0°C), and 1,000 mm annual rainfall.

Dairy ewes and lactation records

The sheep flock at the demonstration farm was in a totally confined (in loose pens) intensive system. Lactating ewes were fed mature oat hay and alfalfa hay in the morning and maize silage in the afternoon as forage base, with a concentrate allocation (in fresh weight) depending on milk yield. Ewes with high milk yield (≥ 1.0 kg/ewe/d) received 1.2 kg/ewe/d, medium (0.700 – 0.900 kg/ewe/d) received 0.9 kg/ewe/d, and ewes with low yields (< 0.700 kg/ewe/d) received 0.7 kg concentrate/ewe/day. The concentrate was split in two allocations in the morning and afternoon.

The concentrate was made in the demonstration farm from maize and sorghum grain, soybean meal, wheat bran, alfalfa pellets, sugarcane molasses, and a mineral and vitamin mix.

Ewes were machined milked once a day in the morning, and milk yields recorded once per week using Waikato milk recorders (Waitako Milking Systems, New Zealand). Milking started after weaning lambs, that on average was at 60 days of age.

Ewes were crossbred, with most frequent genotypes being ½ Assaf, ½ Awassi, ½ East Friesian, ½ Laucane, 100% Awassi, and 100% East Friesian; with Awassi and East Friesian being the predominant sire breed, with 43% and 31% of the ewes. Ewes were grouped as Awassi (Aw) and East Friesian (Ef), and other (Ot) if they had ≥ 50% genes from those breeds.

The initial data set comprised 194 lactation records but those lactations that lacked ewe identification, breed, lambing date, birth date, sire and dam breed information, lactation number, or litter size at birth were omitted. A total of 4,312 weekly milk yield records from 133 lactations (32 records per lactation) of 110 ewes recorded during 2014 and 2015 were analysed.

Lactation curve model

Lactation curves for milk yield for each combination of ewe-parity were modelled from day 1 to day 305 of the lactation using random regression models with orthogonal polynomials of fifth order, with the MIXED procedure of the Statistical Analysis System version 9.4 (SAS Institute Inc., Cary, NC, USA). Predicted values for each day were obtained from the polynomial function for each ewe-parity. The polynomial utilised was described in equation as:

$$y_{mt} = (\beta_0 P_0 + \beta_1 P_{1t} + \beta_2 P_{2t} + \beta_3 P_{3t} + \beta_4 P_{4t} + \beta_5 P_{5t}) + (\alpha_{0m} P_0 + \alpha_{1m} P_{1t} + \alpha_{2m} P_{2t} + \alpha_{3m} P_{3t} + \alpha_{4m} P_{4t} + \alpha_{5m} P_{5t}) + e_{mt}$$

where y_{mt} represents the daily milk yield for ewe-parity m in day t of the lactation after lambing, β_0 to β_5 are fixed regression coefficients representing the lactation curve of the population, α_{0m} to α_{5m} are random regression coefficients for ewe-parity m, P_0 to P_{5t} are orthogonal polynomial functions of order 0 to 5 as defined below, and e_{mt} is the random residual error. Coefficients of the orthogonal polynomial at day t were calculated as:

$P_{0t} = 1$, $P_{1t} = x$, $P_{2t} = \frac{1}{2}(3x^2\text{-}1)$, $P_{3t} = \frac{1}{2}(5x^3\text{-}3x)$, $P_{4t} = \frac{1}{8}(35x^4\text{-}30x^2+3)$

and $P_{5t} = \frac{1}{8}(63x^5\text{-}70x^3+15x)$, where $x = -1 + 2\frac{(t\text{-}1)}{(1\text{-}305)}$.

