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Reproductive and productive performance of hair sheep in a semi-intensive system in southeastern Mexico

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Abstract

Productivity measured as kilograms of lamb weaned per ewe is a composite trait of economic importance and can be used as selection criterion of maternal breeds. The objective of this study was to estimate the reproductive, preweaning growth and productivity performance of hair breed ewes, and the effect some nongenetic factors influencing them under semi-intensive conditions in southeastern, Mexico. Information of purebreds and crossbred ewes and their lambs was used to develop a composite productivity index. The final mixed model used (except for age at first lambing, AFL), included the fixed effect of breed group, year (Y, 2016-2019) and season of lambing (dry, rainy and wind and rainy), lambing number (1, 2, … ≥ 5), litter size (LS, single and double for weaning traits), and the random effects of ewe within breed group and residual error. Except for the AFL, the effect of the breed group and all other non-genetic factors were significant ($P < 0.0100$). No breed or crossbred was superior for all traits studied, yet Commercial Katahdin (K) excelled the most, despite of its reproductive performance. Traits in the productivity index (litter size at lambing, adjusted litter weaning weight and lambing interval) could not be used as an optimal indicator for the identification of the best breed for crossbreeding. The K showed the best maternal ability, except for lambing interval and AFL, influenced by all non-genetic factors which could be improved by sound flock management.

Keywords: Hair breeds; Reproduction; Preweaning; Productivity index; Tropics.

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Additional information and declarations can be found on page 13

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Study contribution

Hair sheep breeds are the most used in tropical production systems, due to their rusticity, parasite resistance and reproductive activity throughout the year. However, there is little information on their relative reproductive and productive performance identifying the most productive ewe breed. A composite trait proposed as a selection criterion for this purpose is the kilograms of lamb weaned per ewe during a productive cycle that allows three lambing per ewe every two years. This study shows that such an index composed of litter size at lambing, adjusted litter weaning weight and lambing interval traits, would not be an optimal indicator to identify the best breed or maternal crossbred. In addition, it highlights the important role of Katahdin breed, because it showed better maternal ability, despite of fertility limitations that can be ameliorated by feeding strategies during rearing and early postpartum.

Introduction

The sheep population in Mexico is around 8.7 million heads, which produce 67.40 t of mutton.[1,2] Hair sheep have had a great boom and expansion in recent years in the different agroclimatic areas of Mexico, especially in the tropics. In this region, hair sheep breeds such as Pelibuey, Blackbelly, Dorper and Katahdin and their crosses are commonly used, and it maintains 24 % of the sheep population, which produces about 28 % of fattening mutton for sale.[3] The income and profitability of sheep farms depend to a large extent on the ewe reproductive performance, and the survival and growth of the lambs.[4-7] Ewe fertility measured as age at first lambing, lambing interval, litter size and weight at lambing and at weaning are traits that together determine the ewe productivity.

While each of these traits can be used as breeding criterions, perhaps litter weight at weaning as a composite character could be more efficient for ewe breed evaluation in weaning production systems in the Mexican tropics.[4,6,7-9] Therefore, it is very important to have an overview of what is expected from these hair breeds and their crosses with each other, considering in the same way the non-genetic factors that could influence the productive performance of the ewe reflected in turn in the flock in general. Consequently, the present study aims to evaluate the reproductive performance, pre-weaning growth and productivity of hair breed ewes, some environmental factors that influence them and to identify the most suitable maternal breed for lamb production under semi-intensive conditions in the tropics of southeastern Mexico.

Materials and methods

The study was carried out in a full-cycle sheep production system in Yucatán, Mexico, which is located between parallels 20° 24´ and 20° 35´ north latitude and meridians 89° 37ʹ and 89° 47ʹ west longitude, at 29 m above sea level.[10] The climate of the region is warm subhumid, with rains in summer (Aw0). The average annual temperature and annual rainfall are 25.5 °C and 697 mm, respectively. The type of soil is rocky or cemented, steep.

