REGULAR ARTICLES

Pre-weaning performance and commercial growth curve in Dorper, Katahdin, and Romanov crossed lambs in a highland zone from central Mexico

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Abstract

The aim was to evaluate the pre-weaning productive performance and growth curve of Dorper*Katahdin (DPr; $n=46$), Kathadin*Kathadin (KTn; $n=204$) and Romanov*Kathadin (RMv; $n=40$) of commercial crossed lambs from central Mexico. We considered 1450 data from 290 crossbred lambs. The variables contemplated in this study were cross (CR), lambing type (LT), sex, birth weight (BW), weaning weight (WW), test days (TD), and daily weight gain (DWG). Correlation analysis and adjustment of growth curve were performed. Differences in CR and sex were found only in BW ($p < 0.05$). No differences in DWG, WW, and TD ($p > 0.05$) by CR and sex were found. Single lambing had the highest ($p < 0.05$) BW, WW, and DWG. Phenotypic correlations differ among crosses. Lambs crossed with DPr presented the highest values in parameters a and b and the lowest in c. The productive behavior of DPr, KTn, and RMv cross with KTn lambs in central Mexico is similar in the pre-weaning period; however, the growth curve and parameters that characterize it suggest that DPr lambs show a tendency to enhance productive behavior in this period.

Keywords Ruminants · Sheep · Genetic improvement · Intensive system · Crosses

Introduction

Due to the increase in sheepmeat demand, traditional production models have been changed to intensive systems (Alhidary et al., 2016), as a consequence of poor management practices and low productivity of local breeds, making it necessary to improve efficiency through the adoption of genetic improvement strategies, to compete against other meat production systems (Esmailizadeh et al., 2012).

For this reason, organized crossbreeding systems can optimize the use of heterosis and complementarity between breeds, since they present a better maturity rate, high feeding efficiency, and high meat productivity, compared to purebred animals, since efficiency and profitability are determined by genetic merit for more efficient growth and nutrient utilization (Fathala et al., 2014; Chay-Canul et al., 2019).

Likewise, in the case of lambs, it is known that pre-weaning growth is affected by breed and lambing type; therefore, intensive crossbreeding has been used to exploit breed complementarity, making it necessary to characterize the curve of commercial growth as part of the initiatives of genetic improvement programs (García-Osorio et al., 2017; López et al., 2018). This is because growth curves help to extract important information at specific points of development, which will make it possible to produce valuable information that will promote the profitability, viability, and sustainability of commercial production, and where, for example, genotypes or early crosses can be identified, more efficient feeding schemes can be established and highly productive animals with help of their growth curve can be selected (Valencia-García et al., 2022; Weber et al., 2021; Mohammadi et al., 2019) as evidenced by Jones et al., 2021, where heavier lambs at weaning produced significantly more

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valuable carcasses. Nevertheless, studies that describe this behavior in commercial crosses in Mexico are scarce (Hinojosa-Cuellar et al., 2013). Therefore, the aim was to evaluate the pre-weaning productive performance and the commercial growth curve of Dorper, Katahdin, and Romanov crossed lambs from a highland zone of central Mexico.

Materials and methods

The study was carried out in a commercial herd ($n = 500$) destined to lamb production, which is constituted by multi-racial hair sheep. The productive unit is located in Nicolás Romero, Estado de México (19° 38′ 11″ N), at 2390masl, with temperate subhumid climate, which mean annual temperature and precicpitation are 16 °C and 800–1000 mm, respectively (García, 2004).

Information from 1450 data from 290 commercial crossbred lambs Katahdin*Katahdin (KTn; $n = 204$), Dorper*Kathadin (DPr; $n = 46$), and Romanov*Katahdin (RMv; $n = 40$) born in the period from May to July, 2020, were considered for this study. The sample size of the groups was not uniform due to the herd characteristics and because the production unit was in absorption to Katahdin breed. Maternal breeds used consisted of commercial Dorper, Romanov, and Katahdin lines, while the rams used were Katahdin breed. In addition, in this herd, the selection of bellies is based on the target weight of the lambs to be used as future ewes.

