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Pre-weaning performance and growth curve in F1 Katahdin x East Friesian crossbred lambs

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ABSTRACT

The aim was to evaluate the pre-weaning performance of F1 Katahdin × East Friesian (Kt x EF) crossbred lambs, focused on growth and weaning weight. A total of 43 lambs with their dams were raised on pasture. Litter size and progeny sex were considered. Five nonlinear models were used to describe the growth curve. A significant interaction effect ($P < 0.05$) was found for sex and group effect for litter size on daily weight gain and weaning weight, with males and lambs from triplet and single births achieving the highest weight gains. No interaction effects or group differences were observed for birth weight, weaning age, or mortality ($P > 0.05$) due to progeny sex or litter size. Positive and significant correlations were observed. The Von Bertalanffy and Richards models showed the best fit for the growth curve, with R^2 values exceeding 98%. In conclusion, under grazing conditions, F1 Kt × EF lambs showed similar birth weights and higher weaning weights in those born as singles or triplets, suggesting a strong heterosis effect. Furthermore, the Von Bertalanffy and Richards models provided the best fit to describe the growth curve.

Keywords: *Crossbreeding, Genetic improvement, Litter size, Meat production, Sheep*

INTRODUCTION

Crossbreeding has become a key strategy in modern sheep production systems, providing producers with an effective approach to enhance reproductive efficiency, growth rate, carcass quality, and environmental adaptability. While purebred systems have traditionally dominated the industry, evolving market demands and increasing environmental challenges demand more flexible and efficient breeding strategies (Rasali *et al*., 2006). The development of composite breeds has enabled the integration of additive genetic merit, heterosis, and breed complementarity into a single, stabilized population (Murray, 2023).

In the United States, home to more than fifty recognized sheep breeds actively used in production, crossbreeding programs are typically designed to align with specific production objectives and environmental conditions (Thorne *et al*., 2021). Successful programs often involve pairing breeds with complementary traits, especially in systems where optimizing maternal performance and lamb survival is essential (Emsen *et al*., 2025; Cobb *et al*., 2019). One of the most promising combinations is the cross between East Friesian and Katahdin sheep. The East Friesian breed is renowned for its high milk production and strong maternal traits, while the Katahdin offers advantages such as resistance to parasites, adaptability to forage-based systems, and desirable meat quality (Bentley *et al*., 2024).

The Katahdin breed, developed in the United States during the mid-twentieth century, was selectively bred for its hair coat, heat tolerance, and resistance to gastrointestinal nematodes, with genetic contributions from the St. Croix breed (Wildeus, 1997). These characteristics make the Katahdin particularly well-suited to pasture-based systems, especially in humid regions where parasite pressure is significant. The combination of East Friesian and Katahdin genetics presents a unique opportunity to develop crossbred ewes with enhanced maternal performance and greater resilience to environmental stressors; however, reports on this cross under grazing schemes are scarce.

Therefore, the aim of this research was to evaluate the pre-weaning performance of F1 Katahdin × East Friesian crossbred lambs, focusing on lamb growth and weaning weight, as an initial step toward developing genetic improvement schemes for lamb production under forage-based management systems.

MATERIALS AND METHODS

This study was approved by the Institutional Animal Care and Use Committee of Lincoln University (Approval Number: ACUC 22-04). The research was conducted at Lincoln University's Carver Farm, located in Jefferson City, Missouri, USA (latitude 38.52°N, longitude 92.14° W).

The experimental site lies within a humid continental climate zone, marked by four distinct seasons and an average annual precipitation ranging from 38 to 42 inches, primarily falling between April and September. Typical summer temperatures range between 29°C and 32°C (85–90°F), while winters generally reach lows of −9° C to −7°C (15–20°F). The area has a growing season that lasts approximately 170 to 190 days. Dominant soil types include silt loams and silty clay loams, mainly from the Menfro and Mexico series. These soils are moderately to well-drained, slightly acidic to neutral (pH 6.0–7.0), and well-suited for the cultivation of pastures, forages, and row crops.

A total of 43 lambs born in spring 2022 were used in the study. They were offspring of 27 second-parity Katahdin (Kt) ewes bred to a single East Friesian (EF) yearling ram. Lambs were tagged and weighed at birth. After a five-day period for colostrum intake, body weight measurements were taken every two weeks until roughly 10 days prior to weaning, which occurred at 90 days of age. Lamb condition and resistance/tolerance to parasites were evaluated using FAMACHA© scores and fecal egg counts as needed.