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The flock was founded in 2002 with ewes and rams from different flocks of the region, with the objective of producing lambs for fattening. Subsequently, in 2004 the flock was registered in the Mexican Association of Ovine Breeders to register specimens of the Pelibuey breed. During 2006, Katahdin flock was also registered. Previously, ewes and rams were acquired from different breeders in the country. Currently the objective of the farm is to sell breeding stock (males and females) of both breeds and fatten lambs.

General management

The farm has an area of 84 ha, of which, 70 ha are used as paddocks with Brizantha grass (*Bracharia brizantha*), 10 with local vegetation and other 4 ha of facilities such as pens, feeders, warehouses, offices. Fifty of the 80 ha of the grazing area are under irrigation. The irrigated area is divided into paddocks fenced with sheep netting. Of the paddocks, 25 are of one hectare and used for lactating ewes, 20 of 0.80 ha for replacement females and 36 of 0.25 ha for grazing pregnant females. The 20 ha without irrigation are divided into 20 paddocks for grazing nonpregnant females. The ewe breeds evaluated were Pelibuey, Blackbelly, Katahdin, Dorper and the crosses between them, through a system of continuous breeding for unregistered sheep and under controlled mating for the Katahdin and Pelibuey breeds, registered in the Mexican Association of Ovine Breeders.

Reproductive management

Future replacement females, both commercial and registered pure breed are phenotypically selected by breed appearance at weaning time and at five months of age by the owner; thereafter, they are move to the batch of future replacements, without an established a specific feeding program. Commercial replacements are incorporated into the breeding batch at 9 months of age, regardless of breed. Once the ewes are incorporated into the breeding herd, they are managed the same as adult sheep flocks. The mating consists of having a breeding batch of 30 females each for 60 days with two rams of different breed, and after pregnancy diagnosis, if the females get pregnant, they are sent to the batch of pregnant females and the no pregnant ones remain in a new breeding batch with different rams giving them one more opportunity to become pregnant and if still non-pregnant, they are discarded. Mating between ewes and rams was random and neither the date nor the ram that mated with the female was recorded.

The batch of pregnant females are visually monitored every two weeks to separate those near to give birth, which are transferred to the pens close to the other females for better surveillance and control at lambing. The newly lambed ewes are monitored every day to identify the offspring of the respective ewes and to detect those ewes that do not want to nurse their young, which are transferred to individual cages to take better care of them. After a week of lambing, ewes and their lambs are moved to maternity pens (approximately 30 ewes per pen) where they remain until weaning 60 days after lambing.

Weaned ewes are incorporated the next day to the breeding batch, but if ewes have a body condition score of two or less (scale of 1 to 5; Russel et al. 1969), they

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are sent to a supplemented batch, and three weeks later they are introduced into a new breeding batch. In the case of pure breed registered ewes, they are usually given an extra period between 15 to 30 more days before introducing them to the corresponding breeding batch. In the same way, the pure registered replacement female lambs are incorporated into the breeding batch at nine months of age with the difference that they will be in breeding pens with males of the same breed (Pelibuey or Katahdin).

The mating period last 60 days, and subsequently the rams are separated and five weeks later the pregnancy diagnosis is performed. The pregnant ewes were incorporated into the batch of pregnant females following the management described above, with the difference that when they were weaned, they were incorporated into the breeding pens and not in the breeding batch of commercial females. Six rams of each breed were handled every year. Rams were used for two years and then culled, so that three young and three adult rams per breed were handled each year.

Feeding management

The feeding of the flock of pregnant ewes consisted of grazing and commercial mineral salts *ad libitum*. Pure ewes during the breeding period were offered around 150 g of a commercial feed with 16 % of crude protein and chopped Taiwan grass. All ewes near to calving and throughout lactation were offered the same commercial food varying the amount 300 g for nearby lambing and 700 g for lactating females. From the fourth week of lactation, the females had access to direct grazing from 8 am to 12 pm and the supply of chopped grass in the pens was suppressed.

