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Optimum timing for assessing phenotypic resistance against gastrointestinal nematodes in Pelibuey ewes

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Summary

The objective was to identify the optimal stage of production to evaluate the resistance of Pelibuey ewes against gastrointestinal nematodes (GIN). Faecal egg count (FEC) was used to classify the ewes as resistant, sensible or intermediate against GIN. Forty-seven ewes were mating during 30 d. The gestation was verified by ultrasonography, and the breeding date was used to calculate the productive stages. Faeces were taken weekly to determine the FEC. Blood samples were taken to determine the packed cell volume (PCV), the peripheral eosinophils count (PEC), plasma protein concentration (PP), and Immunoglobulin A (IgA) against *Haemonchus contortus*. The body condition score (BCS) was recorded at each visit. Six moments during the study (early, mid and late gestation; early, mid and late lactation) were considered. The ewes were classified according to FEC (mean FEC ± three standard errors). The higher FEC occurred during all lactation stages than during early and mid-gestation stages (P<0.05). PCV, PP, and BCS during early gestation stage were higher than shown during the lactation stages (P<0.01). The PEC and IgA were higher during all lactation stages than early and mid-gestation stages (P<0.05). Concerning the type of birth, double births showed higher FEC than single birth (P<0.01). The highest values of accuracy (100 %) and concordance (Youden's J = 1.0) were found during early lactation. Therefore, it is concluded that the optimal stage of production to evaluate phenotypic resistance against GIN infections in Pelibuey ewes was during the early lactation.

Keywords: Gestation; Lactation; FEC; PCV; Eosinophils; Pelibuey

Introduction

The major challenge for sheep producers in grazing production systems is the infections with gastrointestinal nematodes (GIN) (Mavrot *et al*., 2015; Notter *et al*., 2017; Ruano *et al*., 2019; Vasileiou *et al*., 2019). GIN can reduce the daily weight gain of growing animals by 40 % and milk production by 10 – 20 % (Vasileiou *et al*., 2019). Effective control of GIN with anthelmintic drugs is no longer possible (Torres-Acosta *et al*., 2012). There is evidence of strains of GIN resistant to all anthelmintic drugs on the market. Even against the monepantel recently introduced on the market (Van den Brom *et al*., 2015; Hamer *et al*., 2018). Nowadays, the targeted selective treatment scheme is the rational option to continue using anthelmintic in the farms (Aguirre-Serrano *et al*., 2020). Other alternative control strategies against GIN include vaccination, dietary supplementation (Mendes *et al*., 2018), second-

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ary plant metabolites, nematophagous fungi and the selection of GIN-resistant animals (Vilela *et al*., 2016). All the approaches could contribute to reducing the use of anthelmintic drugs. However, they are not yet widely used. The selection of resistant animals to GIN infections has been using phenotypic indicators or markers of predictive ability (Figueroa-Castillo *et al*., 2011; Notter *et al*., 2018). The fecal egg count (FEC) of GIN has been the primary marker (Oliveira *et al*., 2018). However, the packed cell volume (PCV), the FAMACHA©, the peripheral eosinophil count (PEC), and body condition score (BCS) have also been used to determine sheep resistance or susceptible to GIN infections (Saddiqi *et al*., 2012; Palomo-Couoh *et al*., 2016; Morgan *et al*., 2019).

The main hair sheep breeds raised in the tropics of Mexico are Blackbelly, Pelibuey, Dorper, and Katahdin (Zaragoza-Vera *et al*., 2019) due to their adaptation to environmental conditions (high temperature and humidity) and to the production systems based on grazing (Muñoz-Osorio *et al*., 2016). All of them has been evaluated in relation to resistance to GIN infections (Palomo-Couoh *et al*., 2016; 2017; Zaragoza-Vera *et al*., 2019; González-Garduño *et al*., 2021). Previous studies compared the mean FEC of GIN in ewes on different physiological stages (González-Garduño *et al*., 2014). However, the classification was conducted during stages of non-gestational, non-lactating (empty) adult ewes. In this regard, it has been postulated that the physiological stage (empty, gestation, lactation) may influence the resistance and resilience to GIN infections (Goldberg *et al*., 2012). Therefore, the objective of the present study was to identify the optimal stage of production to assess the resistance of grazing Pelibuey ewes against GIN infections using phenotypic markers during gestation and lactation period.