The flock composed of 24 ewe lambs and 19 ram lambs was maintained on pastures planted with a mix of cool-season grasses and legumes. The botanical composition included 62% tall fescue, 25% orchard grass, 8% ladino clover, and 5% red clover. A rotational grazing system was implemented across 14 paddocks, with each paddock grazed for 2 to 4 days. Grazing was managed with a target of 50% forage use, aiming to reduce gastrointestinal parasite exposure.

The analysis considered variables such as litter size (LS: single, twin, triplet), sex of offspring, and birth weight (BW). Birth weights were recorded within four hours after delivery. Subsequent weights were obtained every 15 days, with lambs in a fasted state, using a hook-type electronic scale (model-300, Rhino, Mexico; ±100 g accuracy; 300 kg capacity). At study completion, weaning weight (WW) was recorded. Weaning age (WA) was calculated as the number of days from birth to weaning. Daily weight gain (DWG) was computed by subtracting BW from WW and dividing by WA. The mortality percentage was also determined.

Data analysis followed a randomized complete block design (RCBD). Mortality data were evaluated through ANOVA, and remaining data were analyzed using the General Linear Model (GLM) procedure under a fixed-effects framework. Tukey's test was used for multiple comparisons. The model used was: $Yijklm = \mu + Ri + LSj + SXk + Tm + SXk*Tl + Eijklm$

Where:
Yijklm: BW, WW, DWG, or WA; μ: overall mean; Ri: fixed effect of the i-th animal within each block (i = 1, 2, 3, ... n); LSj: fixed effect of the j-th litter size category (j = 1, 2, 3); SXk: fixed effect of the k-th sex (k = 1, 2); Tl: fixed effect of the l-th time point (l = 1, 2, 3, ... n); SXk*Tl: interaction between sex and time; Eijklm: random error, assumed to be normally distributed.

In addition, Pearson's correlation was calculated to explore relationships among BW, WW, DWG, and WA, and between sexes.

Five nonlinear models (Table 1) were applied to describe lamb growth. In biological terms: W(t) represents live weight at time t; "A" is asymptotic weight, indicating mature size; "B" is related to initial weight and age; "k" denotes the maturation rate, how fast adult size is approached; "m", the shape parameter, identifies the inflection point where growth shifts from acceleration to deceleration.

Initial weight was assumed to lack maternal influence, allowing clean interpretation of growth curves (Onogi *et al*., 2019; Kopuzlu *et al.,* 2014). Model parameters were estimated using the NLMixed procedure.

Model fit was assessed using four statistical indicators: (1)Akaike Information Criterion [AIC]; (2) Bayesian Information Criterion [BIC] = −2 × log-likelihood + log(n) × k; (3) Mean Square Error [CME] = SSE / (n − k); (4) R^2 [coefficient of determination] = 1 − (SSE / SST), where SSE = error sum of squares, SST = total sum of squares (Posada and Noguera, 2007).

RESULTS AND DISCUSSION

Table 2 presents the productive performance results by sex of the F1 crossbred Kt*EF lambs. A significant interaction effect (P < 0.05) was observed for daily weight gain (DWG) and weaning weight (WW), with males exhibiting the highest values. No significant interaction effects or differences between groups (P > 0.05) were found for birth weight (BW), weaning age (WA), or mortality.

These findings differ from those reported by Castillo-Hernández *et al*. (2022), who observed higher performance values for male and female Kt crossbred lambs. However, while DWG and WW did not differ by sex in their study, the reported values were still higher, even though the lambs were evaluated at similar ages to those in the present study (90.1 days). Similarly, Chay-Canul *et al*. (2019) reported BW values comparable to those observed here in purebred Kt lambs, but with lower DWG than in our study.

Although higher DWG and WW values were observed in males, Sharif *et al.* (2021) reported that females may achieve faster maturation rates and reach mature weight at a younger age than males. Additionally, variation in lamb performance is mainly attributed to two factors: the production system and the genotype. Animals raised under confinement typically show better productive performance than those raised on pasture (Moloney *et al*., 2023). However, genotypes also play a significant role, as heterosis effects resulting from crossbreeding can greatly enhance productivity, particularly for traits such as weaning weight, yearling weight, and carcass characteristics (Getahun *et al*., 2019).