Lambs were offered a pre-initiator with 18 % of crude protein *ad libitum*, which was located at a place where only lambs have access all the time until 28 days of age, and from that age until weaning, restricted suckling was practiced letting the lamb suckle 2 h in the morning (6-8 am) and 2 h in the afternoon (2-4 pm), while the rest of the time they remain locked up with access to the pre-initiator.

Sanitary management

Deworming was carried out with ivermectin and closantel every six months, as well as vaccination against clostridia and Pasteurella every year to the entire breeding herd. Future replacements were given the usual medication at weaning and a booster of the vaccine three weeks postweaning.

Data management

The information collected was based on productive records of flock from 2016 to 2019. The total data analyzed, after editing the database, were 979 ewes of different breed groups (Table 1).

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Table 1. Number of ewes by breed group

Breed	Number of ewes
Registered Pelibuey (RP)	154
Registered Katahdin (RK)	104
Commercial Pelibuey (CP)	180
Commercial Katahdin (K)	117
Commercial Blackbelly (B)	74
Katahdin × Pelibuey (K × CP)	133
Katahdin × Blackbelly (K × B)	78
Dorper × Katahdin (D × K)	71
Dorper × Blackbelly (D × B)	68
Total	979

The database included the identification of the ewe, breed group (BG), age at first lambing (AFL), lambing number (LN), date of lambing, year (Y) and season of lambing (S), litter size at lambing (LSL) and at weaning (LSW), lambing litter weight in kilogram (LLW) and at weaning (LWW), lambing interval (LI) and to simulate the possibility of obtaining three lambing per ewe every two years, a composite trait index was derived and called productivity measured as kilogram of weaning produced per 240 day cycle (KGWLW). LWW was adjusted to 60 days, using the formula:

$$\text{LWWA} = \frac{\text{LWW} - \text{LLW}}{\text{Weaning age}} \times 60 + LLW$$

where: LWWA = 60 day adjusted weaning litter weight, LWW = litter weaning weight, and LLW = lambing litter weight.

The productivity (KGWLW) was carried out as: (LWWA/LI) × 240;[9] and litter size (LS) was classified as single and double, while for season of lambing the categories were dry (February-April), rainy (June-October) and windy and rainy (November-January). The database consisted of ewes with one or more lambing, registered breed group with or without date at first lambing, including ewes that remained in the flock. To determine the presence of the ewe, a physical inventory was carried out registering the identification of each one, as well as its breed group. The inventory served as a filter to compare the record of the breeds groups of the ewes with that recorded in the flock software and thus verify the visual reliability of the breed group information of the ewes.

Once this was done, the information concerning each productive indicator by genotype was extracted from the database (Table 2). The number of LSL and LSW data are the same because the ewes that lost the entire LSW were considered as zero. The LWW was the result of the sum of the adjusted individual weight of each lamb concerning the same parity of each ewe. Because the breed of sire and the identity of the sire were not recorded in the breeding lots of the unregistered ewes, the paternal breed of the lambs was not known. In the batches of registered ewes, the breed and identity of the services to each lamb were recorded.

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Table 2. Number of observations by breed group used for each trait evaluated

Breed group	AFL*	LI*	LSL*	LLW(kg)*	LSW*	LWW(kg)*	KGWLW*
Registered Pelibuey (RP)	141	314	474	474	474	474	302
Registered Katahdin (RK)	121	183	284	282	282	282	175
Commercial Pelibuey (CP)	104	268	422	422	422	401	251
Comercial Katahdin (K)	97	243	360	360	360	337	229
Commercial Blackbelly (B)	–	113	157	157	157	148	106
Katahdin × Pelibuey (K × CP)	90	412	665	665	665	624	388
Katahdin × Blackbelly (K × B)	–	119	165	165	165	158	114
Dorper × Katahdin (D × K)	65	149	217	217	217	208	143
Dorper × Blackbelly (D × B)	–	90	135	114	135	128	87

* AFL (age at first calving), LI (lambing interval), LSL (litter size at lambing), LLW (lambing litter weight), LSW (litter size at weaning), LWW (litter weight at weaning) and KGWLW (kilogram of weaning produced per 240 day cycle).

