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Anemia and intestinal parasites in farmers and family members and sheep in two agro-ecological zones in Senegal

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ABSTRACT

The burden of anemia in Senegal is high, particularly in children and women in rural households. The main objectives of the study reported here were (i) to measure and compare the prevalence of anemia and intestinal parasitic infections in farmers and family members and sheep in two agro-ecological zones in Senegal and (ii) to examine the association between anemia and age or sex in farmers and family members. The study was conducted in Mpal (250 km from Dakar, the capital city) and Diawara (700 km from Dakar, a remote location near the Malian border). **In humans**, the prevalence of anemia was higher in Diawara (64/86 = 74%), compared to Mpal (13/29 = 45%) ($p < 0.01$). Using logistic regression, the odds of anemia were 20.3, 5.7, and 3.2 times higher in children 1–4 years old, children 5–12 years-old, and teenagers 13–19 years old, respectively, compared to adults 20–60 years old, after controlling for study site and sex ($p < 0.05$). In Diawara, the odds of anemia were 2.9 times higher in women, compared to men, after controlling for age ($p = 0.06$). The prevalence of intestinal parasites (*Giardia* sp.) was the same (7%) at both locations. **In sheep**, the prevalence of low packed cell volume (PCV) and low body condition was higher in Diawara (48/60 = 60% and 11/60 = 18%, respectively), compared to Mpal (23/46 = 50% and 0/46 = 0%, respectively) ($p < 0.05$). Clinical anemia was associated ($p < 0.01$) with low PCV and a positive diagnosis of *H. contortus*. **Overall,** the prevalence of anemia was higher in farmers and family members and owned sheep in Diawara. In addition, anemia was more common in children and women, an indication that intra-household food allocation may be regulated in favor of men and older age groups. The consequences of livestock affected with anemia and undernutrition can be significant. High morbidity and mortality in livestock can lead to low household income, inadequate household access to and individual consumption of animal source foods, and subsequent risk of anemia in children and women in rural households in Senegal.

1. Introduction

The burden of anemia in Senegal is high, particularly in children and women. In a national study, the prevalence of anemia in children less than five years-old and women 15–49 years-old was 65–85% and 53–56%, respectively [1]. In that study, the prevalence of severe anemia in children was higher in rural households (7%), compared to urban households (2%). A high prevalence of anemia presents an obstacle to reducing maternal and neonatal mortality and to healthy early childhood development [2]. In Senegal, the most important cause of anemia is due to dietary iron deficiency associated with a diet poor in bioavailable iron, deficiencies of folate, vitamin B12, and vitamin A; other causes include malaria parasitemia, schistosomiasis, and intestinal parasite infections [3–5].

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Although livestock ownership can provide food security and access to animal source foods (ASF), evidence that it can improve anemia in children and women, or nutrition and health in children is inconclusive [6,7]. In one study, livestock ownership was associated with higher ASF consumption, but the odds of child anemia were 10% higher in households with livestock, compared to those without [6]. In another study, livestock ownership had a protective effect on stunting in rural children in 22 of 30 Sub-Saharan African countries, but not in Senegal and seven other countries [7]. In another study, rural community members responded that livestock are needed for income, not for consumption, and are sold to finance education and health care [8]. In addition, even when livestock products are consumed, food allocation can be highly regulated within the family in favor of men and older age groups; but the strength of evidence of this practice is not strong [8,9].

Senegal remains one of the world's poor countries, with average per capita GDP of only $1448 per year in 2017 [10]. Rural households in Senegal rely on several sources of farm and non-farm income including crops, livestock, wage labor, and remittances [11]. About 80% of rural households keep livestock, and 50% of them receive income from livestock sales [12]. Annual income per household is higher in regions close to Dakar, the capital city, compared to those in more remote areas; contributing social factors include road infrastructure, access to markets, and access to relatively high-return non-farm opportunities [11,12]. Livestock are important sources of income in remote rural households, but they only contribute ≤16% of household income due to starvation, diseases, low productivity, and low incentives for commercialization of livestock [11,12].

