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Paper

Investigating Seasonal and Host Sex-Age Effects on Endoparasites in a Captive population of the Vulnerable Barbary sheep (North Algeria)

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Abstract

This study examines the seasonal and host sex-age effects on endoparasite infections in a captive population of Barbary sheep (*Ammotragus lervia*) at the Ben Aknoun zoological park, Algiers, northern Algeria. A total of 440 faecal samples were collected from May 2024 to April 2025 and processed using direct smears and a modified McMaster flotation technique. Parasite prevalence and intensity were analysed using generalised linear mixed models (GLMMs), followed by Tukey-adjusted pairwise comparisons between seasons and host sex-age classes. Microscopic examinations revealed nematodes (strongyles and *Strongyloides* sp.), cestodes (*Moniezia* sp. and *Taenia* sp.), and protozoa (*Eimeria* spp. and *Balantidium* sp.). Overall parasite prevalence was high (72.05±2.14%) ranging from 68.75 ±4.38% in summer to 74.07±4.22 % in spring. Strongyles (47.05±2.38%) and *Eimeria* spp. (46.59±2.38%) were the most prevalent, while *Strongyloides* sp. showed the lowest prevalence (10.45±1.46%). Overall parasite prevalence did not vary significantly among seasons or sex-age groups ($p > 0.05$ for all seasonal and sex-age class contrasts), however, *Eimeria* spp. and *Balantidium* sp. prevalence showed significant seasonal differences, both peaking in the wet season. Intensity varied significantly between sex-age classes for *Moniezia* sp. with adult animals having higher mean egg counts than juveniles; and for *Balantidium* sp. with males having higher mean cyst counts than females and juveniles. Parasitological surveillance especially of vulnerable host classes during periods of risk, anti-parasitic treatments based on confirmed infection cases, and improved enclosure hygiene are needed to preserve animal health and to support conservation efforts for this threatened ungulate species.

Keywords

Ammotragus lervia, Captivity, Endoparasites, Host-parasite, seasonality

Introduction

Ammotragus lervia (Pallas, 1777), commonly known as the Aoudad or Barbary sheep, is currently classified by the International Union for Conservation of Nature (IUCN) as Vulnerable under criterion C1. The Aoudad was widely distributed across rugged and mountainous habitats, ranging from deserts and semi-deserts to open forests throughout North Africa. However, the species has undergone a significant population decline, primarily due to poaching and competition with domestic livestock (Bounaceur et al., 2016; Cassinello et al., 2022).

Although precise population estimates are lacking, current assessments suggest a total of approximately 5,000–10,000 mature individuals (Cassinello et al., 2022). In Algeria, some natural populations are thought to persist, in addition to other populations kept within protected reserves and conservation areas (Bounaceur et al., 2016; Bounaceur et al., 2022). Our surveys have identified the presence of around 50 Barbary sheep within the Ben Aknoun Civil Concord Zoological and Leisure Park (*Parc Zoologique et de Loisir la Concorde Civile*, *Ben Aknoun*), located in Algiers, the capital of Algeria. Nevertheless, diseases, including those caused by parasitic infections, may threaten the successful maintenance of wild animals in captivity.

Endoparasites can adversely affect host health, reproduction, and survival, making parasitological monitoring a fundamental component of wildlife management in captivity, as it enables the identification of parasite diversity and prevalence while also supporting the management of health risks, the detection of zoonotic threats, and a better understanding of parasite transmission within confined environments.

Previous studies have documented the presence of various endoparasites in captive *Ammotragus lervia*. Reported taxa include gastrointestinal nematodes such as *Trichostrongylus* spp. and *Nematodirus* spp., as well as protozoan parasites such as *Eimeria* spp. and *Toxoplasma gondii* (Cherif et al., 2024; Kamel and Abdel-Latef, 2021; Taki, 2023). However, despite the conservation importance of this species, current knowledge remains largely descriptive and fragmented, with most available studies based on limited sample sizes and short durations. In particular, data on the influence of seasonal fluctuations and host-related factors, such as sex and age, on parasitic infections in captive *Ammotragus lervia* are scarce, and population-level epidemiological patterns remain poorly documented, especially in North Africa.

Seasonal variations, particularly changes in temperature and rainfall, play a role in determining the survival, development, and transmission of parasitic stages in the environment (Altizer et al., 2006), while host sex and age are consistently associated with differences in parasitic infection levels (Hayward et al., 2009; Poulin, 1996). However, parasitism patterns can be altered under captive conditions (Dărăbuş et al., 2014). Therefore, the present study aims to investigate the prevalence and intensity (Margolis et al., 1982) of endoparasites in the captive population of Barbary sheep at the Ben Aknoun Zoological Park (Algiers, Algeria), with particular emphasis on the effects of seasonal variation and host sex-age classes on these parameters, using a non-invasive coprological approach.

Materials and methods

Study site

The Ben Aknoun Park, located approximately at 36° 44′ 56″ North and 3° 00′ 24″ East, lies in the heart of the urban area of Algiers, Algeria. Established in 1982, it is recognised as the first major amusement park and zoo in Algiers. It spans an extensive area of 304 hectares, including approximately 200 hectares of wooded forest (Figure 1).

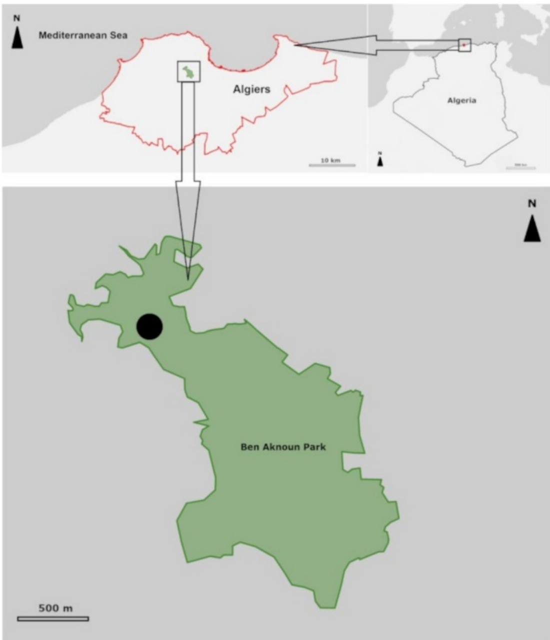

Figure 1. Map showing the location of the study area, with the black circle indicating the sampling site.

The zoological structure of the park comprises three main animal zones: the *Village Africain* (African Village), the *Cirque des Fauves* (Big Cats Arena), and the *Colline des Antilopes* (Antelope Hill), where species such as Barbary sheep are housed in enclosed and secure habitats. Access to enclosures is strictly limited to veterinarians and animal caretakers.

The Ben Aknoun region has a Mediterranean climate marked by hot and dry summers and relatively mild wet winters. Climate data for the study period were obtained from the climate dataset produced by the Copernicus Climate Change Service of the European Centre for Medium-Range Weather Forecasts for the Ben Aknoun zoo area (Muñoz Sabater, 2019) (Figure 2).

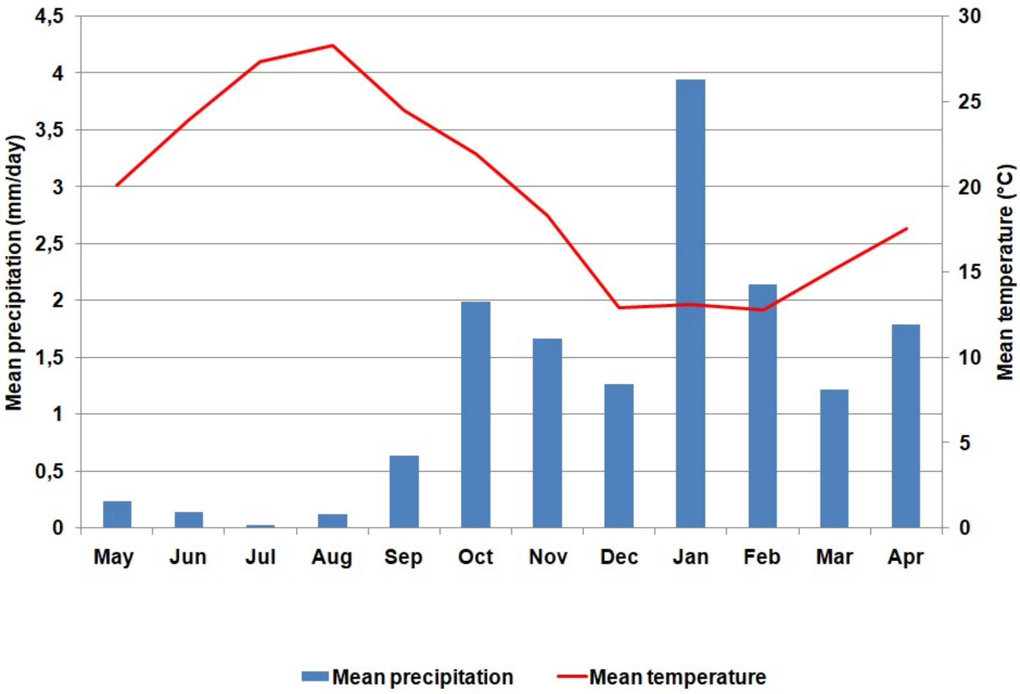

Figure 2. Climatic records (mean precipitation and mean temperature) in Ben Aknoun during the study period.