Information analysis

The ewes were breed grouped using dynamic tables, comparing in first instance the indicators through descriptive statistics. Thereafter the general linear model procedure of the statistical package Statistical Analysis System (SAS, 2005) was used including the with fixed effects of no-genetic effects (Y, S, LN, LS) and ewe breed group. The first statistical analyses included some first-order interactions considered relevant between the breed group and the other environmental factors; however, they were eliminated from the final model since they were not significant (P > 0.0500). The final mixed model used, except for AFL included the fixed effect of breed group (BG, with nine levels described in Table 1), year of lambing (Y, 2016–2019), season of lambing (S, dry, rainy-windy, and rainy), lambing number (LN, 1, 2, … ≥ 5), litter size (LS, single and double for weaning traits), and random effects of ewe within breed group and error.

Ethical statement

During the study, no animal was handled, only the information recorded by the herd administrator and visual inspection of the sheep were used to verify their racial group according to what was recorded.

Results

Age at first lambing, litter size at lambing and litter size at weaning

In Table 3, reference is made to AFL, LSL and LSW where it is clearly observed that there was no difference for AFL between breed groups for this trait, which means ranged from 15.73 to 16.93 months of age. Regarding LSL, the Registered Pelibuey (RP) and Katahdin × Blackbelly (K × B) breed groups had the highest mean values (1.44 lambs for each group), although they were not statistically different (P = 0.0645) from the other genetic groups, except Commercial Katahdin (K) and Katahdin × Pelibuey (K × CP), whose LSL were lower. For LSW, RP and K × B, also had the highest values of 1.29 and 1.32 lambs, respectively. K × P and Commercial Blackbelly (B) ewes had the lowest LSW least squares mean.

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Table 3. Parameters of litters and environmental factors assessed

Factor	AFL (months)			LSL			LSW		
	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE
Breed group		NS			***			***	
Commercial Pelibuey (CP)	141	15.83^{a}	0.52	422	1.37^{abc}	0.02	422	1.24^{bc}	0.02
Registered Pelibuey (RP)	104	16.10^{a}	0.40	474	1.44^{a}	0.02	474	1.29^{ab}	0.01
Commercial Katahdin (K)	97	16.34^{a}	0.53	360	1.32^{c}	0.02	360	1.18^{c}	0.02
Registered Katahdin (RK)	121	16.93^{a}	0.56	284	1.42^{ab}	0.03	284	1.23^{bc}	0.02
Commercial Blackbelly (B)	–			157	1.40^{abc}	0.03	157	1.19^{c}	0.03
Katahdin × Pelibuey (K × CP)	90	15.73^{a}	0.36	665	1.34^{bc}	0.02	665	1.20^{c}	0.01
Katahdin × Blackbelly (K × B)	–			165	1.44^{a}	0.04	165	1.32^{a}	0.03
Dorper × Katahdin (D × K)	65	15.91^{a}	0.92	217	1.38^{abc}	0.03	217	1.24^{bc}	0.02
Dorper × Blackbelly (D × B)	–			135	1.39^{abc}	0.04	135	1.24^{bc}	0.03
Year		***			***			***	
2017	128	16.98^{a}	0.34	371	1.36^{b}	0.03	371	1.20^{b}	0.02
2018	118	16.23^{ab}	0.36	581	1.32^{b}	0.02	581	1.20^{b}	0.01
2019	70	15.22^{b}	0.48	1119	1.43^{a}	0.01	1119	1.27^{a}	0.01
2020				806	1.36^{b}	0.01	806	1.21^{b}	0.01
Season		**			***			***	
Dry	138	15.56^{b}	0.34	921	1.44^{a}	0.02	921	1.27^{a}	0.01
Rainy	59	16.15^{ab}	0.48	1045	1.34^{b}	0.02	1045	1.21^{b}	0.01
Windy and rainy	119	16.72^{a}	0.37	911	1.35^{b}	0.02	911	1.22^{b}	0.01
Lambing number	NI				***			***	
1				319	1.28^{c}	0.03	319	1.06^{d}	0.03
2				852	1.31^{c}	0.02	852	1.17^{c}	0.01
3				652	1.40^{b}	0.02	652	1.26^{b}	0.01
4				474	1.41^{b}	0.02	474	1.28^{b}	0.02
≥ 5				580	1.48^{a}	0.02	580	1.34^{a}	0.02
Litter size	NI			NI				***	
Single							1784	0.93^{b}	0.01
Double							1093	1.72^{a}	0.02

