

Association Between Haematocrit, Estimated Haemoglobin, and Helminth Egg Shedding in Creole Cattle from Peru

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Article Details: Received: 2026-01-15 | Accepted: 2026-04-27 | Available online: 2026-09-30

<https://doi.org/10.15414/afz.2026.29.03.310-317>

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Gastrointestinal and hepatic parasites affect cattle worldwide, and their impact may vary with husbandry and biological factors. In high-Andean production systems, where exposure to infective stages is continuous, identifying subclinical alterations associated with parasitism is particularly relevant. This study aimed to evaluate the association between directly measured haematocrit (Hct), estimated haemoglobin (Hb), and eggs per gram of faeces (EPG) of *Fasciola hepatica* and gastrointestinal nematodes (GIN) in Creole cattle slaughtered in Cajamarca, Peru. Blood and faecal samples were collected from 50 animals. Hct was determined by microhaematocrit centrifugation, whereas Hb was estimated from Hct using a standard conversion factor. Faecal egg counts were performed using the natural sedimentation technique and flotation with saturated sodium chloride solutions. In the mutually exclusive diagnostic categories, haematological values of parasite-negative cattle ($n = 8$, 16%) were similar to those of cattle infected only with *F. hepatica* ($n = 20$, 40%), only with GIN ($n = 11$, 22%), or with mixed infection ($n = 11$, 22%) ($p > 0.05$). The GIN group exhibited slightly higher Hct/estimated Hb than the other two infected groups ($p < 0.05$). In *F. hepatica* infection, Hct/estimated Hb levels were similar between mild and moderate infections ($p = 0.731$). In contrast, in GIN infections, moderate infections showed values more than three units lower than those observed in mild infections ($p = 0.006$). EPG in animals positive for *F. hepatica* showed a moderate negative correlation with Hct/estimated Hb ($\rho = -0.464$; $p < 0.001$), whereas no significant correlation was observed between GIN EPG and Hct/estimated Hb ($\rho = 0.120$; $p = 0.406$). In conclusion, although the infections occurred without marked alterations, patent fasciolosis was moderately associated with lower Hct/estimated Hb. However, this association should be interpreted as observational and limited to the low-to-moderate egg-shedding range evaluated.

Keywords: *Bos taurus*, haematology, internal parasite, nematode, trematode

1 Introduction

Creole cattle constitute a central component of family-based agriculture in rural Andean areas. Their hardiness, capacity to adapt to high-altitude environments, and efficiency in utilising low-quality forage render them a strategic resource for food security and local economies (Núñez-Domínguez et al., 2016). In the Peruvian highlands, these animals are predominantly managed by smallholders under extensive grazing systems based on natural pastures, frequently with tethering practices, and they fulfil multiple roles, including meat and milk production as well as draught power for ploughing and crop sowing (Delgado & García, 2018). This production context is relevant because repeated exposure to contaminated pastures and moist grazing areas may

influence helminth transmission and the interpretation of subclinical haematological responses.

Among the health-related factors affecting cattle in extensive systems, gastrointestinal parasitoses are particularly relevant owing to their high prevalence and the economic losses they entail (Charlier et al., 2020; Strydom et al., 2023). Parasitic infections reduce feed efficiency, impair weight gain, and may trigger severe clinical conditions in young or stressed animals (Charlier et al., 2020; Strydom et al., 2023). Their predominantly subclinical nature favours the persistence of chronic infections and hampers early detection, thereby contributing to an underestimation of their true impact on productive performance (Rashid et al., 2019). Consequently, epidemiological and physiological

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monitoring of these infections constitutes a key component of health management in small and medium-scale cattle production systems.

The most frequently reported gastrointestinal nematodes (GIN) in cattle include genera such as *Haemonchus*, *Ostertagia*, *Cooperia*, *Trichostrongylus*, among others, which induce variable haematological and metabolic disturbances depending on parasite burden, pathogenicity, and the nutritional status of the host (Cheptoo et al., 2025; González-Garduño et al., 2026; Sabatini et al., 2023). In parallel, *F. hepatica* is endemic across large areas of the Andean region of Peru, a distribution favoured by agroecological conditions suitable for the survival of its intermediate host (Arias-Pacheco et al., 2020; Zárate-Rendón et al., 2023). Parasite co-infections are common and may potentiate adverse effects on host physiological homeostasis, particularly in cases of mixed infection.