Population size and structure

According to zoo staff, the Barbary sheep population remained stable at approximately 50 individuals throughout the study period. This estimate was consistent with repeated visual observations conducted by us during sampling sessions, although counts were performed from a distance in accordance with zoo safety regulations, and visibility was sometimes limited by enclosure features. The herd was reported to have a relatively balanced sex ratio between males and females, with juveniles present in smaller numbers. All animals were born within the park, and no transfers (additions or removals) were recorded during the study period. A single juvenile mortality was reported shortly after the final sampling event in April 2025, but the cause of death was not communicated.

Anti-parasitic treatments

According to zoo veterinarians, an antiparasitic treatment protocol is routinely implemented for Barbary sheep. Treatments are administered orally by mixing anti-parasitic agents with feed, either every three months or once during each major season (dry and wet). The antiparasitic agents used include ivermectin, albendazole, and fenbendazole. However, during the study period, the only confirmed treatment events occurred in January and April 2025, both of which took place after our monthly sampling. The specific compounds used during each treatment event were not reported. Because treatments were expected to influence our results, the study design incorporated monthly rather than seasonal sampling in order to reduce their potential confounding effects on infection dynamics and to provide more representative estimates of seasonal infection patterns.

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Sampling method

A total of 440 freshly deposited faecal samples were collected from the enclosure over a 12-month period (May 2024 - April 2025), yielding 109 samples in winter, 108 in spring, 112 in summer, and 111 in autumn.

To reduce repeated sampling, defecation sites were not sampled more than once. When possible, samples were collected immediately after direct observation of defecation, allowing accurate identification of animal sex and age class (male, female, or juvenile) (Bounaceur et al., 2022). For samples from unobserved animals, sex and age were inferred from pellet morphology following Bachiri et al. (2021). Male pellets were generally larger and oblong with a pointed tip, female pellets were intermediate in size and stockier, and juvenile pellets were smaller and rounded. Across the study period, we were able to collect 198 female samples, 188 male samples, and 54 juvenile samples. The smaller number of juvenile samples reflects the lower population size of this age group within the enclosure. We acknowledge that pellet size and shape may vary depending on environmental factors and animal conditions, which may introduce some degree of misclassification. In the present study, pellet morphology was used to provide a broad classification of sex and age categories, and the resulting estimates should be regarded as approximations of demographic structure.All faecal samples were preserved in 2.5% potassium dichromate ($K_2Cr_2O_7$) to allow sporulation of potential coccidian oocysts and facilitate later identification (Dărăbuş et al., 2014). Samples were transported in cooling boxes to the Laboratory of Ecology and Biology of Terrestrial Ecosystems, University of Tizi-Ouzou, and stored at 4 °C until examination.

Parasitological analyses

Faecal samples were first examined by direct smear for preliminary parasite identification, followed by quantitative analysis using the modified McMaster method with a sodium chloride (NaCl) flotation solution of a specific gravity of 1.2 (Zajac et al., 2021). Parasitic elements were microscopically identified according to the morphological keys described by Zajac et al. (2021), and Bowman and Georgi (2021).

Data analyses

Parasite prevalence was analysed using a binomial generalised linear mixed model (GLMM), while parasite intensity was analysed using a negative binomial GLMM to account for overdispersion. Parasite intensity was expressed as eggs per gram (EPG), oocysts per gram (OPG), and cysts per gram (CPG) of faeces.Season and sex-age class were included as fixed effects. Because individual animals were not uniquely identified, some samples may have originated from the same individuals, resulting in pseudoreplication. To minimise this risk, sampling was distributed monthly across seasons to increase sample size and maximise population coverage, and month was included as a random intercept in the GLMMs to account for repeated sampling occasions. While this approach reduces bias, it does not eliminate pseudoreplication, and therefore our models support inference at the population level rather than at the individual level. Tukey-adjusted pairwise contrasts were then performed to compare prevalence and intensity between seasons, between sex-age classes, and between classes within each season.

Statistical significance was assessed at $\alpha = 0.05$. All analyses were conducted in R (version 4.5.2) (R Core Team, 2016), with mixed models fitted using the glmmTMB package (Brooks et al., 2017) and Tukey post hoc comparisons performed using the emmeans package (Lenth and Piaskowski, 2025).

Results

Parasitological analyses of *Ammotragus lervia* faecal samples from Ben Aknoun Zoo revealed nematodes (strongyles and *Strongyloides* sp.), two cestodes (*Moniezia* sp. and *Taenia* sp .) and two protozoans (*Eimeria* spp . and *Balantidium* sp.). These parasites belong to three major groups: Nemathelminthes, Platyhelminthes, and Protozoa. Although preliminary microscopy allowed tentative identification of strongyle eggs at the generic level (Figure 3), all strongyle eggs were grouped together for statistical analyses to reduce potential misclassification bias due to their morphological similarity.

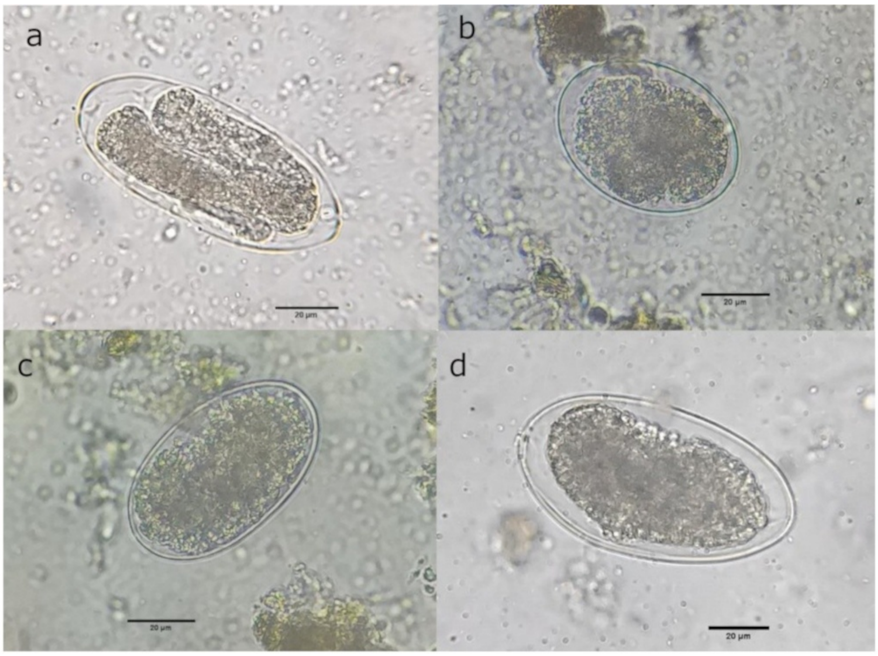

Figure 3. Photomicrographs of strongyle eggs observed under the microscope at x400 magnification. Scale bar = 20 µ: (a) *Cooperia* sp.; (b) *Oesophagostomum* sp.; (c) *Ostertagia* sp.; (d) *Trichostrongylus* sp.

Out of the 440 faecal samples examined, 317 were found to be positive, yielding an overall prevalence of 72.05 ± 2.14%. Among the identified endoparasites, strongyle-type eggs and *Eimeria* spp. were the most frequently detected, with prevalence values of 47.05 ± 2.38% and 46.59 ± 2.38% recorded for strongyles and *Eimeria* spp. respectively. The remaining parasites exhibited lower prevalence, with the lowest value (10.45 ± 1.46%) observed in *Strongyloides* sp. As for mean intensities, values ranged from 176.09 ± 10.46 EPG observed in strongyles to 74.63 ± 5.14 EPG recorded in *Taenia* sp. (Figure 4).