Lambs were selected from birth to weaning (~ 90 days of age). Management was carried out following the producer's usual activities, in order to induce the least possible stress. This management is characterized by being carried out completely intensive, where in addition to ewe milk, lambs from 8 days received a creep feeding diet (Table 1) at a 250 gr day^{-1} rate. The lambs had free access to mineral salts and fresh clean water.

Cross (CR), lambing type (LT; single or multiple), sex, and birth weight (BW) were considered. BW was taken within the first 4 h after birth. Afterward, BW was recorded every 15 days at 6:00 h fasting. BW was taken in grams (g) using an electronic scale with a hook with 45 kg ± 5 g capacity (Metrology, Nuevo León, Mexico), prior to weighing, lambs were separated from their mother the afternoon before weighing around 20:00 h. At the end of the experiment, weaning weight was recorded (WW), test days were also counted (TD; period from birth to weaning), daily weight gain was determined (DWG), calculated by subtracting BW from WW and dividing by TD.

Data were analyzed under a randomized complete block design. All data were analyzed with GLM procedure under a fixed-effects model and mean comparison with Tukey test. The general structure of the model was as follows:

Table 1 Ingredients and chemical composition of creep feeding diet offered to crossbred lambs in central Mexico

Ingredient	(%)
Cotton seed	5.0
Sesame paste	4.0
Biscuits [1]	20.0
Molasses	4.0
Corn	40.0
Urea	0.5
Canola	24.0
Sodium bicarbonate	1.0
Premix vitamins and minerals *	1.5
Nutritional content	
CP (%)	17.3
NE (Mcal)	3.11

[1]Biscuit industry waste; *CP*, crude protein; *NE*, net energy; *vitasal sheep fattening ovino plus®; *MCal*, mega calories.

$$Y_{ijklm} = \mu + R_{i(j)} + CR_j + LT_k + SX_1 + E_{ijklm}$$

where Y_{ijklm}: BW, WW, DWG, and/or TD; μ: constant; R_i: fixed effect of ith animal within group ($i = 1,2,3…n$), CR_j: fixed effect of jth cross ($j = 1,2,3$), LT_k: fixed effect of k-th lambing type ($k = 1,2,3$); SX_l: fixed effect of lth sex of offspring ($l = 1, 2$); E_{ijklm}: random error, which was assumed normally distributed. In addition, a Pearson correlation analysis was carried out, to learn the relationship among quantitative traits (BW, WW, DWG, and TD) for each genetic group.

Non-linear mixed models von Bertalanffy [$y = a(1 - be^{-kt})^3 + \varepsilon$], Gompertz [$y = ae^{Be(-kt)} + \varepsilon$], and Brody [$y = a(1 - be^{-kt}) + \varepsilon$] was used to adjust the growth curve (Silva et al., 2012):, where y: live weight at age "t"; a: asymptotic weight, interpreted as adult weight; b: is an integration parameter related to initial body weight, which is defined by the initial values of "y" and "t"; k: maturation rate, interpreted as the change in weight concerning mature weight, indicating how quickly the animal reaches its adult weight; ε: random error, normally distributed with zero mean and constant variance. It was assumed that the initial weight of the test did not have a maternal effect, which could interfere with growth curve analysis (Onogi et al., 2019). Parameters of both models were estimated using the NLMixed procedure.

In order to determine the model goodness fit, four criteria were used AIC (Akaike information criterion); BIC (Bayesian information criterion) $= -2 * \log \text{Lik} + \log (n) * k$, where log Lik: logarithm of maximum likelihood; n: number of observations; k: number of model parameters (Posada y Noguera, 2007); R^2 (determination coefficient) $= 1 - (SCE/SCT)$; where SSE: sum of squares error; STS: sum of total squares (Posada y Noguera, 2007); and convergence rate

(CR, Agudelo-Gómez et al., 2009), which was calculated as an animal percentage with individual convergent curves (Nocedal y Wright, 2006).

