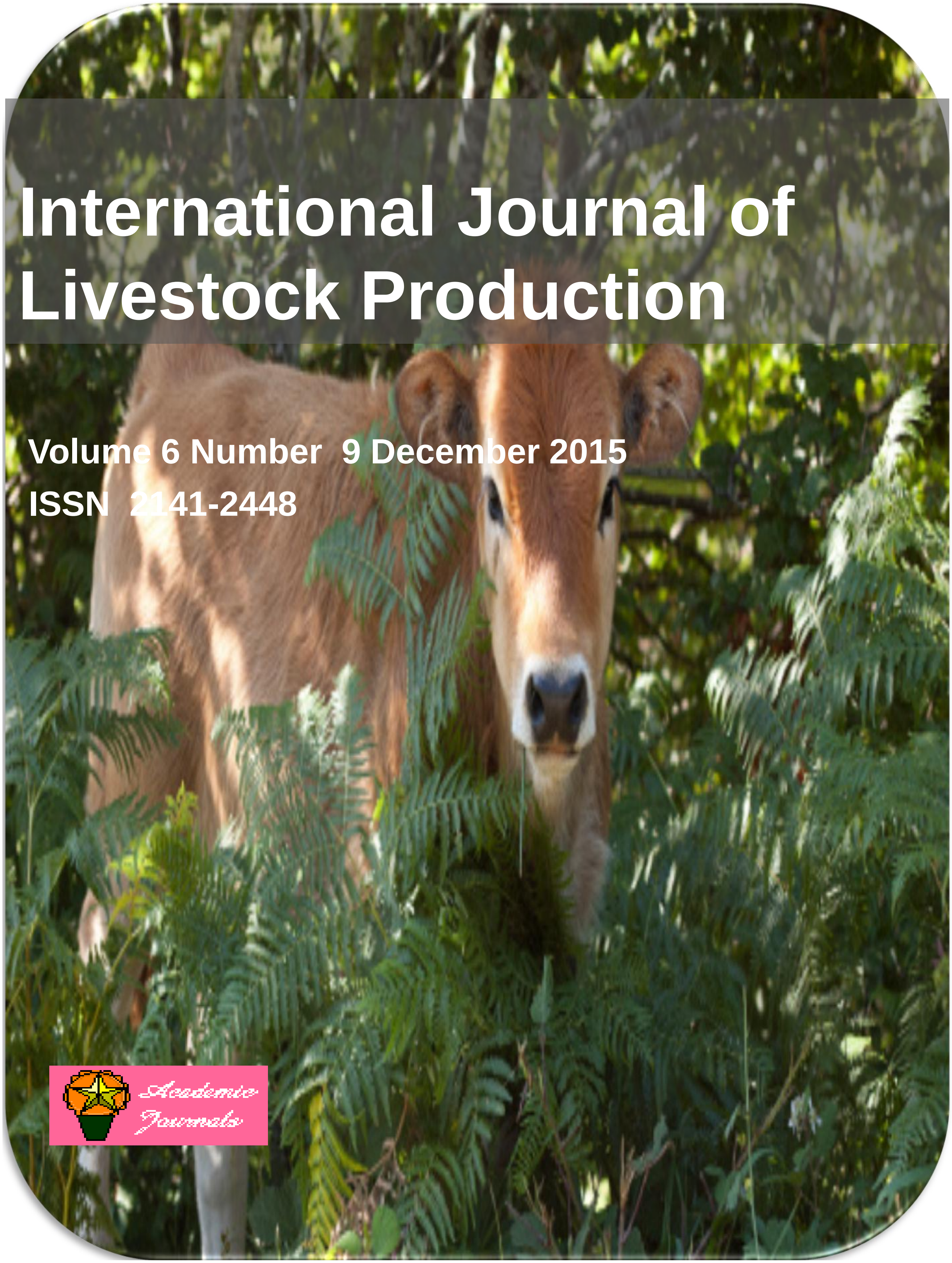
International Journal of Livestock Production

Volume 6 Number 9 December 2015
ISSN 2141-2448



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International Journal of Livestock Production (IJLP) (ISSN 2141-2448) is monthly (one volume per year) by Academic Journals.