Haematological parameters, particularly haematocrit and haemoglobin concentration, are sensitive indicators of erythropoietic status and of the balance between erythrocyte production and loss. In veterinary medicine, their use as indirect markers of parasitism is well established, especially in infections caused by haematophagous helminths or in conditions associated with chronic blood loss or inflammatory anaemia (Malede et al., 2025; Ullah et al., 2025). In Creole cattle raised in the Andean region of Peru, the haematocrit value was $45.9 \pm 0.5\%$ and haemoglobin $12.9 \pm 0.2 \text{ g}\cdot\text{dL}^{-1}$ (Gonzales et al., 2020), although these parameters may be altered in the presence of parasite infections that disrupt erythropoiesis or increase erythrocyte destruction.

Despite the sanitary and productive importance of these infections, evidence directly linking the level of GIN and *F. hepatica* infection with variations in Hct and Hb in Creole cattle from Cajamarca remains scarce. Given that these animals exhibit particular physiological and adaptive traits (Delgado & García, 2018), the generation of local data is essential to better understand their haematological responses to parasitism. In this context, this study aimed to evaluate directly measured Hct and estimated Hb values across mutually exclusive parasitological diagnostic categories and to determine the parasite-specific association between these haematological indicators and EPG of *F. hepatica* and GIN in Creole cattle slaughtered in Cajamarca, Peru.

2 Material and Methods

2.1 Study Site

The study was conducted in the city of Cajamarca. Faecal and blood samples were collected from Creole cattle slaughtered at the municipal abattoir of the city. Laboratory analyses were performed at the facilities of the Faculty of

Veterinary Sciences (FVS), National University of Cajamarca, Peru.

The sampled animals corresponded to phenotypically heterogeneous Creole cattle presented for slaughter at the municipal abattoir. Phenotypic information was retained only as contextual evidence of the local Creole cattle population evaluated and was not used as an analytical variable in the present study (Figure 1).

Cajamarca is located in the northern highlands of Peru, at approximately 2,700–2,750 m above sea level. The local climate is temperate to cool, with marked daily thermal variation and a seasonal rainfall pattern. Mean annual temperature is approximately 12–14 °C, with daytime temperatures commonly ranging between 18 and 22 °C and lower night-time temperatures. Relative humidity is usually moderate to high, particularly during the rainy season. Rainfall is concentrated mainly between October and April, whereas the dry season extends from May to September. These seasonal conditions favour the persistence of moist grazing areas and temporary water bodies, which may support the development of free-living stages



Figure 1 Phenotype of Creole cattle at the facilities of the municipal abattoir of Cajamarca, Peru

of gastrointestinal nematodes and the intermediate snail hosts involved in the transmission of *F. hepatica*. The predominant soils in the surrounding livestock areas are Andean agricultural soils with variable clay-loam texture and moderate water retention, especially in irrigated or poorly drained pastures. The photoperiod is relatively stable throughout the year because of the tropical latitude, with approximately 11.5–12.5 h of daylight (SENAMHI, 2025).

2.2 Sample Size

The sample size was calculated a priori using the formula for comparison of two independent means (Kim, 2016), in order to detect a clinically relevant difference of 2 g·dL⁻¹ in estimated haemoglobin concentration between two broad comparison groups representing lower and higher expected haematological contrast, with a 95% confidence level and 80% statistical power. An intermediate standard deviation of haemoglobin of 1.8 g·dL⁻¹, reported for Creole cattle from the Peruvian highlands, was assumed (Gonzales et al., 2020). This calculation was used to guide recruitment in an exploratory field study and was not intended to define the final inferential structure as a balanced four-group design.

The final analytical categories reflected the epidemiological distribution observed at the abattoir and were therefore unequal in size. Moderate infection, defined by EPG intensity, and mixed infection, defined by co-detection of *F. hepatica* and GIN eggs, were treated as biologically distinct dimensions and were not interpreted as a single comparator. Consequently, multigroup and subgroup analyses were interpreted cautiously, particularly where cell sizes were small.

2.3 Sample Collection and Processing

At the abattoir facilities, 3 mL of blood was collected from each animal by coccygeal venepuncture into 5 mL vacuum tubes containing anticoagulant (K₂-EDTA). Samples were transported to the Veterinary Physiology Laboratory of the FVS.

