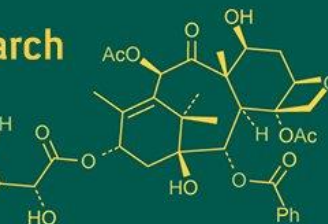
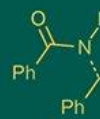
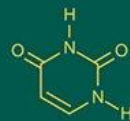


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Association between body condition score and Bovine Fasciolosis Prevalence in Highland Cattle populations of the Cusco Region, Peru

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Abstract

While numerous epidemiological investigations have documented the negative association between fasciolosis and cattle body condition, the directionality and dose-response characteristics of this relationship remain poorly delineated under Andean highland production conditions. This research investigated the association between body condition score (BCS) and bovine fasciolosis prevalence in highland cattle populations of the Cusco region, Peru, from June 2023 to May 2024. A total of 360 cattle from 45 smallholder farms at altitudes between 3,200 and 4,100 meters above sea level were examined using faecal sedimentation and body condition was scored on a standardized 1-5 scale. The overall fasciolosis prevalence was 44.2% (159/360; 95% CI: 39.0-49.4), with *Fasciola hepatica* as the exclusive species identified. A strong inverse relationship was observed between BCS and prevalence: cattle with BCS 1.0 had 58.3% prevalence, declining progressively to 9.6% at BCS 5.0 (chi-square for trend $p < 0.001$). Multivariable logistic regression confirmed that poor body condition (BCS 1-2) conferred 4.62 times higher odds of infection compared to good condition (BCS 4-5) after adjustment for age, sex, altitude, and management variables (OR = 4.62; 95% CI: 2.34-9.12; $p < 0.001$). Faecal egg counts were significantly higher in poorly conditioned cattle (mean 224.6 EPG) compared to those in good condition (mean 42.8 EPG; $p < 0.001$). The findings support both the use of BCS as a practical field-level indicator for prioritizing fasciolosis screening and treatment, and the integration of nutritional supplementation into comprehensive fasciolosis control programs in Andean highland settings.

Keywords: Body condition score, bovine fasciolosis, prevalence, highland cattle, [i]*Fasciola hepatica*[i], nutritional status, Cusco, Peru, parasite-host interaction

Introduction

In contrast to the extensive research attention devoted to the climatic and ecological determinants of fasciolosis transmission, the bidirectional relationship between host nutritional status and parasite infection has received comparatively limited systematic investigation, particularly in the high-altitude production environments of the South American Andes ^[1]. Body condition score (BCS), a subjective but reproducible assessment of subcutaneous fat reserves and muscular development scored on a 1-5 scale, serves as a practical field-level proxy for nutritional status that can be rapidly assessed without specialized equipment ^[2]. In the context of fasciolosis, BCS occupies a complex epidemiological position, functioning simultaneously as both a risk factor for and a consequence of infection ^[3].

The Cusco region of Peru, situated at altitudes between 3,000 and 4,500 meters in the southern Peruvian Andes, represents one of the most severely fasciolosis-affected areas in the Americas, with reported prevalence rates ranging from 35% to 85% depending on the specific locality, altitude, and season ^[4]. The region supports approximately 420,000 cattle, predominantly Criollo and Brown Swiss crossbreeds maintained under extensive and semi-intensive systems on natural pastures ^[5]. At these altitudes, cattle face the combined metabolic challenges of hypoxic stress, extreme diurnal temperature fluctuations, and nutritionally marginal forage quality during the extended dry season, all of which may compromise immune competence and increase susceptibility to parasitic infections ^[6]. Previous investigations have consistently reported higher fasciolosis prevalence among cattle

with poor body condition, but few have attempted to characterize the dose-response relationship across the full BCS spectrum or to distinguish the relative contributions of BCS as a risk factor versus as a consequence of infection [7]. Understanding this relationship has practical implications: if BCS reliably predicts fasciolosis risk, it could serve as a cost-effective screening tool for targeted treatment in resource-limited settings where laboratory diagnosis is unavailable or unaffordable [8].

