A comparison of Criollo and Suffolk ewes for resistance to *Haemonchus contortus* during the periparturient period

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**ABSTRACT**

Criollo and Suffolk ewes were compared for resistance to an experimental infection with *Haemonchus contortus* in the periparturient period. Measures on days −28, −14, 0 (lambing date), 14, 28, and 42 were taken on number of eggs per gram of faeces (EPG), packed cell volume (PCV), blood eosinophil numbers (BEN), and body weight (BW) in 28 Criollo and 25 Suffolk ewes. One half of the ewes of each genotype was inoculated orally with 3000 L3 of *H. contortus* in a single dose. Phenotypic correlations between response variables were estimated. Criollo ewes had lower means than Suffolk ewes for EPG (570.7 ± 208.1 vs. 1363.9 ± 245.5) and BW (50.4 ± 1.2 vs. 81.0 ± 1.4 kg), and a higher mean for PCV (35.0 ± 0.6 vs. 32.7 ± 0.6%). BW of inoculated Criollo ewes increased from day −28 to day 42, while that of inoculated Suffolk ewes decreased. Non-inoculated Criollo and Suffolk ewes had slightly increased BW from day −28 to lambing date; after lambing, BW of inoculated Suffolk ewes decreased, while that of inoculated Criollo ewes increased. Birth type and lambing number affected (p < .05) EPG, PCV, and BW. Negative correlations were found (p < .01) between EPG and PCV with BW. Criollo ewes were more resistant than Suffolk ewes to *H. contortus*.

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**1. Introduction**

One of the gastrointestinal nematodes that adversely affects sheep production in many regions of the world is *Haemonchus contortus*. This nematode is a highly prolific blood-sucking parasite that causes anaemia, loss of appetite, poor feed conversion, undernutrition, and may cause death, depending on the severity of the infection (Saddiqi et al. 2011; Goldberg et al. 2012). For many years, control of gastrointestinal parasites has been made with anthelmintics, but its application has negative effects on the environment (Beynon 2012). Because anthelmintic resistance is found in some strains of *Haemonchus, Teladorsagia*, and *Trichostrongylus* (Papadopoulos 2008; Torres-Acosta et al. 2012), it has been proposed, as a strategy for their control, that the use of sheep breeds such as Florida Native, St. Croix, Blackbelly, Red Massai, and Gulf Coast Native, have been proved to resist their infections (Bishop & Morris 2007; Piedrafita et al. 2010), and breed differences in the number of nematode eggs in faeces and adult worm burdens have a genetic influence (Good et al. 2006).

During gestation and early lactation of ewes, an increase of nematode eggs in faeces, called ‘periparturient increase’ (PPi) is observed, which initiates the last weeks before lambing and reaches the peak between the sixth and eighth week post-lambing (Courtney et al. 1984; Goldberg et al. 2012). Factors that may influence PPI have been related to genotype (Rocha et al. 2011), gestation, lambing, lactation, climate, undernutrition (Goldberg et al. 2012), and hormonal changes (Beasley et al. 2010a), in addition to the individual capacity of the ewe to withstand the infection. Some studies (Courtney et al. 1984, 1985) have mentioned that sheep breeds which are resistant to gastrointestinal nematodes as lambs have confirmed this resistance as adults during the PPI; however, results have not been reported in Criollo sheep. Alba-Hurtado et al. (2010) found that Criollo lambs in Mexico were more resistant than Suffolk lambs when they were subjected to an experimental infection with *H. contortus*. Utilizing the same populations, objectives of this study were: (a) to compare Criollo and Suffolk ewes for resistance to *H. contortus* in the periparturient period, (b) to evaluate effects of environmental variables, and (c) to estimate phenotypic correlations between response variables.

**2. Materials and methods**

This study was conducted at the Sheep Unit of the Experimental Farm, Universidad Autónoma Chapingo (UACH), located in Chapingo, Ed. de México, Mexico, between the coordinates 19° 29′ N and 98° 53′ W, at an altitude of 2250 masl. The climate of this region is sub-humid temperate, with summer rains and drought in the winter, according to the Köppen classification system. Annual temperature and rainfall averages are 16°C and 644.8 mm, respectively (INEGI 2011).

