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Mammalian ectoparasite threats and management under a changing climate in the Global South

Epidemiological assessment of ectoparasite prevalence in the dromedary camel (*Camelus dromedarius*) in the Sahara Desert

Évaluation épidémiologique de la prévalence des ectoparasites chez le dromadaire (*Camelus dromedarius*) dans le désert du Sahara

Evaluación epidemiológica de la prevalencia de ectoparásitos en el camello dromedario (*Camelus dromedarius*) en el desierto del Sahara

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Abstract

Dromedary camels *Camelus dromedarius* Linnaeus (Artiodactyla, Camelidae) are vital to the livelihoods of nomadic and pastoralist communities in the Sahara Desert. However, they are susceptible to ectoparasites, which can significantly impact their health and productivity, as well as their potential role in transmitting zoonotic diseases. This study aimed to investigate the prevalence, species composition and infestation levels of ectoparasites in dromedaries from different camel herds (CH) across northern Algeria's Sahara Desert. Additionally, we assessed the effects of CH and camel age and sex on parasite loads and infestation patterns regarding the host's affected body region. A total of 68 camels out of 135, randomly selected from four herds CH1–CH4, were surveyed for ectoparasites. Ectoparasites were counted, collected and identified in the laboratory. Pearson correlation tests were employed to analyse the relationship between parasite indices. Similarity analysis was conducted to compare ectoparasite species composition among the sampled CH. The overall infestation level of ectoparasites across the CH was 61.76% with 511 ectoparasite individuals identified. Significant regional variation in tick prevalence was observed: CH1

(88.24%), CH2 (64.71%), CH3 (58.82%) and CH4 (35.29%) ($p < 0.001$). The most prevalent ectoparasites were ticks, with four species identified: *Hyalomma dromedarii* Koch (Ixodida, Ixodidae) (45.21%), *Hyalomma marginatum marginatum* Koch (Ixodida, Ixodidae) (18%), *Rhipicephalus sanguineus* sensu lato Latreille (Ixodida, Ixodidae) (7.63%) and *Ixodes ricinus* Linnaeus (Ixodida, Ixodidae) (4.9%). In addition, one mite species *Sarcoptes scabiei* Linnaeus (Sarcoptiformes, Sarcoptidae), one flea species *Ctenocephalides arabicus* Jordan (Siphonaptera, Pulicidae) and one fly species *Wohlfahrtia magnifica* Schiner (Diptera, Sarcophagidae) were identified. Similarity analysis showed a 70% overlap in ectoparasite species composition between herds, suggesting common environmental and management-related risk factors. Overall, the abdomen exhibited the highest percentage of ectoparasites at 22.7%, followed by the neck and sternum (17.8%), and the anal and tail area (17.4%). Adults accounted for 86.1% of infestations, with notable contributions from the abdomen (17.0%) and neck/sternum (15.9%), while young camels made up only 13.9%. The high ectoparasite infestation level, particularly ticks, underscores the need for a comprehensive control plan, especially in herds managed under extensive or nomadic systems. Future research should focus on identifying risk factors and exploring ectoparasite control strategies to reduce the burden on camel health and prevent potential zoonotic disease transmission in the region.

KEYWORDS

arid environment, camelids, ectoparasite, extensive breeding system, peri-urban livestock breeding system, ticks

INTRODUCTION

Drylands, particularly the Sahara Desert, host unique bioresources that play pivotal roles in sustaining livelihoods and supporting biodiversity in arid and semi-arid regions. These ecosystems, despite their harsh climatic conditions, have adapted flora and fauna that provide critical resources for local communities (Chenchouni et al., 2025; Chenchouni & Neffar, 2025). Among these, livestock such as camels serve as a cornerstone for food security, economic stability, and cultural identity, especially in the face of increasing climate variability (Boudalia et al., 2023; Volpato & Howard, 2014). Camels, specifically the dromedary camel *Camelus dromedarius* Linnaeus (Artiodactyla, Camelidae), are invaluable in such regions due to their resilience and multifunctionality, offering a sustainable means of utilizing sparse natural resources. Historically, the dromedary camel has played a significant role in human life in Algeria. It contributes substantially to protein production through its milk and meat and serves as a means of transportation for local populations (Padalino & Faye, 2024). This species is well-adapted to arid environments and possesses considerable potential for food production, thereby enhancing economic security for local communities, particularly in the context of climate change (Boudalia et al., 2023; Harek et al., 2022).