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International Journal of Livestock Production

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Vol. 6(9), pp. 99-108, December 2015
DOI: 10.5897/IJLP2015.0261
Article Number: 34AAB8B56811
ISSN 2141-2448

http://www.academicjournals.org/IJLP

International Journal of Livestock Production

Full Length Research Paper

Wool production of Romney Marsh Criollo Chiapas sheep breed and their crosses analyzed by random regression

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Received 27 April, 2015; Accepted 9 November, 2015

Wool produced (kg of fleece/shearing) by 371 sheep from the genetic groups of Romney Marsh (31) Criollo Chiapas sheep (135) and their hybrids (205) was analyzed using repeated measures models and random regression analysis. One thousand one hundred and eight production records collected over a period of 12 years, under extensive production conditions in the region of the Altos de Chiapas, Mexico, were analyzed. The genetic groups displayed wool production differences (P < 0.0001), with Romney Marsh showing the highest performance (2.21±0.94 kg of fleece/shearing), the F1 animals were intermediate (1.397±0.07) and the Criollo sheep showed the poorest performance (0.881±0.07). Heterosis estimation for fleece weight (kg) per shearing was -0.1517±0.0543, P = 0.0055. Romney Marsh animals were the most affected by the environmental effect of animal age at shearing since its negative linear slope was four to ten times steeper than the linear slopes of the F1 and the Criollo animals, respectively. The Criollo Chiapas Sheep remained the longest period of time in the flock. The environmental effects of age of animal (P < 0.0001), gender (P = 0.037), number of shearing (P < 0.001) and year (P < 0.0001) were important on wool production. Wool production for the first four years of age was similar, and it decreased from the fifth year on; males were 6.9% superior to females; the first three shearings were similar between them (P > 0.06), but lesser than the last ones (P < 0.05). Criollo sheep showed remarkable environmental adaptation; therefore, the preservation of this animal genetic resource is extremely important for the indigenous community that makes use of it.

Key words: Criollo sheep, heterosis, wool production, random regression.

INTRODUCTION

The use of Criollo sheep in certain regions of Mexico is, in some cases, a viable alternative of production, due to its environmental, nutritional and management adaptation within a cultural, social and economic surrounding; as is the case of livestock in the Altos de Chiapas, Mexico. This medium-sized, double-coated sheep population is associated with the sociocultural traditions of the indigenous Totzil community, in the elaboration of handmade ceremonial wear and every day wear, as it has been described by Perezgrovas and Castro (2000).

The mating of rams and ewes of different breeds or different genetic groups has been widely used to increase reproductive and productive characteristics in the short term (Hassen et al., 2004; Malik and Singh, 2006; Mishra et al., 2007; Ghită, 2007; Kremer et al., 2010). Burfening and Carpio (1995) in Peru, observed that, because of lamb survival, Criollo sheep are well adapted to environmental conditions; however, animal growth and fleece weight can be increased by crossing this breed with specialized breeds, as long as all socioeconomic and production aspects are considered. Nawaz et al. (1992) in Pakistan, analyzed the productive response when crossing Rambouillet rams with Kaghani ewes with different genetic levels, observing a better growth and wool production response from crossbred animals than that of animals from the local breed, suggesting that the best crossbreeding strategy depends on the objective of local production.

The mating of rams and ewes of different breeds or Criollo genetic groups crossed with specialized exotic breeds, as a tool for improving production, has generated the dissolution or loss of local genetic diversity, with a loss estimated by FAO of one breed each two weeks (FAO, 2007; Köhler-Rollefston et al., 2009). Other alternative for improving production is through identification of genetically outstanding animals, used under controlled breeding programs. Castro-Gámez et al. (2008) estimated heritability value of 0.31±0.05 for fleece production in Chiapas sheep, while Gizaw et al. (2007) obtained a value of 0.393±0.016 in Menz sheep of Ethiopia for the same trait.

Due to the aforementioned, the objective of this study was to evaluate fleece production by crossing Romney Marsh rams with Chiapas Criollo Sheep ewes managed in extensive conditions in Chiapas, Mexico.