Materials and Methods

Location and date of the study

This study was conducted during the months of February to september 2021 at the Centre for Training and Reproduction of Minor Species (CECAREM) located in Villahermosa, Tabasco, Mexico (17º59'13" North latitude and 92º55'10" East longitude), with an altitude of 9 meters above sea level. The climate in the region is warm and humid, with an average temperature of 27 °C, relative humidity above 90 % and rainfall of 1,677.4 mm per year (CONAGUA, 2021).

Animals and design of the study

The study include forty-seven adult Pelibuey ewes with an average age of 3.4 ± 0.76 years, average body condition score of 3.1 ± 0.4 and average live weight of 49.4 ± 9.1 kg were included. The ewe feeding system was based on grazing of *Cynodon dactylon* (7.6 % crude protein) for eight hours and supplemented with commercial feed (500 g/day; 14 % crude protein).

According to the reproductive management of the farms, controlled breeding was carried out for 30 days; ewes were synchronized using "male effect" (Alavez-Ramírez *et al*., 2016). The gestation was confirmed by ultrasonography 30 days after the end of the breeding period. Only the pregnant ewes were included in the study. No anthelmintic treatment was performed three months previously to the breeding or during the period of the study. The variability of FEC of GIN of ewes was assessed throughout gestation and lactation until weaning their lambs at 70 days of age.

Collection of samples and measurements

The ewes were sampled weekly from the first week of gestation to the last week of weaning during the two physiological stages of evaluation (gestation and lactation). Five-ten grams of faeces were obtained directly from the rectum of each animal by means of polyethylene bags and were placed in coolers with ice for transport to the Tropical and Vector-Borne Diseases Laboratory, of the Juarez Autonomous University of Tabasco, Mexico. Samples were processed using the modified McMaster technique to determine the FEC (Rodríguez-Vivas & Cob-Galera, 2005) with sensitivity of 50 eggs/g^{-1}. The genera of GIN involved in the infections were determined by coprocultures performed fortnightly from a pool of feces during the gestation and lactation periods following the methodology described by Corticelli & Lai (1963), and the identification was made as described by Van Wyk & Mayhew (2013).

Blood samples were collected from each ewe by jugular vein venipuncture using tubes with EDTA (Vacutainer; BD Biosciences, Franklin Lakes, NJ, USA). Samples were used to determine the packed cell volume (PCV %), the number of eosinophils in peripheral blood (PEC, cells$10^3/\mu L$), the plasma protein concentration (PP, g/dL) and the level of Immunoglobulin A (OD % against a positive control) against *Haemonchus contortus* in plasma. The PCV was determined through a hematological analyzer (Medonic CA 620/530 Vet, Brand Boule Medical AB, Stockholm, Sweden). The PEC was calculated through Neubauer cameras using Carpentier's solution, following the methodology of Torres-Acosta (1999). The concentration of PP was determined by refractometry, and the level of IgA against *Haemonchus contortus* by indirect ELISA according to González-Garduño *et al*. (2018). Briefly, serum samples from each ewe were used to determine the level of antibodies against *H. contortus* using an indirect ELISA. A crude *H. contortus* extract was produced as described by (De la Chevrotière *et al*., 2012). The extract was diluted at the rate of 2.5 μg/ml in carbonate buffer (0.1 M sodium carbonate, 0.1 M sodium bicarbonate, pH 9.6). One hundred-microliter aliquots were added to respective wells in 96-well plates and were incubated at 4 °C overnight. After incubation, wells were washed three times with a PBS solution with 0.1 % Tween 20 (PBST). The non-specific binding sites were blocked and incubated for 1 h with skim milk (5 %). The wells were washed three times with PBST before the addition of sera from respective lambs. Subsequently, 100 μl of each working serum was diluted at 10 μl per ml of PBST, added to each well, and left to incubate at room temperature for 1 h. The plate was washed three times with PBST (5 min per wash). A 100-μl aliquot of the conjugate (1:5000 poly- clonal anti-IgA rabbit sheep) was added for each, and plates were incubated at room temperature for 1 h. Plates were washed three times with PBST and dried, and 50 µl of chromogen 3,3',5,5'-tetramethylbenzidine (TMB) was applied before incubation at room temperature for 15 min. After that time, the reaction was stopped by adding 50 µl of 1 M sulfuric acid and the optical density (OD) of each well was immediately determined (450 nm). Each plate contained three positive controls, three negative controls, and three blank controls. The negative control consisted of serum from a lamb raised free of *H. contortus* infections. The positive control was obtained from the serum of a lamb infected with *H. contortus*. The blank consisted of PBST solution. The OD results were recalculated to a percentage of the OD values of the positive reference serum (Kanobana *et al*., 2001).