Intestinal parasite infections are considered a major cause of low productivity and mortality in small ruminants in Sub-Saharan Africa [13]. *Haemonchus contortus* (a highly pathogenic blood-feeder that causes anemia) is the most economically significant parasite in small ruminants worldwide. Its short generation interval leads to severe parasitism and rapid development of anthelmintic resistance, resulting in anemia and mortality if appropriate treatment is not provided [14]. In Senegal, knowledge about the burden of anemia and intestinal parasite infections in small ruminants is very limited. In one study, the frequency of small ruminants with a positive diagnosis of *H. contortus* at a slaughter facility in Dakar was 3/30 (10%) [15]. In another study, 796/1024 (78%) sheep were diagnosed with *H. contortus* at slaughter [16]. To our knowledge, the prevalence of confirmed anemia in sheep in Senegal has not been investigated.

The objectives of the study reported here were (i) to measure and compare the prevalence of anemia and intestinal parasite infections in farmers, family members, and sheep in two agro-ecological zones in Senegal and (ii) to quantify the magnitude of association between anemia and age or sex in farmers and family members.

2. Materials and methods

2.1. Ethical and permit approval

This study was approved by the University of Florida's Institutional Review Board (protocol # 201400702) and Institute of Animal Care and Use Committee (protocol # 201408239).

2.2. Approach

A one health approach was used to measure and compare the prevalence of anemia and intestinal parasite infections in farmers, family members, and sheep in two agro-ecological zones in Senegal.

Fig. 1. Study sites: (A) Mpal, 250 km from Dakar, near Saint Louis and (B) Diawara, 700 km away from Dakar, along the Senegal River, north of Ballou, near the borders of Mauritania and Mali.

2.3. Study sites

The study was conducted on two farms with sheep in Mpal and Diawara, along the Senegal River during 15–26 June 2015 (Fig. 1). The two farms are part of a network of sentinel sites used by the ***Institut Sénégalais de Recherches Agricoles*** **(ISRA)** for early detection of Rift Valley Fever virus infections in animals and people. Mpal is located in Sant-Louis Region, about 250 km from the capital city of Dakar. The average annual rainfall is about 380 mm, and the rainy season is from late June to early October. Diawara is a remote location in Tambacounda Region, on the Senegal River Valley, near the Malian border; about 700 km from Dakar. The average annual rainfall is about 600 mm, and the rainy season is from early June to October.

2.4. Study farms

The study farm in Mpal included about 30 family members and 50 sheep raised under agro-pastoral system conditions, with sufficient availability of feed supply for the sheep from crop residues. The study farm in Diawara included about 90 family members and 300 sheep raised under pastoral, transhumance system conditions, with insufficient access to feed supply from crop residues. A convenience sample of 29/30 (97%) family members and 46/50 (92%) sheep in Mpal, as well as 86/90 (96%) family members and 60/300 (20%) sheep in Diawara were included in the study. In humans, the study sample were those present, willing to participate, and signed a consent form. In sheep, the study sample included animals present the day investigators visited each farm (46 in Mpal and 60 in Diawara); animals were identified with an ear-tag and a unique number.

2.5. Diagnosis of anemia in humans

A finger-stick capillary-blood sample was collected from study participants by medical personnel from the Ministry of Health in Diawara and Mpal by using a HemoCue microcuvette [HemoCue, Angelhölm, Sweden]. The sample was tested on-site for diagnosis of anemia as defined by **World Health Organization (WHO)** guidelines (normal: Hemoglobin (Hb) $\geq$ 12.0 g/dL; mild anemia: Hb 11.0–11.9 g/dL; moderate anemia: Hb 7.1–10.9 g/dL; severe anemia: Hb $\leq$ 7.0 g/dL). Anemia status was assessed by measuring Hb concentration using the HemoCue photometer at a field laboratory set up next to a *Poste de la Santé* on each study site.