MATERIALS AND METHODS

Animals

The production records of dirty fleece (kg/ewe/shearing) collected from Criollo (CR), Romney Marsh (RM) and the cross between Romney Marsh rams and Criollo ewes (F1), for the period 1983 to 1989 were used. They were obtained from the Centro de Fomento Ovino de Chiapas of the Universidad Autónoma de Chiapas, located in the municipality of Teopisca, Chiapas, at 16°32'24'' North latitude and 92°28'19'' West longitude and at 1, 780 ASL. (Secretaría de Gobernación del Estado de Chiapas, 1988). The animals were managed extensively in tropical pastures (mainly *Pennisetum clandestinum*) and had free access to water. Health management of the flock consisted of deworming for the control of gastrointestinal parasites and oxytetracycline administration in case of respiratory disease. Shearing machines were used and dirty fleece weight was recorded for each animal once a year (April).

Database edition

Each animal was identified by genetic group, gender, month and year of birth, shearing number and kg of fleece collected at each shearing. The shearing number was classified from one to six or more. The unidentified records (genetic group or age) were eliminated from the analysis, giving a final number for the analysis of 1108 fleece production records (kg/ewe/shearing) of 371 sheep of the genetic groups: 135 Criollo (119 females, 16 males); 31 Romney Marsh (25 females, 6 males) and 205 from the cross between Romney Marsh males and Criollo females (128 females, 77 males).

Statistical analysis

All fleeces were weighed after each shearing of each animal within its genetic group; for which, the variation between measurements within the same individual, may present homogeneous variances or may differ throughout time and correlated between them. Measurements in the same individual throughout time, are not generally independent, for which, the adequate structure of variances and co-variances for model selection was defined by comparing the statistical data of restricted maximum likelihood: Log likelihood function [log(L)] = -2log (ML_k); Akaike information criterion (AIC) AIC_k = -2log (ML_k) + $2p_k$ (Akaike, 1973) and the Bayesian information criterion (BIC): BIC_k = -2log(ML_k) + p_k log(n) (Littel et al., 2006).

Analysis of variance for repeated measures

Database edition

The age of the animal ranged from 1 to 12 years. Seven categories were generated for the analysis: initial, animals ≤ 2 years of age; final, ≥ 8 years of age and intermediate (3, 4, 5, 6 and 7 years of age). Fleece weight at each shearing was adjusted to a mixed-model for repeated measures using the MIXED procedure (SAS, 2011), according to the following statistical model:

$$Y_{ijklmno} = \mu + G_i + E_j + S_k + A_l + T_m + GxE_{ij} + animal_n + e_{ijklmno}$$

Where: $Y_{ijklmno}$ is fleece weight (kg) of the n-th animal measured at the m-th shearing; μ is the overall mean; G_i is the fixed effect of i-th genetic group (i = Criollo, F1, Romney Marsh); E_j is the fixed effect of j-th age-class (j = 2, …, 8); S_k is the fixed effect of k-th gender (k = female, male); A_l is the fixed effect of l-th year in which shearing was performed (l = 1983, …, 1989); T_m is the fixed effect of m-th shearing (m = 1,…, 6); GxE_{ij} is the fixed effect of the genotype by age class interaction; $animal_n$ is the random effect of the n-th animal ~ niid($0,\sigma_a^2$); and $e_{ijklmno}$ is the random error ~ niid($0,\sigma_e^2$).

The animal was used as subject in the REPEATED statement of the model. Following a similar procedure as suggested by Littell et al. (2000), the model was adjusted to each of the following covariance structures: compound symmetry (CS), heterogeneous compound

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Table 1. Number of estimated parameters ((co)variances)) and information criteria generated by adjusting the analysis-of-variance model for repeated measures, considering different covariance structures.