Parameters of the lactation curve for each combination of ewe-parity were obtained from the predicted daily milk yields. These parameters were day of peak production (DP), peak yield (PY; kg/day), persistency (P), lactation length (LL; days), total milk yield (TMY; kg/lactation), 305-day milk yield (TMY305d, kg), and 150-day milk yield (TMY150d, kg). Persistency was calculated as $P = \frac{(y_{150} - y_{42})}{(150\text{-}42)} \times 1000$ where y_{150} and y_{42} are milk yields at days 150 and 42 of the lactation, respectively. This definition of persistency is the slope of the regression line from day 42 to day 150 of the lactation, expressed as grams per day. The more negative the value, the less the persistency of the lactation.

Statistical analysis

The data were analysed using the MIXED procedure of SAS (2002) to determine the effects of parity number (P; 1, 2 and 3 or more (+3)), litter size (L; 1 and 2 or more (+2)) and lambing season (S; Spring-Summer (SS) and Autumn-Winter (AW)) on DP, PY, P, LL, TMY, TMY305d and TMY150d. The linear model was represented with the following equation:

$$y_{ijkn} = \mu + P_i + L_j + S_k + B_l + a_n + e_{ijkn}$$

where, y_{ijkln} is the dependent variable (DP, PY, P, LL, TMY, TMY305d and TMY150d) measured in ewe n, P_i is the fixed effect of parity number (i = 1, 2 and +3), L_j is the fixed effect of litter size at birth (j = 1 and +2), S_k is the fixed effect of lambing season (k = SS and AW), B_l is the fixed effect of breed group (l = Aw, Ef and Ot), a_n is the random effect of ewe n with mean zero and σ^2_a, and e_{ijkn} is random residual error with mean zero and variance σ^2_e.

Repeatability of curve parameters, which is a measure of the tendency of animals to maintain their performance over time, was calculated using the variance components obtained from the analysis with the model described above. Repeatability was estimated as:

$$\text{Repeatability} = \frac{\sigma^2_a}{\sigma^2_a + \sigma^2_e} \times 100$$

where σ^2_a is the variance component of ewe and σ^2_e is the variance component of temporary environmental effects.

Pearson correlation coefficients between evaluated parameters describing the lactation curve were obtained with the CORR procedure of the SAS program (SAS, 2002).

Results

Table 1 shows the mean values and coefficient of variation for parameters of the lactation curve of all the lactations considered in this study. Coefficients of variation of curve parameters ranged from 34.5% (TMY150d) to 79.7% (P).

Table 1
Mean values and coefficient of variation of the lactation curve parameters of crossbred dairy ewes in a flock in the central highlands of Mexico.

	Mean	**CV (%)**
Day of peak yield (days)	41.9	78.9
Peak yield (kg/day)	1.2	41.0
Persistency (g/day)	-3.5	-79.7
Total milk yield (kg)	189.7	74.6
Total milk yield 305 days (kg)	188.9	40.6
Total milk yield 150 days (kg)	124.3	34.5
Lactation length (days)	269.0	47.5

Least-squares, standard errors and p-values for lactation number, lambing season and litter size, and breed effects for DP, PY, P, LL, TMY, TMY305d and TMY150d are presented in Table 2. Effect of parity number was significant on all parameters of the lactation curve except on DP and P. Ewes of first and second parity outperformed ewes of third or greater parity for TMY and LL. Third or greater parity ewes had higher PY and shorter LL than first and second parity ewes. First parity ewes had lower TMY150 and TMY305 yields than second and third or greater parity ewes.

Table 2
Least-squares means (Mean) and standard errors (SE) for parity number, lambing season and litter size, and breed effects for day of peak production (DP), peak yield (PY, kg/day), persistency (P; g/day), lactation length (LL, days), total milk yield (TMY, kg/lactation), TMY at 305-day milk yield (TMY305, kg), TMY at 150-day milk yield (TMY150) and repeatability (%) in dairy ewes in a flock in the central highlands of Mexico.

