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Brief Report

Enteroparasitism and C-Reactive Protein in Children from High-Andean Communities of Acocro, Ayacucho, Peru: A Cross-Sectional Study

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Abstract

Background/Objectives: Inflammation contributes to the persistence of childhood anemia in the Peruvian Andes, but low-cost acute-phase markers have rarely been evaluated together with intestinal parasitism in high-altitude rural communities. We assessed the association of enteroparasitism and anemia with qualitative C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) in children from Acocro, Ayacucho. Methods: Cross-sectional analytical study conducted between January and June 2025 in three rural communities located at 3388–3472 m above sea level, with quota selection by anemia and parasitic status. We evaluated 110 children aged 1–12 years with stool examination (spontaneous tube sedimentation), altitude-adjusted hemoglobin, CRP latex agglutination, and capillary ESR. Prevalence ratios (PRs) were estimated with modified Poisson regression adjusted for age and sex; when no unexposed child had the outcome, risk differences (RDs) and two-sided Fisher's exact tests were used. Results: Of 72 children with stool examination, 42 were parasitized (58.3%); *Entamoeba coli*, *Giardia lamblia*, and *Hymenolepis nana* were the most frequent species. No non-parasitized child had a positive CRP (0/30), compared with 11 of 42 parasitized children (26.2%; RD 26.2 percentage points, 95% CI 10.5–41.1; $p = 0.002$); ESR > 10 mm/h showed the same pattern. Carriage of a pathogenic parasite was associated with CRP positivity (adjusted PR 3.8; 95% CI 1.2–12.3), whereas the association with anemia was not significantly (adjusted PR 1.7; 95% CI 0.7–4.3). Conclusions: A latex-detectable acute-phase response was confined to parasitized children among the 72 children with stool examination results and was not associated with anemia. Stool examination should be integrated into the approach to childhood anemia in the rural Andes, while interpretation of anemia at high altitude should consider the adjustment method used.

Keywords: intestinal parasitic diseases; C-reactive protein; anemia; inflammation; altitude; child; Peru

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1. Introduction

Anemia affects 40% of children aged 6–59 months worldwide [1]. In Peru, its prevalence among children aged 6–35 months fell from 56% to 41% between 2006 and 2011, then

stagnated and returned to 43% in 2023 despite more than a decade of iron supplementation and fortification [2], with the highest burden among Indigenous, poor, and non-coastal groups [3]. Childhood anemia in Peru is multifactorial and cannot be attributed solely to iron deficiency or inflammation. Inadequate dietary intake, malnutrition, intestinal infections, and limited access to safe drinking water may contribute to its persistence, while socioeconomic disadvantage and rural residence shape the distribution of risk [3–5]. Intestinal parasitism may further compromise nutritional status through intestinal dysfunction and impaired nutrient absorption. Part of this persistence reflects anemia of inflammation: chronic immune activation induces hepcidin, which blocks intestinal iron absorption and iron release from macrophages and restricts erythropoiesis even when dietary intake is adequate [6,7]. Inflammation also distorts iron-status indicators [8], and among young children in Puno it was associated with almost half of anemia cases, compared with one quarter attributable to iron deficiency [9].

In 2024, the World Health Organization (WHO) updated hemoglobin cutoffs and the altitude adjustment, and Peru incorporated the guideline into its national norms [10,11]. Altitude adjustment is necessary because chronic exposure to hypobaric hypoxia stimulates erythropoiesis, resulting in higher hemoglobin concentrations at high elevations; measured hemoglobin is therefore corrected downward before applying anemia diagnostic cutoffs. The resulting change in prevalence varies by region and adjustment method [11]. However, altitude-adjusted hemoglobin may classify some children as anemic despite the absence of biochemical evidence of iron deficiency. Furthermore, hemoglobin alone has limited accuracy for identifying iron deficiency, which requires assessment using specific iron-status biomarkers, such as ferritin or transferrin saturation [12–14]. At the same time, intestinal parasites remain common in Andean children: in Cusco, intestinal parasitosis has been reported in 45–47% of children, with *Giardia* spp. and *Hymenolepis nana* among the most frequent agents and anemia close to 50% [15,16].

Evidence on the link between enteroparasitism and systemic inflammation is inconsistent. In Mexican schoolchildren, parasitic infection was associated with intestinal inflammation but not with CRP or circulating cytokines [17]; in Cuban preschoolers, one third had elevated CRP or α1-acid glycoprotein, which modified the estimated prevalence of iron deficiency [18]. We found no studies in high-Andean Peruvian communities combining stool examination, altitude-adjusted hemoglobin, and acute-phase markers. We therefore evaluated the association of enteroparasitism and anemia with qualitative C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) in children from rural communities of Acocro, Ayacucho.

2. Materials and Methods

2.1. Design, Setting, and Participants

This cross-sectional analytical study was conducted between January and June 2025 in the rural communities of Pomapuquio (3388 m above sea level), Pampamarca (3420 m), and Chontaca (3472 m), Acocro district, Huamanga province, Ayacucho, Peru. Reporting follows the STROBE statement for cross-sectional studies [19] (Supplementary File S1).