2.6. Diagnosis of intestinal parasites in humans

Medical personnel from the Ministry of Health in Diawara and Mpal coordinated sanitary procedures for collection of fecal samples from study subjects after normal defecation. A first fecal sample was collected the following day (day 2) and a second sample was collected the day after (day 3). Fecal samples were submitted to at a designated laboratory at the *Centre Hospitalier National Universitaire Fann* in Dakar for further processing. Diagnosis of intestinal parasites in human fecal samples was performed using the formalin-ethyl acetate sedimentation technique [17]. Two direct smears of fresh feces preserved with Zinc-PVA were prepared from each sample and stained following standard trichrome procedures for identification of intestinal protozoa [18].

2.7. Diagnosis of anemia in sheep

The FAMACHA© system was used for identification of sheep affected with clinical anemia [18]. The color of the ocular mucous membranes of sheep were examined by two University of Florida veterinarians (FPM and SMR) and classified into one of five categories according to the FAMACHA© eye color chart: 1 = red, non-anemic; 2 = red-pink, non-anemic; 3 = pink, mildly-anemic; 4 = pink-white, anemic; 5 = white, severely anemic. In this study, scores of 3–5 were used to classify sheep as affected with clinical anemia. In addition, blood samples were collected (via jugular venipuncture into EDTA tubes) to measure **packed cell volume (PCV)**. Blood samples were kept cool and processed within 48 h after collection at a designated laboratory at ISRA in Dakar.

2.8. Diagnosis of intestinal parasites in sheep

Fecal samples were collected rectally from sheep by the University of Florida veterinarians. Feces were placed in a sealed specimen cup, properly identified and maintained at 4 °C until processed at ISRA. Samples were evaluated by centrifugational fecal flotation procedure using Sheather's solution (specific gravity = 1.25–1.27) [17]. If parasite ova were observed during the flotation procedure, a modified McMaster's fecal quantification exam was performed using two grams of feces to determine the eggs per gram of feces for each parasite in each animal [17]. Samples containing eggs of the family Trichostrongylidae (trichostrongyles) with at least 100 eggs per gram of feces and two grams of remaining feces were further examined using a fluorescein-labeled peanut agglutinin assay for identification of *H. contortus* eggs [19].

2.9. Data collection

In humans, the following data were collected form each study subject: site (Diawara, Mpal), study number identification, age (years), sex (male, female), anemia (normal, mild, moderate, severe), and diagnosis of intestinal parasites (positive, negative). **In sheep**, the following data were collected: site, ear-tag number, age (lamb, adult), sex, body condition score (1.0 = thin to 5.0 = fat), body weight (kg) estimated via weight tape, PCV (low $\leq$26%; normal = 27–45%), FAMACHA© score (1–5), and diagnosis of intestinal parasites. Body condition scores were measured by palpation of the lumbar vertebrae and associated soft tissue using a scale of one (thin) to five (fat) with subcategories where appropriate (e.g., 2.5 for scores in between 2 and 3).

2.10. Data analysis

In humans, age, sex, anemia, and a positive diagnosis of intestinal parasites were compared between study sites by using a chi-square test. Body weight was compared between sites by using the Wilcoxon rank sum test. Logistic regression was used to quantify the magnitude of association between anemia and age and sex in humans, after controlling for study site. **In sheep**, age, sex, FAMACHA© scores, PCV, low body condition, late pregnancy, and positive diagnosis of intestinal parasites were compared between sites by using a chi-square test. Body weight was compared between sites by using the Wilcoxon rank sum test. Associations between FAMACHA© scores and PCV values or a positive diagnosis of *H. contortus* were tested by using the Kruskal-Wallis test and a chi-square test, respectively. Finally, the association between low PCV and low body condition was tested by using a chi-square test. In all analyses, p-values <0.05 were considered significant.

3. Results

3.1. Anemia in humans

The prevalence of anemia was higher in Diawara (64/86 = 74%), compared to Mpal (13/29 = 45%) ($p < 0.01$) (Table 1). Among females, the prevalence was higher in Diawara (44/55 = 80%), compared to Mpal (4/15 = 27%) (p < 0.01).