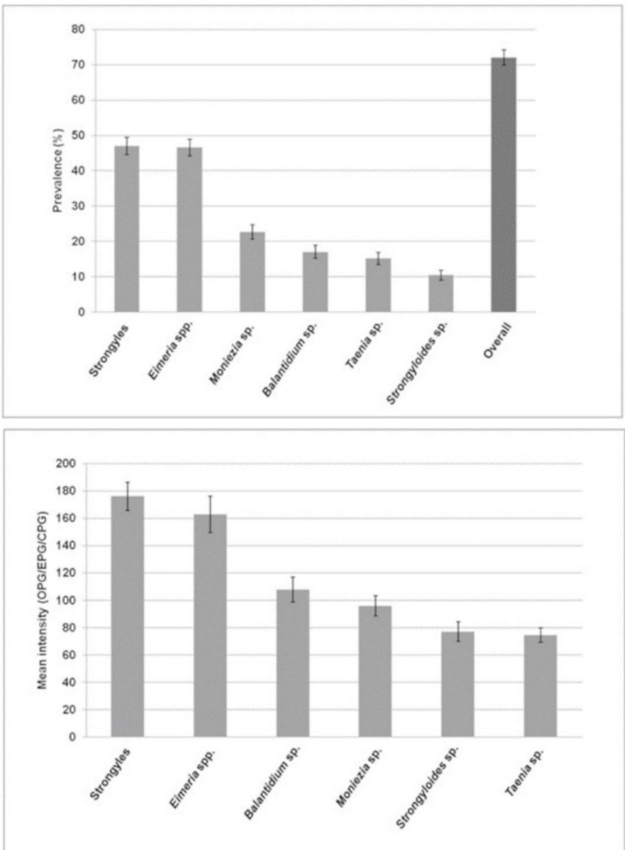

Figure 4. Parasite prevalence and mean intensities in Barbary sheep at Ben Aknoun Zoo over the study period. Prevalence and mean intensities are shown with standard error bars.

Significant pairwise contrasts from the GLMM analyses of parasite prevalence and intensity are presented in Table I. There was no significant seasonal effect on overall parasite prevalence; it remained high throughout the study period, ranging from 68.75 ± 4.38% in summer to 74.07 ± 4.22% in spring (Figure 5). Likewise, overall prevalence did not differ significantly between sex–age classes. The highest prevalence was recorded in juveniles (79.63 ± 5.48%), whereas males showed the lowest prevalence (66.49 ± 3.44%) (Figure 6). Additionally, no variation in overall prevalence between sex–age classes reached statistical significance within any season. Prevalence values for each sex-age class across seasons are shown in Figure 7.

GLMM Model	Parasite taxa	Pairwise comparisons	Odds ratio	*p*-values
Binomial (Prevalence)	*Balantidium* sp.	Winte/Summer	5.65	$p = 0.0087$**
	Balantidium sp.	Summer/Autumn	0.21	$p = 0.0275$*
	Eimeria spp.	Winter/Spring	2.20	$p = 0.0254$*
	Eimeria spp.	Spring /Autumn	0.38	$p = 0.0031$**
	Strongyles	Females/Males (Spring)	3.46	$p = 0.0123$*
Negative binomial (Intensity)	**Parasite taxa**	**Pairwise comparisons**	**Mean count ratio**	***p*-values**
	Balantidium sp.	Females/Males	0.65	$p = 0.0042$**
	Balantidium sp.	Juveniles/Males	0.37	$p = 0.0007$***
	Balantidium sp.	Females/Males (Summer)	0.34	$p = 0.0285$*
	Moniezia sp.	Females/Juveniles	1.82	$p = 0.0182$*
	Moniezia sp.	Juveniles/Males	0.56	$p = 0.0280$*
	Moniezia sp.	Females/Juveniles (Winter)	2.37	$p = 0.0066$**
	Strongyles	Females/Males (Spring)	1.75	$p = 0.0228$*
	Strongyles	Females/Juveniles (Summer)	2.12	$p = 0.0172$*
	Strongyloides sp.	Females/Juveniles (Spring)	0.27	$p = 0.0061$**
	Strongyloides sp.	Juveniles/Males (Spring)	3.75	$p = 0.0118$*
	Taenia sp.	Females/Males (Autumn)	1.69	$p = 0.0083$**

(*) $p<0.05$: Significant; (**) $p<0.01$: Highly significant; (***) $p<0.001$: Very highly significant

Table I. Significant Tukey-adjusted pairwise contrasts from the GLMM analyses of parasite prevalence and intensity in Ammotragus lervia at Ben Aknoun Zoo, Algiers.

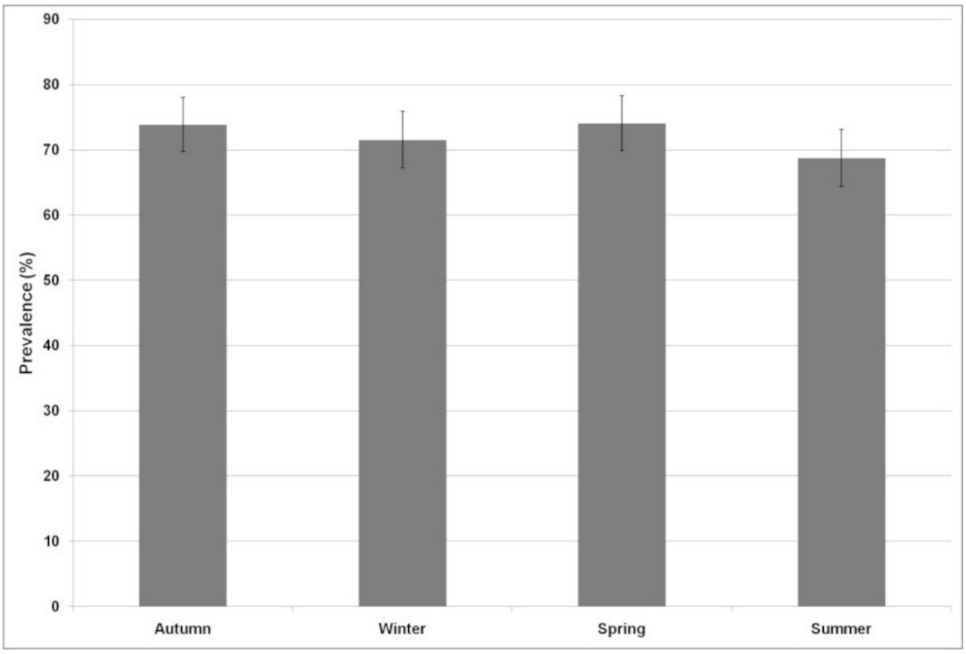

Figure 5. Seasonal overall parasite prevalence in Barbary sheep at Ben Aknoun Zoo. Prevalence values are shown with standard error bars.

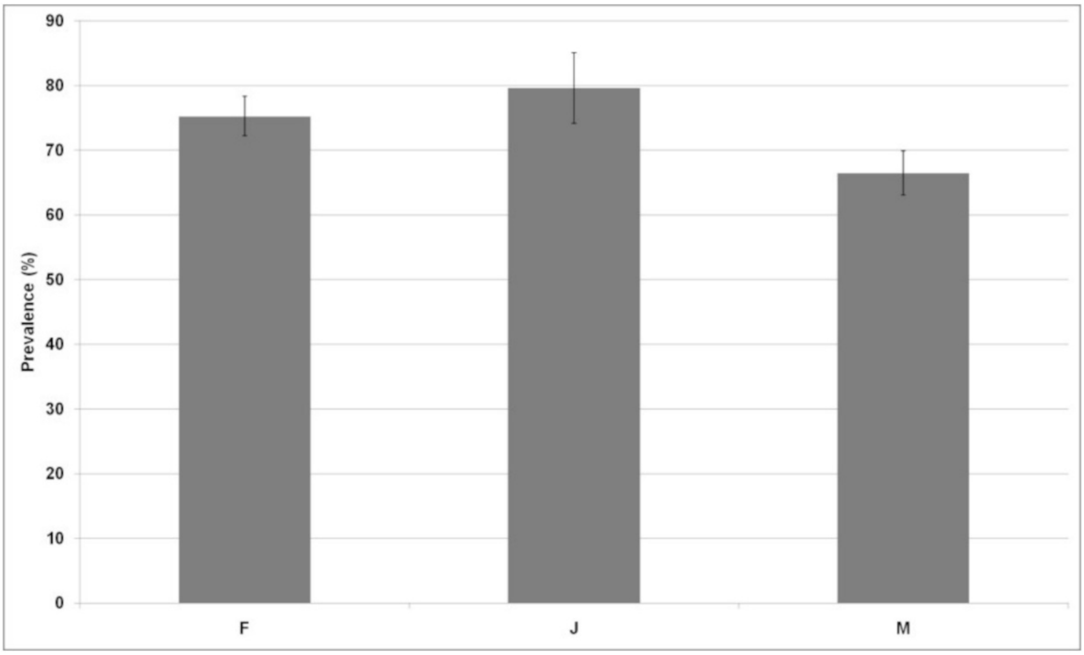

Figure 6. Overall parasite prevalence in females (F), juveniles (J), and males (M) of Barbary sheep at Ben Aknoun Zoo over the study period. Prevalence values are shown with standard error bars.