Children aged 1–12 years living in the three communities were recruited through home visits and community meetings using quota selection: groups of children with and without anemia and with and without enteroparasitism were completed for the evaluation of inflammatory markers. Recruitment followed approximate minimum representation targets of 25% for each category of anemia status (with and without anemia) and enteroparasitic status (with and without enteroparasitism). These categories were not mutually exclusive, as children could present both conditions. The sample size was pragmatically determined according to study feasibility and available resources; no formal a priori statistical sample

size calculation was performed. Inclusion criteria were age 1–12 years, residence in one of the three study communities, written informed consent from a parent or guardian, and provision of at least one biological sample (blood or stool). Children who did not meet these criteria were considered ineligible. Some families did not deliver a stool sample despite repeated home visits; once quotas were filled, collection was not pursued further. Overall, 110 children were enrolled: 105 had hemoglobin measurement, 72 stool examination, and 101 CRP and ESR. Because of non-probability quota sampling, the observed frequencies of anemia and enteroparasitism describe the analyzed sample and should not be interpreted as population prevalence estimates. Potential selection bias associated with quota-based recruitment and incomplete stool sample collection cannot be excluded. Furthermore, parasitological analyses were restricted to children who provided stool samples, and potential selection bias due to incomplete stool collection cannot be excluded. Concurrent infections and other acute inflammatory conditions were not systematically assessed or recorded at the time of sample collection.

2.2. Laboratory Procedures

Stool samples were collected by the children's parents or guardians at home using labeled containers provided by the study team. No preservatives were added. Samples were transported in a cooler box with ice at approximately 8–12 °C and processed within 2–3 h after collection at the Microbiology Laboratory of the Faculty of Biological Sciences, Universidad Nacional de San Cristóbal de Huamanga, using the spontaneous tube sedimentation technique [20]. One sample per child was examined with Lugol's iodine at 10× and 40×.

Venous blood was drawn into EDTA tubes and processed the same day at the clinical laboratory of the Chontaca Health Center. Hemoglobin was measured by the cyanmethemoglobin method on a semi-automated biochemistry analyzer (SFRI BSA 3000). CRP was determined by latex agglutination (PCR-látex directo, Wiener Lab, Rosario, Argentina) and recorded as positive or negative according to the manufacturer's insert (detection limit [6 mg/L]). ESR was measured in an anticoagulated capillary tube kept vertical for 1 h and read in millimeters; this procedure differs from the Westergren reference method recommended by the International Council for Standardization in Haematology (ICSH) [21].

2.3. Variables and Definitions

Enteroparasitism was defined as the detection of at least one protozoan or helminth species. *Giardia lamblia*, *Hymenolepis nana*, and *Ascaris lumbricoides* were considered pathogenic, and *Entamoeba coli* and *Iodamoeba butschlii* commensal [22]; polyparasitism was defined as two or more species.

Hemoglobin was adjusted for altitude according to the Peruvian Ministry of Health technical standard for the management of anemia [23], which subtracts 2.4 g/dL at 3361–3425 m and 2.5 g/dL at 3426–3490 m above sea level; thus, 2.4 g/dL was applied in Pomapuquio (3388 m) and Pampamarca (3420 m) and 2.5 g/dL in Chontaca (3472 m). The resulting altitude-adjusted hemoglobin values were used for anemia classification and subsequent analyses. Anemia was defined using the WHO 2024 age-specific cutoffs—10.5 g/dL (12–23 months), 11.0 g/dL (24–59 months), 11.5 g/dL (5–11 years), and 12.0 g/dL (12 years)—with the severity thresholds of the same guideline [10]. Because the factor applied at each site was known, measured hemoglobin was back-calculated by adding it, and children were reclassified with the WHO 2024 altitude equation [10], since the community of residence was not recorded for each child, this sensitivity analysis was repeated for each of the three site-specific combinations of factor and altitude. Inflammation was defined as a positive CRP; ESR > 10 mm/h was analyzed as a secondary marker.

2.4. Statistical Analysis

Normality of continuous variables was assessed with the Shapiro–Wilk test; because age, hemoglobin, and ESR were not normally distributed (all $p < 0.001$), they are presented as median and interquartile range (IQR) and were compared with the Mann–Whitney U test. Proportions are presented with Wilson 95% CIs. Because the outcomes were not rare, associations with CRP positivity and ESR > 10 mm/h were estimated as prevalence ratios (PRs) with 95% CIs using Poisson regression with robust (HC0) standard errors (modified Poisson regression) [24], rather than odds ratios, which overstate the association when the outcome is common. Models were fitted without adjustment and adjusted for age and sex; with 11 to 13 outcome events per model, no further covariates were included. Model fit was assessed with the Pearson χ^2 statistic divided by its degrees of freedom and with the deviance goodness-of-fit test. When no unexposed child had the outcome (complete separation), as occurred for enteroparasitism with both CRP and ESR, the PR cannot be estimated by regression; for these comparisons, the risk difference (RD) with the Newcombe hybrid-score 95% CI [25] and the two-sided Fisher's exact test are reported. Analyses were based on complete cases for each comparison; denominators therefore vary according to the measurements available, and no imputation was performed. As sensitivity analyses, the hemoglobin comparison was repeated after excluding three children with altitude-adjusted values ≥ 17 g/dL, and the association between anemia and CRP was re-estimated after reclassification with the WHO 2024 altitude equation (Section 2.3). With 96 children with hemoglobin and CRP, the study had approximately 80% power to detect a PR of 3.6 (equivalent to an odds ratio of 5) between anemia and CRP positivity (two-sided Fisher's exact test, $\alpha = 0.05$; Monte Carlo simulation, 5000 replicates). Because both conditions were used for quota selection, the association between anemia and enteroparasitism was not estimated. Analyses were performed in R version 4.6.1 (R Foundation for Statistical Computing, Vienna, Austria) using base functions (stats) and the sandwich (v3.1.3) and lmtest (v0.9.40) packages; figures were produced with ggplot2 (v4.0.3) and patchwork (v1.3.2).