Haematocrit percentage (Hct, %) was determined using the microhaematocrit centrifugation method. Haemoglobin concentration (Hb) was not measured independently; it was estimated from Hct using the factor 0.334, according to the formula $Hb\text{ (g·dL}^{-1}\text{)} = Hct\% \times 0.334$ (Wennecke, 2004). Therefore, Hb was retained as a clinically familiar derived descriptor, whereas inferential interpretation was based primarily on Hct. Because Hb was mathematically derived from Hct, statistical significance was necessarily identical for both parameters and should not be interpreted as an independent analytical outcome.

Simultaneously with blood collection, approximately 100 g of faeces were obtained directly from the rectum by manual stimulation of the anal sphincter and placed in appropriately labelled polyethylene bags. Samples were transported to the laboratory in expanded polystyrene boxes, where the corresponding analyses were performed.

Diagnosis and egg count of *F. hepatica* were carried out using the natural sedimentation technique according to the protocol validated by Rojas-Moncada et al. (2024). Gastrointestinal nematode egg counts were determined as standard EPG values using a conventional McMaster chamber after concentration flotation with saturated sodium chloride solution (Willis, 1921). The minimum detectable count of the McMaster procedure was 50 EPG. All parasitological analyses were conducted at the Veterinary Parasitology Laboratory of the FVS-UNC.

Infection intensity was classified descriptively according to the EPG thresholds proposed by Ueno & Gonçalves (1998) for cattle. These thresholds were used to organise parasitological categories and were not intended to predict haematocrit or haemoglobin changes directly. For *F. hepatica*, the specific thresholds proposed for this trematode were used: mild infection at approximately 10 EPG, moderate infection at 10–25 EPG, and heavy infection at 25–50 EPG. For gastrointestinal nematodes, because species-level identification was not performed, EPG values were interpreted using the mixed-infection criteria for cattle proposed by Ueno & Gonçalves (1998), in which 200–700 EPG corresponds to moderate infection and 700 EPG or higher corresponds to heavy infection. Egg counts below 200 EPG were interpreted as low-level GIN egg shedding rather than as a formal mild category under the mixed-infection criteria. Mixed infection in this study was defined as the simultaneous detection of *F. hepatica* and GIN eggs in the same animal. *F. hepatica* and GIN egg counts were interpreted separately and were not summed as a single combined EPG value. Throughout the manuscript, EPG was interpreted as an indicator of egg shedding rather than as a direct measure of adult worm burden, blood loss, or mechanistic pathogenicity.

The study was approved by the Faculty of Veterinary Sciences (FVS), National University of Cajamarca, Peru: Resolution No. 006-2026-FCV-UNC.

2.4 Statistical Analysis

Data were organised in MS Excel 2021 and subsequently analysed using SPSS Statistics v27 (IBM Corporation, USA). Normality of model residuals was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated with Levene's test.

Comparisons of mean Hct and estimated Hb values among groups (negative, *F. hepatica*, GIN, and mixed infection) were performed using one-way analysis of variance (ANOVA). After verification of residual normality and homogeneity of variances ($p > 0.05$), Duncan's post hoc test was applied for multiple comparisons among all groups. Additionally, Dunnett's test was used to compare each infected group with the parasite-negative groups.

Within-category comparisons of infection intensity were conducted using the independent-samples *t*-test when equality of variances was assumed (Levene $p > 0.05$) and Welch's *t*-test when heterogeneity of variances was detected (Levene $p < 0.05$). In addition to categorical comparisons based on established EPG thresholds, parasite EPG was analysed as a continuous variable using Spearman's rank correlation coefficient according to parasite-specific positivity. For this analysis, all cattle with detectable *F. hepatica* eggs were included in the *F. hepatica* correlation, regardless of whether infection was single or mixed. Similarly, all cattle with detectable GIN eggs were included in the GIN correlation, regardless of whether infection was single or mixed. Mixed infection was not analysed as a combined EPG variable because *F. hepatica* and GIN egg counts are not biologically equivalent and should not be summed as a single parasite-burden measure.

The frequencies of animals among the parasitological diagnostic categories (negative, *F. hepatica*, GIN, and mixed infection) were compared using Pearson's chi-square test.