Least squares mean (x̄) and standard error (SE) for age at first lambing (AFL), litter size at lambing (LSL), and litter size at weaning (LSW) of each breed group (GG).
NI= not included in the analysis. NS= no statistical difference, **P < 0.0100; ***P < 0.0010.
[abc] Different letters in the same column for each factor denote significant differences (P < 0.0500).

Year and season had significant effects on AFL, being shorter during the last year assessed, whereas ewes lambing during the dry season had shorter AFL than those from the windy and rainy season (P < 0.0001). For LSL and LSW all the environmental factors had significant effects (P < 0.0001); year did not show any trend for both traits and season showed that ewes lambed during the dry season had better performance than those lambing in the other two seasons. LSL and LSW improved as the lambing number increased.

Lambing interval, lambing litter weight, lambing weaning weight and kilograms weaned per cycle

Table 4 shows that Blackbelly ewes had shorter LI means (242.05 days; P < 0.0001), but like their crosses with Katahdin and Dorper. However, the registered Katahdin breed had the highest LI (287 days), other breed group had values between the range of Registered Katahdin (RK) and B means. Regarding LLW, RK ewes had the

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Table 4. Factors of litters

Factor	LI (days)			LLW (kg)			LWW (kg)			KGWLW (kg)		
	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE
Breed group		***			***			***			***	
Commercial Pelibuey (CP)	268	249.65^{cd}	4.45	422	4.52^{de}	0.04	401	22.35^{cd}	0.21	251	23.64^{bc}	0.43
Registered Pelibuey (RP)	314	269.62^{b}	3.99	474	4.63^{d}	0.04	442	21.99^{d}	0.20	302	22.45^{d}	0.40
Commercial Katahdin (K)	243	261.24^{bc}	4.57	360	4.84^{bc}	0.05	337	23.66^{b}	0.23	229	24.45^{ab}	0.45
Registered Katahdin (RK)	183	286.78^{a}	5.26	282	5.13^{a}	0.05	262	24.48^{a}	0.26	175	23.25^{cd}	0.49
Commercial Blackbelly (B)	113	242.05^{d}	6.70	157	4.41^{c}	0.07	148	21.98^{d}	0.34	106	23.98^{bc}	0.59
Katahdin × Pelibuey (K × CP)	412	260.52^{bc}	3.78	665	4.64^{d}	0.04	624	23.23^{b}	0.18	388	24.08^{bc}	0.39
Katahdin × Blackbelly (K × B)	109	249.54^{cd}	6.92	165	4.49^{de}	0.07	158	22.30^{cd}	0.33	104	23.78^{bc}	0.60
Dorper × Katahdin (D × K)	149	259.06^{bc}	5.79	217	4.87^{b}	0.06	208	24.32^{ab}	0.29	143	25.35^{a}	0.53
Dorper × Blackbelly (D × B)	90	251.64^{cd}	7.42	135	4.66^{cd}	0.08	128	22.98^{bc}	0.36	87	24.14^{abc}	0.63
Year		***			***			***			***	
2016	367	268.72^{a}	4.29	371	4.86^{ab}	0.05	347	21.74^{c}	0.24	343	21.50^{b}	0.36
2017	572	259.08^{b}	3.23	581	4.88^{a}	0.04	554	23.24^{b}	0.19	547	23.19^{a}	0.27
2018	942	248.90^{c}	2.61	1119	4.78^{b}	0.03	1055	23.86^{a}	0.14	866	23.73^{a}	0.23
2019	-			806	4.21^{c}	0.04	752	23.29^{b}	0.18	-		
Season		***			***			***			***	
Dry	664	268.06^{b}	3.27	921	4.80^{a}	0.03	862	22.24^{a}	0.17	630	22.14^{c}	0.34
Rainy	463	267.89^{b}	3.68	1045	4.55^{c}	0.03	983	23.37^{b}	0.18	437	23.84^{b}	0.44
Wind and rainy	754	240.75^{a}	3.68	911	4.70^{b}	0.04	863	23.47^{b}	0.22	718	25.75^{a}	0.42
Lambing number		***			***			***			***	
1	177	275.97^{a}	6.32	319	4.23^{c}	0.06	280	21.66^{c}	0.30	160	21.56^{c}	0.58
2	651	251.32^{b}	2.97	852	4.59^{b}	0.03	804	22.30^{b}	0.16	615	23.51^{b}	0.36
3	476	249.85^{c}	3.30	652	4.86^{a}	0.04	615	23.47^{a}	0.17	447	24.94^{a}	0.37
4	317	258.75^{b}	4.15	474	4.85^{a}	0.04	458	23.78^{a}	0.20	309	24.67^{a}	0.40
≥ 5	260	258.62^{b}	4.82	580	4.89^{a}	0.04	551	23.93^{a}	0.19	254	24.86^{a}	0.43
Litter size		***			***			***			***	
Single	NI			1784	3.41^{b}	0.03	1723	16.15^{b}	0.21	1219	16.86^{b}	0.34
Double	NI			1093	5.53^{a}	0.05	1005	27.15^{a}	0.28	566	28.11^{a}	0.50