In the arid regions of Algeria, the dromedary camel is regarded as the social foundation for certain Saharawi tribes (Ben Aissa, 1989). Additionally, through leisure and tourism activities, using camels for riding, photography and desert safaris, camels serve as a source of income for livestock-rearing families in the most touristic areas (Faye et al., 2014). Furthermore, peri-urban camel farming is gaining increasing importance in Algeria, particularly in the steppe and northern Sahara regions (Mammeri, 2016a, 2016b; Mammeri et al., 2014; Mammeri & Khir, 2018). However, on natural rangelands, where these livestock obtain the majority of their food, they face numerous challenges, including health issues that impact growth and necessitate prevention and treatment measures (Padalino & Faye, 2024). Several researchers have highlighted the significance of external parasitism in *C. dromedarius* herds in Algeria (Defaye et al., 2022; Faye et al., 2014; Ouchene-Khelifi et al., 2020). Ectoparasitosis due to haematophagous arthropods is a major concern for camel breeders. Among the most frequently reported external parasitic conditions are sarcoptic mange and ticks, which are among the most prevalent infestations affecting camels (Ogni et al., 2014). Ticks inflict damage by affecting the animals' hides, producing toxins, causing weight loss, reducing milk production, and stunting growth (Shahid et al., 2022). In most cases, pathogen transmission from infected ticks occurs by injection of infected saliva through the tick bite wound.

Previous studies have indicated that ticks pose serious health risks to both humans and other animals, particularly as they can be associated with zoonotic diseases. When present in large numbers, they also lead to economic losses for breeders (Betatache et al., 2024; Padalino & Faye, 2024). Ticks cause harm both directly, through lesions and harmful effects and indirectly, by transmitting a wide range of pathogens including viruses, bacteria and protozoa. Globally, ticks are recognized as the primary vectors of serious tick-borne diseases such as anaplasmosis, babesiosis, tick-borne encephalitis and Lyme borreliosis (Chadi et al., 2024; Vilibić-Čavlek et al., 2024). Humans who work closely with animals are particularly vulnerable to tick bites (Khan et al., 2022). In Algeria, camels are observed to be highly parasitized with *Hyalomma* spp. mainly *Hyalomma dromedarii* Koch (Ixodida, Ixodidae) (Chaibi et al., 2024) and their cohabitation with other animal species increases the risk of infestation of animals living in close proximity (Ouchene-Khelifi et al., 2020).

According to Chaibi et al. (2024), seasonal variations, climatic conditions and herd management practices are all significant contributors to the ectoparasitic burden in *C. dromedarius* populations. The impact of ectoparasites on the overall health and productivity of dromedaries is an area of concern that warrants further exploration (Padalino & Faye, 2024). Currently, the scientific community, along with numerous non-governmental organizations (NGOs), are focused on linking research and development activities related to camelids, given their ability to survive in arid environments, endure periods of drought and ensure greater productivity compared with other livestock raised under similar conditions. In this context, the present cross-sectional study aimed to investigate the prevalence, dominant species and infestation levels of ectoparasites in *C. dromedarius* herds reared in northern Algeria's Sahara Desert, as well as factors that influence their prevalence and distribution.

MATERIALS AND METHODS

Study area

Ouled Djellal Province is situated in the northeastern part of the Algerian Sahara Desert, covering an area of 11,410 km^2 and situated within 34.43° N and 5.06° E. It shares borders with the Governorates of M'sila, Biskra, Djelfa, El Mghair and Ouargla (Figure 1) (Mihi et al., 2019). The Ouled Djellal region experiences a typical hot desert climate characterized by long, extremely hot summers and mild winters, with an average annual temperature of 21.8°C (Min: 17.4°C, Max: 28.8°C). The average annual humidity is 41% (Min: 23.4%, Max: 55.5%), and precipitation is limited to only 128.8 mm per year. Winds occur frequently during two distinct periods: relatively wet winds in the winter and sandy winds in the spring, resulting in a hyperarid climate (National Meteorological Office, 2024).

Camel herd sampling and epidemiological survey conduct

The four surveyed herds were situated in the following municipalities: Gharbaa (CH1), Chaîba (CH2), Bir Nâam (CH3) and Doucen (CH4). The four sites were investigated using simple random sampling (Figure 1). They were characterized by three modes of camel husbandry: peri-urban intensive (CH3 and CH4), semi-extensive (CH2) and extensive pastoral ambulatory system (CH1) (Attir et al., 2025). The peri-urban intensive system is dominant, and it focuses on the daily selling of camel milk to travellers on the main roads. In the extensive system, camels travel long distances over several days in search of pasture and only stop to drink. The semi-extensive system is a combination of the other two systems (Table 1).

Herd sizes varied from 17 to 40 camels, with a higher number of females than males (Table 1). The age range of camels varied from 4 months to 8 years. The main camel breeds identified in this study include Sahraoui, Naili, Reguibi, Châambi and Ouled Sidi Cheikh.