3 Results and Discussion

Of the 50 Creole cattle evaluated, the highest proportion was infected with *F. hepatica* (40%), followed by GIN (22%) and mixed infection with GIN and *F. hepatica* (22%). Sixteen per cent of the animals were parasite-negative. The frequencies across diagnostic categories did not differ significantly, as assessed by Pearson's chi-square test ($p = 0.090$).

Hct and estimated Hb values varied according to diagnostic category. Animals with mixed infection exhibited the lowest mean Hct/estimated Hb values. However, these did not differ statistically from the parasite-negative group or from animals infected with *F. hepatica* ($p > 0.05$). Cattle infected exclusively with GIN showed higher Hct/estimated Hb values, exceeding those observed in the *F. hepatica* and mixed-infection groups ($p < 0.05$), but did not differ from parasite-negative animals ($p > 0.05$) (Table 1).

When infection level was compared within each group, only cattle infected with GIN showed significant

Table 1 Percentage of animals by parasitological diagnostic category and haematocrit (Hct) and haemoglobin (Hb) values in Creole cattle slaughtered in Cajamarca, Peru ($n = 50$)

Category	<i>n</i> (%)	Hct (%)		Hb (g·dL ⁻¹)		CV (%)
		mean ±SD	range	mean ±SD	range	
Negatives	8 (16%)	32.84 ±3.43 ^{ab}	26–39	10.97 ±1.15 ^{ab}	8.68–13.03	10.44
<i>F. hepatica</i>	20 (40%)	31.88 ±4.00 ^a	24–39	10.65 ±1.34 ^a	8.02–13.03	12.54
Nematodes	11 (22%)	34.90 ±2.24 ^b	30–39	11.66 ±0.75 ^b	10.02–13.03	6.42
Mixed	11 (22%)	31.51 ±3.29 ^a	24–36	10.53 ±1.10 ^a	8.02–12.02	10.43

ab – different superscript letters within the same column indicate statistically significant differences ($p < 0.05$; one-way ANOVA, Duncan post hoc test); SD – standard deviation; CV – coefficient of variation; the CV was identical for Hct and Hb because Hb was estimated from Hct using a constant

Table 2 Haematocrit (Hct) and haemoglobin (Hb) estimated values according to parasite-specific infection in Creole cattle slaughtered in Cajamarca, Peru ($n = 50$)

Infection	Range EPG (level)	<i>n</i> (%)	Hct (%) / Hb (g·dL ⁻¹)**	
			mean ±SD	<i>p</i> -value
Negative	–	8 (16%)	32.84 ±3.43 / 10.97 ±1.15 ^a	na
<i>F. hepatica</i> ($n = 20$)	2–10 (mild)	15 (30%)	31.83 ±4.04 / 10.63 ±1.35 ^a	0.731 ^t
	12–16 (moderate)	5 (10%)	31.23 ±2.37 / 10.43 ±0.79 ^a	
Nematodes ($n = 11$)	50–150 (low-level)	5 (10%)	36.90 ±1.52 / 12.32 ±0.51 ^a	0.006 [*]
	250–400 (moderate)	6 (12%)	33.80 ±1.40 / 11.29 ±0.47 ^a	
Mixed ($n = 11$)	<i>F. hepatica</i> -positive and GIN-positive	11 (22%)	31.51 ±3.29 / 10.53 ±1.10 ^a	na

a – identical superscript letter indicates the absence of statistically significant differences between groups (one-way ANOVA, $p = 0.017$, Dunnett post hoc test, $p > 0.05$); *significant at $p < 0.05$ (Welch's *t*-test); ^t – Student's *t*-test; **as – Hb was derived from Hct using a constant, statistical significance was identical for both parameters; na – not applicable; mixed infection was defined as the simultaneous detection of *F. hepatica* and GIN eggs; a combined EPG value was not used because egg counts from *F. hepatica* and GIN are not directly equivalent

differences between low-level and moderate egg shedding ($p = 0.006$). When Hct and estimated Hb values of each infected group were compared with those of the parasite-negative group, no significant differences were observed ($p > 0.05$) (Table 2).