	DP		**PY**		**P**		**LL**		**TMY**		**TMY305**		**TMY150**	
Parity	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	41.0	5.5	1.0[a]	0.1	-3.4	0.5	293.0[a]	19.2	194.1[ab]	19.7	169.8[a]	10.8	104.9[a]	6.2
2	48.0	4.2	1.3[ab]	0.1	-3.3	0.4	292.0[a]	14.6	220.0[b]	15.1	202.8[b]	8.2	131.5[b]	4.8
+3	37.5	5.1	1.4[b]	0.1	-4.5	0.5	227.0[b]	17.4	152.2[a]	17.8	181.3[ab]	9.9	126.4[b]	5.7
P-value	0.19		0.03		0.10		<0.01		<0.01		<0.01		<0.01	
Lambing season														
SS[1]	46.0	4.3	1.1	0.1	-3.4	0.3	250.3	15.6	153.6	16.2	168.1	8.5	112.6	4.7
AW[2]	38.0	4.3	1.3	0.1	-3.9	0.4	291.3	15.3	224.3	15.9	201.2	8.4	129.4	4.7
P-value	0.17		0.04		0.34		0.04		<0.01		<0.01		0.01	
Litter size														
1	43.0	3.9	1.2	0.1	-2.9	0.3	272.0	14.0	185.3	14.6	177.9	7.6	115.4	4.2
+2	41.0	4.5	1.3	0.1	-4.5	0.4	270.0	15.6	192.5	16.1	191.4	8.7	126.4	4.9
P-value	0.67		0.26		<0.01		0.9		0.66		0.20		0.09	
Breed group														
Awassi	35.0	5.6	1.0[a]	0.1	-4.1	0.4	203.0[a]	21.4	104.0[a]	22.7	138.6[a]	11.1	97.5[a]	6.0
East Friesian	43.0	4.7	1.3[b]	0.1	-3.1	0.4	306.7[b]	17.9	227.0[b]	19.0	209.8[b]	9.4	134.5[b]	5.1
Other	48.0	6.4	1.3[b]	0.1	-3.8	0.5	302.7[b]	24.2	239.0[b]	25.6	205.5[b]	12.7	130.7[b]	6.9
P-value	0.35		0.01		0.27		<0.01		<0.01		<0.01		<0.01	
Repeatability (%)	66		5		26		86		89		72		50	

[a,b] Means within each column and effect with different superscript are significantly different (P<0.05)

[1] Include ewes that lambed in spring and summer.

[2] Include ewes that lambed in autumn and winter.

Lambing season had significant effect on PY, LL, TMY, TYMY305 and TMY150 with higher yields and longer lactations of ewes lambing in autumn-winter (P<0.05). Litter size was only significant on persistency (P<0.01). Ewes that lambed a single lamb had higher lactation persistency (-2.9 g/day) than ewes that lambed twin lambs (-4.5 g/day).

Breed effects were significant on PY, LL, TMY, TMY305d and TMY150d (P=0.01), where Aw ewes had lower values of the curve parameters, whereas EF and Ot performed the same.

Table 3 shows the mean and standard deviation of the estimates of the regression coefficients of the 5th order orthogonal polynomial for the flock and three breed groups, and Figure 1 shows the respective the standardized lactation curves up to 305 days in milk. Ef ewes start lactation with higher yields achieving the highest PY with better persistency afterwards. The onset of lactation of Ot ewes was low and similar to Aw, however, they reached the second highest PY at later days after Ef ewes. Persistency of the lactation curve of Ot ewes improved in the last third of the lactation, feature that is common to the main flock and Aw and Ef lactation curves.

Table 3
Mean and standard deviation (SD) of the estimates of the regression coefficients of the 5th order orthogonal polynomial modelling the lactation curve of the flock and predominantly Awassi, East Friesian and other crossbred ewes in the central highlands of Mexico.