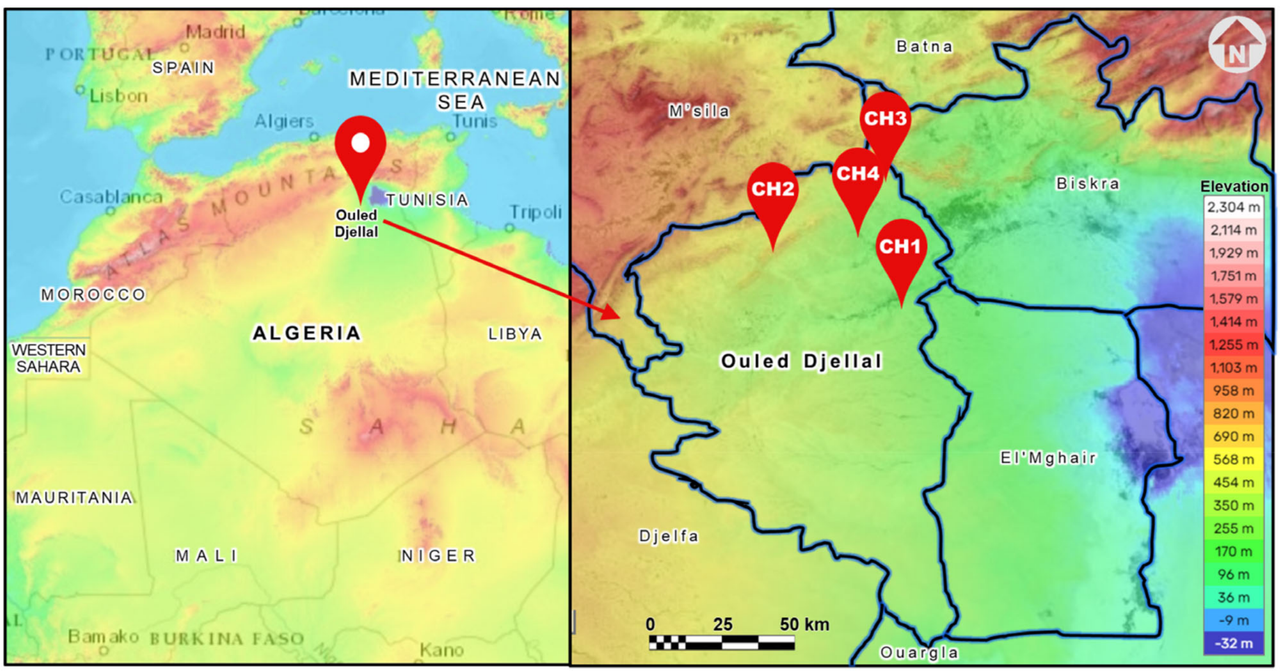

FIGURE 1 Elevation map showing the distribution of surveyed camel herds (CH1–CH4) in the region of Ouled Djellal, northern Sahara Desert of Algeria.

TABLE 1 Characteristics of the sampled herds and camel breeders according to age and sex in the region of Ouled Djellal, northern Sahara Desert of Algeria.

	Sampled herds				
Camel herd codes	CH1	CH2	CH3	CH4	Total
Geographical location	Gharbaa	Chaîba	Bir Nâam	Doucen	
Type of livestock management	Extensive pastoral	Semi-extensive	Peri-urban intensive	Peri-urban intensive	
Mixed livestock farming (Yes/No)	Yes	Yes	No	Yes	
Total number of camels	40	38	40	17	135
Number of examined camels	17	17	17	17	68
Number of examined females	13	14	13	12	52
Number of examined males	4	3	4	5	16
Number of examined adults	14	13	13	13	53
Number of examined calves	3	4	4	4	15
Number of infested camels	11	15	6	10	42

Camel breeders have varying levels of experience in camel husbandry, ranging from 10 years (CH4) to 15 years (CH1). Other breeders (CH2, CH3) have acquired their knowledge of this occupation through succession from family members (father or grandfather), having interacted with camels since childhood without undergoing specialized training in the field. Notably, the majority of breeders (75%) also raise several other animal species, such as sheep, goats and cattle, in the same stable.

The study started in March and concluded in June 2021, coinciding with the onset of the hot dry season in the study area. The assistance of public veterinarians was essential to facilitate access to the farms and communication with breeders. Firstly, the present research topic was validated and approved by the scientific committee of the Faculty of Natural and Life Sciences and then by the committee of members of the Laboratory of Genetics, Biotechnology, and Valorization of Bioresources (LGBVB), University of Biskra. Then, the owners of the surveyed camels provided their verbal consent for tick sample collection. The total number of camels across the four surveyed herds was 135 (Table 1).