Results and discussion

Productive behavior due to crosses is shown in Table 2. Differences were only found in BW ($p < 0.05$) and where the highest values were found in DPr lambs. Regarding DWG, WW, and TD, no differences were observed ($p > 0.05$); however, it is interesting to see a trend in DPr towards higher WW and DWG and lower TD, in which probably differences between genotypes would be identified until evaluation in fattening period. In this sense, the production environment must be able to sustain the cross or genotype used; therefore, it is desirable that crosses be evaluated not only in terms of their behavior but also in terms of adaptation, especially to environmental conditions (Esmailizadeh et al., 2012). Similarly, Fathala et al. (2014) evaluated Romanov lambs and some crosses and concluded that crosses were superior in all productive traits; however, weaning weights were higher, compared to those found in our study. Besides, Hinojosa-Cuellar et al. (2013) evaluated productive behavior of DPr and KTn crossed lambs and no differences were found in BW, but weight at weaning, where DPr crosses presented the best behavior, which in this case must be directly related to the environment, since the evaluations were carried out in

a tropical climate, with completely different characteristics from those of our study.

Besides, when the data were analyzed by lambing type (Table 2), it was observed that single lambs had the highest BW, DWG, and WW ($p < 0.05$). In this regard, results coincide with García-Osorio et al. (2017), where single lambs showed the best DWG and WW. Likewise, Chay-Canul et al. (2019) reported that multiple lambs presented the lightest weights in all characteristics evaluated and Mellado et al. (2016) pointed out that BW decreases when litter size increases, similar to our results. Moreover, Mirderikvandi et al. (2016) pointed out that WW in Lori Bakhtiari lambs is affected by sex, but not by the type of birth, which differs from our findings.

Regarding the behavior given by sex (Table 2), similar results were found to those found for CR with differences only in BW ($P < 0.05$), with males being the heaviest. In this regard, our results differ from Mellado et al. (2016) who found no differences in BW between crosses of KTn lambs.

Moreover, results for DWG, WW, and TD show similar trends to CR evaluation and according to data behavior, it would be expected that differences could be found in a longer test period, which is, considering the fattening stage. In this regard, Balan et al. (2017) point out that males have higher weights than females except in BW. Sharif et al. (2021) mention that females reach a higher maturity rate and mature weight at an earlier age compared to males. Frequently, a greater growth in males is expected because growth hormone influences a better productive performance

Table 2 Means ($\pm$ s.e.) of birth weights, daily weight gain, weaning weight, and test days in lambs from a highland zone from central Mexico, according to the cross, lambing type, and sex

Cross						
Trait	RMv	KTn	DPr	R^2	C.V.	P-value
BW	3.89 ± 0.13[b]	4.07 ± 0.08[b]	4.43 ± 0.12[a]	0.15	19.96	0.0215
DWG	0.202 ± 0.01	0.212 ± 0.01	0.219 ± 0.01	0.08	25.22	0.2595
WW	22.16 ± 1.52	23.47 ± 1.28	24.75 ± 1.52	0.03	30.77	0.2484
TD	94.36 ± 7.06	91.50 ± 4.41	88.54 ± 5.95	0.03	35.17	0.7568
Lambing type						
	Single		Multiple			
BW	4.72 ± 0.14[a]		3.91 ± 0.08[b]	0.15	19.96	0.0021
DWG	0.222 ± 0.01[a]		0.205 ± 0.01[b]	0.08	25.22	0.0404
WW	27.20 ± 1.57[a]		20.49 ± 0.79[b]	0.03	30.77	0.0281
TD	91.83 ± 7.32		87.35 ± 4.43	0.03	35.17	0.8568
Sex						
	Male		Female			
BW	4.28 ± 0.08[a]		3.82 ± 0.09[b]	0.15	19.96	0.0179
DWG	0.213 ± 0.01		0.200 ± 0.01	0.08	25.22	0.4729
WW	22.75 ± 0.90		22.61 ± 0.98	0.03	30.77	0.6846
TD	87.44 ± 4.16		94.98 ± 4.56	0.03	35.17	0.3317
N	154		136	-	-	-

RMv, Romanov; *KTn*, Katahdin; *DPr*, Dorper; *BW*, birth weight; *DWG*, daily weight gain; *WW*, weaning weight; *TD*, test days; R^2, determination coefficient; *C.V.*, variation coefficient; [ab]different letters between columns indicate difference ($p < 0.05$); *N*, number of evaluated males or females.