During each visit to the CECAREM, the body condition (BCS) of each ewe was recorded using the Russel scale (1984).

The present study was approved by the Bioethics Committee of the Campus of Biological and Agricultural Sciences of the Autonomous University of Yucatan (CB-CCBA-D-2017-001). The samples were taken by expert Veterinarians according to the Mexican Official Standard guideline 051-Z00-1995 and the Mexican Official Standard to technical specifications for production, care and use of experimental animals.

Determination of phenotypic resistance during the physiological stages

The ewes were evaluated in the following period of gestation: early (1 – 4 weeks/February), mid (10 – 12 weeks/March) and late (20 – 21 weeks/June). During lactation period: early (1 – 3 weeks/July), mid (6 – 7 weeks/August) and late (9 – 11 weeks/September). For every stage, the mean and standard error (SE) of FEC were calculated. With these values, the cut-off point was determinate to classify ewes as susceptible to GIN (FEC values higher than mean + three SE), as resistant (FEC lower values than mean - three SE) and intermediate (FEC values between FEC > FEC - three SE and FEC < FEC + three SE) according to the methodology described by Morteo-Gómez *et al*. (2004).

Analysis of the variables evaluated in the ewe

Statistical analysis of the productive period early lactation was carried out using the GLM procedure (SAS, 2004). The FEC was transformed into the logarithm [Log (FEC +1)] to reduce the variance and bring the model closer to a normal distribution. The statistical model was as follows:

$Y_{ijkl} = \mu + \theta_i + \delta(\gamma)_{ij} + \zeta\,\delta(\gamma)_{ijk} + \varepsilon_{ijkl}$

Given that Y_{ijkl} = is the response variable (FEC, PCV), µ = Overall average, θ_i = Fixed effect type of birth (i=single, double), $\delta(\gamma)_{ij}$ = Nested effect of study period on productive stage (i = 1-4, 10-12, 20-21 in gestation and 1-3, 6-7, 9-11 in lactation), $\zeta\,\delta(\gamma)_{jk}$ = Effect of animal type (Susceptible, intermediate and resistant) in each study period nested in productive stage, ε_{ijkl} = Experimental error ~ IIDN (0, σ^2). The comparison of means of each evaluated group was carried out with Tukey's test.

In order to know the validity of each productive stage, the following were calculated: the concordance value (Youden's J), sensitivity, specificity, positive and negative predictive values, the proportion of false positives and false negatives and the accuracy (Palomo-Couoh *et al*., 2016).

With the FEC data of ewes resistant and not resistant a 2 x 2 table was constructed during the period of greatest FEC (early lactation) as a reference model and the periods in gestation and lactation was compared. In each period the ewes were determined as: a) True positives (TP): those resistant ewes that were resistant in the diagnostic stage of interest. False positives (FP): Ewes that were not resistant and were resistant in the evaluated diagnostic stage. True negatives (TN): non-resistant ewes that were negative (not resistant) in the diagnostic stage, and False negatives (FN): those resistant ewes that were negative (not resistant) in the diagnostic stage. With these data the Sensitivity = TP / (TP + FN), Specificity = TN / (FP + TN), Positive predictive value = TP / (TP + FP), Negative predictive value = TN / (FN + TN), Proportion of false positives = FP / (FP + TN) = 1 – Specificity, Proportion of false negatives = FN / (TP + FN) = 1 – Sensitivity, Accuracy = (TP + TN) / (TV + FP + FN + TN), Youden´s J Index (Diagnostic Safety) = Sensitivity + Specificity – 1.