Sampling and collection of ectoparasites

We used quota sampling, taking 17 camels from each herd. Each quota sample (n) comprised two age categories: adult camels aged 3–8 years, and calves aged ≤6 months, including both sexes. Sampling was conducted in accordance with species life profiles, as recommended by Walker et al. (2003). To count ectoparasites and collect samples for laboratory identification, a visual inspection of all body parts was carried out to check for ectoparasites by two researchers for each camel for 10–15 min. Ectoparasites such as ticks, mites and fleas were enumerated. For the estimation of *Wohlfahrtia magnifica* Schiner (Diptera, Sarcophagidae) infestation, all lesions or injuries were considered and inspected. The collected samples were placed individually in labelled vials. Collection was performed using specialized forceps, ensuring that the rostrum of the parasite was completely removed from the animal's skin. The ectoparasites collected were stored in hermetically sealed vials with 70% alcohol until the identification stage.

Identification of ectoparasitic species

The confirmation of ectoparasite identification was conducted in the parasitology laboratory at Biskra University (Algeria), where a voucher of the specimens also was deposited and preserved for future reference. After measuring body tick size, the specimens were examined using a binocular magnifying glass (MOTIC, 20×), followed by an optical binocular microscope with 40× magnification. Samples were photographed and identified based on the determination keys and identification criteria outlined by Walker et al. (2003) and Meddour-Bouderda and Meddour (2006). Abundance data were obtained by counting the number of individuals of each species.

Parasitological indices

To assess the parasitism levels, three parasitological indices were calculated (Bush et al., 1997) where:

- NIC is number of infested camels, NEC is the number of examined camels, and Np: number of parasites.
- Specific infestation prevalence (P in %): P% = (NIC/NEC) × 100.
- Average parasite intensity (API): API = Np/NIC.
- Average parasite abundance (APA): APA = Np/NEC.

Data analysis

The statistical analyses were performed using R version 4.4 (R Core Team, 2024). Descriptive statistics (mean, standard deviation, minimum and maximum) were calculated for the prevalence of ectoparasite groups (fleas, flies, mites and ticks), the overall tick load for each herd, and the distribution frequencies of ectoparasites according to the camel's parasitized body areas. Using the abundance of ectoparasite species (Attir et al., 2025), Pearson's Chi-squared tests were conducted to assess the independence between the following categories: affected body regions versus sampling herds; affected body regions versus age classes; parasite groups versus affected body regions; parasite groups versus age classes; and parasite groups versus sexes. A Pearson correlation test was performed to compare the tick prevalence across the four herds (regions) and the average parasite abundance for ticks in adult camels and calves. A P-value of less than 0.05 was considered significant.

The assessment of ectoparasite species distribution and overlap among the sampling herds involved several analytical steps. First, a four-set Venn diagramme was constructed to illustrate the distribution of ectoparasite species across the four sampling herds (CH1–CH4) using the R package {venn} version 1.11 (Dusa, 2022). To facilitate a comprehensive comparison of ectoparasite community structures among the sampled camel herds, similarity was analysed using species presence-absence data through the Sørensen index and Jaccard index, and using abundance-based data through the Morisita-Horn index and Bray-Curtis index. Similarity analysis was conducted using EstimateS software version 9.1 (Colwell, 2013), while the R package {d3heatmap} version 0.6.1.2 (Cheng & Galili, 2018) was employed to generate heatmaps that visualize similarity indices and include clustering analysis between camel herds based on their similarity scores.

RESULTS

Systematic list and abundances of ectoparasite species

Table 2 provides a summary of the ectoparasites identified in dromedary camels across various sampled herds. The ectoparasite species were taxonomically classified, and their absolute and relative abundances were documented for each herd. The inventory included seven species across six genera, four families, four orders and two classes. Four species of ticks were identified: *Hyalomma marginatum marginatum* Koch (Ixodida, Ixodidae), *H. dromedarii*, *Ixodes ricinus* Linnaeus (Ixodida, Ixodidae) and *Rhipicephalus sanguineus* sensu lato Latreille (Ixodida, Ixodidae), each exhibiting varying prevalence of infestation across sampled regions; notably, *H. dromedarii* was the most abundant species (Table 2). Additionally, a single case of sarcoptic mange caused by *Sarcoptes scabiei* Linnaeus (Sarcoptiformes, Sarcoptidae), was recorded in CH1. Myiasis due to larvae of *W. magnifica* was observed in CH2, while fleas represented by *Ctenocephalides arabicus* Jordan (Siphonaptera, Pulicidae) were noted in CH1.

In total, 511 ectoparasites were identified from 68 camels sampled from the four herds. The distribution of ectoparasites collected from the examined camels indicated a high infestation level in CH1, with 218 ectoparasites, followed by CH2 with 194 ectoparasites, CH4 with 53 ectoparasites and finally CH3 with 46 ectoparasites (Table 2).

Ectoparasite infestation indices in camel herds

The overall global prevalence of ectoparasites across all herds was 61.76%. Among the total number of ectoparasites identified in this

TABLE 2 Systematic list and geographical distribution of abundances (n, %) of the ectoparasite species identified in one-humped camels of Ouled Djellal region, northern Sahara Desert of Algeria.