Covariance structure	Number of parameter	Information criterion[1]		
		Δ (-2RLog L)	Δ (AIC)	Δ (BIC)
CS	2	63	25	0
CSH	7	35	7	1
AR(1)	2	86	48	23
ARH(1)	7	51	23	18
TOEP	6	52	22	13
TOEPH	11	22	2	12
UN	21	0	0	49

[1]Expressed as difference of the model that generated the lowest value of the respective information criterion; -2RLog L = -2 x Residual Log (Likelihood); AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; CS = Compound symmetry; CSH = Compound symmetry with heterogeneous variances; AR(1) = autoregressive type 1 (AR(1)); ARH(1) = Autoregressive type 1 with heterogeneous variances; TOEP= Toeplitz; TOEPH = Toeplitz with heterogeneous variances; UN = unstructured.

symmetry (HCS), autoregressive (Type 1 (AR(1)), heterogeneous AR(1), Toeplitz (TOEP), heterogeneous Toeplitz (TOEPH) and unstructured (UN). After fitting the model, Akaike information criterion (AIC), likelihood function (-2 LogResL) and Bayesian information criterion (BIC) generated by PROC MIXED (SAS, 2011) were used to select the covariance structure that generated the best model. Table 1 presents each information criterion, the differences with respect to the generated by the best model, as well as to the number of parameters (that is, variances and covariances) estimated by each model.

According to the Bayesian information criterion, the best adjustment was generated by including in the model a compound symmetry covariance structure (CS) or a heterogeneous compound symmetry (HCS) structure. However, the CS option was chosen because it involves the estimation of a smaller number of parameters. It must be highlighted that, either AIC as well as the -2ResLogL, showed the unstructured option, as best covariance structure, which is the one that requires the estimation of greater number of parameters. With these results, and using BIC, CS option was the most appropriate to be included in the final analysis of variance.

Once the covariance structure that generated the best adjustment was identified, the final model was adjusted and least squares means were calculated for the effects of genotype, age, gender, shearing year, shearing number and the genotype by animal's age-class interaction. Heterosis for fleece weight at shearing was calculated using the ESTIMATE statement in PROC MIXED (SAS, 2011), where the fixed effect of the genetic group was used to generate a contrast with the coefficients -0.5, 1.0 and -0.5 for Criollo, F1 and Romney Marsh genotypes, respectively; while the difference of the F1 group with respect to the Criollo animals, was estimated using the contrast 1, -1 and 0, respectively.

Analysis of variance using random regression

The information was also analyzed adjusting Legendre orthogonal polynomials with random regression, using PROC MIXED (SAS, 2011). In this case, all animal age records were used, with a range of 1 to 12 years. The fitted random regression model is:

$$y_{kml} = \sum_{i=0}^{a} G_l b_i P(x)_{kl}^{i} + \sum_{i=0}^{b} G_l \alpha_{im} P(x)_{kml}^{i} + e_{kml}$$

Where: y_{kml} is the *k-th* observation of the fleece weight at shearing, recorded in the *m-th* animal belonging to the *l-th* genotype; b_i are coefficients from the fixed regression for age at shearing (b_0 = intercept, b_1 = linear effect, b_2 = quadratic effect, and b_3 = cubic effect); α_{im} is the *i-th* random regression coefficient (α_{0m} = intercept, α_{1m}= linear effect, α_{2m}= quadratic effect, and α_{3m} = cubic effect) of the wool production curve per year of age, belonging to the *m-th* animal (m = 1,…, 368) of the *l-th* genotype (l = Criollo, F_1, Romney Marsh); x_{kml}^{i} is the *k-th* observation of age, standardized, at the moment of shearing, of the *m-th* animal, belonging to the *l-th* genotype, raised to the power of 0, 1, 2, or 3; e_{kml} is the error associated with the observation y_{kml}. The standardized unit of time (x) was the age of the animal at the moment of shearing, with a range of -1 to +1, and it was calculated using the following expression:

$$x = 2\left(\frac{t - t_{min}}{t_{max} - t_{min}}\right) - 1$$

Where: *t* is the age of the animal at the moment of shearing, t_{min} is the youngest age at which shearing was done, and t_{max} is the oldest age with a record of shearing. In this study, t_{min} was 1 and t_{max} was 12 years. According to Spiegel (1971), the first three Legendre polynomials for the standardized unit of time (*x*) were:

$$P(x)^0 = 1;$$
$$P(x)^1 = x; P(x)^2 = \frac{1}{2}(3x^2 - 1); P(x)^3 = \frac{1}{2}(5x^3 - 3x)$$

The adjustment of the random regression models was done following a similar procedure as suggested by Hanford (2005). The restricted maximum likelihood method was specified in the model statement. The specified covariance type for random effects was unstructured and the individual identification of the animal was used as subject in the RANDOM statement in PROC MIXED (SAS, 2011). In order to select the best-fitted model, different combinations of Legendre polynomials of degree were analyzed, either in the fixed part or in the random part of the regression model. BIC was used as comparison criterion; the best-fitted model consisted of a third degree polynomial in the fixed part of the random regression and a random intercept, as shown in the differences for BIC in Table 2.