For the graphical and correlation analyses, parasite-specific positivity was considered. Thus, the *F. hepatica* panel included all cattle with detectable *F. hepatica* eggs, including animals with single *F. hepatica* infection and those with mixed infection ($n = 31$). The gastrointestinal nematode panel included all cattle with detectable GIN eggs, including animals with single GIN infection and those with mixed infection ($n = 22$). Mixed infection was not analysed as a combined EPG variable because *F. hepatica* and GIN egg counts are not biologically equivalent and should not be summed as a single parasite-burden measure. Therefore, the sample sizes in Figure 2 differ from the mutually exclusive diagnostic categories reported in Tables 1 and 2. The scatterplots are presented as a descriptive visualisation of the non-parametric Spearman analyses and do not include fitted linear regression equations.

In accordance with Spearman's correlation coefficient ($\rho = -0.464$; $p < 0.001$), *F. hepatica* EPG showed a moderate inverse association with Hct/estimated Hb values among *F. hepatica*-positive cattle. This association should be interpreted cautiously because the correlation was moderate and the sample size was limited, indicating an associative pattern rather than evidence of a strong or mechanistically established erythroid effect.

In contrast, GIN EPG was not significantly correlated with Hct/estimated Hb values according to Spearman's analysis ($\rho = 0.120$; $p = 0.406$). These results suggest that, under the conditions evaluated, GIN egg shedding was not detectably associated with Hct-derived values in this dataset (Figure 2).

In Creole cattle slaughtered in Cajamarca, infections with *F. hepatica* and GIN were associated with mild alterations, predominantly subclinical haematological variation. Fasciolosis was the most common condition and showed a moderate inverse correlation between EPG and Hct/estimated Hb values. GIN EPG was not significantly correlated with Hct/estimated Hb values, although cattle with exclusive GIN infection showed lower Hct-derived values in moderate infections than in low-level egg shedding ($p < 0.05$). As a mutually exclusive diagnostic category, mixed infection exhibited the lowest mean Hct/estimated Hb values, but these differences were not significant compared with parasite-negative cattle. This finding should be interpreted at the diagnostic-group level rather than as evidence of an additive quantitative effect of *F. hepatica* and GIN egg counts, because EPG values from both parasite groups are not directly equivalent.

The higher frequency of *F. hepatica* observed in the present study is consistent with the endemic status described for high-Andean regions of Peru, where the ecological and agroclimatic conditions favour the maintenance of transmission cycles involving the intermediate snail host (Arias-Pacheco et al., 2020; Claxton et al., 1998; Zárate-Rendón et al., 2023). Similar epidemiological patterns have been described in areas with irrigated or poorly drained pastures, where cattle may be repeatedly exposed to infective stages of the parasite. Therefore, the predominance of fasciolosis in the sampled animals is consistent with the epidemiological context of Cajamarca, although the abattoir-based nature of the study limits direct inference about farm-level prevalence or seasonal transmission dynamics.

Although no significant differences were detected between parasite-negative cattle and infected diagnostic categories, the inverse association between