					Sampled camel herds (CH)				
Class	Order	Family	Species		CH1	CH2	CH3	CH4	Total
Arachnida	Ixodida	Ixodidae	*Rhipicephalus sanguineus* sensu lato (Latreille)	n	10	29	–	–	39
				%	4.59	14.95	–	–	7.63
Arachnida	Ixodida	Ixodidae	*Hyalomma dromedarii* (Koch)	n	48	102	39	42	231
				%	22.02	52.58	84.78	79.25	45.21
Arachnida	Ixodida	Ixodidae	*Hyalomma marginatum marginatum* (Koch)	n	27	54	–	11	92
				%	12.39	27.83	–	20.75	18.00
Arachnida	Ixodida	Ixodidae	*Ixodes ricinus* (Linnaeus)	n	18	–	7	–	25
				%	8.26	–	15.22	–	4.89
Arachnida	Sarcoptiformes	Sarcoptidae	*Sarcoptes scabiei* (Linnaeus)	n	1	–	–	–	1
				%	0.46	–	–	–	0.20
Insecta	Siphonaptera	Pulicidae	*Ctenocephalides arabicus* (Jordan)	n	114	–	–	–	114
				%	52.29	–	–	–	22.31
Insecta	Diptera	Sarcophagidae	*Wohlfahrtia magnifica* (Schiner)	n	–	9	–	–	9
				%	–	4.64	–	–	1.76
			Total	N	218	194	46	53	511
				%	100	100	100	100	100

Note: –: absent.

study, their spatial distribution by herd was as follows: 43% (CH1), 38% (CH2), 9% (CH3) and 10.37% (CH4). The infestation level per camel for all ticks was recorded by herd as follows: 12.82% (CH1), 11.41% (CH2), 2.71% (CH3) and 3.12% (CH4) (Table 3). According to the Pearson correlation test, a strong positive correlation was found between the number of infested camels and parasite prevalence in the four herds ($r = 0.999$, $p < 0.001$). However significant variations in prevalence were observed across different regions, with a higher prevalence in CH1 (88.24%), followed by CH2 (64.71%), CH4 (58.82%) and CH3 (35.29%). The total number of ticks across the four CHs was 387, resulting in an average tick intensity of 9.21 and an average tick abundance of 5.69. Ticks were found to be dominant in CH1, CH2 and CH4, while they were classified as satellite in CH3 (Table 3).

Ectoparasite distribution across dromedary age classes and sexes

Figure 2 shows the distribution of ectoparasite abundances among different parasite groups in adult and young dromedaries. The highest percentage was observed in adults, with ticks comprising 71.2% of the total ectoparasitic load, indicating their predominant presence in this age group. Tick abundance averaged 6.87 and 1.47 in adults and young camels, respectively. Fleas also made up a notable portion in adults at 14.7%, while young dromedaries had lower overall percentages, with fleas accounting for 7.8% and flies for 1.8%. Average abundance of fleas was 2.67 and 1.42 in young and adult camels, respectively. Flies averaged 0.60 per infested young camel. The stark contrast in tick prevalence between adults and young dromedaries (71.2% versus 4.3%) highlighted the significant impact of ticks on adult dromedaries compared with their limited effect on young camels. The Chi-squared test revealed a highly significant association between the ectoparasitic groups and the dromedary age classes ($\chi^2 = 119.5$, $df = 3$, $p < 0.001$). Additionally, the Pearson correlation test demonstrated no significant relationships between the average parasite abundances of adults and calves ($r = 0.323$, $p < 0.677$). It was noted that females were more parasitized than males in all surveyed herds. However, there were no significant statistical differences in the prevalence of tick infestations between sexes.

Distribution and prevalence of ectoparasites across camel body regions and sampled herds

The chord diagramme in Figure 3 illustrates the distribution of ectoparasites across various body regions of dromedaries. Overall, the abdomen exhibited the highest percentage of ectoparasites at 22.7%, followed by the neck and sternum at 17.8% and the anal and tail area at 17.4%. Ectoparasites in CH1 contributed the most, comprising a total of 42.7%,

TABLE 3 Parasitic indices in the surveyed camel herds for different ectoparasitic groups in Ouled Djellal region, northern Sahara Desert of Algeria.