3. Results

A total of 110 children (56 boys; 50.9%) with a median age of 9 years (IQR 6–10; range 1–12) were evaluated. Table 1 summarizes the characteristics of 72 children with stool examination according to parasitic status. Parasitized children were slightly younger than non-parasitized children (median 8 vs. 9.5 years) and had a lower median hemoglobin (12.0 vs. 13.2 g/dL; $p = 0.057$), although this difference depended on three non-parasitized children with altitude-adjusted hemoglobin ≥ 17 g/dL ($p = 0.23$ after their exclusion).

Table 1. Characteristics of children with stool examination according to parasitic status, Acocro, Ayacucho, 2025 ($n = 72$).

Characteristic	Without Enteroparasites ($n = 30$)	With Enteroparasites ($n = 42$)	p
Age, years, median (IQR)	9.5 (7–11)	8 (6–10)	0.18 [a]
Male sex, *n* (%)	16 (53.3)	19 (45.2)	0.63
Altitude-adjusted hemoglobin, g/dL, median (IQR) [c]	13.2 (12.4–14.0)	12.0 (10.7–13.8)	0.057 [a]
Anemia, *n*/*N* (%) [b]	5/26 (19.2)	18/41 (43.9)	—
Positive CRP, *n* (%)	0 (0.0)	11 (26.2)	0.002
ESR > 10 mm/h, *n* (%)	0 (0.0)	12 (28.6)	<0.001

IQR, interquartile range; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate. Two-sided Fisher's exact test unless indicated. [a] Mann–Whitney U test. [b] No hypothesis test: both groups were selected by quota. [c] Available for 26 and 41 children, respectively; three non-parasitized children had altitude-adjusted hemoglobin values ≥ 17 g/dL and were excluded in a sensitivity analysis ($p = 0.23$).

3.1. Enteroparasitism

Of the 72 children with stool examination, 42 were parasitized (58.33%). *Entamoeba coli* was the most frequent species (27 children), followed by *Giardia lamblia* (17), *Hymenolepis nana* (10), *Ascaris lumbricoides* (2), and *Iodamoeba butschlii* (1). Fourteen parasitized children (33.3% of parasitized children) had polyparasitism; 26 (61.9% of parasitized children) carried at least one pathogenic parasite, whereas 16 (38.1% of parasitized children) carried commensal species only (Table 2).

Table 2. Intestinal parasite species and their distribution by CRP result and anemia ($n = 72$ examined).

Species or Condition	*n* (% of Examined)	Positive CRP, *n*/*N*	Anemia, *n*/*N*
Entamoeba coli	27 (37.5)	7/27	12/27
Giardia lamblia	17 (23.6)	6/17	8/17
Hymenolepis nana	10 (13.9)	4/10	4/9
Ascaris lumbricoides	2 (2.8)	0/2	0/2
Iodamoeba butschlii	1 (1.4)	1/1	1/1
Monoparasitism	28 (38.9)	5/28	—
Polyparasitism (≥2 species)	14 (19.4)	6/14	—
Commensals only	16 (22.2)	3/16	—
At least one pathogen	26 (36.1)	8/26	—

Species are not mutually exclusive. Commensals: *E. coli*, *I. butschlii*. Pathogens: *G. lamblia*, *H. nana*, *A. lumbricoides*.

3.2. Anemia and Acute-Phase Markers

Twenty-seven of 105 children (25.7%) had anemia based on altitude-adjusted hemoglobin: 10 mild, 17 moderate, and none severe; median hemoglobin was 13.0 g/dL (IQR 11.4–14.0) (Figure 1a). With the WHO 2024 altitude equation, 25 of 105 children (23.8%) were classified as anemic in each of the three site-specific scenarios. CRP was positive in 13 of 101 children (12.9%; 95% CI 7.7–20.8). All 13 CRP-positive children had ESR > 10 mm/h (median 16 mm/h; IQR 15–18), whereas the median ESR among the 88 CRP-negative children was 5 mm/h (IQR 3–6; $p < 0.001$) and only one exceeded that threshold. CRP-positive children were younger than CRP-negative children (median age 7 vs. 9 years; $p = 0.030$), with no difference by sex (4/51 girls vs. 9/50 boys; $p = 0.15$). After adjustment for sex and carriage of a pathogenic parasite, each additional year of age was associated with a lower prevalence of positive CRP (PR 0.82; 95% CI 0.73–0.92).