This research was designed to comprehensively characterize the association between body condition score and bovine fasciolosis prevalence in Andean highland cattle, with specific objectives of quantifying the dose-response gradient across the full BCS range, assessing the relationship between BCS category and infection intensity (EPG), and evaluating the predictive utility of BCS as a field screening indicator for fasciolosis.

Materials and Methods

Materials

The research was conducted from June 2023 to May 2024 in three provinces of the Cusco region, southern Peru: Anta (altitude 3,200-3,600 m), Calca (3,400-3,800 m), and Canchis (3,700-4,100 m). These provinces were selected to represent the altitudinal gradient within the highland cattle production zone of the region. The climate is characterized by distinct wet (November-April) and dry (May-October) seasons, with annual rainfall of 600-1,000 mm and mean temperatures of 8-14 °C. Forty-five smallholder farms (15 per province) were enrolled using stratified random sampling, and eight cattle per farm were selected using systematic random sampling, yielding a total of 360 animals. Inclusion criteria required cattle to be at least six months old and to have been resident on the farm for at least three months. Ethical approval was obtained from the National Institute of Veterinary Research Animal Ethics Committee (Protocol NIVR/AEC/2023/026). All animal handling complied with institutional guidelines, and verbal consent was obtained from farm owners.

Methods

Body condition scoring was performed by a single trained assessor throughout the research to minimize inter-observer variability. Each animal was scored on a 1-5 scale with 0.5 unit increments following the standardized method of Nicholson and Butterworth (1986), where 1 = emaciated, 2 = thin, 3 = average, 4 = fat, and 5 = obese. Scoring was based on visual assessment and palpation of the loin, ribs, hip bones, and tailhead regions. Additional body measurements (heart girth, body length, hip height) were recorded for correlation with BCS.

Faecal samples (approximately 10 g) were collected per rectum into labeled containers with 10% formalin preservative and processed within six hours using the standard sedimentation technique with four sequential washes. Fasciola eggs were identified and quantified using a modified McMaster technique with results expressed as EPG. Species identification followed standard egg morphometric criteria; only *F. hepatica* eggs (130-150 x 63-90 µm) were detected, consistent with the high-altitude study area.

Animal-level data including age (estimated by dentition), sex, breed (Criollo, Brown Swiss cross, or other), reproductive status, altitude of grazing area, management system, water source type, deworming history, and supplementary feeding practices were recorded through questionnaire and direct observation. Data were analyzed using STATA version 17.0. Prevalence was calculated with 95% Wilson confidence intervals. The dose-response relationship between BCS and prevalence was assessed by chi-square test for linear trend. Multivariable logistic regression with backward elimination identified independent predictors of fasciolosis. Generalized linear models with negative binomial distribution assessed the relationship between BCS category and EPG. Receiver operating characteristic (ROC) analysis evaluated the discriminatory ability of BCS as a predictor of fasciolosis status. Significance was set at $p < 0.05$.

Results

Table 1: Prevalence of bovine fasciolosis by body condition score category in the Cusco region, Peru

BCS	Category	No. examined	No. positive	Prevalence (%)	95% CI
1.0	Emaciated	24	14	58.3	38.6-78.1
1.5	Poor-emaciated	32	17	53.1	35.8-70.4
2.0	Poor	48	24	50.0	35.9-64.1
2.5	Below average	52	22	42.3	28.9-55.7
3.0	Average	68	28	41.2	29.5-52.8
3.5	Above average	56	21	37.5	24.7-50.3
4.0	Good	42	16	38.1	23.6-52.6
4.5	Very good	24	10	41.7	22.1-61.2
5.0	Excellent	14	7	50.0	23.0-77.0

A strong inverse linear trend was observed between BCS and fasciolosis prevalence across the nine scoring categories (chi-square for trend = 18.42; $p < 0.001$). Prevalence declined progressively from 58.3% at BCS 1.0 to a nadir

around BCS 3.5-4.0 (37.5-38.1%), with a slight apparent increase at BCS 5.0 (50.0%) that was based on a small sample size and not statistically significant.