		Sampled camel herds (CH)				
Ectoparasite groups	Variables	CH1	CH2	CH3	CH4	Total
	NEC	17	17	17	17	68
	NIC	11	15	6	10	42
	P%	64.71	88.24	35.29	58.82	61.76
Total parasites	Np	218	194	46	53	511
	API	19.82	12.93	7.67	5.30	12.17
	APA	12.82	11.41	2.71	3.12	7.51
Fleas	Np	115	—	—	—	115
	API	10.45	—	—	—	2.74
	APA	6.76	—	—	—	1.69
Flies	Np	—	9	—	—	9
	API	—	0.60	—	—	0.21
	APA	—	0.53	—	—	0.13
Mites	Np	1	—	—	—	1
	API	0.09	—	—	—	0.02
	APA	0.06	—	—	—	0.01
Ticks	Np	102	185	46	53	386
	API	9.27	12.33	7.67	5.30	9.19
	APA	6.00	10.88	2.71	3.12	5.68

Abbreviations: APA, average parasite abundance; API, average parasite intensity; NEC, number of examined camels; NIC, number of infested camels; Np, number of parasites; P%, parasite prevalence.

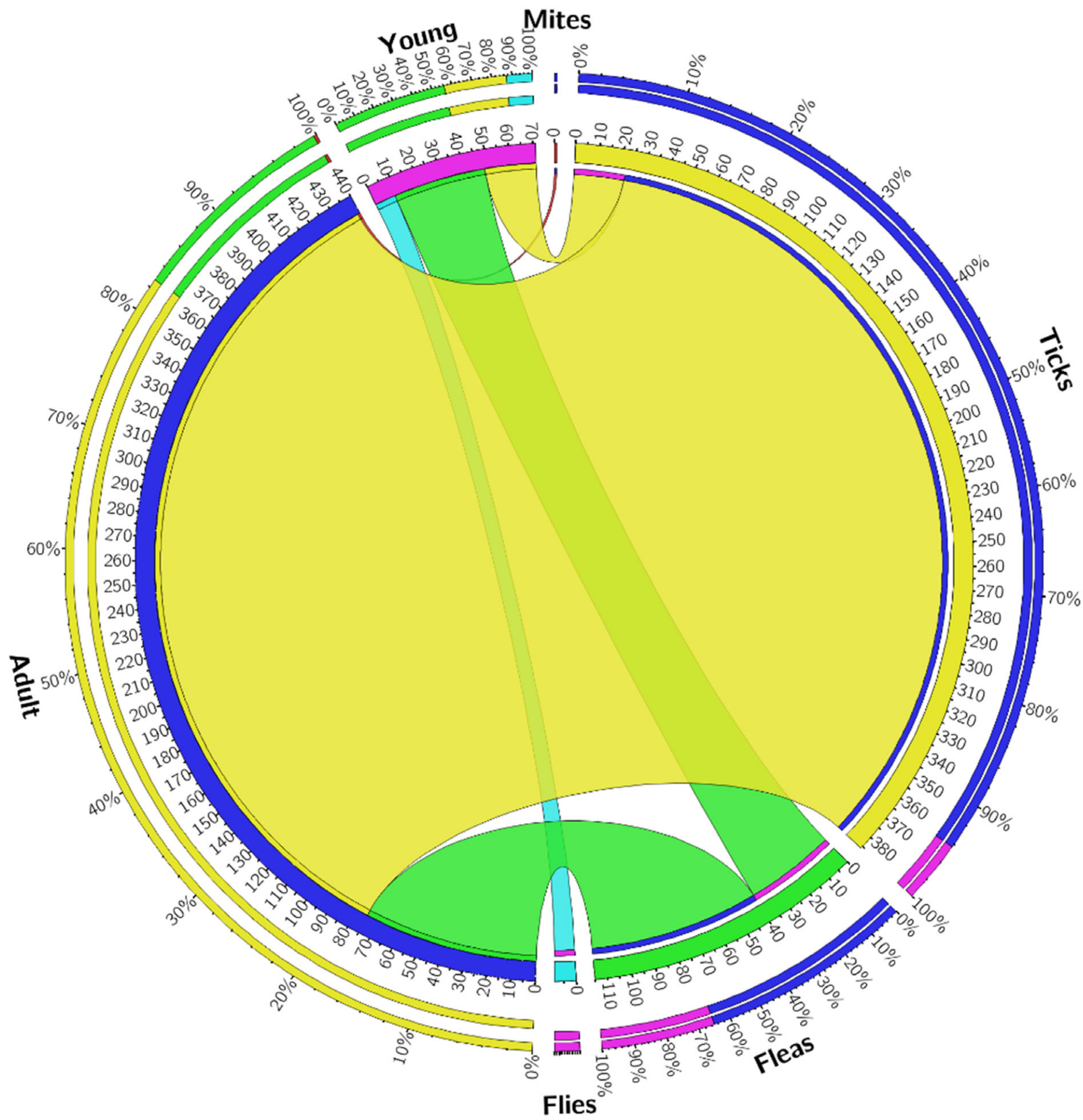

FIGURE 2 Chord diagramme displaying the distribution of ectoparasite abundances for different parasite groups in adults and calves of the dromedary camel in the region of Ouled Djellal, northern Sahara Desert of Algeria. Chord diagrammes visually represent relationships between entities using a circle divided into segments, with connections (chords) between them. The thickness of a chord indicates the strength or volume of the relationship between the connected entities. Larger arcs indicate larger values, and the visual flow of the diagramme reveals patterns and trends in the data.