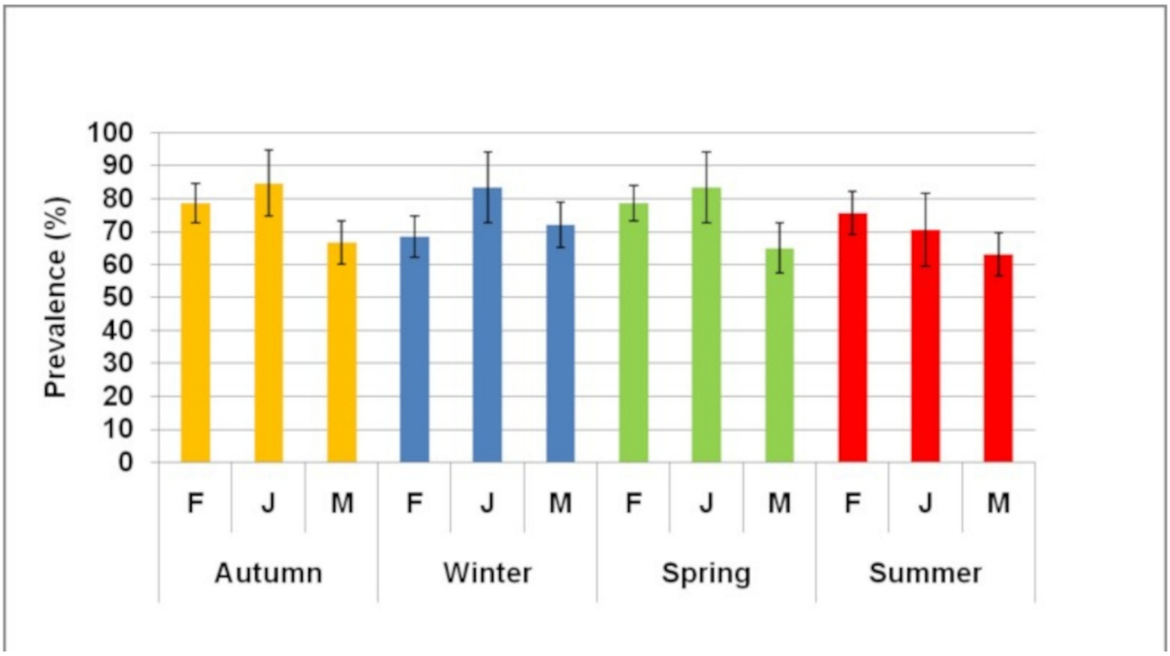

Figure 7. Overall parasite prevalence in females (F), juveniles (J), and males (M) of Barbary sheep at Ben Aknoun Zoo across seasons. Prevalence values are shown with standard error bars.

For each parasite taxon, no significant seasonal effect on strongyle prevalence was detected, with the highest prevalence being observed in spring (51.85 ± 4.81%) and the lowest in autumn (44.14 ± 4.71%) (Table II). Similarly, prevalence did not differ significantly among sex-age classes, with values ranging from 42.02 ± 3.60% recorded in males to 53.70 ± 6.79% recorded in juveniles (Figure 8). However, a significant difference was detected in strongyle prevalence in spring between females (62.50 ± 6.47%) and males (32.50 ± 7.41%) (Table III). There was no significant difference in strongyle intensity between seasons, with mean intensity ranging from 132.65 ± 12.25 EPG recorded in autumn to 225 ± 28.55 EPG recorded in spring. Also, intensity did not differ significantly among sex-age classes, with females showing the highest mean intensity (200.51 ± 18.01 EPG) and juveniles the lowest (143.10 ± 19.96 EPG) (Figure 9). However, significant contrasts were observed between females (255.71 ± 40.98 mean EPG) and males (126.92 ± 38.65 mean EPG) in spring, and between females (208.33 ± 36.66 mean EPG) and juveniles (100.00 ± 25.00 mean EPG) in summer.

Season	Parasite taxa	Prevalence ± SE (%)	Mean intensity ± SE
Autumn	*Balantidium* sp.	23.42 ± 4.02	117.31 ± 17.75
	Eimeria spp.	55.86 ± 4.71	157.26 ± 15.20
	Moniezia sp.	19.82 ± 3.78	79.55 ± 10.74
	Strongyles	44.14 ± 4.71	132.65 ± 12.25
	Strongyloides sp.	6.31 ± 2.31	57.14 ± 7.14
	Taenia sp.	16.22 ± 3.50	77.78 ± 10.08
Winter	*Balantidium* sp.	27.52 ± 4.28	93.33 ± 8.88
	Eimeria spp.	51.38 ± 4.79	150.89 ± 12.90
	Moniezia sp.	29.36 ± 4.36	110.94 ± 13.97
	Strongyles	46.79 ± 4.78	161.76 ± 15.88
	Strongyloides sp.	19.27 ± 3.78	85.71 ± 12.02
	Taenia sp.	22.02 ± 3.97	81.25 ± 9.90
Spring	*Balantidium* sp.	11.11 ± 3.02	91.67 ± 17.23
	Eimeria spp.	32.41 ± 4.50	177.14 ± 56.78
	Moniezia sp.	19.44 ± 3.81	92.86 ± 18.99
	Strongyles	51.85 ± 4.81	225.00 ± 28.55
	Strongyloides sp.	9.26 ± 2.79	85.00 ± 19.79
	Taenia sp.	11.11 ± 3.02	62.50 ± 6.53
Summer	*Balantidium* sp.	6.25 ± 2.29	164.29 ± 52.00
	Eimeria spp.	46.43 ± 4.71	173.08 ± 28.26
	Moniezia sp.	22.32 ± 3.93	94.00 ± 14.81
	Strongyles	45.54 ± 4.71	178.43 ± 19.01
	Strongyloides sp.	7.14 ± 2.43	62.50 ± 8.18
	Taenia sp.	11.61 ± 3.03	69.23 ± 12.06

Table II. Seasonal prevalence and mean intensity of endoparasites in Barbary sheep at Ben Aknoun Zoo.

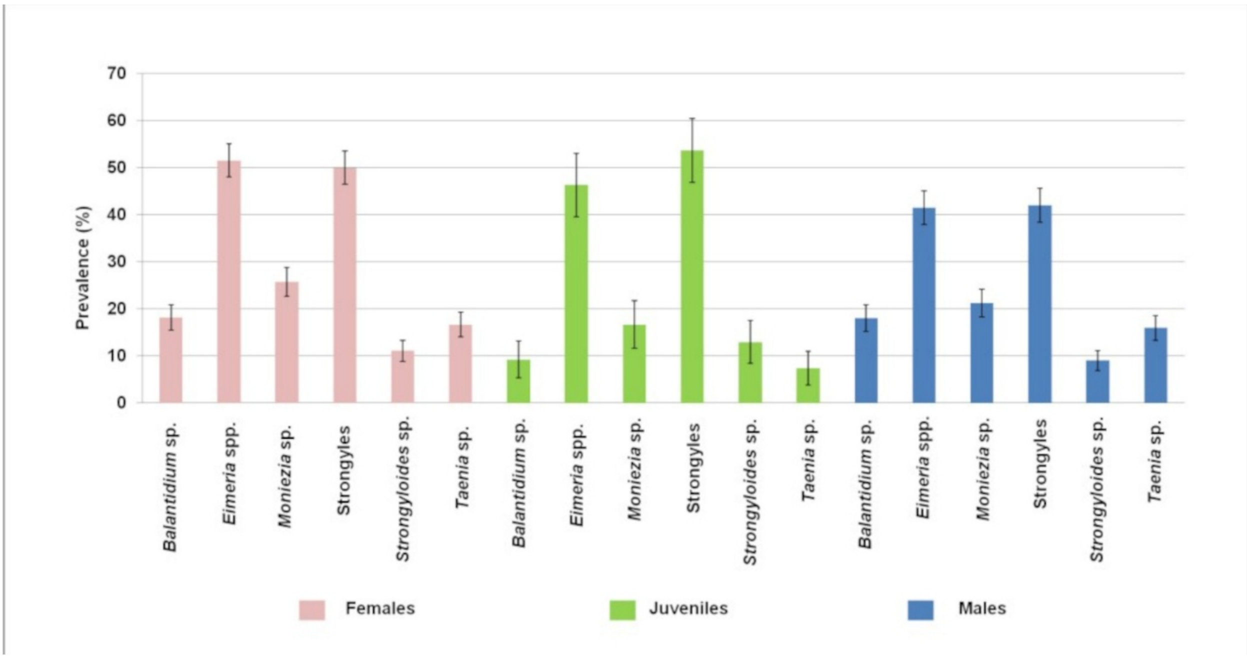

Figure 8. Parasite prevalence across sex-age classes of Barbary sheep at Ben Aknoun Zoo. Prevalence values are shown with standard error bars.