3.2. Intestinal parasites in humans

Overall, the prevalence of intestinal parasite infections in humans in Diawara and Mpal was 8/115 = 7% (95% CI = 4%, 13%). *Giardia* sp. was the only parasite diagnosed in fecal samples. The prevalence was not different between Diawara (6/86 = 7%) and Mpal (2/29 = 7%) ($p =$

Table 1
Study sample and prevalence of anemia and intestinal parasite infections in farmers and family members in Diawara and Mpal.

Variable	Category	All $n = 115$ (100%)	Diawara $n = 86$ (100%)	Mpal $n = 29$ (100%)	p
Study sample					
Sex[1]	Female	70 (60.9)	55 (64.0)	15 (51.7)	0.24
	Male	45 (39.1)	31 (36.0)	14 (48.3)	
Age[1]	20-60 years	39 (33.9)	26 (30.2)	13 (44.8)	0.40
	13–19	17 (14.8)	14 (16.3)	3 (10.3)	
	5–12	38 (33.0)	31 (36.0)	7 (24.1)	
	1–4	21 (18.3)	15 (17.4)	6 (20.7)	
Pregnant women 20–60 years old[1]	No	24 (85.7)	15 (83.3)	9 (90.0)	0.62
	Yes	4 (14.3)	3 (16.7)	1 (10.0)	
Body weight (kg) by age group[2,3]	20–60 years	65.0 (59.0, 80.0)	63.5 (51.5, 78.0)	70.0 (64.0, 91.0)	0.04
	13–19	43.0 (31.5, 65.0)	40.5 (29.7, 67.5)	58.0 (38.0, 65.0)	0.57
	5–12	17.5 (13.7, 21.2)	16.0 (13.0, 20.0)	22.0 (15.0, 24.0)	0.07
	1–4	8.0 (6.5, 10.0)	8.0 (6.0, 8.0)	14.5 (9.5, 18.2)	< 0.01
Anemia					
All	Normal	38 (33.0)	22 (25.6)	16 (55.2)	< 0.01
	Mild	36 (31.3)	28 (32.6)	8 (27.6)	
	Moderate	41 (35.6)	36 (41.8)	5 (17.2)	
All	No	38 (33.0)	22 (25.6)	16 (55.2)	< 0.01
	Yes	77 (67.0)	64 (74.4)	13 (44.8)	
Anemia in females[1]	No	22 (31.4)	11 (20.0)	11 (73.3)	< 0.01
	Yes	48 (68.6)	44 (80.0)	4 (26.7)	
Anemia in males[1]	No	16 (35.5)	11 (35.5)	5 (35.7)	0.99
	Yes	29 (64.5)	20 (64.5)	9 (64.3)	
Intestinal parasites					
Intestinal parasites (*Giardia* spp)[1]	No	107 (93.0)	80 (93.0)	27 (93.1)	0.98
	Yes	8 (7.0)	6 (7.0)	2 (6.9)	

[1] Data are reported as n (%).
[2] Data are reported as median (first, third quartiles).
[3] Normal: Hb ≥ 12.0 g/dL; Mild: Hb 11.0–11.9 g/dL; Moderate: Hb 7.1–10.9 g/dL.

0.98). The prevalence was higher in females (7/70 = 10%), compared to males (1/45 = 2%); but the difference was not significant ($p = 0.10$). In addition, the prevalence was not different between age groups (2/39 = 5% in 1–4 years-old; 1/17 = 6% in 5–12 years-old; 3/38 = 8% in 13–19 years-old; and 2/21 = 10% in 20–60 years-old) ($p = 0.91$).

