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LACTATION PERFORMANCE AND LACTATION CURVE TRAITS IN GRAZING KATAHDIN SHEEP

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ABSTRACT

The aim of this study was to assess lactation traits, lactation curve shape and curve parameters in Katahdin sheep under a grazing-based feeding system. A total of 27 second-parity Katahdin ewes were evaluated. The animals were kept on a pasture composed of cool-season grasses and legumes. The variables recorded included litter size, lamb sex, daily milk yield per ewe, total milk yield per lactation, lactation length, prolificacy, and gestation duration. Statistical analysis was conducted using the GLM procedure. Ewes with twins and female lambs produced more milk per day (58 and 34%), respectively, and per lactation (23%) (p<0.05). The lactation length and milk yield did not differ (p>0.05) when considering litter size and lamb sex. Parameters "a" and "b" showed the highest standard error values with lower estimator values, while parameter "c" showed lower estimator and standard error values. It is concluded that Katahdin ewes under grazing conditions achieve adequate milk production, with positive effects associated with litter size and lamb sex. Additionally, the lactation curve displayed the characteristic shape, with peak production occurring at 3 and 4 weeks postpartum.

Keywords: milk production, small ruminants, hair sheep, selection criteria**.**

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INTRODUCTION

Tropical sheep breeds consist primarily of hair sheep; whose productivity varies depending on the region where they are raised. Therefore, it is crucial to evaluate their productive performance in areas where these breeds have found a development niche (Hinojosa-Cuellar et al., 2015). In this regard, hair breeds are widely distributed in tropical and subtropical regions of the Americas, mainly due to their low seasonality and adaptability to warm climates (Cruz-Sánchez et al., 2022).

The Katahdin breed was developed in Maine, USA, by Michael Piel, who selected traits including hair coat (absence of wool), high meat quality, high fertility, and flocking. Piel crossed African Hair Sheep with wool breeds, and by the 1970s, the Katahdin breed was established. These sheep are widely used in crossbreeding systems in the U.S. due to their resistance to internal parasites and low maintenance requirements (KHSI, 2023).

On the other hand, the productivity and disease resistance of the ewe is the most important economic trait for lamb production, as well as for predicting biological indices that facilitate selection decisions in genetic improvement programs (Pérez-Álvarez et al., 2016). Therefore, even in meat production systems, ewe productivity must consider milk yield, as variables such as lamb mortality, daily weight gain, and pre-weaning growth rates largely depend on the mother's milk production. Low milk yield reduces the amount of feed available to nursing lambs, directly decreasing production efficiency and ultimately affecting farm profitability (Castillo-Hernández et al., 2025a; Bayril et al., 2023; Sardinha et al., 2020).

Several factors affect milk production in sheep, including the feeding system, diet composition, parity, and birth type, among others (Burgos-González et al., 2018). Various studies have identified differences in lactation performance between hair and wool sheep breeds. However, despite being widely distributed in North, Central, and South America, there is limited research on the productivity of the Katahdin, particularly regarding milk production under grazing conditions (Burgos-González et al., 2018; Sánchez-Davila et al., 2011).

Few scientific studies have investigated lactation performance and lactation curves in Katahdin sheep. Therefore, this study aimed to describe the lactation of purebred Katahdin ewes under a grazing-based feeding system in order to generate information that may support the development of selection criteria aligned with this production system.

MATERIALS AND METHODS

The study was conducted at the George Washington Carver Farm of Lincoln University in Jefferson City, Missouri, USA (38.52 N, 92.14 W). A flock of 27 second-parity Katahdin ewes bred in November 2021 for spring lambing was used. Management stress was minimized throughout the experimental period. All animal procedures were performed according to the Animal Care and Use Committee (ACUC) guidelines of the Lincoln University and approved under protocol ACUC 22-04.