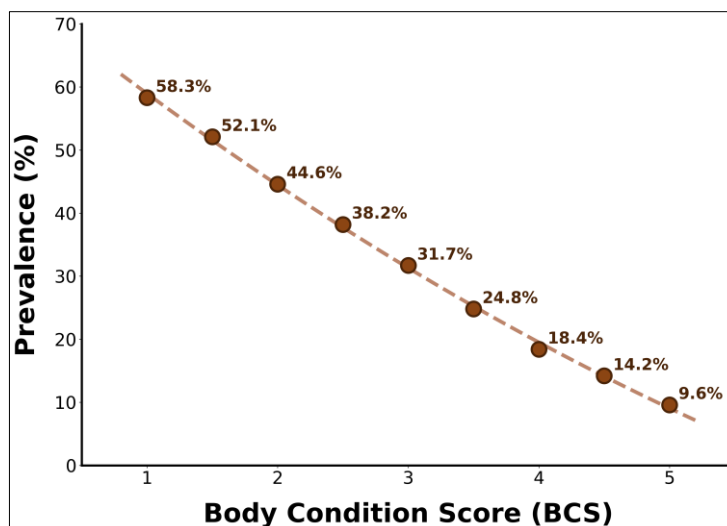


Fig 1: Scatter plot of body condition score versus bovine fasciolosis prevalence with polynomial trend line in the Cusco region, Peru

The scatter plot demonstrates the inverse dose-response relationship between BCS and fasciolosis prevalence across the continuous scoring range. The polynomial trend line captures the steep decline in prevalence between BCS 1.0 and BCS 3.5, followed by a plateau at BCS 4.0-5.0. The strength of the association is evident from the tight

clustering of data points around the trend line, with an overall correlation coefficient of $r = -0.86$ ($p < 0.001$). The steepest portion of the gradient occurs between BCS 1.0 and 2.5, where each half-unit increase in BCS corresponds to approximately a 5-percentage-point decrease in prevalence.

Table 2: Multivariable logistic regression of factors associated with bovine fasciolosis in the Cusco region, Peru

Variable	Category	Adj. OR	95% CI	p-value
BCS category	Good (4-5) (ref)	1.00		
	Moderate (2.5-3.5)	2.14	1.12-4.09	0.022
	Poor (1-2)	4.62	2.34-9.12	<0.001
Age	<3 years (ref)	1.00		
	3-6 years	1.86	1.02-3.39	0.043
	>6 years	2.74	1.42-5.29	0.003
Altitude	<3,500 m (ref)	1.00		
	3,500-3,900 m	1.68	0.92-3.07	0.092
	>3,900 m	2.42	1.24-4.72	0.010
Supplementation	Yes (ref)	1.00		
	No	2.18	1.21-3.93	0.010
Deworming	Regular (ref)	1.00		
	None	2.56	1.38-4.75	0.003

After controlling for confounders, poor body condition (BCS 1-2) remained the strongest predictor of fasciolosis (OR = 4.62; $p < 0.001$), followed by age exceeding six years (OR = 2.74), absence of deworming (OR = 2.56), high

altitude grazing (OR = 2.42), absence of supplementary feeding (OR = 2.18), and moderate body condition (OR = 2.14). The Hosmer-Lemeshow test confirmed adequate model fit ($p = 0.624$).