Least squares mean ($\bar{x}$) and standard error (SE) by breed group and some environmental effects for lambing interval (LI), lambing litter weight (LLW), litter weaning weight (LWW) and kilograms weaned per cycle (KGWLW).

***P < 0.0010

^{abcd} Different letters in the same column denote significant difference P < 0.0500.

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highest value (5.13 kg; P < 0.0001) followed by Dorper × Katahdin (D × K) and K (4.87 kg and 4.84 kg, respectively), whereas the Blackbelly breed had the lowest LLW (4.41 kg). Litters with RK and D × K dams had the highest weaning weights (24.48 kg and 24.32 kg, respectively (P < 0.0001). B and RP ewes had the lowest LWW (21.98 and 21.9 kg, respectively) with respect to the other breed groups.

Although the RK showed the best values for LLW (5.13 kg) and LWW (24.48 kg) due to their highest LI, when they were evaluated as a composite trait that combines reproductive and productive performance in KGWLW, they performed the worst getting the lowest value (23.25 kg). For this composite trait the ewe best group was D×K followed by K with 25.35 kg and 24.45 kg, respectively.

The traits here studied, except KGWLW did not show any improvement with the years. LLW and LWW means from ewes that lambed during the dry season had heavier litters; however, it was not the case for KGWLW or LI, where the ewes lambing during the windy and rainy season had the best performance. All traits improved as lambing number increased. Ewes that gave birth twins performed better compared to those with single lambs.

Discussion

Even though the analysis of this trait was based on a smaller number of observations and that some ewe crossbreed groups were not included due to lack of data, the results indicate that AFL was similar in all breed groups ranging from 15.73 to 16.93 months. These values are like those from previous studies in the tropical region of Mexico with hair sheep. In Pelibuey ewes, Andrade-Montoya et al.,(11) Gonzalez-Garduño et al.,(12) reported values 15.7 and 17.4 months, respectively. However, Tec-Canche et al.,(13) Luna-Palomera et al.(14) notified values of 18.56 and 18.2 months, respectively, which are higher than those here obtained. This could be attributed to the fact that in the tropics of Mexico does not exist a strict management scheme for future replacement females.