Table 3 shows the results by litter size. As with the sex of the progeny, significant effects (P < 0.05) were found only for DWG and WW, with lambs from triplet litters achieving the highest weight gains, along with those from single births. In contrast, BW, WA, and mortality did not differ between groups (P > 0.05).

These results partially align with those reported by Castillo-Hernández *et al.* (2022), who found differences in DWG and WW, but also in BW, with single-born lambs exhibiting the high-

Table 1. Nonlinear Models were Considered to Describe the Growth Curve in F1 Crossed Kt*EF Lambs

Model	Equation
Von Bertalanffy	$W(t) = A[1 - B\exp(-kt)]^3$
Gompertz	$W(t) = A\exp[-B\exp(-kt)]$
Brody	$W(t) = A[1 - B\exp(-kt)]$
Logistic	$W(t) = A/[1 + B\exp(-kt)]$
Richards	$W(t) = A[1 - B\exp(-kt)]^{1/m}$

Table 2. Productive Performance by Progeny Sex in F1 Crossbred Katahdin x East Friesian Lambs

	Male	Female	P-Value	SX*T	R^2	C.V.
Birth weight (kg)	3.909±0.154	3.601±0.149	0.4714	0.1746	0.1936	18.07
Daily weight gain (kg)	0.153±0.009[a]	0.127±0.004[b]	0.0191	0.0308	0.1829	47.64
Weaning weight (kg)	19.029±1.106[a]	15.73±1.098[b]	0.0022	0.0086	0.6541	17.21
Weaning age (d)	91.73±3.22	89.78±3.21	0.2416	0.3242	0.1631	10.92
Mortality (%)	13.3±0.3	8.9±0.2	0.1807	-	-	-
N	19	24	-	-	-	-

Sx*T= Sex* time interaction; R^2= Coefficient of determination; C.V.= Coefficient of variation.

est values. Similarly, BW trends followed expected patterns, with lighter birth weights observed as litter size increased (Mellado *et al*., 2016). Generally, lambs from single births have higher birth weights than those from multiple births. However, DWG and WW in multiple-born lambs can be high enough to match those of single-born lambs (Pinto *et al*., 2025). This is particularly important since live weight is a selection criterion used in genetic improvement programs to enhance lamb survival rates.

In this context, although lower BW values were observed in multiple births, DWG and WW were higher in these groups. This suggests an extraordinary heterosis effect resulting from the Kt*EF cross, consistent with the findings of Pokhyl *et al.* (2024), who emphasized a pronounced heterosis effect in the productive performance of multiple-born lambs. Nevertheless, McHugh *et al*. (2017) and Hocking-Edwards *et al*. (2018) also highlight the importance of adequate maternal nutrition during gestation, as it is directly related to the pre-weaning performance of the offspring.

The correlation matrix (Table 4) shows a positive and significant relationship between daily weight gain (DWG) and weaning weight (WW) with weaning age (WA) in male lambs. While, significant and positive relationship were found among birth weight (BW) and weaning weight (WW) with weaning age (WA) in females. In contrast, in this particular cross, birth weight (BW) shows a negative relationship with all of the variables considered in males, whereas, DWG is negatively related to WW and WA in females.

In this regard, the results partially align with those reported by Castillo-Hernández *et al*. (2022); Castillo-Hernández *et al*. (2025), who found significant positive correlations between age and weaning weight. However, they also reported a significant negative correlation between age and DWG in Kt and Columbia lambs, which differs from our findings. Similarly, Ngere *et al*. (2017) indicate that BW is closely related to all growth variables in Kt lambs. Therefore, models that incorporate permanent maternal additive effects may better estimate breeding values for this cross.

These findings reinforce the argument that hybrid vigor is highly beneficial for the Kt*EF cross, which is a promising indicator for establishing specific growth trait patterns. Growth and conformation traits are closely related to breed type (López-Carlos *et al*., 2010).