The synchronization protocol involved the use of controlled internal drug release devices (CIDRs) specifically for the ewes. Pfizer CIDRs containing 0.3 g of progesterone were applied on November 5, 2021, and were removed in staggered intervals (5, 10, and 15 d) to facilitate ram breeding and to prevent all 27 ewes from entering estrus simultaneously. The breeding period lasted 35 d, after which the ewes were not re-exposed to males until November 2022. Pregnancy diagnosis was conducted on February 8, 2022, using a portable Pharvision ultrasound device equipped with a convex transducer. Of the 27 ewes, 25 were confirmed as pregnant, and ultimately all animals lambed during the lambing period.

The ewes grazed on a pasture consisting of cool-season grasses and legumes, including fescue (62%), orchard grass (25%), white clover (8%), and red clover (5%). Grazing was managed through rotation across fourteen paddocks, where the flock remained for two to four days in each paddock and utilized up to 50% of the available forage. This management practice was employed to prevent parasite contamination while optimizing pasture utilization.

Litter size (single or twin), sex (male or female), and lamb body weight were recorded. Partial milk yield (PMY) over a 12-hour period was measured using the weigh-suckle-weigh technique, which has been proven to accurately assess milk yield in small ruminants (Maldonado-Jáquez et al., 2023; Peniche et al., 2015). Measurements were performed every two weeks between 7:00 and 8:00 a.m., starting on the 5th d postpartum to ensure adequate colostrum intake. For each measurement, lambs were separated from their mothers the evening before the weighing, at approximately 6:00 p.m., while maintaining visual contact to minimize stress.

On the control day, lambs were weighed while in a fasting and then placed with their mothers to nurse. After the nursing period, they were weighed again, and the difference in body weight was used to determine PMY of the ewes. PMY during the experiment was measured using a commercial hook-type electronic scale with a capacity of 45 kg ± 5 g (Metrology, Nuevo León, Mexico). The partial milk production measurements were intended to generate practical lactation monitoring technology, allowing producers to adopt the method without altering their management system. PMY (d^{-1}) was calculated according to the formula indicated by Landi et al., 2021:

$$y=[(Pn+P(n-1) /2]^{*} d$$

where y = PMY; Pn = milk production on control day n; P(n−1) = milk production on the previous control; and d = number of days between two controls. Total milk yield per lactation (TMY, kg^{-1}) was calculated using the Fleischmann method (Takma et al., 2009), following the equation:

$$y_i = P1^{*}D1+ \sum P_i+P_j+1/ 2^{*} D_i+P_k+1^{*}DEP$$

Where y_i = TMY; D1= interval between lambing and the first record; P1= milk production at the i^{th} record; Di= interval between the i^{th} record and the $(i+1)^{th}$ record (for i= 1,… k); and DEP = assumed to be the number of days between records. Lactation length (LL, d^{-1}) was determined as a parameter characterizing the lactation curve. The incomplete gamma function of Wood was used in its nonlinear form to determine the parameters that characterize the lactation curve, under the following model:

$$y^n=an^b e^{-cn}$$

where y^n = milk production on the n^{th} day of lactation; ^{e} = base of the natural logarithm; and "a," "b," and "c" are constants, where "a" represents the initial milk yield (the amount of daily milk yield for each sheep after lambing, kg). "b" represents the rate of milk yield increase to peak during the ascending phase (kg, week), and "c" represents the rate of milk yield decrease to peak during the descending phase (kg, week).

Statistical analyses were performed using the SAS v9.4 statistical package. Prior to analysis, the assumptions of normality, independence, and homogeneity of variances were evaluated. Partial milk yield (PMY), total milk yield per lactation (TMY), and lactation length (LL) were analyzed under a fixed effects model in a completely randomized design. Additionally, PMY, TMY, and LL were analyzed by birth type and progeny sex. All analyses were conducted using the GLM procedure, following the structure of the model:

$$Y_{ijkl}=\mu+ID_i+TP_j+SX_k+E_{ijkl}$$

where: Y_{ijkl} = parameter of the curve (a, b, c) and/or milk production (day, lactation, or length); μ = constant characterizing the population; ID_i = random effect of the i^{th} animal (for I = 1,2,3,…27); TP_j = fixed effect of the j^{th} type of birth (for j = 1,2); SX_k = fixed effect of the k^{th} sex of the lambs (for l = 1,2); and E_{ijkl} = random error. The random components were assumed to be normally distributed with a mean of zero and common variance.