In addition, the ewes were not fed and taken care to have a proper growth and development, since when managing the diet, the differences between breeds in mature weight, age and weight at puberty were not considered. The Dorper and Katahdin breeds were 10 to 20 kg heavier and 20 to 40 days of age older at puberty than Pelibuey and Blackbelly breeds.(15) The present study includes the effects of year and season at the first lambing, which is different from the reports of other authors that include the effects of the year and season of birth of the ewe.(9, 12, 13) Under these conditions the differences are associated with changes in management in general and pasture availability, which are often poor in quality during replacement rearing as was pointed out by other authors.(16)

Gonzalez-Garduño et al.(12, 17) and Hinojosa-Cuéllar et al.(18) reported LSL of 1.2, 1.27 and 1.2, respectively for Pelibuey, Blackbelly and crosses with Katahdin under Mexican humid tropical conditions; means that are lower than the range of values in the present study, varying from 1.32 lambs for K to 1.44 lambs for RK, CP and K×B. Although, these mean values are similar to those reports by Magaña-Monforte et al.(9) in CP, 1.41 lambs. Other reports in the Mexican tropics have found higher values, such as 1.55, 1.71, 1.50, 1.56 lambs, respectively.(7, 11, 13, 19)

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Notter et al.(20) in Katahdin under USA conditions reported 1.82 lambs, showing the greatest maternal advantage of the breed for this trait, which is slightly higher than those obtained here. In addition, in the present study the B breed did not show good prolificacy as was expected, being the best the RK and Katahdin × Blackbelly (K × B) groups with 1.44 lambs. This same breed and cross, weaned more offspring (89 and 91.6 %, respectively) in relation to their LSL (LSW/LSL) survival. Year of lambing was an important source of variation; however, it did not show improvement for LSL over the year as found in the same area of study due to the variability in the amount and quality of pasture among years.(9, 13)

Postpartum feeding management of the lamb and ewe as in the present study, could offer favorable results increasing the size of the litter at birth and weaning as was pointed out by Heimbach et al.(21) In addition, there was no interest in improving fertility and growth via genetics, because the selection of replacements was based exclusively on appearance. Also, the results of the present study show effects of lambing season on both traits, where ewes that lambed during the rainy, and windy and rainy seasons had smaller litter size compared to those that lambed during the dry season.

This situation has been discussed previously, which mentioned that this effect could be attributed to the fact that the ewes that conceive during the dry and early rain season do not get enough grass in the pasture and very possibly weaned their previous litter with low body condition. Furthermore, if they were immediately introduced to the breeding lot, their ovulation rate will be poor having small litter sizes at birth and at weaning, as in the present study.(11, 13, 22-24) Regarding this situation, has been pointed out that the ewe reproductive and productive performance under grazing conditions and continuous suckling could be maximized. Regardless of the age at weaning, as long as the ewes and lambs were supplemented and avoiding that in the ewes, as a consequence of the greater nutritional demands during the early lactation, do not lose body condition, which could cause deep anestrus and late restart of ovarian activity.(21, 25, 26)

Registered Katahdin (RK) ewes had the largest LI (286.8 days) followed by RP, K, K × CP (Commercial Pelibuey) and D × K with 269.60, 261.20, 260.50 and 259.10 days, respectively; wheras B, CP, K × B and Dorper x Blackbelly (D x B) were alike to each other with short LI. The difference of registered animals with respect to the commercial ones could be attributed, in part, to the voluntary rest period that is given to RK and RP after weaning; this period ranged from 15 to 30 more days than for the ewes of the other breed group. LI mean for female CP were shorter than those reported in Venezuela with 284.30, 268.80 days, respectively.(27, 28)

In addition, similar LI were reported in other regions of the Mexican tropics with minimal supplementation such as in Veracruz 274 ±84 days(12); in Yucatán 255.90 and 259.40 days(6, 13), whereas in Tabasco(11, 14) notified a similar mean of 295 days. Significant effects of year, season and parity number have been reported in some studies;(29, 19, 12, 13) although the effect of year was not significant in Pelibuey in Yucatan.(9) The effect of lambing season agrees with the report of Magaña-Monforte et al.(9) with shorter LI duration in the dry season than in the other two seasons, although different results were notified by Tec-Canche et al.,(13) differences that are probably related to the availability of pasture and herd management.