Table 5 presents the parameter estimates of the growth curves for F1 Kt*EF crossbred lambs. The highest R^2 values, with accuracy exceeding 98%, and the lowest values in AIC, BIC, and MSE criteria were observed for the Von Bertalanffy and Richards models. Thus, these two models are the most suitable for describing the pre-weaning growth curve for this particular cross.

Figure 1 illustrates a typical growth curve in male and female lambs, where most of the observed and predicted values from the models von Bertalanffy and Richards with the best fit are closely align with the predicted trend. This further supports the high R^2 values obtained during the model fitting stage.

These results are consistent with those reported by Kopuzlu *et al*. (2014), who observed R^2 values of 0.99 for the Richards model in Hemsin lambs. Similarly, Castillo-Hernández *et al*. (2022) reported R^2 values comparable to those found in this study for the Gompertz and Brody models, although lower values were noted for the Von Bertalanffy model. These findings confirm that the models employed are effective for modeling growth curves in sheep, particularly in the Kt*EF crossbred population.

Table 3. Productive Performance by Litter Size in F1 Crossbred Kt*EF Lambs

	Single	Double	Triplet	P-Value	R^2	C.V.
Birth weight (kg)	3.990±0.172	3.673±0.136	3.401±0.259	0.3486	0.1936	18.07
Daily weight gain (kg)	$0.169±0.009^a$	$0.116±0.004^b$	$0.185±0.018^a$	<0.0001	0.1829	47.64
Weaning weight (kg)	$21.274±1.043^a$	$14.707±0.785^b$	$20.24±2.412^{ab}$	<0.0001	0.6541	17.21
Weaning age (d)	94.73±3.04	88.40±2.29	91.00±7.04	0.2641	0.1631	10.92
Mortality (%)	6.7±0.2	6.7±0.2	8.9±0.4	0.3961	-	-
N	14	23	6			

R^2= Coefficient of determination; C.V.= Coefficient of variation.

Table 4. Phenotypic Correlation Matrix for Pre-weaning Behavior Traits F1 Crossbred Kt*EF Male and Female Lambs

	Males				Females			
	BW	DWG	WW	WA	BW	DWG	WW	WA
BW	1.00				1.00			
DWG	-0.04	1.00			-0.05	1.00		
WW	-0.08	0.10*	1.00		0.28	-0.15	1.00	
WA	-0.27	0.14	0.69***	1.00	0.46*	-0.35	0.71***	1.00

BW= birth weight; DWG= daily weigth gain; WW= Weaning weight; WA= weaning age; **=P <0.01; ***=P<0.000

Table 5. Curve Parameters and Goodness-of-fit Criteria of the Pre-weaning Growth Curve in F1 Crossbred Kt*EF Lambs

Model	Parameters			Goodness-of-fit criteria			
	A	B	K	AIC	CIB	CME	R^2
Von Bertalanffy	42.52±1.63	0.437±0.003	0.024±0.0005	1015.9	1024.5	1.294	99.8
Gompertz	40.80±1.55	1.657±0.016	0.029±0.0006	1020.0	1030.6	1.304	93.6
Brody	49.26±2.02	0.854±0.003	0.013±0.0005	1039.6	1050.1	1.433	92.3
Logistic	37.93±1.47	3.56±0.069	0.046±0.0008	1060.8	1071.3	1.553	84.9
Richards	42.11±1.88	0.363±0.19	0.026±0.0002	1017.5	1028.1	1.293	98.6

A, B, K= Biological parameters to describe growth curve; AIC= Akaike information criterion; BIC= Bayesian information criterion; CME= Mean square of error; R^2 = Coefficient of determination.