Ethical Approval and/or Informed Consent

The Bioethics Committee of the Campus of Biological and Agricultural Sciences of the Autonomous University of Yucatan, Mexico, approved the present study for its development under authorization number CB-CCBA-D-2017-001.

Results

The least mean squares of FEC of GIN during the different productive stages evaluated varied considerably. The highest FEC (Mean ± SE) was registered in the early lactation stage (weeks 1 – 3 of lactation, 1573 ± 386.81 SE) and the lower FEC was found in the early gestation stage (weeks 1 – 4 of gestation, 32 ± 25.06 SE), as seen in Table 1.

The Figure 1 (n=47) shows the transformed values of FEC of GIN (Mean ± SE) according to ewe classification (susceptible, intermediate or resistant) during the different productive stages. In the productive stage early lactation, susceptible ewes had a mean FEC of 4369 ± 94.65 (21.73 % of the total ewe evaluated), the intermediate ewes group presented FEC of 1312 ± 33.86 (39.13 % of the total) and resistant ewes showed FEC of 353 ± 38.78 (39.13 % of the ewes evaluated).

The GIN genera identified from the larvae present in the coprocultures were *Haemonchus* spp (93.5 %), *Trichostrongylus* spp (2.5 %) and *Oesophagostomum* spp (4.0 %). Due to the high prevalence of *Haemonchus* spp during the study, the results over time are not reported.

Table 1. Predictive variables studied to identify resistance against GIN in pregnant and lactating Pelibuey ewes naturally infected during grazing under humid tropic conditions.

Reproductive stage	Weeks	N	FEC		PCV %		PEC cell $10^3/\mu l$		PP g/dL		IgA %		BCS	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Early		32.0	25.1 [c]	30.2	0.6 [b]	0.021	0.001 [d]	-	-	-	-	3.1	0.1 [a]
Gestation	Mid	47	166.9	71.4 [c]	34.2	0.7 [a]	0.023	0.001 [d]	7.00	0.08 [a]	-	-	3.0	0.0 [ab]
	Late		518.0	139.8 [b]	29.0	0.5 [bc]	0.428	0.033 [c]	6.86	0.07 [a]	10.4	1.1 [b]	3.0	0.0 [ab]
	Early		1572.8	386.6 [a]	27.9	0.6 [cd]	0.538	0.043 [c]	6.57	0.08 [b]	10.6	1.8 [b]	3.0	0.0 [ab]
Lactation	Mid	47	650.1	253.2 [b]	26.4	0.7 [de]	0.776	0.054 [b]	6.59	0.08 [b]	18.0	2.3 [a]	2.9	0.1 [b]
	Late		322.5	201.8 [c]	25.5	0.6 [c]	0.990	0.066 [a]	6.37	0.08 [b]	14.7	2.4 [a]	2.7	0.1 [c]

FEC: Fecal egg count; PCV: Packed Cell Volume; PEC: Peripheral Eosinophil Count; PP: Plasmatic Protein; IgA: Immunoglobulin A; BCS: Body Condition Score; SE: Standard Error. Different letter in the same column means statistical difference $P<0.05$; - values of PP and IgA not obtained in these periods.

Table 2. Predictive variables to classify Pelibuey ewes resistant against GIN according to the type of lambing under natural conditions of humid tropic of Mexico.

Variables	Single (n=20)			Double (n=27)		
	N	Mean	SE	N	Mean	SE
FEC	117	331	68 [b]	161	605	95 [a]
PCV %		30.3	0.4 [a]		28.0	0.4 [b]
PEC cell $10^3/\mu l$		0.491	0.045 [a]		0.437	0.035 [a]
PP g/dL		6.78	0.05 [a]		6.59	0.05 [b]
IgA %		15.2	1.4 [a]		12.0	1.0 [a]
BCS		3.0	0.0 [a]		3.0	0.0 [a]

FEC: Fecal egg count; PCV: Packed Cell Volume; PEC: Peripheral Eosinophil Count; PP: Plasmatic Protein; IgA: Immunoglobulin A; BCS: Body Condition Score; SE: Standard Error. Different letter in the same row means statistical difference $P<0.05$.