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A total of 28 Criollo and 25 Suffolk ewes with 1 and 2 or more lamblings were randomly taken from the sheep flock established in 1995 at UACH, and since then they have not had access to grazing. Feeding was based on a commercial diet with 16% crude protein and corn silage that satisfied their nutritional requirements (NRC 2007). They had access to clean fresh water always.

Initially ewes were dewormed with commercial anthelmintics (Virbamec L. A., VIRBAC) and they were kept in total confinement always. One half of the ewes of each genotype received 3000 L3 larvae of H. contortus orally in a single dose 21 days before faeces samples were collected. Then four treatments were randomly assigned by breed to the ewes: (1) inoculated Criollo (IC), (2) non-inoculated Criollo (NIC), (3) inoculated Suffolk (IS), and (4) non-inoculated Suffolk (NIS). In days −28, −14, 0 (lambing date), 14, 28, and 42 rectal faeces samples were collected on the ewes and placed in plastic bags to determine the number of eggs per gram of faeces (EPG) by the McMaster technique (Whitlock 1948) to assess the resistance/susceptibility status between and within breeds of sheep, and it is also both a repeatable and heritable trait (Eady 1995). EPG was measured in this study because it can be used to assess the resistance/susceptibility status between and within breeds of sheep, and it is also both a repeatable and heritable trait (Eady 1995). PCV is another important trait that is positively correlated with weight gain and negatively correlated with EPG (Chauhan et al. 2003). BEN is frequently correlated with nematode infection (Dawkins et al. 1989), and it is also a heritable trait involving H. contortus infection (Davies et al. 2005). BW is an indicator trait that is commonly used for evaluating the resilience status (Woolaston & Baker 1996).

Response variables were EPG, PCV, BEN, and BW. The Shapiro–Wilk test for normality of PVC and BW was performed using the UNIVARIATE procedure (SAS 2006). EPG and BEN data were transformed by the logarithmic functions [Ln(EPG + 25)] and [Ln(BE + 1)], respectively, for the purpose of homogenizing the variance and approximate normality. Statistical analysis was performed using a mixed model with repeated measures (Littell et al. 1998), which included ewe genotype (G: Criollo, Suffolk), treatment (T: inoculated and non-inoculated), birth type of lamb (BT: single, twin), ewe lambing number (LN: primiparous, multiparous), measure day (MD: before lambing, after lambing), and measure day (MD: nested within MP) as fixed effects, first and second order interactions, and the random effect of ewe nested within genotype, in addition to the experimental error. Phenotypic correlations between the response variables were also estimated.

### 3. Results

#### 3.1. Effect of ewe genotype

Criollo ewes had lower means (p < .05) than Suffolk ewes in EPG and BW, but they had higher means (p < .05) in PCV (Table 1), even though PCV values were similar (p > .05) in the pre- and post-lambing periods. Both genotypes had maximum EPG values on day −14 (1121.2 vs. 2619.1, for Criollo and Suffolk ewes, respectively).

Both inoculated and non-inoculated Criollo ewes had lower (p < .05) means in EPG and BW than Suffolk ewes, but they had higher means (p < .05) in PCV and BEN than Suffolk ewes (Table 2). Means of inoculated Criollo and Suffolk ewes for EPG increased from day −28 to day 14 (where they peaked), and decreased thereafter until day 42; however, means of inoculated Criollo ewes were always lower (p < .05) than those of inoculated Suffolk ewes (Table 3). A similar pattern was found for non-inoculated Criollo and Suffolk ewes.