RESULTS AND DISCUSSION

Variables such as gestation duration, prolificacy, and lactation performance are presented in Table 1. No recent studies were found that report gestation length specifically for Katahdin sheep; however, evidence indicates that gestation duration varies among breeds. Local sheep have been reported to exhibit gestation periods ranging from 144 to 159 d (Pinto et al., 2025; De la Rosa et al., 2013). Similarly, gestation duration in Tabasco hair sheep and West African sheep is approximately 149 d (Combellas, 1980). Overall, these values do not differ significantly from the general observations reported for the species (Gual et al., 2022).

As for the prolificacy results, they fall within the ranges reported for the breed. However, the prolificacy found was higher than that reported by Magaña-Monforte et al. (2024) and Limas-Martínez et al. (2023) for Katahdin sheep

Table 1. Productive performance and general lactation characteristics in pure Katahdin ewes during their second lambing.

Trait	Mean±S.E.	R^2	C.V.
Gestation length (days, d)	152.30±6.47	-	-
Prolificacy	1.63±0.63	-	-
Daily milk yield (kg)	0.494±0.33	0.4012	51.68
Total milk yield (kg)	47.82±14.52	0.3751	25.74
Lactation length (days, d)	89.21±10.64	0.5915	8.17

S.E. = Standard error; R^2 = Coefficient of determination; C.V. = Coefficient of variation.

in northern and southeastern Mexico. These slight differences primarily can be attributed to the lambing season and feeding management (Murphy el at., 2023; Rastle-Simpson et al., 2016), as well as to the number of births, since primiparous ewes tend to exhibit slightly lower prolificacy (Vicente-Pérez et al., 2021) than that found in the present study.

In general, the lactation performance observed in this study differ from that reported by Chay-Canul et al. (2019a) and Burgos-González et al. (2018), who found higher daily milk yields in pure Katahdin ewes (1.77 and 1.38 kg d^{-1}, respectively). These discrepancies may be attributed to the differences in feeding strategies and management practices. Nevertheless, the production levels observed for the Katahdin breed in the present study are higher than those reported for other hair sheep breeds, such as Pelibuey, which typically achieves yields between 0.390 and 0.440 kg d^{-1} (Rodriguez-Álvarez et al 2021; Arcos-Álvarez et al., 2020).

Regarding total milk yield, Olvera-Aguirre et al. (2020) report levels similar to those found in this study in crossbred genotypes of Pelibuey × Katahdin. However, under intensive management conditions, pure Katahdin animals exhibit higher production levels (Chay-Canul et al., 2019a), where milk production nearly doubles compared to that observed under grazing conditions. Additionally, the production levels recorded are lower than those reported by Marshall et al. (2023) and Estrada-López et al (2025) for dairy sheep in New Zealand and Mexico under grazing conditions. Thus, when contrasting the results reported in the literature, it can be inferred that breed has a significant effect on milk production, and that environmental factors, at least under the conditions of this study, do not appear to limit productivity in Katahdin ewes. This finding supports the breed's successful adaptation to various environments and highlights its potential under different management systems (Sánchez-Ramos et al., 2023; Aguilar-Martínez et al., 2017; Kremer et al., 2014).

Regarding lactation length, no reports were found specifically for the Katahdin breed. However, some studies on specialized milk production genotypes report considerable differences relative to the present findings, as the lactation duration for these genotypes can be up to three times longer than those for meat genotypes, with milk production levels as much as five times higher (Velarde-Guillén et al., 2022). Additionally, crosses between specialized dairy genotypes and local or meat-producing breeds exhibit significant increases in milk yield (Ángeles-Hernández et al., 2018), indicating that breed remains a decisive factor in improving this trait.