3.3. Associations

Among the 72 children with stool examination, none of the 30 non-parasitized children had a positive CRP (95% CI 0–11.4), compared with 11 of 42 parasitized children (26.2%; 95% CI 15.3–41.1), a risk difference of 26.2 percentage points (95% CI 10.5–41.1; $p = 0.002$) (Table 3, Figure 1b); because of this complete separation, the PR could not be estimated. The pattern was identical for ESR > 10 mm/h (0/30 vs. 12/42; RD 28.6 percentage points, 95% CI 12.5–43.6; $p < 0.001$). Carriers of at least one pathogenic parasite had a higher prevalence of positive CRP than the remaining children (8/26 vs. 3/46; PR 4.7, 95% CI 1.4–16.2), which persisted after adjustment for age and sex (PR 3.8; 95% CI 1.2–12.3). Among parasitized children, CRP positivity was similar in carriers of at least one pathogen (8/26; 30.8%) and in carriers of commensals only (3/16; 18.8%; $p = 0.49$), and more frequent with polyparasitism (6/14; 42.9%) than with monoparasitism (5/28; 17.9%; adjusted PR 2.0, 95% CI 0.8–5.1). The prevalence of positive CRP was higher in children with anemia (6/27 vs. 7/69; PR 2.2, 95% CI 0.8–5.9; adjusted PR 1.7, 95% CI 0.7–4.3), but the estimate was not statistically significant; after reclassification with the WHO 2024 altitude equation, the adjusted PR was 1.1 (95% CI 0.4–2.9) in all three scenarios. All models showed adequate fit (Pearson χ^2/df 0.78–1.05; deviance goodness-of-fit $p \geq 0.93$).

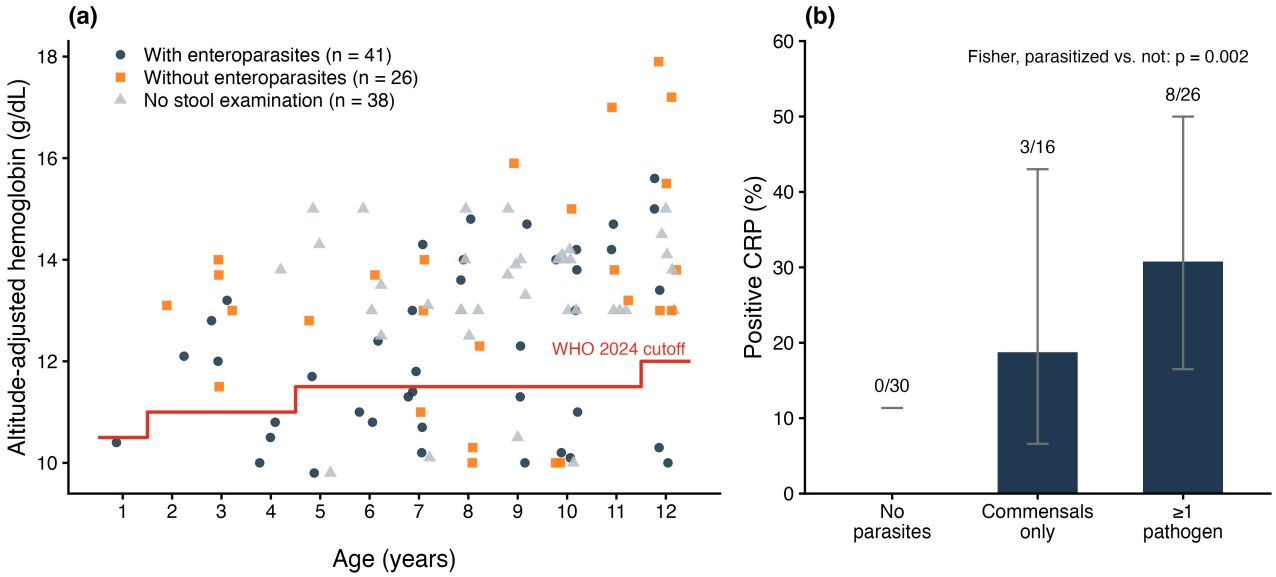

Figure 1. (**a**) Altitude-adjusted hemoglobin by age in 105 children from Acocro, according to parasitic status; the line shows the WHO 2024 cutoff. (**b**) Proportion of positive CRP by parasitic status ($n = 72$); error bars, Wilson 95% CI.

Table 3. Associations of enteroparasitism and anemia with acute-phase markers: prevalence ratios from modified Poisson regression and risk differences.