Season	[a]Class	Parasite taxa	Prevalence ± SE (%)	Mean intensity ± SE
Autumn	F	*Balantidium* sp.	29.79 ± 6.67	96.43 ± 21.90
		Eimeria spp.	65.96 ± 6.91	170.97 ± 22.21
		Moniezia sp.	25.53 ± 6.36	75.00 ± 11.51
		Strongyles	44.68 ± 7.25	116.67 ± 14.36
		Strongyloides sp.	8.51 ± 4.07	62.50 ± 12.50
		Taenia sp.	21.28 ± 5.97	95.00 ± 15.72
	J	*Balantidium* sp.	7.69 ± 7.39	50.00 ± 0.00
		Eimeria spp.	46.15 ± 13.83	100.00 ± 25.82
		Moniezia sp.	7.69 ± 7.39	50.00 ± 0.00
		Strongyles	61.54 ± 13.49	112.50 ± 22.66
		Strongyloides sp.	0.00 ± 0.00	0.00 ± 0.00
		Taenia sp.	0.00 ± 0.00	0.00 ± 0.00
	M	*Balantidium* sp.	21.57 ± 5.76	150.00 ± 29.39
		Eimeria spp.	49.02 ± 7.00	154.00 ± 24.82
		Moniezia sp.	17.65 ± 5.34	88.89 ± 21.70
		Strongyles	39.22 ± 6.84	157.50 ± 23.86
		Strongyloides sp.	5.88 ± 3.29	50.00 ± 0.00
		Taenia sp.	15.69 ± 5.09	56.25 ± 6.25
Winter	F	*Balantidium* sp.	27.78 ± 6.10	86.67 ± 10.31
		Eimeria spp.	51.85 ± 6.80	144.64 ± 19.30
		Moniezia sp.	27.78 ± 6.10	133.33 ± 20.51
		Strongyles	46.30 ± 6.79	188.00 ± 25.54
		Strongyloides sp.	14.81 ± 4.83	93.75 ± 23.97
		Taenia sp.	18.52 ± 5.29	75.00 ± 8.33
	J	*Balantidium* sp.	25.00 ± 12.50	50.00 ± 0.00
		Eimeria spp.	58.33 ± 14.23	107.14 ± 41.44
		Moniezia sp.	50.00 ± 14.43	58.33 ± 8.33
		Strongyles	41.67 ± 14.23	90.00 ± 29.15
		Strongyloides sp.	25.00 ± 12.50	50.00 ± 0.00
		Taenia sp.	16.67 ± 10.76	100.00 ± 50.00
	M	*Balantidium* sp.	27.91 ± 6.84	112.50 ± 16.43
		Eimeria spp.	48.84 ± 7.62	173.81 ± 17.80
		Moniezia sp.	25.58 ± 6.65	109.09 ± 26.81
		Strongyles	48.84 ± 7.62	147.62 ± 21.12
		Strongyloides sp.	23.26 ± 6.44	90.00 ± 16.33
		Taenia sp.	27.91 ± 6.84	83.33 ± 17.77
Spring	F	*Balantidium* sp.	7.14 ± 3.44	87.50 ± 23.94
		Eimeria spp.	33.93 ± 6.33	213.16 ± 102.80
		Moniezia sp.	21.43 ± 5.48	100.00 ± 26.83
		Strongyles	62.50 ± 6.47	255.71 ± 40.98
		Strongyloides sp.	10.71 ± 4.13	66.67 ± 10.54
		Taenia sp.	10.71 ± 4.13	58.33 ± 8.33
	J	*Balantidium* sp.	8.33 ± 7.98	50.00 ± 0.00
		Eimeria spp.	33.33 ± 13.61	87.50 ± 23.94
		Moniezia sp.	0.00 ± 0.00	0.00 ± 0.00
		Strongyles	66.67 ± 13.61	250.00 ± 45.32
		Strongyloides sp.	8.33 ± 7.98	250.00 ± 0.00
		Taenia sp.	0.00 ± 0.00	0.00 ± 0.00
	M	*Balantidium* sp.	17.50 ± 6.01	100.00 ± 26.73
		Eimeria spp.	30.00 ± 7.25	150.00 ± 33.71
		Moniezia sp.	22.50 ± 6.60	83.33 ± 27.64
		Strongyles	32.50 ± 7.41	126.92 ± 38.65
		Strongyloides sp.	7.50 ± 4.16	66.67 ± 16.67
		Taenia sp.	15.00 ± 5.65	66.67 ± 10.54
Summer	F	*Balantidium* sp.	7.32 ± 4.07	66.67 ± 16.67
		Eimeria spp.	58.54 ± 7.69	147.92 ± 25.45
		Moniezia sp.	29.27 ± 7.11	87.50 ± 17.54
		Strongyles	43.90 ± 7.75	208.33 ± 36.66
		Strongyloides sp.	9.76 ± 4.63	75.00 ± 14.43
		Taenia sp.	17.07 ± 5.88	57.14 ± 7.14
	J	*Balantidium* sp.	0.00 ± 0.00	0.00 ± 0.00
		Eimeria spp.	47.06 ± 12.11	250.00 ± 159.24
		Moniezia sp.	11.76 ± 7.81	50.00 ± 0.00
		Strongyles	47.06 ± 12.11	100.00 ± 25.00
		Strongyloides sp.	17.65 ± 9.25	50.00 ± 0.00
		Taenia sp.	11.76 ± 7.81	50.00 ± 0.00
	M	*Balantidium* sp.	7.41 ± 3.56	237.50 ± 71.81
		Eimeria spp.	37.04 ± 6.57	172.50 ± 27.02
		Moniezia sp.	20.37 ± 5.48	109.09 ± 27.65
		Strongyles	46.30 ± 6.79	182.00 ± 26.12
		Strongyloides sp.	1.85 ± 1.83	50.00 ± 0.00
		Taenia sp.	7.41 ± 3.56	100.00 ± 35.36

([a])Class: F = females; J = juveniles; M = males

Table III. Seasonal prevalence and mean intensity of endoparasites across sex-age classes of Barbary sheep at Ben Aknoun Zoo.

Seasonal variations in *Eimeria* spp. prevalence were statistically significant, with higher prevalence recorded in autumn (55.86 ± 4.71%) and winter (51.38 ± 4.79%). However, prevalence did not differ significantly between sex-age classes, ranging from 41.49 ± 3.59% in males to 51.52 ± 3.55% in females. Likewise, no variation between sex-age classes reached statistical significance within any season. There were no significant differences in *Eimeria* spp. intensity between seasons, with mean intensity ranging from 150.89 ± 12.90 OPG in winter to 177.14 ± 56.78 OPG in spring. Similarly, intensity did not differ significantly among sex-age classes, with mean values ranging from 148.00 ± 52.32 OPG in juveniles to 166.18 ± 21.53 OPG in females. No significant differences in *Eimeria* spp. intensity were detected between sex-age classes within seasons.

No significant seasonal variation was observed in *Moniezia* sp. prevalence, which ranged from 19.44 ± 3.81% in spring to 29.36 ± 4.36% in winter. Also, prevalence did not differ significantly between sex-age classes and ranged between 16.67 ± 5.07% observed in juveniles and 25.76 ± 3.11% observed in females. In addition, no difference in prevalence reached statistical significance between sex-age classes within seasons.*Moniezia* sp. intensity also showed no significant seasonal variation, with mean egg counts ranging from 79.55 ± 10.74 EPG in autumn to 110.94 ± 13.97 EPG in winter. However, significant contrasts were found between females (100.98 ± 10.24 mean EPG) and juveniles (55.56 ± 5.56 mean EPG), and between juveniles and males (98.75 ± 12.85 mean EPG). A significant difference was also detected in winter between females (133.33 ± 20.51 mean EPG) and juveniles (58.33 ± 8.33 mean EPG).