Regression	**Flock**		**Awassi**		**East Friesian**		**Other**	
coefficient	Mean	SD	Mean	SD	Mean	SD	Mean	SD
α0	0.6210	0.0255	0.4563	0.1594	0.7087	0.1733	0.6825	0.3600
α1	-0.3882	0.2298	-0.3663	0.1960	-0.4287	0.2497	-0.3414	0.2271
α2	-0.0374	0.2969	0.0068	0.2750	-0.0527	0.2994	-0.0696	0.3236
α3	0.1502	0.3072	0.1337	0.2993	0.1312	0.2861	0.2094	0.3600
α4	-0.1238	0.1779	-0.1435	0.1915	-0.0814	0.1482	-0.1772	0.1962
α5	0.0721	0.1066	0.1035	0.0975	0.0504	0.0967	0.0698	0.1273

Repeatability of curve parameters yields was moderate for TMY150d and DP (50 and 66%, respectively) and high for LL, TMY, TMY305 (86, 89 and 72%, respectively), whereas PY and P had the lowest repeatability (5 and 26%, respectively).

All correlations among curve parameters were strongly significant ($P \leq 0.01$), except for the correlation between LL and PY (0.12, $P>0.05$), and between P and TMY150d (-0.09, $P<0.05$) (Table 4). DP was negatively correlated with PY (-0.27), whereas PY was negatively correlated with P (-0.47). Correlations of persistency with LL, TMY and TMY305d were weak; 0.35, 0.35 and 0.19, respectively. Lactation length was strongly correlated with TMY (0.91), while TMY and TMY305d were also strongly correlated (0.84).

Table 4
Correlation coefficients between day of peak (DP), peak yield (PY; kg/day), persistency (P; g/day), lactation length (LL; days), total milk yield (TMY; kg/lactation), TMY at 305 days (TMY305d) and TMY at 150 days in dairy ewes in a flock in the central highlands of Mexico.

	PY	**P**	**LL**	**TMY**	**TMY305d**	**TMY150d**
DP	-0.27 ***	0.65 ***	0.40 ***	0.41 ***	0.31 ***	0.11 0.20
PY		-0.47 ***	0.12 NS	0.28 ***	0.51 ***	0.68 ***
P			0.35 ***	0.35 ***	0.19 **	-0.09 NS
LL				0.91 ***	0.63 ***	0.46 ***
TMY					0.84 ***	0.69 ***
TMY305						0.94 ***
, * Indicates significantly different from cero P < 0.001, P < 0.01 and NS = P > 0.05						

Discussion

A large range in the coefficients of variation for the parameters describing the lactation curve of these dairy sheep was observed, ranging from 34.5 for TMY150d to -79.7% for P. Carta et al. (1995) reported coefficients of variation between 22 and 65%, which are in the same range as found in this study. The large coefficients of variations are due to temporal environmental factors such as management system, grazing, confinement, and season, among others (Angeles-Hernandez et al. 2013; Vázquez-Peláez et al. 2014), or due to genetic factors (Cappio-Borlino et al. 1997).

In this study the flock was comprised of crossbred ewes of different parity number, lambing at different seasons of the year with different litter sizes at birth. All these factors created large coefficients of variation in the estimates of the regression coefficients modelling the lactation curves for individual lactations.

Total milk yields observed in this study were lower than 258 kg milk/lactation reported for crossbred ewes in Spain (Abecia et al. 2019). In contrast, Morgan et al. (2006) reported production levels of 107 kg/lactation in 90 days with PY of 1.2 kg/day in crossbred ewes which were the progeny of Ef sires and non-dairy dams.

Several studies have reported that ewes from specialized dairy sheep breeds can sustain longer lactations with higher yields than crossbred ewes (Rhind et al. 1992; Pollott and Gootwine, 2004; Morgan et al. 2006). In this study, Ef and Ot ewes had longer LL (300 and 306 days) and produced □111 kg (+37%) more TMY than the average of the flock (190 kg/lactation). In contrast, Awassi ewes produced □ 9% less milk than Ef and Ot breed ewes.

In general, second parity ewes had higher total milk production than 1st and +3 parity ewes, which is similar to that reported by Peralta-Lailson et al. (2005) in the Chiapas white (non-dairy) breed where second-lactation ewes had their highest TMY. Lower PY and TMY in first parity ewes most likely was due to the fact that their mammary glands are not totally developed (Abdelsayed et al. 2014). Angeles-Hernandez et al. (2018), reported higher TMY in third lactation ewes grazing irrigated pastures in an organic production system in central Mexico, which are contrary to our results where the highest TMY were achieved by 1st and 2nd parity ewes.