Exposure → Outcome	*n*	Exposed with Outcome	Unexposed with Outcome	Crude PR (95% CI)	Adjusted PR (95% CI) [a]	*p*
Enteroparasitism → positive CRP	72	11/42 (26.2%)	0/30 (0%)	RD 26.2 (10.5–41.1) [b]	—	0.002 [d]
Pathogenic parasite → positive CRP [c]	72	8/26 (30.8%)	3/46 (6.5%)	4.7 (1.4–16.2)	3.8 (1.2–12.3)	0.027
Polyparasitism → positive CRP [e]	42	6/14 (42.9%)	5/28 (17.9%)	2.4 (0.9–6.5)	2.0 (0.8–5.1)	0.13
Enteroparasitism → ESR > 10 mm/h	72	12/42 (28.6%)	0/30 (0%)	RD 28.6 (12.5–43.6) [b]	—	<0.001 [d]
Anemia → positive CRP	96	6/27 (22.2%)	7/69 (10.1%)	2.2 (0.8–5.9)	1.7 (0.7–4.3)	0.25
Positive CRP → ESR > 10 mm/h	101	13/13 (100%)	1/88 (1.1%)	RD 98.9 (75.5–99.8) [b]	—	<0.001 [d]

PR, prevalence ratio from Poisson regression with robust (HC0) standard errors; RD, risk difference in percentage points. [a] Adjusted for age (years) and sex; *p* from the adjusted model unless indicated. [b] Newcombe hybrid-score 95% CI; the PR was not estimable because no unexposed child had the outcome (complete separation). [c] Reference: non-parasitized children and carriers of commensals only. [d] Two-sided Fisher's exact test. [e] Among parasitized children ($n = 42$); reference: monoparasitism.

4. Discussion

Among the 72 children with available stool examination results from high-Andean communities of Ayacucho, positivity of a low-cost acute-phase marker was confined to parasitized children: none of the 30 children with a negative stool examination had a positive CRP, compared with one in four parasitized children, and ESR reproduced the same pattern. In contrast, no statistically significant association between CRP positivity and anemia was detected. Taken together, these findings suggest that stool-based parasitological assessment may provide information on acute inflammatory activity that is not captured by hemoglobin status alone.

The association between enteroparasitism and CRP contrasts with findings in schoolchildren from Querétaro, Mexico, where infection was associated with fecal leukocytes but not with CRP or serum cytokines [17]. Qualitative latex CRP detects concentrations above the 6 mg/L threshold used to define inflammation in population surveys [26], so a positive result here reflects an overt acute-phase response; in addition, the Mexican population had a high prevalence of obesity, which raises baseline CRP. In our sample, positivity was higher with polyparasitism, and persistent *Giardia* infection may increase intestinal permeability [27], a plausible route to systemic inflammation; conversely, helminths induce

type 2 and regulatory responses that can dampen it [28]. The similar frequency of positive CRP among carriers of *E. coli* only, a commensal proposed as an indicator of hygienic conditions [22], suggests that the marker reflects the intensity of fecal–oral exposure and undetected coinfection rather than the effect of a single species. Younger children were more often CRP-positive, and adjustment for age and sex attenuated but did not remove the association with pathogenic parasites. The design does not allow causal inference. Nevertheless, the concordant CRP and ESR findings indicate that enteroparasitism may identify children in whom an overt inflammatory response warrants closer clinical attention.

The lack of a statistically significant association between CRP and anemia should not be interpreted as evidence of no association. The adjusted PR of 1.7 (95% CI 0.7–4.3) is compatible both with no effect and with a clinically relevant association, and with 13 CRP-positive children the study had adequate power only for strong associations (PR ≈ 3.6, equivalent to an odds ratio of 5); the result is therefore inconclusive. Interpretation is further limited because the diagnosis of anemia of inflammation requires ferritin, transferrin saturation, or hepcidin [6–8], and a qualitative CRP captures only the acute, intense fraction of inflammation; in Puno, inflammation measured by interleukin 6 accounted for almost half of childhood anemia [9]. In high-altitude Cusco, low iron status, stunting, and younger age, but not helminth infection, were associated with anemia [29], which suggests that iron deficiency and nutritional factors not measured here may contribute more than acute inflammation.

The observed anemia frequency (26%) does not estimate community prevalence because selection was by quota. Moreover, at high altitude, anemia classification depends on the adjustment convention: pre-2024 corrections overadjusted hemoglobin at high altitude [23], whereas the current equation reduces this adjustment. However, studies in Peruvian children indicate that altitude adjustment may still overestimate anemia and reduce the ability of hemoglobin to identify iron deficiency [13,14]; among 578,576 Peruvian children, prevalence ranged from 3.2% to 33.7% depending on the criterion used [30], and the WHO table and equation also differ [11]. In the present study, hemoglobin was adjusted with national factors of 2.4–2.5 g/dL, slightly larger than the 2.26–2.32 g/dL given by the WHO 2024 equation at these altitudes. Reclassification with the WHO equation reduced the anemia frequency from 25.7% to 23.8% and moved the PR for CRP closer to 1, without changing the conclusions. Future field studies should record the unadjusted hemoglobin measurement and the community of residence of each participant, and document the altitude-adjustment factor applied. Thus, in high-altitude settings, the reported anemia burden should be interpreted together with the adjustment method used rather than as a measurement-independent estimate.