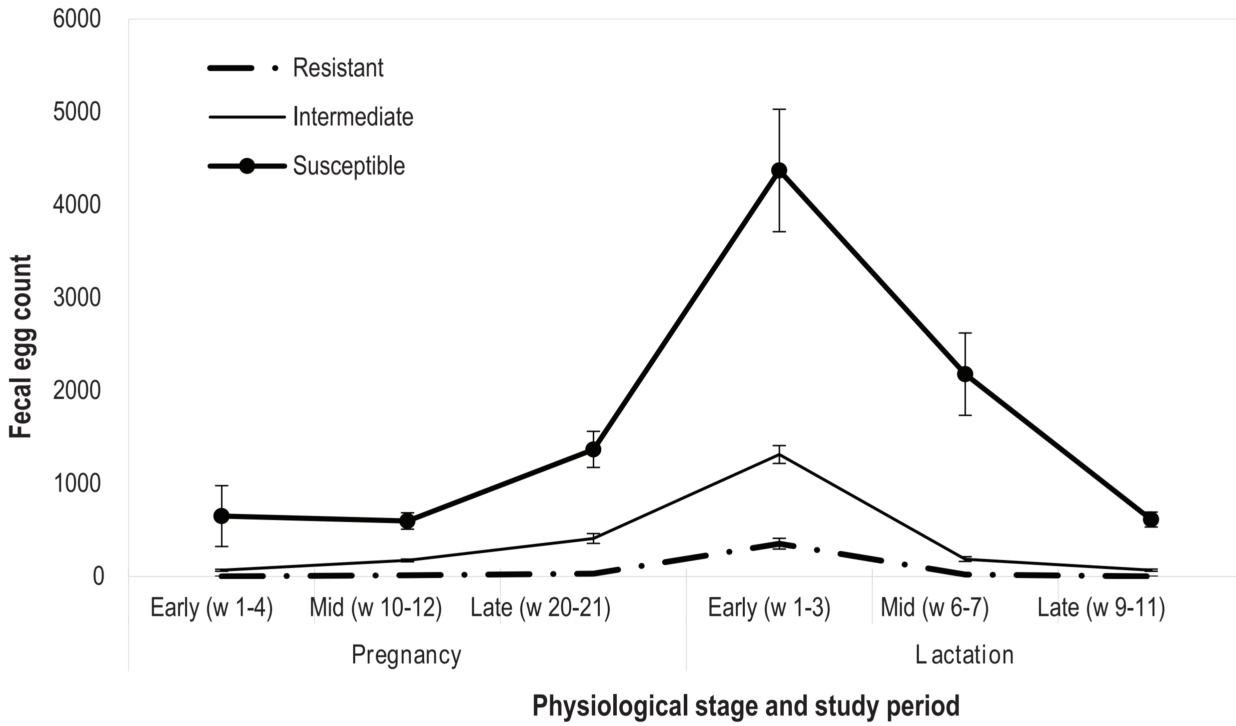

Fig. 1. Means and standard error of back transformed fecal egg count (FEC; mean ± SE) from Pelibuey ewes classified as resistant, intermediate, and susceptible to GIN infection during pregnancy (early, mid and late) and lactation stages (early, mid and late) during grazing in humid tropic conditions.

As can be seen in Table 1, PCV values decreased as the gestation and lactation periods progressed (P<0.05). Similar, PEC displayed a steady increase (P<0.05) during the study. PP levels decreased gradually as gestation progressed and showed lowest values during lactation periods (P<0.05).

IgA values showed differences according to the productive stage (late gestation-initial lactation and the rest of lactation) (P<0.05), highest values were obtained in mid and late lactation periods. A reduction in BCS was also evident during mid and late lactation periods (P<0.05).

About the type of birth, ewes with double birth showed higher means of FEC, PCV, and PP compared to single birth (P<0.05; Table 2). However, there were no differences to PEC, IGA, and BCS (P>0.05).