Estimated PY in this study (1.3 kg/day) was lower than that reported by Morgan et al. (2006) of 2.1 kg milk/d in first lactation crossbred ewes out of Merino dams and sires from different breeds grazing in Australia; although milk let-down was enhanced by oxytocin injections.

The effects of lambing season on parameters describing the lactation curve were similar to another study in Mexico (Angeles-Hernandez et al. 2018). Ewes lambing in autumn and winter had 15% higher PY and longer LL, produced 32% more milk than ewes lambing in spring and summer. However, our findings are contrary to a report from Spain (Abecia et al. 2019) where crossbred ewes lambing in spring and summer had higher yields (269 and 260 kg milk/lactation respectively) than those that lambed in autumn or winter (246 and 246 kg milk/lactation respectively).

Morgan et al. (2006) also reported that crossbred ewes lambing in spring-summer yielded 12% more milk than those lambing in autumn-winter under grazing conditions of Australia; although the authors noted a possible effect of age at lambing since ewes lambing in spring-summer were younger (12 months old) than ewes lambing in autumn-winter (19 months old).

Pollot and Gootwine (2004) with data from Assaf ewes in Israel also found higher milk yields for ewes lambing in spring-summer compared with ewes lambing in autumn-winter, when changes in ambient temperature and shorter photoperiod (shorter days towards winter), reduced the length of lactation; while ewes lambing in spring-summer benefitted from longer photoperiods and therefore showed longer lactations.

The results from our study contradicts this trend. The ewes lambing in autumn-winter had higher PY, LL, TMY, TMY305 and TMY150 than the ewes lambing in the spring-summer season. The fact that the flock was managed in total confinement with homogeneous feeding management across seasons and no direct exposition to sun light, and less harsh winter climate, could be a factor that explains our results.

Litter size only had a significant impact on lactation persistency where single lambing resulted in more persistent lactations than twins or triplets, for the rest of the parameters there was no differences which is in contrast with the results reported by Pollot and Gootwine (2004) who observed a significant increase on TMY (6%) in ewes that had two or more lambs. The overall trend is that ewes that start the lactation with twin and triplets have higher TMY than ewes that start the lactation with single lambs (Cardellino and Benson 2002; Morgan et al. 2006; Angeles-Hernandez et al. 2018; Chay-Canul et al. 2020). This is due to the number of lambs born during pregnancy affect the development of the mammary gland, which is stimulated by an increase in the blood concentration of placental lactogen (Lérias et al. 2014; Selvaggi et al. 2017; Knight and Sorenson, 2001; Gootwine, 2004).

The shape of the lactation curve of the flock and the Aw, Ef and Ot breeds is similar to the standard lactation curve reported by Ruiz et al. (2002). However, about day 250 of lactation persistency tended to improve showing increases in milk yields. This effect is more manifest in lactations of ewes of other breeds. The mean shape of the lactation curves in this study are contrary to reports in Mexico that showed lactations without PY and downwards trend from the beginning to the end of lactation. (Angeles-Hernandez et al. 2013; Vázquez-Peláez et al. 2014). Cappio-Borlino et al. (1997) stated that these atypical lactation curves may be due to the low genetic merit of the ewes as well as due to environmental factors that limit the genetic potential of dairy ewes. The lactation curve of Awassi ewes was always below the lactation curve of Ef ewes, which agree with the breed effects presented in Table 2.