Table 2. Number of estimated parameters ((co)variances)), estimated residual variance ($\hat{\sigma}_e^2$) and information criteria generated by adjusting different combinations of legendre polynomials in the fixed and random part of the random regression model, adjusted to information on fleece weight of Criollo, F_1 and Romney Marsh genotypes.

Fixed	Random	$\hat{\sigma}_e^2$	Number of parameters	Information criterion[1]		
				Δ (-2RLogL)	Δ (AIC)	Δ (BIC)
p_0	p_0	0.1511	2	247	239	225
p_0,p_1	p_0	0.1321	2	31	22	9
-	p_0,p_1	0.1367	4	30	23	14
p_0,p_1,p_2	p_0	0.1327	2	22	13	2
-	p_0,p_1	0.1299	4	19	12	3
-	p_0,p_1,p_2	0.1214	7	1	0	3
p_0,p_1,p_2,p_3	p_0	0.1329	2	24	16	0
-	p_0,p_1	0.1302	4	22	15	6
-	p_0,p_1,p_2	0.1202	7	1	0	2
-	p_0,p_1,p_2,p_3	0.1112	11	0	7	25

[1]Expressed as difference of the model that generated the lowest value of the respective information criterion; -2RLog L = -2 x Residual Log(Likelihood); AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion. p_i = Fixed or random regression coefficients on Legendre polynomials.

RESULTS

Repeated measures

Least squares means for the main effects are shown in Table 3. There were differences between the three genetic groups (P < 0.0001), being the estimate of heterosis calculated, with its standard error, for fleece weight of -0.1517±0.05435, P = 0.0055. This result showed that the average production of wool for crossbred animals, was below the average of the specialized breed individuals, but above Criollo animals 0.5159±0.05 (P < 0.0001). An effect of age was observed, being fleece production similar to the age of four (P > 0.05), decreasing after the age of five (P < 0.05), with males being 6.9% superior in fleece production per shearing than females (P = 0.037), while shearing number (P < 0.001) showed that the first three shearings were similar between them (P > 0.06), but different to the last shearings (P < 0.05). Finally, a fluctuation between the years of study is observed (P < 0.0001), being 1983 and 1986 the more productive years, and 1989 the less productive year. The means of genetic group by age-class interaction are depicted in Figure 1. Romney Marsh (specialized genetic group) decreased (P < 0.0001) fleece production over time (-1.047 kg), while F1 and Criollo groups decreased at a slower rate (-0.2997 and -0.112 kg, respectively).

Random regression

The estimates of the regression coefficients for a fixed Legendre polynomial of third order per genotype is shown in Table 4. The differences between genotypes were marked, for the information of F1 genetic group, the adjustment of an intercept (p_0) was enough, while for the Romney Marsh group, an intercept and a linear effect (p_0 and p_1) was required, and for the Criollo group, the adjustment of an intercept and linear, quadratic and cubic effects of the Legendre polynomial were needed (Table 4).

The adjusted curves per genetic group of animals are shown in Figure 2. Thicker lines are the curves per group representing the overall fixed regressions, while thinner lines represent the random regression of each individual animal in the population analyzed. The fitted overall fixed regression line for Romney Marsh is a thick continuous black line, for the F1 individuals it is a broken black line, and for the Criollo genotype it is a continuos grey line. The results showed that the Romney Marsh sheep group showed better performance for fleece production per shearing, the F1 group was intermediate and the Criollo group produced the lower amount of wool. While specialized breed animals produced greater quantity of fleece, these were more affected by the environmental effect of age, as it can be observed by the negative slopes, four times greater with respect to the crossbred group and 10 times more with respect to the Criollo animals. Conversely, there was longer stayability of the Criollo genotype in the flock, as shown by the records of shearing beyond 9 years of age, which was the level of the peak either for F1 or Romney Marsh animals (Figure 2).