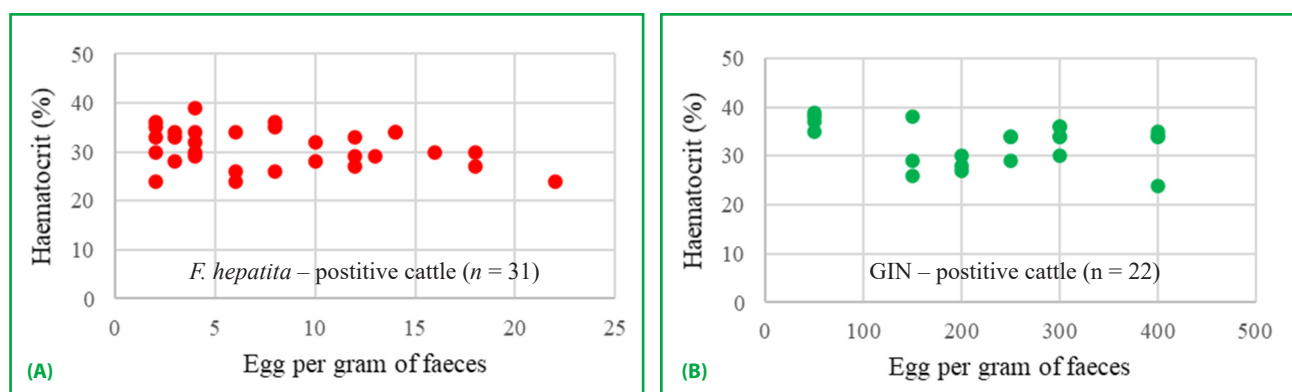


Figure 2 Relationship between haematocrit and parasite egg counts in Creole cattle from Cajamarca, Peru (A) *F. hepatica*-positive cattle, including animals with single *F. hepatica* infection and mixed infection ($n = 31$); (B) gastrointestinal nematode-positive cattle, including animals with single GIN infection and mixed infection ($n = 22$); the panel is a descriptive scatterplot corresponding to the Spearman correlation analysis; no linear regression model was fitted

F. hepatica EPG and Hct/estimated Hb values suggests that higher egg shedding may be accompanied by a modest reduction in erythroid parameters. This interpretation agrees with the recognised subclinical but production-relevant impact of fasciolosis and other helminth infections in ruminants, in which physiological effects may occur without overt clinical disease (Charlier et al., 2020; Rashid et al., 2019). However, EPG reflects only patent infection and does not capture the early migratory phase of *F. hepatica*, during which hepatic tissue damage may occur before eggs are detectable in faeces. Consequently, the present results should be interpreted as an association between egg shedding and haematological values rather than as a complete measure of parasite-induced erythroid impairment.

In cattle infected exclusively with GIN, Hct-derived values were higher than those observed in the fasciolosis and mixed-infection groups, although values were lower in cattle with moderate GIN egg shedding than in those with low-level shedding. This differs from the expected pattern in infections dominated by highly haematophagous nematodes, where stronger reductions in erythroid indicators may occur, but is compatible with the variable pathogenicity of GIN infections in cattle (Charlier et al., 2020; Sabatini et al., 2023). A possible explanation is that the GIN infections detected in this study may have involved parasite burdens or nematode genera with limited haematological expression. However, because larval culture or molecular identification was not performed, genus-specific pathogenicity cannot be inferred, and the findings should be interpreted only at the broader parasite-group level.

The mixed-infection group exhibited the lowest mean Hct-derived values, but these differences were not statistically significant when compared with parasite-negative cattle. This finding does not provide sufficient evidence for an additive quantitative effect of *F. hepatica* and GIN egg counts, particularly because egg counts from trematodes and nematodes are not biologically equivalent and should not be summed as a single parasite-burden measure. The most cautious interpretation is that the lower mean values observed in mixed infection may reflect the low to moderate parasite burdens detected, the limited subgroup size and the heterogeneity inherent to naturally infected abattoir animals, rather than compensatory physiology, adaptive tolerance or confirmed interspecific parasite interactions.

The use of EPG-based infection categories should also be interpreted cautiously. The thresholds proposed by Ueno & Gonçalves (1998) are useful for diagnostic classification of helminth egg counts, but they were

not developed to predict changes in haematocrit or haemoglobin. Compared with continuous EPG analysis, categorical classification may simplify biological variation and may obscure gradual dose-response patterns; for this reason, the present study also considered parasite-specific correlations between EPG and Hct/estimated Hb values. Even so, EPG remains an indirect measure of egg shedding rather than a direct estimate of worm burden, blood loss or erythroid damage, since it may be influenced by parasite fecundity, stage of infection, host immunity, faecal consistency and diagnostic sensitivity (Sabatini et al., 2023).

The haematological values observed in parasite-negative cattle were lower than those previously reported for Creole cattle raised in the Andean region of Peru, where mean Hct values close to 46% and Hb concentrations close to 13 g·dL⁻¹ have been described (Gonzales et al., 2020). This difference may be related to variation in animal origin, nutritional status, age structure, management system, physiological condition and altitude, rather than to parasitism alone. In particular, the present study was conducted using abattoir-sampled cattle in Cajamarca, at approximately 2,700–2,750 m above sea level, whereas reference values may vary among Andean populations according to environmental and productive conditions. Therefore, altitude should be considered as a contextual factor, but not as an isolated explanation for the lower Hct/estimated Hb values observed.