The negative correlation between DP and PY indicate that early DP will result on higher PY. The correlations between DP and persistency suggested that ewes that reach peak yield later during lactation would have higher persistency as reported in dairy cows (Tekerli et al. 2000). The negative correlation between PY and persistency (-0.47) indicate that lactation curves with high peaks would be associated with lower persistency as reported also in dairy cows (Tekerli et al. 2000). The strong correlation between TMY and lactation length agrees with reports by Angeles-Hernandez et al. (2018) from a study with dairy breed ewes in central Mexico. This means that the longer the LL the greater the TMY. The correlations between P and TMY and TMY305 indicated that the lower decreased of milk yield after PY (higher persistency) had a significant impact on higher milk yields.

Repeatability has been described as the proportion of total phenotypic variation that is explained by the sum of the permanent environmental effects and the genetic variation. This parameter is useful to indicate if the trait is repeatable through the life of the animals. If a trait has high repeatability, then animals can be selected or culled based on the first records of their life. The estimation of permanent environmental effects for single animals are required to calculate productive values and have been used to develop culling indices for dairy cattle (Kelleher et al. 2015). The lowest repeatability estimates in this study were for PY (5%) and P (28%) which agree with estimates for these traits reported by Pollott and Gootwine (2004) in Assaf sheep. On the contrary, repeatability estimates for LL and TMY were high (86% and 89%, respectively) indicating that animals can selected or culled for these traits based on the first records.

It is concluded that ewes of second parity had longer lactations and were the most productive. Autumn and winter lambing season had an important effect resulting on higher milk productivity; whereas ewes lambing single lambing had higher persistency than ewes lambing twins or triplets. Breed had a significant effect both on peak yield and total milk yield. Awassi breed was the least productive breed in the flock outperformed by Ef and other crossbred ewes.

Declarations

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Conflicts of interest/Competing interests

The authors declare that they have no conflict of interest.

Ethics approval

Research did not involve direct work with animals or persons, and followed guidelines accepted by *Universidad Autónoma del Estado de México*.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material (data transparency)

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability (software application or custom code)

Not applicable.

Authors' contributions

José Velarde-Guillén: Data collation, writing – original draft, review and editing final manuscript.

Nicolás López-Villalobos: Conceptualization and statistical analyses, editing final manuscript.

Aurora Sainz-Ramírez: Data collation, writing – original draft.

Minerva González-Sánchez: Investigation, data collection, writing – original draft.

Carlos Manuel Arriaga-Jordán: Conceptualization, writing – review and editing.

Albarrán-Portillo Benito: Methodology, formal analyses, writing - review and editing

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Figures

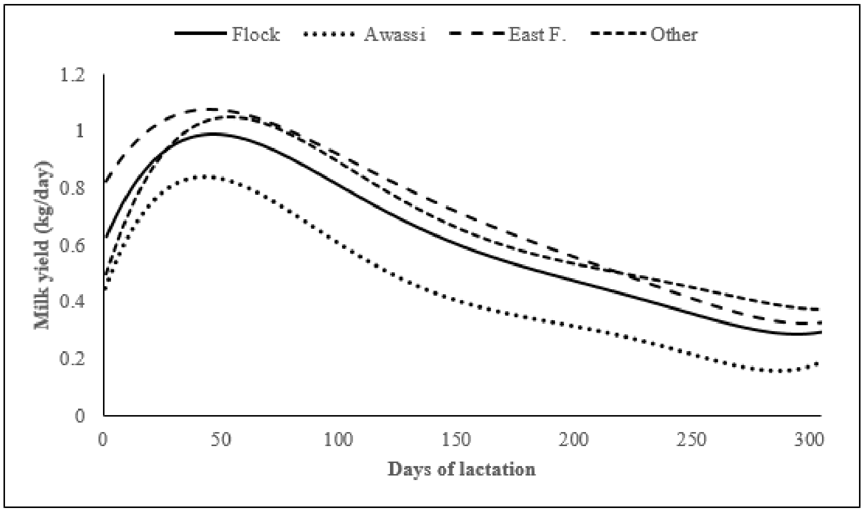

Figure 1

Mean lactation curve of the flock, Awassi, East Friesian Other cross bred dairy ewe in a dairy flock in the central highlands of Mexico.