3.3. Anemia in humans as a function of region, age, and sex

Using logistic regression, the odds of anemia were 3.8 times higher in Diawara, compared to that in Mpal, after controlling for sex and age ($p < 0.01$) (Table 2A). The association between anemia and region was not confounded by age or sex. Overall, the odds of anemia were 20.3, 5.7, and 3.2 times higher in children 1–4 years-old, 5–12 years-old, and teenagers 13–19 years-old, respectively, compared to adults 20–60 years-old, after controlling for sex and site ($p < 0.05$). The Hosmer–Lemeshow goodness of fit test (2.64; df = 5; $p = 0.75$) indicated there is no evidence of a poor fit for the data. A positive diagnosis of intestinal parasites was not associated with anemia ($p = 0.78$). In Diawara, the odds of anemia were 2.9 times higher in females, compared to males, after controlling for age ($p = 0.06$) (Table 2B). In Mpal, anemia was not associated with sex, after controlling for age (p = 0.48) (Table 2C).

3.4. Anemia in sheep

The prevalence of clinical anemia was higher in sheep in Diawara (28/60 = 47%), compared to Mpal (17/46 = 37%); but the difference was not significant ($p = 0.33$) (Table 3). The frequency of sheep with low PCV was higher in Diawara (48/60 = 80%) compared to Mpal (23/46 = 50%) ($p < 0.01$). Finally, frequency of sheep with low body condition (score < 3.0) was higher in Diawara (10/60 = 17%) compared to Mpal (0/46 = 0%) (p < 0.01).

3.5. Intestinal parasites in sheep

The prevalence of intestinal parasite infections was not different between Diawara (44/60 = 73%) and Mpal (35/45 = 78%) ($p = 0.65$) (Table 3). In both sites, most sheep were infected with *Eimeria* spp. or had co-infections with *Eimeria* spp. and trichostrongyles (Table 4). The frequency of sheep infected with *H. contortus* was not different between Diawara 7/60 = 12% and Mpal 4/45 = 9% ($p = 0.75$).

3.6. Associations between FAMACHA© scores and low PCV, a positive diagnosis of H. contortus, or low body condition in sheep

High FAMACHA© scores 3–4 or 4 were associated with low PCV values (Table 5) or a positive diagnosis of *H. contortus*, respectively (Table 6). In addition, low body condition was more frequent in sheep with low PCV (11/71 = 15%), compared to sheep with normal PCV (0/35 = 0%) ($p = 0.01$).

4. Discussion

4.1. Anemia in humans

The odds of anemia were 3.8 higher in farmers and family members

Table 2A
Univariable and multivariable analyses of anemia as a function of site, age, and sex in farmers and family members in Diawara and Mpal.

Variable	Category	n	OR	95% CI	p	aOR	95% CI	p
Site	Mpal	29	1.00	-	-	-	-	-
	Diawara	86	3.58	1.49, 8.61	< 0.01	3.84	1.38, 1.11	< 0.01
Age (years)	20–60	39	1.00	-	-	-	-	-
	13–19	17	3.45	1.02, 11.71	0.04	3.24	0.90, 11.70	0.03
	5–12	38	5.39	1.97, 14.76	< 0.01	5.79	1.94, 17.24	< 0.01
	1–4	21	13.65	2.83, 65.96	< 0.01	20.36	3.53, 117.20	< 0.01
Sex	Male	45	1.00	-	-	-	-	-
	Female	70	1.20	0.56, 2.66	0.64	1.83	0.70, 4.77	0.17

OR = crude odds ratio.
aOR = adjusted odds ratio.
95% CI = 95% confidence interval.
Hosmer-Lemeshow statistic = 2.64; df = 5; $p = 0.73$.

Table 2B
Univariable and multivariable analyses of anemia as a function age and sex in farmers and family members in Diawara.

Variable	Category	n	OR	95% CI	p	aOR	95% CI	p
Age (years)	20–60	26	1.00	-	-	-	-	-
	13–19	14	3.67	0.83, 16.26	0.08	4.21	0.89, 19.87	0.26
	5–12	31	5.20	1.52, 17.75	< 0.01	6.77	1.81, 25.33	< 0.01
	1–4	15	13.94	1.72, 112.72	0.01	15.08	1.65, 137.10	< 0.01
Sex	Male	31	1.00	-	-	-	-	-
	Female	55	2.20	0.82, 5.91	0.11	2.96	0.95, 9.26	0.06

Hosmer-Lemeshow statistic = 5.93; df = 4; *p* = 0.20.