Table 2 presents the values obtained for lactation by type of birth and sex of the offspring. It is observed that ewes with twin births produced a greater amount of milk per day and total milk production per lactation ($P < 0.05$). However, the duration of lactation was shorter compared to those with single births ($P > 0.05$). These results align with the findings of Chay-Canul et al. (2020), who reported similar patterns in Katahdin ewes, noting that those with twin births produced significantly more milk than those with single offspring. Additionally, the increased milk production in this breed (approximately 20% higher) leads to heavier weaning weights compared to other hair breeds (Dorper and Pelibuey), which contributes to the

Table 2. Lactation characteristics by birth type and offspring sex in pure Katahdin ewes during their second lambing.

	By lambing type (mean±S.E.)				
	Single	**Double**	**P-Value**	**R^2**	**C.V.**
Daily milk yield (kg)	0.402±0.30[b]	0.638±0.32[a]	<0.0001	0.4012	51.68
Total milk production per lactation (kg)	44.18±12.96[b]	54.63±15.51[a]	0.0226	0.3751	25.74
Lactation length (days, d)	94.00±8.65	82.50±9.77	0.1357	0.5915	8.17
	By sex type (mean±S.E.)				
	Female	**Male**	**P-Value**	**R^2**	**C.V.**
Daily milk yield (kg)	0.514±0.29[a]	0.381±0.32[b]	0.0048	0.2428	59.68
Total milk production per lactation (kg)	45.02±38.59	39.38±13.38	0.2901	0.1825	35.50
Lactation length (days, d)	86.21±10.79	89.15±12.36	0.8359	0.5896	8.89

[ab] Letters between columns indicate difference ($p<0.05$); S.E.= Standard error; R^2 = Coefficient of determination; C.V. = Coefficient of variation.

overall success of the Katahdin (Chay-Canul et al., 2019b; Magaña-Monforte et al., 2018).

On the other hand, the sex of the offspring affected ($P < 0.05$) milk production. The ewes gave birth to female lambs exhibiting the highest values. However, the duration of lactation and total milk production did not differ ($p > 0.05$) when considering lamb sex. These results are consistent with the findings of Abecia and Palacios (2018), who indicated that the sex effect on milk production is positive in Churra and Lacaune sheep, where ewes that give birth to females produce more milk (0.730 kg) than those with males (0.690 kg). Nevertheless, several studies conclude that the primary factor affecting milk production and fertility in ewes is nutrition (Nápoles-Castillo et al., 2025; Iturralde et al., 2019; Pesántez-Pacheco et al., 2019; Sadek et al., 2017). Thus, adequate nutrition will positively influence body development and consequently, milk production, whereas underfeeding will lead to slower growth rates and prolificacy in lambs due to lower milk production.

The parameters characterizing the lactation curve are shown in Table 3. It was found that the model is significant ($P < 0.05$). Parameters "a" and "b" exhibited the highest standard error values with lower estimator values, whereas parameter "c" had a lower estimator and standard error. In this regard, previous studies demonstrate that the Wood model adequately fits the total milk production modeling in sheep (Castillo-Hernández et al., 2024; Ángeles-Hernández et al., 2014; Cilek and Keskin 2008, Cilek et al 2009).

Fig. 1 shows the observed and predicted values for the lactation of purebred Katahdin ewes during their second lambing under grazing conditions. A typical lactation curve is observed, with an initial increase in milk production, peaking around week 4, followed by a gradual decline as lactation progresses (Castillo-Hernández et al., 2024). The model shows an adequate fit, as the magnitude of over- or underestimation of observed values compared to predicted values is low, consistent with other reports on dairy sheep (Ángeles-Hernández et al., 2014).

These results also align with the typical shape of the lactation curve for Katahdin ewes under intensive management in temperate climates

Table 3. Lactation curve parameters (a, b, c) in pure Katahdin ewes during their second lambing.