The parasite profile, predominantly protozoa, with *G. lamblia* as the main pathogen and *H. nana* as the most frequent helminth, is consistent with reports from the Cusco highlands [15,16]. The low frequency of *A. lumbricoides* may reflect school deworming with benzimidazoles, which targets soil-transmitted helminths [31], although the timing of any previous school deworming was not recorded. The predominance of protozoa therefore supports the value of maintaining broad parasitological surveillance rather than focusing exclusively on soil-transmitted helminths.

Nevertheless, several limitations should be acknowledged. The small sample size limited statistical power and resulted in wide confidence intervals, reducing the precision of the estimates. The cross-sectional design precludes causal inferences, while quota-based recruitment and incomplete stool sample collection limit generalizability; the main parasitism–inflammation analyses included only 72 children. A single stool examination may also have underestimated parasitic infections. Furthermore, CRP was assessed qualitatively, and ESR was measured using a capillary method rather than the reference Westergren

method [21]. Other relevant biomarkers, including eosinophils, total IgE, procalcitonin, and fecal calprotectin, were not measured. Concurrent infections and other acute inflammatory conditions were not systematically assessed or recorded, and their potential contribution to CRP and ESR levels cannot be excluded. Relevant environmental factors, including water and sanitation conditions, housing characteristics, and dietary patterns, as well as hereditary factors such as hemoglobin variants, were not evaluated.

Despite these limitations, this study has several strengths. It provides data from rural high-altitude communities in the Peruvian Andes, an underrepresented population in research on enteroparasitism and inflammation. The combined assessment of parasitological findings, including pathogenic infections and polyparasitism, with two inflammatory markers (CRP and ESR) enabled a broader characterization of these associations. Additionally, anemia assessment incorporated altitude-adjusted hemoglobin values and a sensitivity analysis using the 2024 WHO recommendations.

From a public health perspective, preventing childhood anemia in high-altitude Peruvian communities requires an integrated approach that addresses its multifactorial etiology. Strategies should include regular screening and appropriate treatment of intestinal parasitic infections, improved access to safe water and sanitation, and nutritional interventions focused on adequate iron intake and other essential micronutrients. Hemoglobin assessment should account for altitude-specific adjustments to avoid misclassification of anemia. Although our findings support the need to monitor enteroparasitic infections and inflammatory responses in these communities, further longitudinal studies incorporating iron-status biomarkers are needed to clarify the contribution of parasitic infections to childhood anemia and guide targeted preventive interventions.

5. Conclusions

In high-Andean children from Ayacucho, among the 72 children with available stool examination results, a latex-detectable acute-phase response occurred only in the presence of enteroparasites, whereas the association between CRP positivity and anemia remained inconclusive. Anemia control in the rural Andes should integrate the diagnosis of enteroparasitism and the assessment of iron status, and field studies should record measured hemoglobin together with the altitude-adjustment factor applied.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/diseases14110413/s1, Supplementary File S1: STROBE Statement—Checklist of items that should be included in reports of cross-sectional studies.

Author Contributions: Conceptualization, A.B.M. and H.A.-A.; methodology, A.B.M., H.A.-A. and O.M.-S.; investigation, A.B.M., J.H.A.-B., R.D.C., O.M.-S. and H.A.-A.; data curation, A.B.M. and O.M.-S.; formal analysis, A.B.M., H.A.-A. and O.M.-S.; writing—original draft preparation, A.B.M., J.H.A.-B., R.D.C., O.M.-S. and H.A.-A.; writing—review and editing, A.B.M., J.H.A.-B., R.D.C., O.M.-S. and H.A.-A.; supervision, H.A.-A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The study was reviewed and approved by the Research Ethics Committee of the Hospital Regional "Miguel Ángel Mariscal Llerena" of Ayacucho, under Protocol Code 003-2025-CEI. The protocol was approved under the category of expedited review, as stated in the Certificate of Approval dated 10 January 2025 (Directorial Resolution No. 00133-2022-GRA-DIRESA-HRMAML/DE).

Informed Consent Statement: Written informed consent was obtained from the parents or legal guardians of all children involved in the study.

Data Availability Statement: The analysis dataset is fully de-identified: it contains no names, identity document numbers, clinical record numbers or any variable permitting re-identification. The dataset, the analysis code and the data preparation pipeline are available from the corresponding author upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CI	Confidence interval
CRP	C-reactive protein
ESR	Erythrocyte sedimentation rate
HC0	Heteroskedasticity-consistent (robust) standard errors
ICSH	International Council for Standardization in Haematology
IQR	Interquartile range
OR	Odds ratio
PR	Prevalence ratio
RD	Risk difference
WHO	World Health Organization