Table 2C
Univariable and multivariable analyses of anemia as a function age and sex in farmers and family members in Mpal.

Variable	Category	n	OR	95% CI	p	aOR	95% CI	p
Age (years)	20–60	13	1.00	-	-	-	-	-
	13–19	3	1.67	0.11, 25.40	0.71	1.56	0.09, 24.73	0.75
	5–12	7	4.44	0.62, 32.05	0.13	3.62	0.46, 28.48	0.22
	1–4	6	16.67	1.36, 203.92	0.02	10.10	0.58, 175.60	0.11
Sex	Male	14	1.00	-	-	-	-	-
	Female	15	0.20	0.04, 0.98	0.04	0.50	0.07, 3.47	0.48

Hosmer-Lemeshow statistic = 1.13; df = 3; *p* = 0.76.

in Diawara, compared to Mpal after controlling for age and sex. In Senegal, the most important cause of anemia is due to dietary iron deficiency associated a diet poor in bioavailable iron, deficiencies of folate, vitamin B12, and vitamin A [3]. Although study subjects in both locations owned livestock and had access to ASF, it is possible that consumption of ASF was lower in farmers and family members in Diawara, compared to Mpal. In addition, two broad factors that can explain a higher burden of anemia in Diawara, compared to Mpal, are geographic region and income. The average annual income per household is 2–3 times higher in regions close to Dakar, the capital city, compared to those in more remote areas [11,12]. Contributing factors that affect remote communities in Senegal include poor road infrastructure, difficult market access, and less opportunities for household income diversification outside farming [11].

The odds of anemia were 20, 5, and 3 times higher in children 1–4 years-old, children 5–12 years-old, and teenagers 13–19 years-old, respectively, compared to adults 20–60 years-old, after controlling for sex and study site. In addition, in Diawara, the odds of anemia were almost 3 times higher in women, compared to men, after controlling for age. These findings support observations in previous studies [7,8] which suggested that food allocation can be regulated within the family in favor of men and older age groups. Pathways and key constrains that limit incorporation of sufficient quantities of ASF in the household diet can include: low income, lack of processing and storage technology, inadequate knowledge and skills of caregivers on the importance of ASF, low empowerment of women, and inequitable household food allocation practices [9]. Furthermore, it is known that women are at a greater risk for developing iron deficiency due to obligate iron losses through menstruation [20]. Finally, in Diawara, the higher prevalence of anemia in women, compared to men, is in line with that reported at the Region level in a national survey in Senegal [1] where the prevalence of anemia was higher in women (61%) than in men (34%) in Tambacounda Region.

4.2. Intestinal parasites in humans

Overall, the prevalence of intestinal parasites (*Giardia* sp.) in humans in Diawara and Mpal was 7% (95% CI = 4%, 13%). The fact that no helminths were detected in study subjects can be explained by a recent history of mass deworming treatment promoted by local public health services in Diawara and Mpal. The observed prevalence of *Giardia* sp. in Diawara and Mpal is lower than that reported in two previous studies in Senegal. In one study conducted in Keur Soce, 200 km South East of Dakar, in January 2010, the prevalence of *G. intestinalis* in children less than five years-old was 115/736 = 16% (95% CI = 13%, 19%) and it was the most common parasite [21]. In another study conducted at a university hospital in Dakar during 2011–2015, the prevalence of parasitic infections was 408/2578 = 16% (95% CI = 14%, 17%), including 377 mono-infections with protozoa (n = 302) and helminths (n = 75), respectively [22]. The prevalence of parasitic infections increased from 8% in 2011 to 29% in 2015, but the prevalence was not compared between dry season and rainy seasons; furthermore, the prevalence of *G. intestinalis* was 44/2578 = 2% (95% CI = 1%, 2%). It is difficult to compare and interpret prevalence estimates observed in this and previous studies identified above because they were conducted in different years or months of the year.