**Table 1.** Overall means (± standard error) of eggs per gram of faeces (EPG), packed cell volume (PCV), blood eosinophil numbers (BEN), and body weight (BW) of Criollo and Suffolk ewes.

|          | Criollo |                | Suffolk |                |
|----------|---------|----------------|---------|----------------|
|          | Inoculated | Non-inoculated | Inoculated | Non-inoculated |
| EPG      | 570.7 ± 208.1a | 350.0 ± 0.6a    | 1,363.9 ± 245.5b | 32.7 ± 2.4a     |
| PCV (%)  | 25.7 ± 2.4a | 32.7 ± 0.6b     | 28.8 ± 2.0a     | 81.0 ± 1.4b     |
| BEN      | 50.4 ± 1.2a | 50.4 ± 1.2a     | 81.0 ± 1.4b     | 50.4 ± 1.2a     |
| BW (kg)  | 1,165.0 ± 226.4a | 32.7 ± 0.6a    | 28.8 ± 2.0a     | 81.0 ± 1.4b     |

a,b: Means with different literals between columns differ (p < .05).

**Table 2.** Least-squares means (± standard error) of eggs per gram of faeces (EPG), packed cell volume (PCV), blood eosinophil numbers (BEN), and body weight (BW) of Criollo and Suffolk ewes, according to treatment.

|          | Criollo |                | Suffolk |                |
|----------|---------|----------------|---------|----------------|
|          | Inoculated | Non-inoculated | Inoculated | Non-inoculated |
| EPG      | 1,650.0 ± 226.4a | 32.7 ± 0.5a    | 28.0 ± 0.6c  | 39.2 ± 1.1d    |
| PCV (%)  | 23.7 ± 2.2a | 33.1 ± 3.9b    | 20.9 ± 2.6c  | 28.8 ± 4.6d    |
| BEN      | 50.2 ± 1.0a | 50.7 ± 1.7a    | 78.7 ± 1.1c  | 83.6 ± 2.0d    |
| BW (kg)  | 1,363.9 ± 245.5b | 32.7 ± 0.6a    | 32.7 ± 0.6b  | 32.7 ± 0.6b    |

a-d: Means with different literals between columns within genotype, differ (p < .05).
and showed a decreasing trend from lambing date to day 42. On the other hand, BW of non-inoculated Suffolk ewes remained constant (p > .05) between days −28 and 14, but showed a decrease between days 14 and 42.

Inoculated Criollo ewes had lower, higher, and lower means of EPG, PCV, and BW, respectively, than inoculated Suffolk ewes (Figure 1). Means of PCV for Criollo ewes were slightly higher than those for Suffolk ewes in both the pre- and post-lambing periods (Figure 2).

Means of EPG for both genotypes showed an increasing trend (p < .05) being roughly parallel from day −14 to day 14, and decreased gradually to day 42; however, except for day −28, means were always higher in Suffolk ewes (Figure 3). Except for lambing date, PCV means in Criollo ewes were higher than those for Suffolk ewes.

3.2. Effects of environmental factors

PCV and BEN values were higher (p < .05) in Suffolk ewes raising twin lambs than in Suffolk ewes raising singles (Table 6). Also, primiparous Criollo ewes were heavier (p < .05) than multiparous Criollo ewes (Table 6).

3.3. Phenotypic correlations

Phenotypic correlations (Table 7) between EPG and PCV were negative (ranging from −0.54 to −0.73, p < .01) on all dates. Except for days 0 (lambing date) and 42 (r = −0.29, p < .05), correlations between EPG and BEN did not differ from zero (p > .05). Negative correlations (ranging from −0.28 to −0.40, p < .01) were found between EPG and BW from day −14 to day 42. Correlations between PCV and BEN for most of the post-lambing period were negative (ranging from −0.29 to −0.48, p < .01). Except for days 0 (lambing date) and 14, correlations between PCV and BW were negative (ranging from −0.31 to −0.53, p < .01). Correlations between BEN and BW did not differ from zero (p > .05) on all dates.

4. Discussion

A maximum EPG value in other sheep breeds has been found in the range from 30 to 50 days post-infection (Williams et al. 2010; Rocha et al. 2011). Rocha et al. (2004) compared the susceptibility of Santa Inês and Ille de France sheep to infection of gastrointestinal nematodes in the periparturient period and found a PPI in both breeds, although Santa Inês ewes had a higher ability to withstand infection of infective larvae, a fact that can be attributed to the resistance of this breed of sheep to gastrointestinal nematodes (Zvinorova et al. 2016). It has been mentioned...
that the highest removal of eggs occurs after lambing. Williams et al. (2010) reported that between one week before and two weeks after lambing, the EPG mean in Merino sheep resistant to gastrointestinal nematodes was very low, while in a non-resistant control group, means increased exponentially between two and three weeks before lambing. It has been mentioned (Mahieu & Aumont 2007) that the periparturient relaxation of immunity is probably linked to the growing needs for energy and protein for growth of the foetus, as well as hormonal changes (Roy et al. 2003).