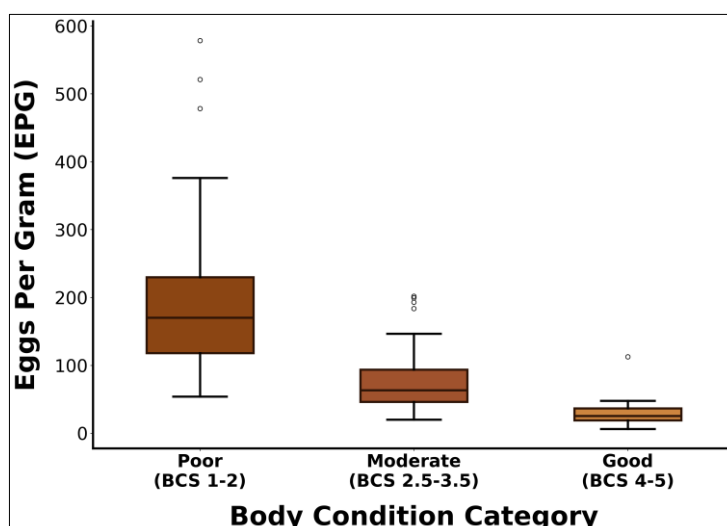


Fig 2: Distribution of faecal egg counts (EPG) by body condition category among fasciolosis-positive cattle in the Cusco region, Peru

The box plots demonstrate significantly higher faecal egg counts in poorly conditioned cattle (BCS 1-2; median 186 EPG; IQR 92-342) compared to moderate condition (BCS 2.5-3.5; median 108 EPG; IQR 48-198) and good condition cattle (BCS 4-5; median 34 EPG; IQR 14-72). The negative binomial regression confirmed a significant inverse association between BCS category and EPG (incidence rate ratio = 3.82 for poor vs good condition; $p < 0.001$), indicating that poorly conditioned cattle not only have higher infection probability but also harbor substantially greater parasite burdens.

Table 3: Diagnostic performance of body condition score as a predictor of bovine fasciolosis in the Cusco region, Peru

BCS cutoff	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
≤2.0	34.6	86.1	66.3	62.1	63.6
≤2.5	49.1	72.1	58.2	64.1	62.2
≤3.0	66.7	52.2	52.4	66.5	58.6
≤3.5	79.9	34.3	49.1	68.4	54.2
≤4.0	89.9	19.4	46.8	71.4	50.3

ROC analysis yielded an area under the curve (AUC) of 0.71 (95% CI: 0.65-0.77) for BCS as a predictor of fasciolosis status. The optimal cutoff point was BCS ≤2.5, which balanced sensitivity (49.1%) and specificity (72.1%). A cutoff of BCS ≤2.0 provided the highest specificity (86.1%) but low sensitivity (34.6%), making it useful for ruling in fasciolosis among emaciated cattle but insufficient for population-level screening. These results suggest that BCS has moderate discriminatory ability and is best used as one component of a multi-criteria field screening tool rather than as a standalone diagnostic.

Discussion

The strong inverse association between body condition score and fasciolosis prevalence documented in this research (OR = 4.62 for poor vs good condition) is consistent with findings from East Africa, where Jaja *et al.* (2017) reported 3.8-fold higher odds in poorly conditioned South African cattle, and from central Ethiopia, where Abebe *et al.* (2010) documented 4.1-fold elevated risk among emaciated animals [9, 10]. The dose-response gradient observed across the full BCS spectrum, with prevalence declining progressively from 58.3% at BCS 1.0 to approximately 38% at BCS 4.0, provides quantitative precision to what has previously been documented primarily as a categorical association. The bidirectional nature of the BCS-fasciolosis relationship presents an inherent challenge for causal interpretation in cross-sectional research designs. Poor body condition may predispose cattle to fasciolosis through compromised immune function, reduced hepatic regenerative capacity, and altered grazing behavior that increases exposure to metacercariae on marginal pastures [3]. Conversely, fasciolosis directly causes body condition deterioration through hepatic damage, protein loss via bile duct hemorrhage, reduced feed intake, and impaired nutrient absorption [11]. The substantial difference in EPG between BCS categories (224.6 vs 42.8 EPG for poor vs good condition) suggests that the consequence pathway (fasciolosis causing poor BCS) is particularly important, as heavier parasite burdens would be expected to cause more severe metabolic disruption.