4.3. Anemia in sheep

In this study, more sheep were diagnosed with low PCV (anemia) and low body condition in Diawara, compared to Mpal. Because the frequency of sheep with a positive diagnosis of intestinal parasites, including *H. contortus,* was similar in Diawara and Mpal, three broad factors that can explain the observed higher frequency of anemia and low body condition in sheep in Diawara are remote geographic location, lower household income, and limited access to livestock feed resources. Annual income per household is higher in regions close to Dakar, compared to those in more remote areas [11]. Mpal is in an agricultural vegetative area of Senegal, and it is part of the groundnut basin where farmers are engaged in peri-urban semi-intensive production systems or in agro-pastoral systems; the two systems are more sedentary and have greater feed supply than pastoral systems [23,24]. In addition, Mpal is relatively close to the *Réserve Sylvo-Pastorale de Pal-Mérinaguène*, forest reserve, which can provide an additional feed source. In contrast, Diawara is in a savannah vegetation area dotted by shrub savannah trees that provide sparse grazing or browsing for livestock [24]. Diawara farmers are pastoralists. They own transhumance herds that use corridor networks within a 5–200 km radius to gain access to forage and water [25]. Livestock nutrition is compromised when livestock mobility is associated with a greater energy cost of walking (MJ metabolizable energy per day) than energy ingestion (feed dry matter per day); the energy cost is more important during the dry season when the quality of feed declines [25].

Table 3
Prevalence of anemia and intestinal parasite infections in sheep in Diawara and Mpal.

Variable	Category	Diawara n = 60 (100%)	Mpal n = 46 (100%)	p
Age group[1]	Lamb	3 (5.0)	7 (15.2)	0.07
	Adult	57 (95.0)	39 (84.8)	
Sex[1]	Male	1 (1.7)	17 (27.0)	< 0.01
	Female	59 (98.3)	29 (63.0)	
FAMACHA score[1]	1	2 (3.3)	7 (15.2)	0.17
	2	30 (50.0)	22 (47.8)	
	3	23 (38.3)	14 (30.4)	
	4	5 (8.3)	3 (6.5)	
FAMACHA score[1]	1–2	32 (53.3)	29 (63.0)	0.33
	3–4	28 (46.7)	17 (37.0)	
Packed cell volume[1]	Low ≤26%	48 (80.0)	23 (50.0)	< 0.01
	Normal = 27–45%	12 (20.0)	23 (50.0)	
Body condition score[1]	2.0	10 (16.6)	0	< 0.01
	2.5	1 (1.7)	0	
	3.0	49 (81.7)	46 (100.0)	
Intestinal parasites[1,2]	None observed	16 (26.7)	10 (22.2)	0.65
	Yes	44 (73.3)	35 (77.8)	
Body weight[3]	Kg	34.1 (28.5, 39.5)	33.0 (26.1, 39.2)	0.54
Adult females only				
Variable	Category	Diawara n = 56 (100%)	Mpal n = 24 (100%)	p
Late pregnancy[1]	No	32 (57.1)	18 (75.0)	0.13
	Yes	24 (42.9)	6 (25.0)	
FAMACHA score[1]	1	2 (3.6)	1 (4.2)	0.87
	2	29 (51.8)	10 (41.7)	
	3	21 (37.5)	11 (45.8)	
	4	4 (7.1)	2 (8.3)	
FAMACHA score[1]	1–2	31 (55.4)	11 (45.8)	0.47
	3–4	25 (44.6)	13 (54.2)	
Packed cell volume[1]	Low ≤26%	48 (85.7)	16 (66.7)	0.05
	Normal = 27–45%	8 (14.3)	8 (33.3)	
Body condition score[1]	2.0	11 (19.6)	0	0.02
	2.5	0	0	
	3.0	45 (80.4)	24 (100.0)	
Intestinal parasites[1]	None observed	15 (26.8)	8 (33.3)	0.59
	Yes	41 (73.2)	16 (66.7)	
Body weight[3]	Kg	34.6 (28.8, 39.8)	33.6 (27.9, 37.3)	0.46

[1] Data are reported as n (%).
[2] In Mpal, 45 of 46 sheep offered a fecal sample.
[3] Data are reported as median (first, third quartiles).