References

1. Stevens, G.A.; Paciorek, C.J.; Flores-Urrutia, M.C.; Borghi, E.; Namaste, S.; Wirth, J.P.; Suchdev, P.S.; Ezzati, M.; Rohner, F.; Flaxman, S.R.; et al. National, regional, and global estimates of anaemia by severity in women and children for 2000–19: A pooled analysis of population-representative data. *Lancet Glob. Health* **2022**, *10*, e627–e639. [CrossRef] [PubMed]
2. Vera-Ponce, V.J.; Ballena-Caicedo, J. Political instability and child anemia in Peru: A national interrupted time-series analysis, 2006–2024. *Front. Public Health* **2026**, *14*, 1880585. [CrossRef] [PubMed]
3. Al-Kassab-Córdova, A.; Kaufman, J.S. Multilevel modelling of structured intersectional inequalities in child anaemia in Peru: A MAIHDA approach. *J. Epidemiol. Community Health* **2026**, *80*, 592–599. [CrossRef] [PubMed]
4. Westgard, C.M.; Orrego-Ferreyros, L.A.; Calderón, L.F.; Rogers, A.M. Dietary Intake, Intestinal Infection, and Safe Drinking Water among Children with Anemia in Peru: A Cross-Sectional Analysis. *BMC Nutr.* **2021**, *7*, 11. [CrossRef] [PubMed]
5. Segoviano-Lorenzo, M.D.C.; Trigo-Esteban, E.; Gyorkos, T.W.; St-Denis, K.; Guzmán, F.M.-D.; Casapía-Morales, M. Prevalence of Malnutrition, Anemia, and Soil-Transmitted Helminthiasis in Preschool-Age Children Living in Peri-Urban Populations in the Peruvian Amazon. *Cad. Saúde Pública* **2022**, *38*, e00248221. [CrossRef] [PubMed]
6. Weiss, G.; Ganz, T.; Goodnough, L.T. Anemia of inflammation. *Blood* **2019**, *133*, 40–50. [CrossRef] [PubMed]
7. Ganz, T. Anemia of inflammation. *N. Engl. J. Med.* **2019**, *381*, 1148–1157. [CrossRef] [PubMed]
8. Suchdev, P.S.; Williams, A.M.; Mei, Z.; Flores-Ayala, R.; Pasricha, S.R.; Rogers, L.M.; Namaste, S.M. Assessment of iron status in settings of inflammation: Challenges and potential approaches. *Am. J. Clin. Nutr.* **2017**, *106*, 1626S–1633S. [CrossRef] [PubMed]
9. Vásquez-Velásquez, C.; Choque-Quispe, B.M.; Suchdev, P.S.; Rees, C.A.; Tapia, V.; Ko, Y.A.; Gonzales, G.F. Changes in anemia prevalence and the proportion of anemia associated with iron deficiency or inflammation in young children residing in Puno, Peru: Analysis using new World Health Organization guidelines for defining anemia. *PLoS ONE* **2026**, *21*, e0342255. [CrossRef] [PubMed]
10. World Health Organization. *Guideline on Haemoglobin Cutoffs to Define Anaemia in Individuals and Populations*; World Health Organization: Geneva, Switzerland, 2024. Available online: https://iris.who.int/bitstream/handle/10665/376196/9789240088542-eng.pdf (accessed on 22 September 2026).
11. Campos-Sánchez, M.; Cordero-Muñoz, L.; Velásquez-Hurtado, E.; Baiocchi-Ureta, N.; Miranda-Cuadros, M.; Sánchez-Griñán, M.I.; Valdivia-Miranda, W. New World Health Organization guideline on anemia cut-off points: Implications for children aged 6–35 months in Peru. *Rev. Peru. Med. Exp. Salud Publica* **2025**, *42*, 115–125. [CrossRef] [PubMed]