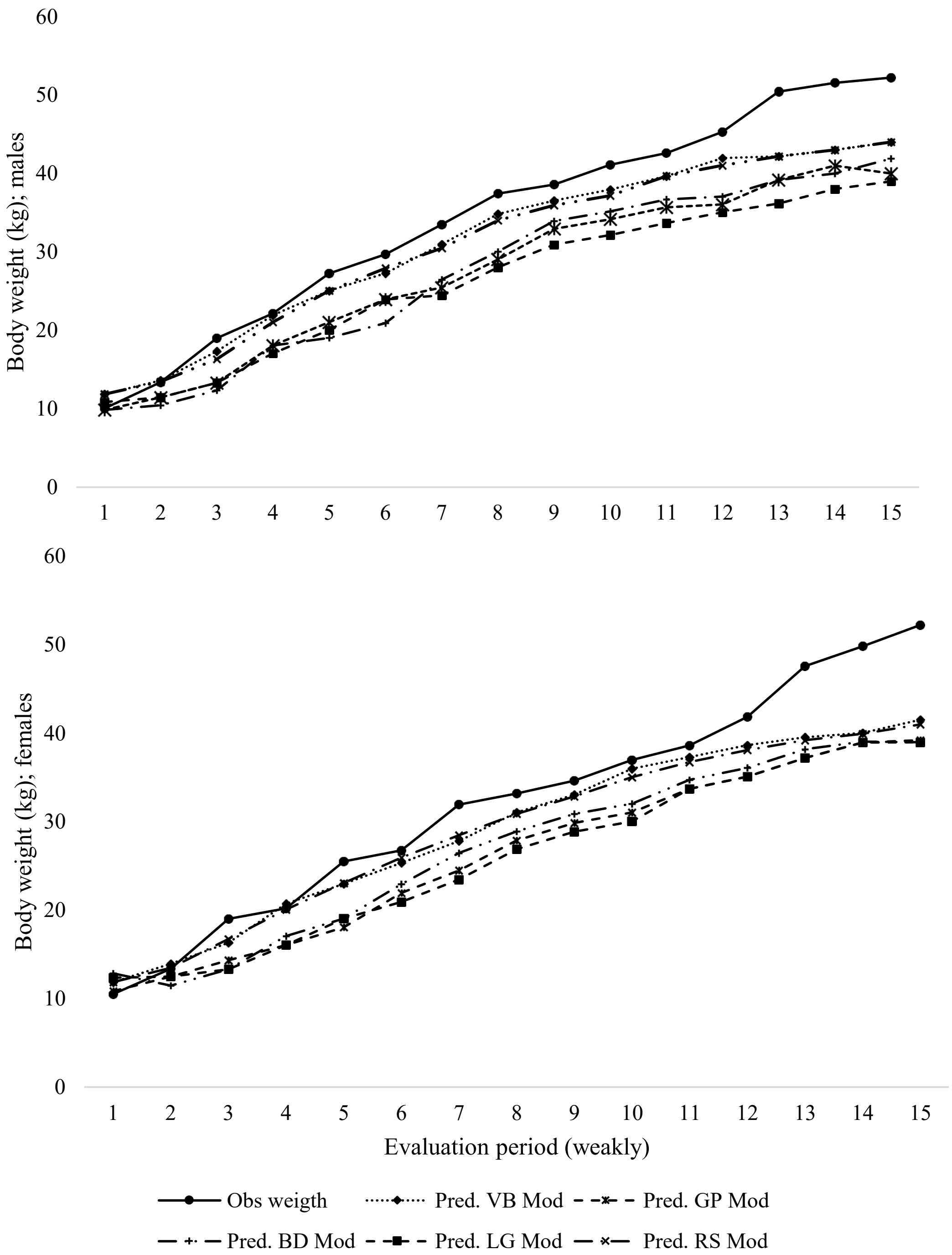

Figure 1. Pre-weaning growth curve in F1 Crossbred KT*EF males lambs (upper) and female lambs (lower). Obs weight ( ) = Observed weight; Pred. VB Mod ( )= predicted values von Bertalanfy model; Pred. GP Mod ( )= predicted values Gompertz model; Pred. BD Mod ( )= predicted values Brody model; Pred. LG Mod ( )= predicted values Logistic model; Pred. RS Mod ( )= predicted values Richards model.

Therefore, growth models with better goodness of fit can facilitate more objective evaluations, enabling the identification of animals with superior growth rates. This, in turn, may increase the percentage of weaned lambs (Moloney *et al*., 2023).

CONCLUSION

It is concluded that the productive performance of F1 Kt*EF crossbred lambs under grazing conditions shows similar birth weights, with superior weaning weights observed in single and triple-born lambs. This suggests a remarkable heterosis effect. Additionally, the Von Bertalanffy and Richards models provided the best fit for modeling the growth curve.

This information is critical for developing genetic improvement schemes tailored to lamb production systems under grazing conditions. However, further in-depth studies are needed to fully describe the production system and the effect of crossbreeding on productive performance and identify key areas for improvement.

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