Parameter	Estimator	S.E.
a	0.9368	0.4126
b	0.3251	0.1844
c	0.0197	0.0055
P-Value	<0.0001	

S.E. = Standard error; "a", "b", and "c" = constants that represents scale factor for milk production at the beginning and before of the peak of milk production.

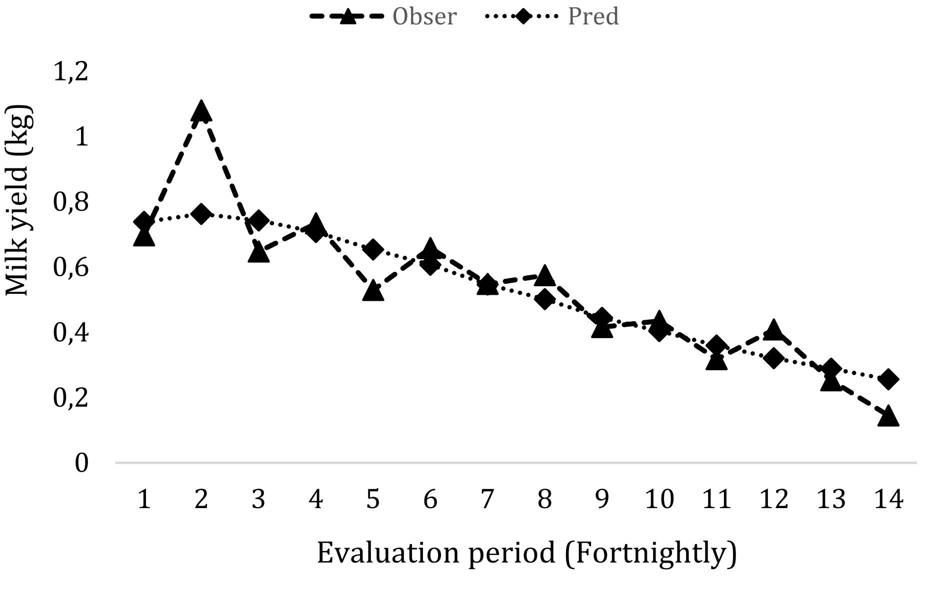

Fig. 1. Milk production curve in purebred Katahdin ewes fed on pasture during their second lambing. Obser= Observed data; Pred= Predicted data.

(Burgos-González et al., 2018; Cilek and Keskin 2008). It is observed that the milk production increases during the first month of lactation, followed by continuous and steady declines until milk production ceases (Castillo-Hernández et al., 2025b; Komprej et al., 2012; Cilek et al 2009). The milk production behavior in this genotype also corresponds to the production curves of Santa Cruz and Pelibuey ewes, respectively (Merchant et al., 2021; Rodríguez-Álvarez et al., 2021), indicating that environmental effects do not significantly influence the variability of milk production (Ramírez-Rojas et al., 2022; Ángeles-Hernández et al., 2014). Under the conditions of this study, these milk production levels can be attributed, with a high degree of confidence, to breed-specific characteristics.

CONCLUSIONS

It is concluded that Katahdin ewes have adequate milk production under grazing conditions. Differences in milk production were observed due to lambing type and sex, although no changes were detected in lactation length. The lactation curve presented a typical shape, with peak production occurring around weeks 3-4 postpartum. These findings are particularly relevant given the limited reports on milk production in Katahdin ewes.

Author contributions

All authors contributed to the conception and design of the study. Data curation: María de Lourdes Alonso Herrera, Homero Salinas González, Eric Groose and Jorge A. Maldonado Jáquez; formal analysis: Jorge A. Maldonado Jáquez, Glafiro Torres Hernández and Homero Salinas González; funding acquisition, supervision and validation: Homero Salinas González, Francisco G. Echavarría Chairez and Eric Groose. The first draft of the manuscript was written by María de Lourdes Alonso Herrera, Alberto Muro Reyes, Luis Humberto Díaz García, Homero Salinas González and Jorge A. Maldonado Jáquez. All authors reviewed and revised earlier versions of the manuscript and approved the final version for publication.

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