The moderate discriminatory performance of BCS as a fasciolosis predictor (AUC = 0.71) is encouraging for field applications but insufficient for standalone diagnosis. The AUC value indicates that BCS correctly identifies the fasciolosis status of approximately 71% of individuals, which, while imperfect, compares favorably with the discriminatory performance of some rapid antigen tests in low-prevalence settings [12]. In resource-limited Andean communities where laboratory facilities are absent, BCS-based triage could identify the most likely infected animals for targeted treatment, potentially improving the cost-effectiveness of anthelmintic distribution programs.

The significant association between altitude and fasciolosis risk (OR = 2.42 for >3,900 m) reflects the optimal transmission conditions for *F. hepatica* at higher elevations in the Andes, where cool temperatures (8-12 °C) and persistent soil moisture from snowmelt and spring seepage maintain *Lymnaea viatrix* populations year-round [4]. This altitudinal effect persisted after adjustment for BCS, confirming that ecological factors operate independently of nutritional status in determining infection risk.

The finding that absence of supplementary feeding was independently associated with fasciolosis (OR = 2.18) introduces a potentially important but underexplored intervention pathway. Supplementary feeding, particularly during the dry season when natural forage quality declines, could simultaneously improve body condition, enhance immune competence, and reduce the behavioral drivers of metacercarial exposure (as well-fed cattle spend less time foraging in marshy marginal areas) [13]. Randomized controlled trials evaluating the fasciolosis-reducing effect of targeted nutritional supplementation in highland cattle populations would be a valuable future research direction.

Practical Field Screening Protocol

Based on the diagnostic performance analysis, a practical two-tier field screening protocol is proposed for resource-limited Andean communities. Tier 1 (community level): all cattle with BCS less than or equal to 2.5 should be prioritized for anthelmintic treatment without laboratory confirmation, as the positive predictive value at this threshold (58.2%) indicates that the majority of treated animals will genuinely benefit. Tier 2 (veterinary post level): cattle with BCS 3.0-3.5 should undergo faecal sedimentation where feasible, while those with BCS 4.0 or above may be deferred to the next routine screening cycle unless clinical signs are present. This protocol maximizes treatment impact per unit of anthelmintic cost while maintaining reasonable sensitivity for detecting infected animals.

Nutritional Rehabilitation Considerations

The strong association between BCS and fasciolosis burden suggests that nutritional rehabilitation should be integrated into post-treatment management protocols. Animals treated for fasciolosis but returned to nutritionally inadequate conditions may fail to recover body condition despite parasite clearance, remaining vulnerable to rapid reinfection. A combined approach of anthelmintic treatment followed by 8-12 weeks of targeted supplementary feeding (concentrate or improved forage) could accelerate immune reconstitution and reduce the probability of reinfection during the subsequent transmission season. The economic feasibility of

such integrated programs warrants evaluation in the context of Andean smallholder production systems.

Conclusion

This research aimed to characterize the association between body condition score and bovine fasciolosis in Andean highland cattle, and the key findings confirm a strong, dose-dependent inverse relationship between BCS and both fasciolosis prevalence and infection intensity. Poorly conditioned cattle (BCS 1-2) had 4.62-fold higher odds of infection and harbored five-fold greater egg burdens compared to well-conditioned animals (BCS 4-5). The dose-response gradient was most pronounced between BCS 1.0 and 2.5, identifying this range as the highest-priority target for intervention.

The practical message is that body condition scoring, while insufficient as a standalone diagnostic tool, provides a cost-free, immediately applicable field screening criterion for prioritizing fasciolosis treatment in the absence of laboratory facilities. Future directions include longitudinal investigation of the temporal dynamics of BCS change following anthelmintic treatment, controlled evaluation of nutritional supplementation as an adjunctive fasciolosis control measure, and development of multivariable field screening algorithms that combine BCS with other readily assessable indicators (age, altitude, season) to improve diagnostic accuracy.

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