Table 4
Diagnosis of intestinal parasites in sheep in Diawara and Mpal*.

Parasites	Diawara n = 60 (100%)	Mpal n = 45 (100%)
None observed	14 (23.3)	10 (22.2)
Eimeria	15 (25.0)	12 (26.7)
Eimeria + Trichostrongyles	14 (23.3)	15 (33.3)
Trichostrongyles	3 (5.0)	1 (2.2)
Eimeria + Trichostrongyles (including *H. contortus*)	5 (5.0)	1 (2.2)
Trichostrongyles (including *H. contortus*)	2 (3.3)	2 (4.4)
Eimeria + Trichostrongyles + *Moniezia*	1 (1.7)	2 (4.4)
Eimeria + Trichostrongyles + *Trichuris*	2 (3.3)	
Eimeria + Trichostrongyles + Trematode	2 (3.3)	
Eimeria + *Trichuris*	1 (1.7)	
Eimeria + *Trichuris* + Pinworm	1 (1.7)	
Eimeria + *Moniezia*		1 (2.2)
Eimeria + Trichostrongyles (including *H. contortus*) + *Moniezia*		1 (2.2)

* In Mpal, 45 of 46 sheep offered a fecal sample.

Table 5
Association between FAMACHA scores and packed cell volume (PCV) in sheep.

PCV %	FAMACHA score			
	1 n = 9	2 n = 52	3 n = 37	4 n = 8
Median (1st, 3rd quartiles)	29 (27, 33)[a]	25 (23, 27)[a]	22 (20, 25)[b]	20 (17, 22)[b]

[a,b]Within row, groups with different superscripts are different ($p < 0.05$).

Table 6
Association between FAMACHA scores and a positive diagnosis of *Haemonchus contortus* in sheep.

H. contortus	FAMACHA score			
	1 n = 8 (100%)	2 n = 52 (100%)	3 n = 37 (100%)	4 n = 8 (100%)
Positive	1 (12.5%)[a,b]	3 (5.7%)[a]	2 (5.4%)[a]	3 (37.5%)[b]

4.4. Intestinal parasites in sheep

In Diawara and Mpal, the prevalence of parasitic infections in sheep was high (73% and 78%, respectively). Most sheep were diagnosed with mono-infections with *Eimeria* spp. or co-infections with *Eimeria* and trichostrongyles; the observed mono- and co-infections agree with previous studies in small ruminants of Western African countries [26]. Fecal samples were collected at the end of the dry season (June) when some species of trichostrongyle larvae that have arrested their development in the host mature and repopulate the intestine as adults, leading to increasing numbers of eggs on pasture [27], as it has been documented in *H. contortus* in sheep in Senegal [13] and Kenya [28]. Some studies have suggested the *H. contortus* hypobiotic larvae also exist with adult worms in the intestine regardless of climatic events [14,28]. In this study, adult and larval parasite burdens were not directly analyzed; thus, the full extent of the role hypobiosis may have had in study results is unknown. Finally, the prevalence of *H. contortus* was similar in Diawara (12%) and Mpal (9%); the prevalence could be expected to be higher at the end of the rainy season (end of September) [13].

5. Conclusions

The prevalence of anemia was higher in farmers and family members in Diawara (a remote location near the Malian border), compared to Mpal (which is located closer to the capital city of Dakar). In addition, anemia was more common in children and women, an indication that intra-household food allocation may be regulated in favor of men and older age groups.

The transhumance sheep herd in Diawara was more affected with anemia and low body condition, compared to the more sedentary, agro-pastoral herd in Mpal. The consequences of livestock undernutrition can be significant. High morbidity and mortality in livestock can lead to low household income, inadequate household access to and individual consumption of ASF, and subsequent risk of anemia in children and women in rural households in Senegal.

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Declaration of Competing Interest

The authors declare no competing interests.

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