(Patel et al., 2019), which was not observed in males from our study.

Phenotypic correlations are shown in Table 3. In this regard, it was found that correlations differ between crosses. For the DPr genotype, WW is positively related ($p < 0.001$) only with DWG and TD. In KTn genotype, TD is negatively related ($p < 0.05$) with BW; DWG is positively ($p < 0.001$) related to BW and negatively ($p < 0.01$) to TD. Likewise, WW is positively related ($p < 0.05$) with TD and DWG. In contrast, the RMv genotype is only negatively related ($p < 0.05$) with TD and WW with BW. The results partially coincide with Ayhan et al. (2018), where significant correlations between weight and various age periods in Norduz lambs are indicated, but do not evaluate crosses or genotypes. Likewise, the lack of differences found in WW indicates that productive behavior is similar in evaluated crosses, which means that lamb management in this zone of central Mexico has a very marked influence on pre-weaning development. Therefore, the determination of genetic and phenotypic correlations represents, for these particular cases,

a fundamental step for the development of breeding values for new characteristics that can be incorporated into genetic evaluation programs focused on improving lamb meat production (Mortimer et al., 2018).

Finally, parameters that characterize the growth curve of crossed lambs from central Mexico (Fig. 1) coincide with what was observed above and although no significant differences were observed in productive behavior. The model with the best fit, based on the goodness-of-fit criteria used, was the Von Bertalanfy (Table 4). Parameters a, b, and c indicate that DPr lambs have better development compared to KTn and RMv, which strengthens the previous argument, which indicates that significant differences in DWG and/or final weight could be detected until the fattening period is considered in these genotypes for this region specifically. About this, Weber et al. (2021) found similar values to ours in a, b, and c parameters for RMv cross, in crosses with Texel, Ile de France, Suffolk, and Hampshire. In the same way, the behavior of the growth curve is similar to that reported by Schiller et al. (2015), in terminal crosses of Charolais, Ile

Table 3 Phenotypic correlation matrix for pre-weaning behavior in crossed lambs with Dorper, Katahdin, and Romanov from a highland zone form central central Mexico

	DPr				KTn				RMv			
	BW	TD	DWG	WW	BW	TD	DWG	WW	BW	TD	DWG	WW
BW	1				1				1			
TD	−0.02	1			−0.21*	1			−0.56**	1		
DWG	0.07	0.17	1		0.35***	−0.25**	1		0.23	-0.08	1	
WW	0.19	0.71***	0.78***	1	0.13	0.61*	0.56***	1	−0.39***	0.91	0.31	1

BW, birth weight; *TD*, test days; *DWG*, daily weight gain; *WW*, weaning weight; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Fig. 1 The pre-weaning growth curve in crossed lambs in a highland zone of central Mexico
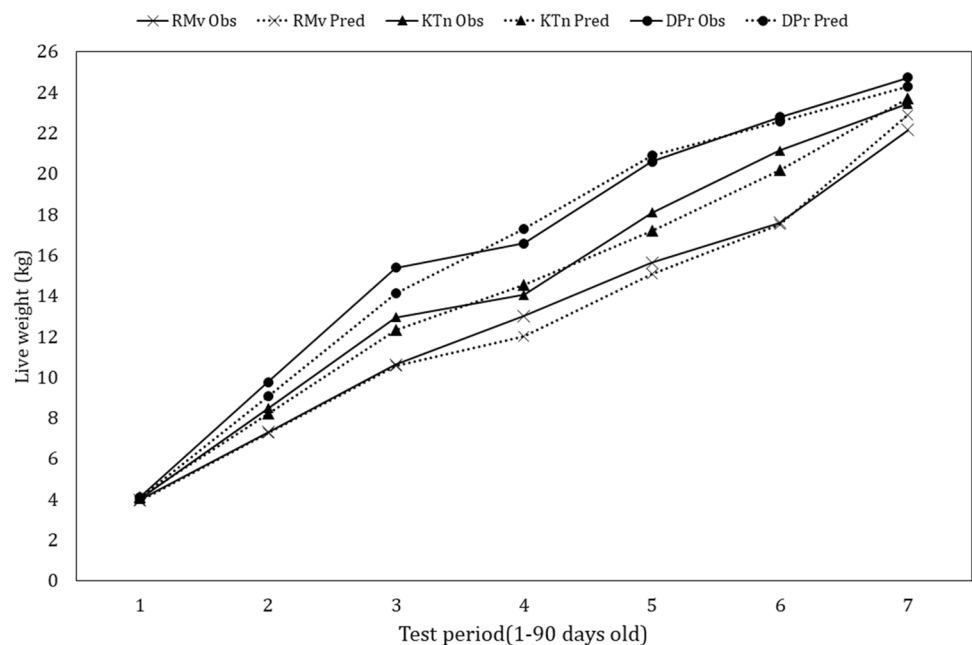
Table 4 Curve parameters (a, b, c) and goodness-of-fit criteria of the pre-weaning growth curve in cross-bred lambs from central Mexico, under the von Bertalanffy, Gompertz, and Brody models