DISCUSSION

The decrease in fleece production per shearing in Romney Marsh, was four and 10 times the amount with

Table 3. Least squares means of fleece weight (kg/animal/year) for the main effects of animal genotype, age class, gender and year of shearing.

Level	Mean±SE
Genotype	
Criollo	0.881±0.068[c]
F_1	1.397±0.069[b]
Romney Marsh	2.216±0.094[a]
Age (years)	
2	1.681±0.097[ab]
3	1.686±0.086[ab]
4	1.665±0.077[a]
5	1.454±0.073[c]
6	1.473±0.074[c]
7	1.335±0.086[cd]
8	1.194±0.103[d]
Gender	
Female	1.448±0.064[b]
Male	1.548±0.076[a]
Year	
1983	1.835±0.366[a]
1984	1.426±0.078[b]
1985	1.517±0.059[b]
1986	1.829±0.049[a]
1987	1.442±0.046[b]
1988	1.352±0.060[b]
1989	1.088±0.062[c]
Shearing	
1	1.353±0.080[a]
2	1.383±0.072[a]
3	1.405±0.073[a]
4	1.596±0.086[b]
5	1.606±0.113[b]
6	1.647±0.126[b]

[a,b,c,d] Means within the column and effect with different letter are different $p < 0.05$; Tukey.

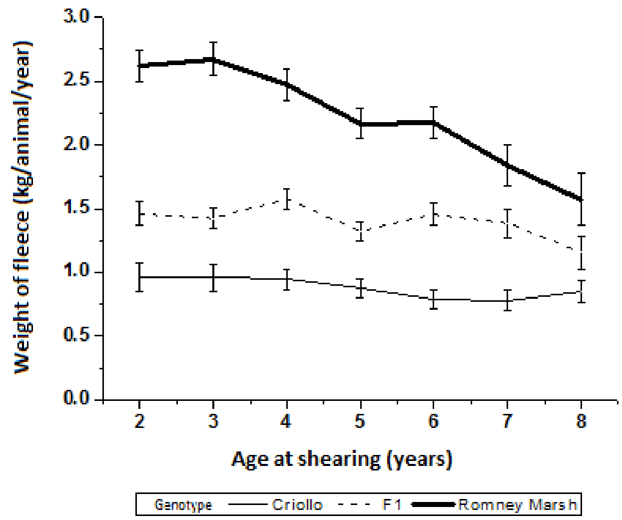


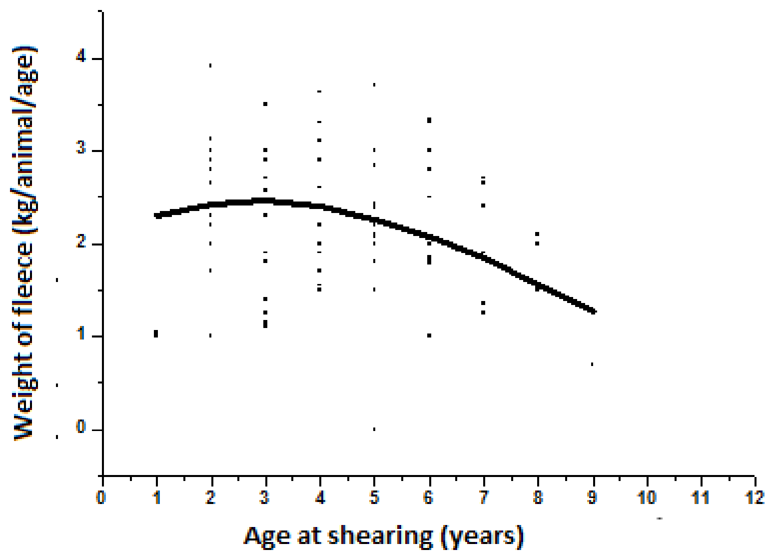
Figure 1. Least squares means for the interaction effect of age at shearing by animal genotype for fleece weight of different sheep genotypes.

Table 4. Estimates of the fixed regression coefficients on Legendre polynomials of the third order per genotype of the animal.