Various authors in the tropics have shown that hair sheep are not very sensitive to seasonality and cycle throughout the year.(30, 22, 31-33) Lambing interval tends to

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improve with the increasing number of lambing in most studies, because primiparous ewes still are growing and their nutrient requirements are higher than for older ewes, therefore the loss of body condition score during lactation in much more than in older ewes. LLW for RK was the highest mean greatest followed by D × K and K, whereas the other ewe breed groups had lower LLW means.

Respect to this trait, Vergara et al.(34) reported values of 3.66, 3.63 and 3.62 for Blackbelly, Katahdin and Pelibuey ewes, respectively. Those values are lower than those obtained here. The heavy weights per litter may be due to the type of management and availability of pasture (main source of food) with irrigation system in the paddocks, and additionally in the case of registered animals, to better feeding during the breeding period, which led to pregnant ewes. likely with better body condition score. during the pregnancy and lambing. Information about the present trait is very scarce and almost all the report available are concern to individual lambing weight.(18, 24, 28, 35)

Respect of LWW, the RK was the best breed followed by D × K, K × P and K as was found by Nasrat et al.(36) in an intensive system. Under a confined and intensive system under dry conditions, the use of either Katahdin or Dorper sire breeds mated to Pelibuey ewes, produced heavier weaned lambs and large litters than the use of Pelibuey sires.(37) Other studies from the tropics of Mexico reported lower LWW values ranging from 16.50 to 19.10 kg.(7, 9, 13) In addition, as for the LLW the most reports are concerned about individual WW.(18, 23, 28, 35)

Based on their results, the last two authors and Nasrat et al.(36) suggest that Katahdin and Dorper breeds could contribute favorably to improve LWW compared to Pelibuey and Blackbelly. Those authors also found effects of year, season, LSW and parity number on LWW, and the lack of studies on productivity. Differences have been attributed to food availability in wet(7, 11) and dry tropics.(9, 33, 36) Mokhtari et al.(5) for Kermani sheep recommended that to improve reproductive and productive performance, selection for KGWLW could be more effective than selecting per other reproductive characters. In Mexico there are very few studies that use this composite indicator to identify the best maternal breed to improve weaning production systems.

That is way, the present study includes hair breeds and their common crosses used in the region, showing the advantages of the crosses of Dorper or Katahdin with the Pelibuey and Blackbelly. Although, the advantages could cause some bias due to the small sample size of the crossover groups involved. In this regard, Nasrat et al.(36) reported the racial advantage of Katahdin and the lack of advantage due to maternal heterosis between the same breeds used here. However, it is important to consider the traits that make up productivity, and although Katahdin offers advantages in LSL and LWW, its disadvantage lies in the longer LI and low productivity.

Therefore, it does not seem that this indicator is the most appropriate to be used as a criterion for identifying the best maternal genetic group, at least under the conditions of the present study and it is very likely that if differences in ewe body weight at lambing were included, this composite trait would support the identification of the best maternal racial group. Other genetic improvement pathways, at least for the Pelibuey breed, despite the low heritabilities for the size and weight of the litter and the calving interval, this indicates that the best selection index that promise a better efficiency relative to the desired selection was the one that included LSL and LWW adjusted to 60 days of age.(38)

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Conclusions

In conclusion, no breed or crossbreed was consistently superior for all traits studied. However, traits that make up the composite trait of productivity (LSL, adjusted LWW and LI) did not suggest it as the optimal indicator for the identification of the best breed or cross. The Katahdin breed is the one that showed the best maternal ability in terms of LWL and LWW, but not for LI and AFL. However, nongenetic factors deserve attention along with improvement via genetic herd management.

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Data availability

Data cannot be shared publicly because of recommendation of the herd owner and manager.

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Conflicts of interest

The authors have no conflict of interest to declare in regard to this publication.

Author contributions

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Data curation: JETC, JRAV
Formal analysis: JGMM, JCSC, GMPB, JETC
Funding acquisition: JETC
Investigation: JETC, JGMM, JCSC
Methodology: JETC, JGMM, JCSC, GMPB
Validation: JGMM, JCSC
Writing-original draft: JETC, JGMM, JCSC, GMPB
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