12. Gonzales, G.F.; Tapia, V.; Vásquez-Velásquez, C. Changes in hemoglobin levels with age and altitude in preschool-aged children in Peru: The assessment of two individual-based national databases. *Ann. N. Y. Acad. Sci.* **2021**, *1488*, 67–82. [CrossRef] [PubMed]
13. Vásquez-Velásquez, C.; Fernandez-Guzman, D.; Quispe-Vicuña, C.; Caira-Chuquineyra, B.; Ccami-Bernal, F.; Castillo-Gutierrez, P.; Arredondo-Nontol, M.; Gonzales, G.F. Evaluating the diagnostic performance of hemoglobin in the diagnosis of iron deficiency anemia in high-altitude populations: A scoping review. *Int. J. Environ. Res. Public Health* **2023**, *20*, 6117. [CrossRef] [PubMed]
14. Gonzales, G.F.; Vásquez-Velásquez, C.; Yucra, S.; Tapia, V.; Gasco, M.; Suchdev, P.S.; Rees, C.A.; Aguilar, J. The new WHO cut-off point for defining high-altitude anemia may be inadequate. *Inquiry* **2025**, *62*, 469580251372827. [CrossRef] [PubMed]
15. Cabada, M.M.; Goodrich, M.R.; Graham, B.; Villanueva-Meyer, P.G.; Deichsel, E.L.; Lopez, M.; Arque, E.; White, A.C. Prevalence of intestinal helminths, anemia, and malnutrition in Paucartambo, Peru. *Rev. Panam. Salud Publica* **2015**, *37*, 69–75. [PubMed]
16. Cabada, M.M.; Morales, M.L.; Lopez, M.; Reynolds, S.T.; Vilchez, E.C.; Lescano, A.G.; Gotuzzo, E.; Garcia, H.H.; White, A.C. *Hymenolepis nana* impact among children in the highlands of Cusco, Peru: An emerging neglected parasite infection. *Am. J. Trop. Med. Hyg.* **2016**, *95*, 1031–1036. [CrossRef] [PubMed]
17. Zavala, G.A.; García, O.P.; Camacho, M.; Ronquillo, D.; Campos-Ponce, M.; Doak, C.; Polman, K.; Rosado, J.L. Intestinal parasites: Associations with intestinal and systemic inflammation. *Parasite Immunol.* **2018**, *40*, e12518. [CrossRef] [PubMed]
18. Pita-Rodríguez, G.M.; Chávez-Chong, C.; Lambert-Lamazares, B.; Montero-Díaz, M.; Selgas-Lizano, R.; Basabe-Tuero, B.; Alfonso-Sagué, K.; Díaz-Sánchez, M.E. Influence of inflammation on assessing iron-deficiency anemia in Cuban preschool children. *MEDICC Rev.* **2021**, *23*, 37–45. [CrossRef] [PubMed]
19. von Elm, E.; Altman, D.G.; Egger, M.; Pocock, S.J.; Gøtzsche, P.C.; Vandenbroucke, J.P.; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Lancet* **2007**, *370*, 1453–1457. [CrossRef] [PubMed]
20. Tello, R.; Terashima, A.; Marcos, L.A.; Machicado, J.; Canales, M.; Gotuzzo, E. Highly effective and inexpensive parasitological technique for diagnosis of intestinal parasites in developing countries: Spontaneous sedimentation technique in tube. *Int. J. Infect. Dis.* **2012**, *16*, e414–e416. [CrossRef] [PubMed]
21. Jou, J.M.; Lewis, S.M.; Briggs, C.; Lee, S.-H.; De La Salle, B.; McFadden, S.; International Council for Standardization in Haematology (ICSH). ICSH review of the measurement of the erythocyte sedimentation rate. *Int. J. Lab. Hematol.* **2011**, *33*, 125–132. [CrossRef] [PubMed]
22. Gomila Sard, B.; Toledo Navarro, R.; Esteban Sanchis, J.G. Amebas intestinales no patógenas: Una visión clinicoanalítica. *Enferm. Infecc. Microbiol. Clin.* **2011**, *29*, 20–28. [CrossRef] [PubMed]
23. Ministerio de Salud Resolución Ministerial N.° 250-2017-MINSA. Available online: https://www.gob.pe/institucion/minsa/normas-legales/189840-250-2017- (accessed on 7 October 2026).
24. Zou, G. A modified Poisson regression approach to prospective studies with binary data. *Am. J. Epidemiol.* **2004**, *159*, 702–706. [CrossRef] [PubMed]
25. Newcombe, R.G. Interval estimation for the difference between independent proportions: Comparison of eleven methods. *Stat. Med.* **1998**, *17*, 873–890. [CrossRef]
26. Merrill, R.D.; Burke, R.M.; Northrop-Clewes, C.A.; Rayco-Solon, P.; Flores-Ayala, R.; Namaste, S.M.; Serdula, M.K.; Suchdev, P.S. Factors associated with inflammation in preschool children and women of reproductive age: Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia (BRINDA) project. *Am. J. Clin. Nutr.* **2017**, *106*, 348S–358S. [CrossRef] [PubMed]
27. Rogawski, E.T.; Bartelt, L.A.; Platts-Mills, J.A.; Seidman, J.C.; Samie, A.; Havt, A.; Babji, S.; Trigoso, D.R.; Qureshi, S.; Shakoor, S.; et al. Determinants and impact of *Giardia* infection in the first 2 years of life in the MAL-ED birth cohort. *J. Pediatr. Infect. Dis. Soc.* **2017**, *6*, 153–160. [CrossRef] [PubMed]
28. Maizels, R.M.; McSorley, H.J. Regulation of the host immune system by helminth parasites. *J. Allergy Clin. Immunol.* **2016**, *138*, 666–675. [CrossRef] [PubMed]
29. Caravedo, M.A.; Morales, M.L.; Tanabe, M.; Lopez, M.; White, A.C.; Cabada, M.M. Demographic characteristics and low iron status markers are associated with hemoglobin levels and anemia among children living at high elevation in Cusco, Peru. *Am. J. Trop. Med. Hyg.* **2024**, *110*, 1014–1020. [CrossRef] [PubMed]
30. Baquerizo-Sedano, L.; Chaquila, J.A.; Aparco, J.P.; Torres Salinas, C.; Woolcott, O.O.; González-Muniesa, P. Extreme variability of anemia prevalence in Peruvian children based on different altitude correction factors: A cross-sectional study. *High Alt. Med. Biol.* **2025**, *26*, 374–381. [CrossRef] [PubMed]
31. Keiser, J.; Utzinger, J. The drugs we have and the drugs we need against major helminth infections. *Adv. Parasitol.* **2010**, *73*, 197–230. [CrossRef] [PubMed]

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