with the highest infestations noted in the abdomen at 12.3% and the neck and sternum at 6.1%. Significant interactions were observed, particularly the strong associations between CH2 and the anal and tail area at 12.7%, as well as between CH1 and the abdomen at 12.3%, highlighting specific body regions that were notably affected by ectoparasitic infestations within these sampling herds. The Chi-squared test indicated a highly significant association between the affected body regions of the dromedary and the sampling herds ($\chi^2 = 103.5$, $df = 18$, $p < 0.001$). It is important to note that larvae of *W. magnifica*, which cause myiasis, were identified exclusively in CH2, specifically located on the head, particularly in the eyes and nostrils (Figure 4f,g).

In terms of tick prevalence according to anatomical locations in adult camels, the body parts were ranked in descending order from the most tick-infested to the least, as follows (Figure 3): anal and tail area for CH2 (prevalence = 35.75%) (Figure 4i), udder or inguinal region (Figure 4b,c) for CH3 (35%) and CH1 (33%), legs and pads (Figure 4d) for CH3 (35%) and CH4 (29.16%), neck and sternum (Figure 4a) for CH2 (24.58%) and CH4 (25%), abdomen for CH1 (21.65%), abdomen for CH4 (18.75%), CH2 (12.85%), and CH3 (12.5%), udder or inguinal region for CH4 (16.66%) and CH2 (16.20%), anal and tail area for CH1 (16.49%), neck and sternum for CH1 (15.46%), neck and sternum for CH3 (10%), legs and pads for CH2 (8.94%), anal and tail area for CH4