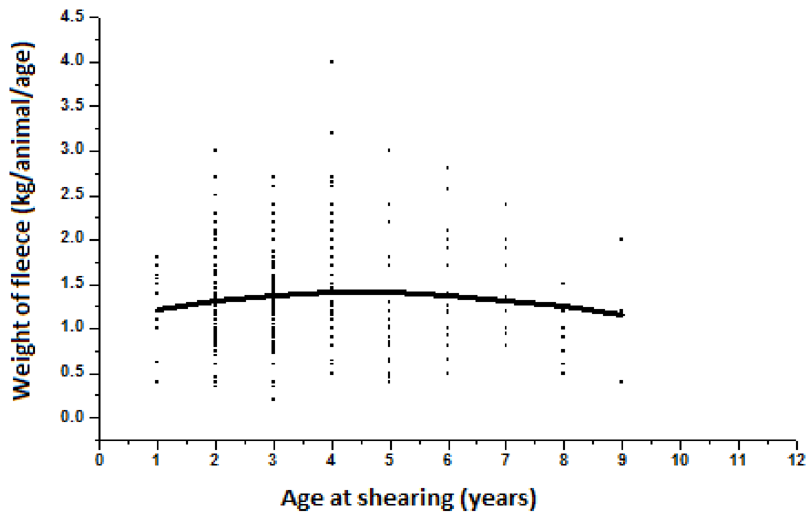
Parameter	Genotype	Estimate±SE	Pr > |t|
	Criollo	0.7404±0.028	<.0001
p_0	F_1	1.2358±0.198	<.0001
	Romney Marsh	1.7547±0.218	<.0001
	Criollo	-0.1179±0.056	0.0363
p_1	F_1	-0.252±0.458	0.5819
	Romney Marsh	-1.1007±0.526	0.0368
	Criollo	-0.164±0.057	0.0044
p_2	F_1	-0.2283±0.42	0.587
	Romney Marsh	-0.4249±0.568	0.4548
	Criollo	-0.1337±0.053	0.0124
p_3	F_1	0.0343±0.214	0.8724
	Romney Marsh	0.1408±0.358	0.6942

Likewise, the specialized breed and the crossbred group showed lesser permanence in the flock with respect to the Criollo group. There is information about poor adaptation of specialized breeds under conditions where Criollo animals have remained (Alderson et al., 1983) in Colombia and Peru (Burfening and Carpio, 1995) in). Similar to the Criollo sheep from the present study, now regarded as Chiapas Breed, that has its origins in the Spanish sheep breeds Churra, Manchega and Lacha (Mendez-Goméz et al., 2014) sheep from Chiloé´s Archipelago has its origins in the Spanish sheep breeds Churra and Castellana (De la Barra et al., 2011, 2014). Both, the Chiapas and the Chilota sheep breed are well adapted to local environmental conditions because of more than 400 years of natural selection in these respect to F1 and Criollo, respectively. This can be due to an effect of lesser adaptability of Romney Marsh breed. populations.

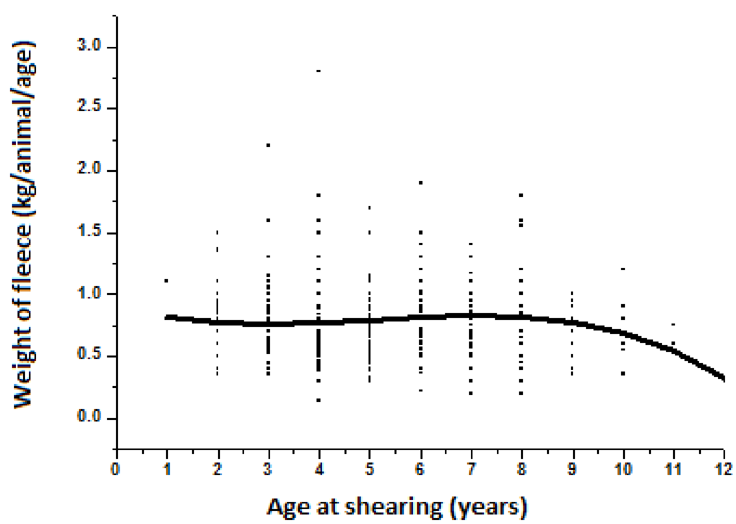
Martínez et al. (2012) showed that, under the agroecological conditions of the Chiloé archipelago, Chilota sheep breed evidenced a greater adaptation since, in the absence of management practices, it proved more productive and resistant than the Romney Marsh and Suffolk breeds. However, Kremer et al. (2010) in Uruguay did not find differences between breeds concerning respiratory diseases, mortality or longevity of the ewe, maybe because the environmental effect is not as severe.