Pre-slaughter conditions should also be considered when interpreting haematological values in this study. Transport, fasting and handling before slaughter may influence physiological parameters, but dehydration generally tends to produce haemoconcentration rather than reduced haematocrit. Therefore, pre-slaughter fasting or water restriction should not be invoked as the primary explanation for the lower Hct/estimated Hb values without direct evidence. A more logical interpretation is that the observed haematological profile reflects the combined influence of abattoir-based sampling, heterogeneous animal backgrounds, unmeasured age and nutritional differences, and naturally acquired parasitic infections.

The absence of genus-level identification of gastrointestinal nematodes is an important limitation for interpreting parasite-specific effects. Although GIN pathogenicity may vary markedly among genera, including haematophagous taxa such as *Haemonchus* and genera with more prominent effects on digestion or nutrient utilisation, the present design does not allow these mechanisms to be differentiated (Charlier et al., 2020; Sabatini et al., 2023). Consequently, comparisons between *F. hepatica* and GIN should be understood as

associations based on coprological diagnostic groups, not as evidence that specific nematode genera produced or failed to produce erythroid alterations.

Likewise, the interpretation of Creole cattle adaptation should remain conservative. Although Creole cattle are recognised for their importance in local production systems and their adaptation to restrictive environments (Delgado & García, 2018; Núñez-Domínguez et al., 2016), the present study did not evaluate genetic resilience, immune tolerance, body condition, diet, productivity or farm-level management. Therefore, any explanation based on adaptive tolerance or homeostatic compensation should be considered hypothetical and should be tested in future studies using longitudinal designs, comparison breeds and integrated parasitological, haematological, nutritional and productive indicators.

Overall, this study provides preliminary local evidence that patent *F. hepatica* infection is moderately associated with lower Hct/estimated Hb values in Creole cattle from Cajamarca, whereas GIN egg shedding showed no significant overall correlation with these erythroid indicators. Compared with categorical diagnostic grouping alone, the parasite-specific continuous analysis helped clarify that the association was more evident for *F. hepatica* than for GIN. However, the exploratory design, unequal group sizes, absence of independent haemoglobin measurement, lack of nematode identification and absence of key covariates such as age, nutritional status and farm-level management require cautious interpretation of the findings.

Future research should therefore include longitudinal sampling, direct haemoglobin determination, larval or molecular identification of GIN, and more complete characterisation of animal-level and farm-level variables. These approaches would allow stronger comparison between parasite groups, more precise assessment of parasite burden, and better evaluation of whether the haematological changes observed in naturally infected Creole cattle have clinical or productive relevance. Such evidence would be particularly valuable in high-Andean cattle systems, where chronic helminth exposure, local breed adaptation and heterogeneous management conditions may interact in complex ways.

4 Conclusions

The findings of this study indicate that, in Creole cattle slaughtered in Cajamarca, patent *F. hepatica* infection was moderately associated with lower Hct values, with estimated Hb showing the same statistical pattern because it was mathematically derived from Hct. This association should be interpreted as observational and limited to the low-to-moderate egg-shedding range

evaluated, without establishing a causal or progressive mechanism.

In contrast, GIN EPG was not significantly correlated with Hct or estimated Hb when all GIN-positive cattle were considered, including animals with single and mixed infections. In the mutually exclusive diagnostic-group analysis, cattle with exclusive GIN infection showed higher Hct/estimated Hb values than those observed in animals with fasciolosis or mixed infection. However, genus-level pathogenic effects cannot be inferred because nematode identification was not performed.

Acknowledgments

The authors express their gratitude to the owners of the sampled animals, as well as to the administrative staff of the municipal abattoir of Cajamarca (Peru), for providing the necessary facilities for sample collection.

Conflict of interest

The authors declare that there is no conflict of interest.

Author contributions

Ghina Abanto: conceptualisation, investigation, resources. Fernando Oblitas: investigation, methodology, validation. Luis Vargas-Rocha: Data curation, formal analysis, visualisation, writing – original draft. All authors contributed to writing, review & editing of the manuscript.

AI and AI-assisted technologies use declaration

The authors declare that generative AI (ChatGPT, OpenAI) were used solely to improve the English language, grammar, and overall clarity of the manuscript. The AI tool was not used to generate scientific content, interpret data, or draw conclusions. All scientific content, data analysis, interpretation, and conclusions were produced entirely by the authors, who take full responsibility for the content of the article.

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