The results of concordance value (Youden's J), sensitivity, specificity, positive and negative predictive values, the proportion of false positives and false negatives, and the accuracy of values of each of the productive stages of evaluation to identify ewe susceptible or resistant to GIN infections are presented in Table 3. The higher sensitivity was observed in the gestation stage. However, specificity values showed a variation of 31 to 79 % and the predictive value of the positives showed a variation of 47 to 75 %. On the other hand, the early lactation stage was the reference model, and for this reason the values of sensitivity, specificity, predictive values of the positive and negative were 100 %. Unlike this stage, during the mean lactation, the sensitivity and predictive value of the negatives decreased as lactation progressed to the mid and late stages. The proportion of false positives ranged from 69 to 20 % during gestation with a gradual decrease reaching 0 % during early lactation. The proportion of false negatives was 0 % during the whole gestation and this value was maintained until the early lactation stage. Finally, the highest values of accuracy (100 %) and concordance (Youden's J = 1.0) were presented during early lactation.

Discussion

The selection of resistant sheep against GIN has been carried out mainly in lambs and to a lesser extent in adult ewes (González-Garduño *et al*., 2014; Palomo-Couoh *et al*., 2016, 2017). Typically, parasite loads in the humid tropics are high which leads to dismal health states and occasionally death of lambs (Jaimes-Rodríguez *et al*., 2019). Selection of both lambs and adult ewes in production is carried out in many sheep farms. The criteria used in lambs should not be used to select adult sheep, since they show resistance to GIN after repeated infections. Therefore, identifying the right moment of greatest sensitivity to infections would be a priority to select adult ewes.

The FEC has been the most used parameter to classify susceptible and resistant ewes to GIN infections (Bouix *et al*., 1998; Douch

Table 3 Sensitivity, specificity, predictive positive and negative values, the proportion of positive and false, accuracy and J of Youden (concordance) of Pelibuey ewes classified susceptible or resistant against GIN during early, mid and late pregnancy and lactation periods.

Variable	Pregnancy			Lactation		
	Early	Mid	Late	Early	Mid	Late
Sensitivity (Se)	100 %	100 %	100 %	100 %	94.4 %	72.2 %
Specificity (Sp)	31.0 %	75.9 %	79.3 %	100 %	100 %	100 %
Predictive Positive Value	47.4 %	72.0 %	75.0 %	100 %	100 %	100 %
Predictive Negative Value	100 %	100 %	100 %	100 %	96.7 %	85.3 %
Proportion of false positive	69.0 %	24.1 %	20.7 %	0 %	0.0 %	0 %
Proportion of false negative	0 %	0 %	0 %	0 %	5.6 %	27.8 %
Accuracy	57.4 %	85.1 %	87.2 %	100 %	97.9 %	89.4 %
Youden's J	0.3	0.8	0.8	1.0	0.9	0.7

The data were not transformed.

et al., 1996; Palomo-Couoh *et al*., 2016; Vineer *et al*., 2019; Aguerre *et al*., 2018;). This study shows that the productive stage (early, mid or late gestation or lactation) of the ewes influences the mean of FEC of GIN. Therefore, the productive stage should be considered at the time ewes are classified.

The variation on FEC showed along gestation to lactation stage is named "periparturient relaxation of immunity" (Gonzalez-Garduño *et al*. 2021). This phenomenon is attributed to the reduction in the immune response of ewes against GIN infections during the lactation period (Beasley *et al*., 2010) because the nutrients redirection to milk production to feed their lambs (Houjdijk *et al*., 2008). The highest FEC excretion observed during early lactation matches the reports of Tembely *et al*. (1998) and Vargas-Duarte *et al*. (2015) regarding ewes examined during the postpartum period. During early lactation stage, the FEC showed their highest value and a slight increase in IgA values was observed (Table 1). In the following stages (mid and late lactation), there was a negative correlation between FEC and IgA levels. It has been postulated that IgA migrate from the intestinal mucosa to the plasma, and then to the milk during early lactation as has been reported in ewes artificial infected with *O. circumcincta* (Jeffcoate *et al*., 1992). These authors suggested that IgA migration might lead to a temporary reduction of abomasal antibody levels in the ewe, allowing the establishment and development of larvae and consequently an increase in the FEC. However, in this study the negative correlation between FEC (decreased) and the IgA levels (increased) in the mid and late lactation periods suggest an increase in protective IgA antibodies days after controlling severe infection during early lactation.