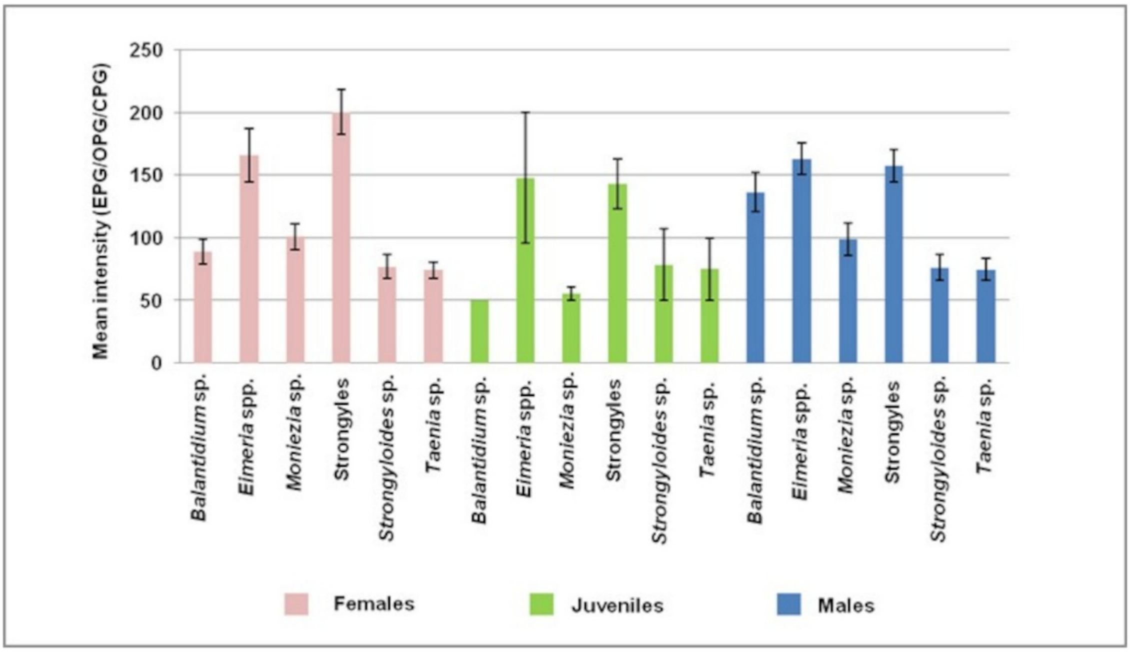

Figure 9. Parasite mean intensities across sex-age classes of Barbary sheep at Ben Aknoun Zoo. Mean intensities are shown with standard error bars.

Significant seasonality was observed in *Balantidium* sp. prevalence, with higher values recorded in winter (27.52 ± 4.28%) and autumn (23.42 ± 4.02%) compared to summer (6.25 ± 2.29%). In contrast, prevalence did not differ significantly between sex-age classes, and ranged from 9.26 ± 3.94% recorded in juveniles to 18.09 ± 2.81% and 18.18 ± 2.74% observed in males and females respectively. No significant differences were detected in *Balantidium* sp. prevalence between sex-age classes within any season. Infection intensity for *Balantidium* sp. showed no statistically significant seasonal pattern, with mean cyst counts ranging from 91.67 ± 17.23 CPG recorded in spring to 164.29 ± 52.00 CPG recorded in summer. On the other hand, males displayed significantly higher intensities (136.76 ± 15.84 mean CPG) than both females (88.89 ± 9.78 mean CPG) and juveniles (50.00 ± 0.00 mean CPG). In summer, intensity was significantly higher in males (237.50 ± 71.81 mean CPG) compared to females (66.67 ± 16.67 mean CPG).

No significant seasonal fluctuation was observed in *Taenia* sp. prevalence; recorded values were low, ranging from 11.11 ± 3.02% in spring to 22.02 ± 3.97% in winter. Likewise, prevalence did not differ significantly between sex-age classes, and it ranged from 7.41 ± 3.56 % in juveniles to 16.67 ± 2.65 % in females. Also, no significant difference in prevalence was found between sex-age classes within seasons. *Taenia* sp. intensity showed no significant seasonal fluctuation, ranging from 62.50 ± 6.53 mean EPG in spring to 81.25 ± 9.90 mean EPG in winter. Intensity differences between sex-age classes were not significant, and mean intensities remained relatively consistent, with values of 74.24 ± 6.20 EPG in females, 75.00 ± 8.89 EPG in males, and 75.00 ± 25.00 EPG in juveniles. However, a significant difference was detected in autumn, when females exhibited higher infection intensity (95.00 ± 15.72 mean EPG) than males (56.25 ± 6.25 mean EPG).

No significant seasonal effect was observed on *Strongyloides* sp. prevalence, which ranged from 6.31 ± 2.31% recorded in autumn to 19.27 ± 3.78% recorded in winter. Similarly, prevalencedid not differ significantly between sex-age classes, with recorded values ranging from 9.04 ± 2.09% in males to 12.96 ± 4.57% in juveniles. No statistically significant difference in prevalence was detected between sex-age classes within seasons. *Strongyloides* sp. intensity showed no significant differences between seasons either, with mean intensity ranging from 57.14 ± 7.14 EPG observed in autumn to 85.71 ± 12.02 EPG observed in winter. Likewise, intensity did not differ significantly between sex-age classes, with mean intensity ranging from 76.47 ± 10.60 EPG recorded in males to 78.57 ± 28.57 EPG observed in juveniles. However, significant contrasts were detected in spring, when juveniles exhibited markedly higher intensities (250.00 ± 0.00 mean EPG) than females (66.67 ± 10.54 mean EPG) and males (66.67 ± 16.67 mean EPG).

Discussion

Previous investigations at zoos in Algiers reported a reduced endoparasitic profile in *Ammotragus lervia* compared with our study. Bellatreche and Benfodil (2013), examining animals in the Hamma Zoological Park, identified only the nematodes *Toxocara vitulorum*, *Capillaria* sp. and *Trichostrongylus* sp. Additionally, a survey in 2015 at Ben Aknoun Zoo detected no parasites in Barbary sheep faeces (Chiedza and Trindad, 2015). Later, Deghdagh and Brahimi (2020) identified only trichostrongyles in faecal samples fromthe same zoo.Berrairia and Meziani (2021) expanded the known parasite spectrum by reporting strongyles, *Eimeria* sp. and *Capillaria* sp. More recently, Benaissi and Hocine (2024) reported a high prevalence of strongyles and coccidia among captive ruminants, identifying Barbary sheep as one of the most susceptible hosts. Cherif et al. (2024) found serological evidence of exposure to *Toxoplasma gondii* in one Barbary sheep.

In the Djelfa hunting reserve, located in a semi-arid region of Algeria, similar parasite assemblages have been reported but with varying compositions. Ben Tourkia and Ben Naiha (2018) identified *Nematodirus* sp. and *Trichostrongylus* sp. as the dominant species, while other taxa such as *Fasciola* sp., *Moniezia* sp., *Toxocara* sp., *Ostertagia* sp., and *Strongyloides* sp. were only weakly represented. In contrast, earlier studies in the same reserve, Zebda (2017) documented a wider parasitic community comprising three phyla: Protozoa represented by *Balantidium coli* and *Eimeria* sp ., Platyhelminthes represented by *Moniezia* sp. and *Mesocestoides* sp., and Nemathelminthes represented by *Nematodirus* sp., *Marshallagia* sp., *Strongyloides* sp. and various strongyles. Our findings are more consistent with those of Zebda (2017), which may suggest similarities in environmental factors or management conditions influencing parasite communities in *Ammotragus lervia* across different localities in Algeria. This may also indicate that, despite regional environmental differences, Barbary sheep tend to host a parasite community dominated by gastrointestinal nematodes, however, this requires confirmation through surveys conducted across a wider range of regions in Algeria.

Comparable findings have been reported across North Africa. In Morocco, *Trichostrongylus* spp., other strongyle-type eggs, and *Eimeria* spp. were found in captive Barbary sheep at Rabat Zoo (Taki, 2023). In Tunisia, *Nematodirus helvetianus* was molecularly identified in wild *Ammotragus lervia* from Bouhedma and Oued Dekouk National Parks (Said et al., 2018), while in Egypt, *Eimeria* spp. and *Trichuris* spp. were reported in Barbary sheep at Beni-Suef Zoo (Kamel and Abdel-Latef, 2021). These studies align with our results regarding gastrointestinal nematodes and coccidian findings, they may also suggest an epidemiological pattern in which these parasite groups tend to dominate endoparasite assemblages in Barbary sheep across North Africa.