Curve parameters				Goodnes-of-fit criteria			
Genotype	A	B	k	AIC	BIC	R^2	TC
Von Bertalanfy model							
KTn	50.57 ± 3.94	0.58 ± 0.001	0.0095 ± 0.00	996.6	1006.5	93.2	86.5
DPr	71.52 ± 12.99	0.62 ± 0.017	0.007 ± 0.00	170.2	171.7	91.5	87.1
RMv	48.81 ± 3.34	0.57 ± 0.011	0.013 ± 0.00	138.5	138.9	88.3	86.3
Gompertz model							
KTn	42.14 ± 2.43	2.38 ± 0.05	0.014 ± 0.00	998.0	1007.9	91.4	86.3
DPr	75.76 ± 7.12	7.59 ± 0.05	0.007 ± 0.00	368.2	369.7	89.1	88.4
RMv	78.10 ± 5.00	0.38 ± 0.00	0.017 ± 0.00	328.3	328.7	87.8	85.2
Brody model							
KTn	73.18 ± 158.59	0.99 ± 0.00	0.0003 ± 0.00	1002.0	1011.9	92.6	85.9
DPr	75.57 ± 12.19	0.99 ± 0.08	0.00003 ± 0.00	174.2	175.7	90.2	87.7
RMv	72.23 ± 19.37	0.96 ± 0.00	0.0033 ± 0.00	144.5	144.9	88.1	86.3

AIC, Akaike information criterion; *BIC*, Bayesian information criterion; R^2, determination coefficient; *TC*, convergence rate.

de Frence, Merino, Dorper, Suffolk, and Texel. Lupi et al., (2015) mention that the parameters of the growth curve can be used as selection criteria to improve lamb growth.

Conclusions and recommendations

It is concluded that the productive behavior of commercial crossbred lambs, Dorper, Katahdin, and Romanov* Katahdin in a highland zone of central Mexico, is similar in the pre-weaning period. However, the growth curve and parameters that characterize it indicate that Dorper lambs show a tendency to enhance productive performance in this period, which will have to be evaluated at a later.

Author contribution All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Gabriela Castillo Hernández, Laura Castillo Hernandez, Omar Salvador Flores y Misael Rubén Oliver González. The first draft of the manuscript was written by Jorge Alonso Maldonado Jáquez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability The datasets generated during and/or analyzed during the current study are not publicly available due to being part of the results of the research project, but are available from the corresponding author on reasonable request.

Code Availability Not applicable.

Declarations

Ethics Approval All the methods used, as well as animal handling are strictly adhered to the accepted guidelines for ethical use, care, and animal welfare used in International Research, according to the Federation of Animal Science Societies (FASS, 2010), National Academy of Medicine (NAM, 2011), and Mexican institution by Universidad Nacional Autonoma de México (UNAM) with PIAPI 2037 project approval.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interest The authors declare no competing interests.

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