On the other hand, it has been observed that progesterone inhibits the development of *H. contortus* by preventing the process of moulting from L_3 to L_4 (Gutiérrez-Amézquita *et al*., 2017). Previous studies have shown that when progesterone levels decrease towards the end of the gestation lead to the development of infective larvae in adults. Thus, the FEC increases in the late gestation stage reaching its highest peaks during early lactation.

Concerning the present study results, during early lactation, the high FEC influenced by nutritional, hormonal, and immunological factors described above showed this productive stage as a period in which the challenge caused by GIN infections is ideal to select ewes.

The low FEC showed during the productive gestation phase could be explained by the nutrients in the ewe that maintain their immune capacity and control their parasite burden (Gonzalez-Garduño *et al*., 2021). The effect of progesterone have been proposed as inhibitors of the development of *H. contortus* by preventing the process of moulting from L3 to L4 (Gutiérrez-Amézquita *et al*., 2017), as consequence, a reduction on the FEC would be observed. The low FEC elimination rate in the productive stage early and mid-gestation could incur classification errors because this low shedding of GIN eggs would be related to the physiological status of the ewes and not to a condition of resistance or susceptibility.

Data for PCV and PP indicate a decrease in these values when comparing gestation with lactation. These results indicate the pathological effects of GIN infections on susceptible sheep. These parameters had a tendency to decrease as the lactation period progressed, which is consistent with reports about Morada Nova and Santa Inés ewe in Brazil (Bezerra *et al*., 2017). The adult parasites burden during early lactation and reinfections during grazing could explain the humoral and cellular immunity levels found in the period (Henderson and Stear, 2006; González-Garduño *et al*., 2021).

Type of birth influences the FEC during early lactation (Aguirre-Serrano *et al*., 2020). It has been reported that lambs born from double births are more susceptible to GIN infections than lambs from single births (Idris *et al*., 2012; Notter *et al*., 2017, 2018). The increase of milk demands to feed more than one lamb implies increasing food requirements of the dam that are not easy to consume for the ewes during grazing. So, the sub nutrition in the ewes reduces the immune response capacity of the dam and explains the increase of FEC in this group of animals. Aguirre-Serrano *et al*. (2020) recently evaluated the effect of litter size on the percentage of dewormed ewes with FEC of GIN ≥ 1000 eggs per gram of feces. Ewes with two or three lambs had a higher rate of deworming than ewes with only one lamb. For this reason, different criteria should be used to classify ewes with single or double births within the farm. Litter size must be included in a mathematical prediction model, or the FEC evaluation should be in similar groups of litter size.

The concordance test performed in the present study showed that physiological stage to classify the ewes as resistant to GIN was the early lactation. The sensitivity, specificity, positive and negative predictive values, accuracy and the statistic of concordance Youden's J indicate that this stage is ideal for establishing ewe classification.

The evaluation of genetic resistance using molecular biology has contributed to identifying several genomic regions associated with decreased FEC. This suggests that parasite resistance involves a large number of genes contributing with small effects (Al Kalaldeh et al., 2019). Therefore, we consider that the proposed methodology in this study is currently more significant than molecular resistance due to involving different physiological stages and several field conditions that must be considered at the time of selection, instead of being limited to finding or not the presence of genes related to resistance. Moreover, we consider this methodology to be more easily applicable.

It is concluded that the optimal stage of production to evaluate phenotypic resistance against GIN infections in Pelibuey ewes was during the early lactation. This study demonstrated that during early lactation, the ewes showed the highest FEC of GIN. Low FEC of GIN during early and mid-gestation productive stages may lead to an erroneous selection of ewes that are not resistant to GIN. The number of lambs born and weaned is a factor that influences FEC independent from GIN resistance.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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