Beyond North Africa, in Spain, Mayo et al. (2013) documented a rich helminth fauna in captive Barbary sheep, with the identification of multiple strongyles, *Nematodirus* spp, *Trichuris* spp, and *Skrjabinema ovis*, whereas surveys from Ukraine (Zvegintsova et al., 2018) recorded 18 helminth species, among them strongyles, *Taenia hydatigena* and *Moniezia expansa*. In the United States, in wild populations of Barbary sheep introduced from North Africa to New Mexico and Texas, multiple strongyles were identified along with *Moniezia expansa* (Allen et al., 1956; Gray et al., 1978). Moreover, in Korea, *Balantidium coli* was identified histologically in the gastric lymph nodes and abomasum of a Barbary sheep (Cho et al., 2006). Taken together, these findings may suggest that *Ammotragus lervia* is capable of hosting a broad parasitic community across geographically distinct regions.Our results, showing infections from three phyla, position the studied captive population among the most parasitologically varied recorded to date, they also show an increase of the endoparasite species infecting *Ammotragus lervia* at the Ben Aknoun Zoo compared with previous records from the same site, which may be explained by several factors. First, differences in sampling design, including the larger number of samples collected over a full annual cycle, likely increased the probability of detecting a wider range of parasite taxa. Second, temporal changes in environmental conditions and enclosure management may have altered host-parasite interactions and facilitated the persistence or introduction of additional parasite species.

Finally, improved diagnostic effort through systematic and repeated coprological examination may have contributed to a more comprehensive detection of parasitic elements compared with earlier surveys.

The present study demonstrates high overall parasite prevalence among the examined Barbary sheep population, comparable to results reported in similar captive and semi-captive ruminant populations. Benaissi and Hocine (2024) observed a prevalence of 75% for gastrointestinal strongyles and coccidia among wild ruminants kept at Ben Aknoun Zoo, identifying Barbary sheep as among the most susceptible hosts to intestinal parasitic infestations. While in the Djelfa hunting reserve, Zebda (2017) reported a markedly higher infection rate (98.57%) listing *Nematodirus* sp. (77.8%) and *Eimeria* sp *.* (61.1%) as the most prevalent species infecting *Ammotragus lervia*. The study at the Rabat Zoo (Morocco) found an overall prevalence of 89% among artiodactyls, with strongyles as the dominant parasites, followed by *Eimeria* spp. (Taki, 2023). In the Parque de Rescate de la Fauna Sahariana (Almería, Spain), Mayo et al. (2013) recorded a prevalence of 87.5% for gastrointestinal helminths, primarily strongyles, in captive Barbary sheep. Moreover, Maesano et al. (2014) reported a similar pattern in the Warsaw Zoological Garden (Poland), where *Nematodirus* spp. and coccidia were the predominant parasites in Barbary sheep. Overall, these studies consistently show high prevalence levels in captive and managed populations, suggesting that confinement, host density, and repeated exposure to infections are key factors in sustaining parasite transmission.

Moreover, our results align with these previous studies, implying that strongyle nematodes and *Eimeria* spp *.* are among the most prevalent gastrointestinal parasites infecting *Ammotragus lervia* populations across different captive environments. Additionally, the present study extends earlier findings by providing a more robust estimation based on larger and exclusively targeted sampling of Barbary sheep, thus improving the accuracy and representativeness of prevalence data for this species.

Seasonal and host sex-age effects on endoparasites prevalence and intensity

Although there was no significant seasonal or sex-age effect on the overall prevalence, we observed higher prevalence in juveniles, which may reflect their immunological immaturity and increased susceptibility to infections (Altizer et al., 2006). The absence of strong seasonal variation in overall parasite prevalence may reflect the specific conditions of captivity. Unlike wild populations, where fluctuations in host density, climate, and pasture contamination drive seasonal transmission dynamics (Altizer et al., 2006; Turner and Getz, 2010), captive herds are maintained at a constant density within restricted enclosures. The enclosure microclimate, routine feeding practices, and limited dispersal of faeces together create a stable environment that supports parasite persistence, while simultaneously favouring reinfection through continuous contamination of soil and food (Lahat et al., 2021; Lalremruati and Solanki, 2020; Pérez Cordón et al., 2008). Studies in other zoological settings similarly found minimal seasonal variation in parasite prevalence, attributed to constant exposure to contaminated environments (Dashe and Berhanu, 2020). In addition, the treatment protocols implemented by the zoo may have interfered with natural transmission cycles, potentially masking seasonal peaks in the present study.

Strongyles

The seasonal prevalence of strongyles was not significantly different,but the highest level was observed in spring. The significantly higher prevalence observed among females during spring may berelated to behavioural factors or to sex-based immune variation (Altizer et al., 2006). We also observed high mean intensity values in spring, and although this observation did not reach statistical significance, it is comparable to the general pattern reported in captive ruminants from Czechoslovakia, including Barbary sheep, where nematode egg shedding peaked during warmer periods (Tilc and Hanuskova, 1976). Also, the significant contrasts in intensity observed between females and males in spring and between females and juveniles in summer, may suggest reduced resistance or increased exposure to strongyle nematodes in females, possibly associated with reproductive stress (pregnancy, lactation, and offspring care) along with higher environmental larval availability during warmer seasons (Altizer et al., 2006). The transmission of strongyle nematodes is dependent on the survival of infective third-stage larvae, which may be influenced by environmental factors such as temperature and moisture, with the developmental cycle tending to proceed more rapidly under warmer conditions (O’Connor et al., 2005)

Eimeria spp.

Similar patterns to our results concerning *Eimeria* spp. have been reported in other ungulates; in a *Gazella cuvieri* population from Algeria, *Eimeria* sp. prevalence was significantly higher in the rainy seasons (Benamor et al., 2023). Also, in Etosha National Park, Namibia, *Eimeria* spp . infections were significantly more frequent in the wet season (Turner and Getz, 2010). Following excretion, oocysts are typically non-infective and require maturation via the process of sporulation before becoming infective; under ideal moist and warm conditions, this process can occur within about one day (Allen and Fetterer, 2002; Venkateswara et al., 2015). The absence of a significant difference in prevalence between host classesmay suggest similar levels of exposure to *Eimeria* spp. Interestingly, we did not observe parallel seasonality in intensity; moreover, although not statistically supported, mean intensity appeared higher during spring and summer in contrast to the prevalence pattern, this may be related to less favourable conditions for *Eimeria* spp. persistence in the environment during the dry season (Marquardt, 1960), which, coupled with possible reduced host immunity, may have contributed to higher *Eimeria* spp. burdens in already infected animals**.** However, this interpretation requires further investigation.

Moniezia sp.

For *Moniezia* sp., comparable patterns to our findings were described by Benamor et al. (2023) in*G. cuvieri*, where *Moniezia* sp. exhibited no marked seasonal variation and low egg-shedding. Adults, particularly females, showed higher intensity than juveniles, which aligns with an observation made on bighorn sheep, where *Moniezia* spp. eggs were mostly found in female faeces (Rijal, 2020); it also agrees with the study by Kanyari et al. (2009), which reported higher mean EPG of *Moniezia* spp . in males and females of goats and sheep in Kenya. The higher mean intensity observed in females during winter may be associated with their immunological status or herding behaviour in that season. Since *Moniezia* species rely on oribatid mites as intermediate hosts, the weak seasonality observed may be linked to the relative stability of soil conditions within the enclosure, possibly sustaining mite populations. If this assumption is correct, practices aimed at reducing intermediate host abundance, such as habitat sanitation and soil desiccation, could therefore help limit infection rates (Chiedza and Trindad, 2015).

Balantidium sp.