PCV means of this study are higher than those of other studies comparing Santa Inês to Ile de France ewes (Rocha et al. 2004) and St. Croix and Katahdin compared to crossbred Dorper ewes in the post-parturient period (Burke & Miller 2002). PCV is a useful indicator of gastrointestinal parasitism especially when the blood-sucking species is *H. contortus* (Gauly & Erhardt 2001). In addition, it has been said that PCV is higher in resistant than susceptible breeds to gastrointestinal parasites (Gray 1995). Higher levels of PCV have been found in resistant than susceptible sheep breeds when they have been infected with *H. contortus* (Mugambi et al. 1996; Amarante et al. 1999).

**Figure 2.** Packed cell volume (PCV) of Criollo and Suffolk ewes, according to measure period.

**Figure 3.** Number of eggs per gram of faeces (EPG) and packed cell volume (PCV) of Criollo and Suffolk ewes, according to measure date.

Burke and Miller (2002) found no differences (*p* > .05) among Dorper, Hampshire, and Katahdin crossbred ewes in EPG, but Hampshire ewes had lower means than hair sheep in PCV (*p* < .01), a result that might be due to the higher resistance of hair sheep to nematodes, compared to wool sheep (Gray 1995). In addition, Hampshire ewes consistently had higher (*p* < .01) BW than hair breeds. Hampshire sheep is also one of the largest sheep breeds that have been utilized for meat production (Shrestha & Vesely 1986).

EPG results regarding the measure period in this study are similar to other studies (Mahieu & Aumont 2007), indicating
Table 6. Least-squares means (± s.e.) of eggs per gram of faeces (EPG), packed cell volume (PCV), blood eosinophil numbers (BEN), and body weight (BW) of Criollo and Suffolk ewes, according to birth type and lambing number.

| Birth type | Criollo | | Suffolk | |
|------------|---------|------------|---------|------------|
|            | Singles | Twins      | Singles | Twins      |
| EPG (lamb) | 741.1 ± 255.9a | 424.04 ± 302.8a | 1604.9 ± 215.4c | 902.9 ± 436.1c |
| PCV (%)    | 34.6 ± 0.6a   | 35.3 ± 0.7a  | 31.6 ± 0.5c | 35.6 ± 1.3d |
| BEN        | 28.2 ± 2.5a   | 29.2 ± 2.9a  | 22.4 ± 2.1c | 27.4 ± 5.3a |
| BW (kg)    | 48.9 ± 1.1a   | 52.0 ± 1.3a  | 79.3 ± 0.9c | 82.9 ± 2.3c |

Table 7. Phenotypic correlation matrix among eggs per gram of faeces (EPG), packed cell volume (PCV), blood eosinophil numbers (BEN), and body weight (BW) of Criollo and Suffolk ewes according to measure day.

|       | EPG   | PCV    | BEN    | BW     |
|-------|-------|--------|--------|--------|
| -28   | 1.00  | -0.08 ns | -0.40** | 1.00   |
| EPG   | 1.00  | 1.00    | 0.23 ns | 1.00   |
| -14   | 1.00  | -0.56** | -0.36** | 1.00   |
| EPG   | 1.00  | -0.21 ns | -0.31* | 1.00   |
| PCV   | 0.05 ns | 1.00 | 1.00   | 1.00   |
| -0    | 1.00  | -0.38** | -0.11 ns | 1.00   |
| EPG   | 1.00  | -0.49** | -0.37** | 1.00   |
| PCV   | 0.17 ns | 1.00 | 1.00   | 1.00   |
| -14   | 1.00  | -0.29** | -0.28* | 1.00   |
| EPG   | 1.00  | -0.19 ns | -0.23 ns | 1.00   |
| PCV   | 0.14 ns | 1.00 | 1.00   | 1.00   |
| 28    | 1.00  | -0.73** | -0.40** | 1.00   |
| EPG   | 1.00  | -0.14 ns | -0.53* | 1.00   |
| PCV   | 0.14 ns | 1.00 | 1.00   | 1.00   |
| 42    | 1.00  | -0.69** | -0.35** | 1.00   |
| EPG   | 1.00  | -0.29** | -0.43** | 1.00   |
| PCV   | 0.48** | 1.00 | 1.00   | 1.00   |
| 0.25 ns | 1.00 | 1.00   | 1.00   |