Romney Marsh



Romney Marsh x Criollo



Criollo

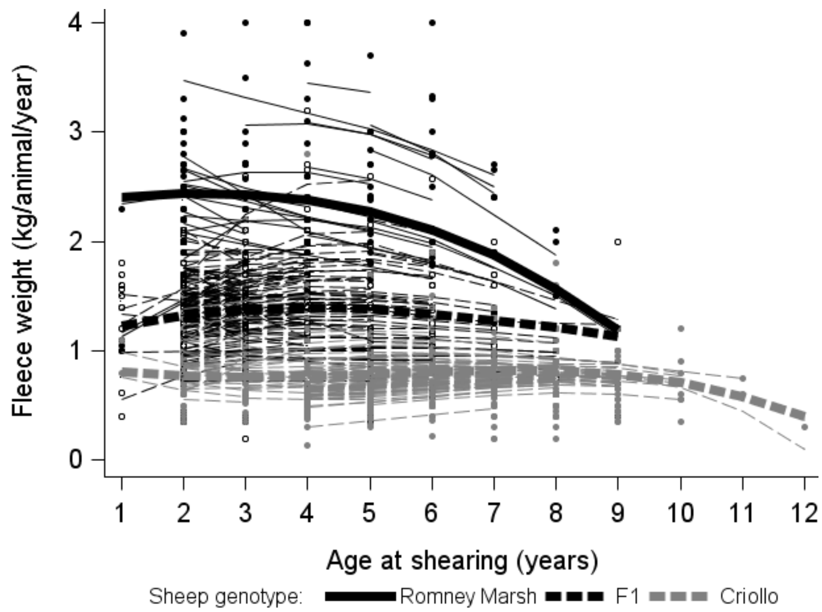


Figure 2. Scatter plot and fitted regression lines for fleece weight as function of the animal's age for Romney Marsh, F1 and Criollo sheep genotypes.

The specialized Romney Marsh breed showed higher performance in fleece production than the Criollo genetic group (+1.335 kg/ewe/shearing), while F1 was intermediate showing negative value of hybrid vigour (-0.15 ± 0.05), being negative heterosis of 9%. Malik and Singh (2006) found small and insignificant heterosis values in a study using 15 genetic groups, crossing Nali ewes with Russian Merino and Corriedale. While F1 did not exceed the average of their parents, local livestock production did increase. Negative heterosis can be a reflection of a greater additive effect of this trait and of the low averages in all the groups, as product of the environmental effect.

The mixed models of repeated measures and random regression are similar; however, the use of random regression and Legendre orthogonal polynomials enables model fleece production at any time of the productive life of the individual, as well as to estimate the interaction between heterosis and environment (Su et al., 2009). The environmental effects of year, age, gender and shearing number in the animal are sources of important variation on production traits; these results coincide with the literature of Hassen et al.(2004).

Conclusion

The results suggest that crossing Romney Marsh with Criollo ewes under extensive systems of management at the Altos de Chiapas is not as promising as improving fleece production, since they show faster wool production decrease with age and lower stay ability in the flock when compared with F1 and Criollo animals, probably due to poor adaptation. Criollo sheep produces fleece without much variability, which makes it an important animal resource that is necessary to preserve. Random regression models may adequately model fleece production throughout the sheep's life span.

ACKNOWLEDGEMENTS

Special thanks for financial support of projects UNAM-PAPIIT IN207707-3 and UNAM-PAPIIT IN205710-3. This research was possible thanks to the agreement between the Facultad de Medicina Veterinaria y Zootecnia of the Unversidad Nacional Autónoma de México and the Centro Universitario de Investigación y Transferencia de Tecnología of the Universidad Autónoma de Chiapas.

Conflict of Interests

The authors have not declared any conflict of interests.

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