As for *Balantidium* sp., our results agree with those of Benamor et al. (2023) who also recorded significantly higher *Balantidium* sp. prevalence in winter in *G. cuvieri*, with low infection intensities. Similarly, Lalremruati and Solanki (2020) found higher *B. coli* infection rates during the monsoon than in the dry seasons. In contrast, Pérez Cordón et al. (2008) reported a low and significantly seasonal *Balantidium coli* prevalence that was higher (11.5 %) in June in captive Artiodactyla in Spain. The significantly higher intensity observed in male hosts, particularly in summer, may suggest sex-related differences in exposure or susceptibility, potentially influenced by behavioural or immunological factors, for example, testosterone and mating activities can cause lowered immunity in males (Altizer et al., 2006). Variations are observed across studies in both the prevalence and intensity of *Balantidium* sp. with management practices and the quality of veterinary care appearing to be the main factors determining infection levels in captive populations (Schuster and Ramirez-Avila, 2008). *Balantidium* sp. infections are typically associated with pigs and primates (Cho et al., 2006), therefore, the infection pattern observed in Barbary sheep at Ben Aknoun Zoo may be influenced by cross-species transmission from wild boar (*Sus scrofa*) inhabiting the surrounding forest (Remini, 2007), which occasionally enter the zoological park, and the risk of infection may be exacerbated in immunocompromised hosts. However, this pathway remains to be confirmed and warrants further investigation by zoo management.

Taenia sp.

To the best of our knowledge, this study constitutes the first record of *Taenia* sp. infection in *Ammotragus lervia* inAlgeria. Similar findings have been documented elsewhere: *Taenia hydatigena* was identified in *Ammotragus lervia* from Ukraine with a 20% prevalence and low intensity (Zvegintsova et al., 2018), and cysticercosis was reported in a Tunisian specimen during necropsy (Petretto and Said, 2014). *Taenia* sp. prevalence, although not statistically significant, appeared highest in winter. Scala and Varcasia (2006) reported that the eggs of *Taenia multiceps* can remain infective for more than 30 days in cold and moist environments, they can also persist for up to six months if moisture is maintained (Bentounsi and Cabaret, 2023). Intensity was found to be higher in female hosts in autumn, this may be attributed to the higher probability of females being infected with *Taenia* sp. due to lower immunity or behavioural shifts in the herd during this season. Ruminants become infested by *Taenia* sp. by consuming grass or water contaminated with eggs shed by canids such as dogs, wolves and jackals (Bentounsi and Cabaret, 2023), species that are often maintained in zoos, therefore, it is possible that the occurrence of *Taenia* sp. in the studied

Barbary sheep population may result from enclosure changes involving infected canids or from indirect transmission by caretakers who move between multiple animal enclosures daily, which represents another aspect that requires further research.

Strongyloides sp.

Regarding *Strongyloides* sp., previous studies on *Ammotragus lervia* populations reported results comparable to ours. *Strongyloides* sp. prevalence in the Djelfa hunting reserve was found to be low (Ben Tourkia and Ben Naiha, 2018). Non-seasonal and low prevalence values have also been reported in zoo ungulates from Spain (Pérez Cordón et al., 2008) and Ethiopia (Dashe and Berhanu, 2020). In contrast, *Strongyloides* sp. infection in a wild population of *G. cuvieri* from Algeria showed clear seasonality, with peak mean intensity reported in winter (Benamor et al., 2023), which may indicate differences in infection dynamics between captive and wild ungulates. In our study, the higher intensity observed in juveniles during spring, may suggest reduced resistance to *Strongyloides* sp. infection in younger individuals during this period. It is worth noting that young animals may become infected via females during early lactation through milk containing infective larvae, although infection most commonly occurs in the external environment via percutaneous penetration or ingestion of L3 larvae (Chiedza and Trindad, 2015).

Endoparasite dynamics in Barbary sheep in relation to environmental and management factors at Ben Aknoun Zoo

The consistently high overall prevalence across all seasons may indicate persistent exposure to helminth and protozoan infections, and possibly reflect weaker immune responses particularly against strongyles and *Eimeria* spp., as well as the possible presence of antiparasitic resistance in the studied Barbary sheep population. Regular Faecal Egg Count Reduction Tests (FECRT) are therefore recommended to evaluate treatment efficacy.

Prophylaxis remains the cornerstone of parasite control in captive ruminants. Zoo management should emphasise improved hygiene, careful monitoring of diet quality, and avoidance of overcrowding. Treatments should only be administered after analyses confirm the need for intervention (Lahat et al., 2021).

Climatic factors likely play a major role in the persistence and transmission of the identified endoparasites in the studied *Ammotragus lervia* population. Algiers' Mediterranean climate has recently shown increasing variability in temperature and rainfall (Haouari, 2024; Keraghel and Gaouaou, 2024), creating favourable environmental conditions for parasite development. The climate records provided in the Materials and Methods indicate a wet season with mild temperatures extending from October to April. For instance, suitable conditions for the transmission of strongyle nematodes such as *Haemonchus contortus* and *Trichostrongylus* include monthly precipitation of approximately 2.5 cm (≈0.83 mm/day on average) and temperatures ranging from 15 to 32 °C for *H. contortus* and from 6 to 20 °C for *Trichostrongylus* (Levine, 1963). *Eimeria* sporulation can occur at temperatures between -5 and 30 °C with sufficient moisture (Marquardt, 1960), and development of *Moniezia* species into cysticercoids within their intermediate host occurs when relatively warm temperatures of 18–20 °C are maintained for a period of 28–97 days (Narsapur and Prokopic, 1979). Our study suggests that the wet season may act as an important driver of *Eimeria* spp. and *Balantidium* sp. infections, which should be considered when implementing management protocols.

Regarding the effect of host sex and age, notable differences in parasite dynamics were observed between adults and younger individuals, as well as between males and females, for several of the identified parasite taxa, either across the entire study period or within specific seasons. We suggest that these variations may be attributed to differences in host physiology and behaviour, including feeding habits, mating activity, and reproductive status, however, our study design did not allow further exploration of these proposed explanations, highlighting the value of complementary studies in this area. Discrepancies between the findings of the present study and those reported in the literature may also reflect the influence of local climatic conditions or management practices. For example, some sex or age classes, particularly juveniles, could have been selectively targeted with antiparasitic treatments during specific seasons which could have influenced our results. Nevertheless, observation of the behaviour of the different herd classes across seasons is recommended to improve management practices and better adapt control measures to periods of increased risk.

It is also noteworthy that Ben Aknoun Park has undergone extensive redevelopment and restructuring over the past two years, with work still ongoing at the time of writing. These modifications, potentially involving habitat redesign, animal translocations, and temporary enclosure crowding, may have contributed to alterations in environmental hygiene and host-parasite contact patterns, thereby facilitating the maintenance and transmission of a more diverse parasitic fauna.

Conclusion

The present study provides the most extensive assessment to date of the endoparasitic profile in a Barbary sheeppopulation in Algeria and on the Mediterranean coast, highlighting a clear expansion of the known parasite spectrum in the studied captive population under Mediterranean climatic conditions. Our study points to a complex and multilayered interplay between host management practices, environmental drivers, and parasite transmission dynamics in captivity. The results suggest that these factors favour the development and transmission of endoparasite communities.

However, as with any research, our study was subject to limitations, which are highlighted throughout the manuscript. Most of these relate to fieldwork and include potential pseudoreplication and the inference of sex and age from pellet morphology, all of which should be considered when interpreting the findings. In addition, parasite identification relied solely on morphological analysis via microscopy, which does not allow reliable species-level differentiation of strongyle-type eggs and may mask species-specific epidemiological patterns. Thus, future investigations incorporating larval culture or molecular techniques would enable more precise identification and provide a deeper understanding of parasite community structure and transmission patterns in captive *Ammotragus lervia* populations. Molecular methods are also valuable for assessing population demographic structure from faecal samples while maintaining non-invasive sampling. Further research should also investigate host immune responses and the behavioural ecology of *Ammotragus lervia*.

Finally, the data collected here provide a valuable foundation for regional conservation and reintroduction programmes for Barbary sheep, supporting the long-term management of this emblematic North African ungulate.

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Ethical approval

This study involved the non-invasive collection of faecal samples from captive animals housed in a zoological facility. As the research was based exclusively on faecal samples collected after natural defecation, no handling, restraint, or experimental manipulation of animals was performed. Authorisation to conduct the research was obtained from the zoo management. Sample collection was carried out under the supervision of the zoo veterinarian and with the assistance of trained animal caretakers, following established zoo guidelines and animal welfare standards.

Conflict of interest

The authors declare no conflict of interest.

Author Contributions

Conceptualisation: OCL, NKEH, FB; Methodology: OCL FB, NKEH; Formal analysis: OCL; Investigation: OCL, FB; Writing original draft preparation: OCL; Writing, review and editing: OCL, FB, NKEH; Visualisation: OCL; Supervision: NKEH, FB; Project administration: NKEH, FB; Funding acquisition: NKEH, OCL.

All authors have read and agreed to the published version of the manuscript.

Data availability

The datasets generated in this study are available from the corresponding author upon reasonable request.

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