*p < .05, **p < .01, ns: non-significant.

one lamb, a result that was found only in Suffolk ewes of our study. The authors of the Martink sheep study defined these sheep as resistant to gastrointestinal nematodes during the PPI due to the fact that only ewes with double or triple offspring required an anthelmintic deworming. The highest BW in primiparous Criollo ewes in the present study could be explained because it was observed that multiparous ewes gave birth to more twins than primiparous ewes, thus, their offspring required a higher demand for more nutrients during pregnancy and later during lactation, and consequently mobilizing more body reserves. This suggests that producers of Criollo sheep in Mexico should sacrifice twinning rate and try to select for a higher BW of ewes, since Criollo sheep are raised under rural semi-extensive conditions, where twinning rate is not fully justified due to an expected higher death rate. Mahieu and Aumont (2007) did not find a significant effect (p > .05) of ewe age (or lambing number) on EPG and PCV.

Correlations between EPG and PCV were negative throughout the experimental period, in agreement with results obtained by Chauhan et al. (2003) in goats and Rocha et al. (2004) in Ile de France ewes undergoing their fourth month of gestation. Correlations between EPG and BEN were mostly negative from day 0 (lambing date) up to day 42, also in agreement with Rocha et al. (2004), who obtained a correlation of −0.71 (p < .01) between these variables in the second month of lactation, and also with Davies et al. (2005) in Scottish Blackface lambs. Rocha et al. (2004) also obtained a correlation of −0.71 (p < .01) between EPG and BEN in Santa Inês and Ile de France ewes in their second month of lactation, a result also in agreement with our study, where the correlations between these variables were mostly negative from day 0 (lambing date) up to day 42. In Merino ewes, Beasley et al. (2010a) reported a correlation of −0.49 (p < .01) between the number of adult worms collected from the small intestine and BEN. Negative correlations were found between PCV and BW, a result that is contrary to that reported by Chauhan et al. (2003), who indicated a positive association between both traits. The failure to detect the real effect of these correlations probably can be attributed to the genetic dissimilarity between these two genotypes in BW; that is, results might have been different if correlations were calculated within genotype. Positive correlations were reported by Lôbo et al. (2009) between EPG with PCV and with BW, thus confirming that lambs with high EPG had a lower PCV during infestation and a higher EPG with a lower BW. The negative correlations between EPG with both PCV and BEN found in the present study suggest that indirect selection can be practised to increase PCV and BEN in order to decrease EPG in this population, since PCV and BEN are much easier to measure than EPG under field conditions, especially in terms of time, cost, and labour.

5. Conclusions and implications

Results of this study showed that Criollo ewes were more resistant than Suffolk ewes to an experimental infection with H.
contortus. Efforts should be made to keep finding sheep breeds (ewes and lambs) resistant to infections caused by gastrointestinal nematodes. Results of a study with adult Merino sheep and lambs in Uruguay (Goldberg et al. 2012) indicated that the correlated response when choosing by EPG in lambs was twice as efficient than direct selection by EPG in adult sheep, due to the highest heritability of the first method (0.25) in comparison to the second one (0.08). Our results indicate that a careful consideration should be given to Criollo sheep in México, especially in terms of management and conservation as a valuable local genetic resource to withstand nematode infections. Birth type in Suffolk ewes and lambing number in Criollo ewes are environmental factors that producers should take into consideration for management and genetic improvement purposes. It is suggested that sheep producers select for increased both PCV and BEN in order to reduce EPG in this population.

Disclosure statement
No potential conflict of interest was reported by the authors.

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