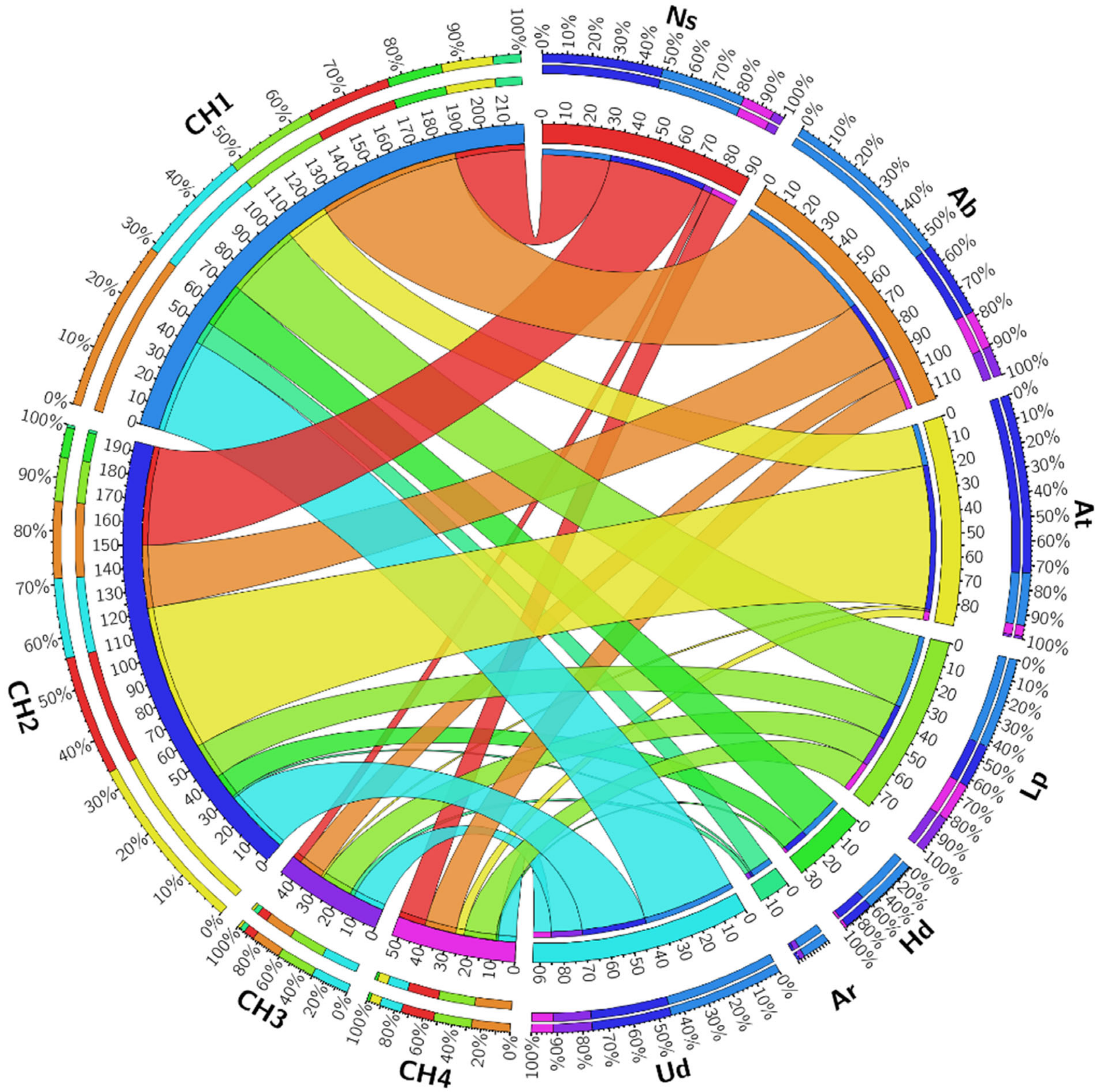

FIGURE 3 Chord diagramme illustrating the abundance-based distribution of ectoparasites across different affected body regions of the dromedary in four sampling camel herds (CH1–CH4) from the region of Ouled Djellal, northern Sahara Desert of Algeria. (Parasitized body areas: Ab: Abdomen, Ar: Auricular area, At: Anal and tail area, Hd: Head except for ears, Lp: Legs and pads, Ns: Neck and sternum, Ud: Udder or inguinal region.) Chord diagrammes visually represent relationships between entities using a circle divided into segments, with connections (chords) between them. The thickness of a chord indicates the strength or volume of the relationship between the connected entities. Larger arcs indicate larger values, and the visual flow of the diagramme reveals patterns and trends in the data.

(8.33%) and CH3 (2.5%), auricular area (Figure 4e) for CH1 (9.33%), CH2 (0.006%), CH3 (5%), and CH4 (0%), and head, excluding ears, for CH1 (0%), CH2 (1.18%), CH3 (0%), and CH4 (2.08%).

Age-related distribution of ectoparasites across dromedary body regions

The chord diagramme in Figure 5 illustrates the distribution of ectoparasites across various body regions of dromedaries, comparing young and adult camels. The infestation level of ectoparasites was notably higher in camels aged 3–8 years compared with calves aged 4–6 months (Figure 5). Adults accounted for the majority of infestations, totaling 86.1%, with significant contributions from the abdomen (17.0%) and the neck and sternum (15.9%). In contrast, young camels represented a smaller total of 13.9%, with the abdomen (5.7%) being the most affected area. In adults, the prevalence of parasites in the anal and tail area was 16.6% of the total, while the udder or inguinal region exhibited an 18.2% infestation rate, highlighting the specific body regions significantly impacted by ectoparasitic infestations in

FIGURE 4 Photographs of affected body regions of the dromedary camels by some ectoparasite genera at different developmental stages on: neck base (a), udder region (b and c), camel pad interdigital space (d), auricular area (e), facial and ocular myiasis with watery eyes due to the larvae of the *Wohlfahrtia magnifica* (f and g), beginning of *Sarcoptes scabiei* scabies near the nostrils (h), and ticks in the perineal area on the ventral side of the tail (i).

these age groups. Regarding prevalence based on ectoparasite anatomical locations in calves, the body parts were ranked in descending order, from the most tick-infested to the least infested, as follows: abdomen for CH3 and CH4 (100%), CH2 (83.33%), and CH1 (40%); followed by the anal and tail area for CH1 (60%) and CH2 (16.66%). The Chi-squared test revealed a highly significant association between the affected body regions of the dromedary and age classes ($\chi^2 = 69.13$, $df = 6$, $p < 0.001$).

Ectoparasite group distribution and prevalence across affected body regions

The distribution of ectoparasite abundances among different parasite groups across various body regions of dromedaries is displayed in Figure 6. Ticks accounted for the highest total percentage at 75.5%, with significant contributions from the anal and tail area at 17.4%, and the udder or inguinal region at 16.2%. Fleas followed, making up 22.5% of the total, primarily affecting the abdomen at 7.8%. The distribution of ticks in the neck and sternum was 14.7%, while fleas accounted for 4.1% in the legs and pads. The Chi-squared test revealed a highly significant association between the affected body regions of the dromedary and the ectoparasite groups ($\chi^2 = 250.1$, $df = 18$, $p < 0.001$).

Among all camels sampled, the udder was the most parasitized by ticks, followed by the legs and pads. In contrast, the auricular area and head were the least parasitized body parts by ticks (Figure 6). For fleas, they were recorded only in camels from CH1. Their prevalence according to anatomical locations in adult camels was ranked in descending order as follows: abdomen (38.66%); head (excluding ears) (16%); legs and pads (14.66%); udder or inguinal region (13.33%); auricular area (9.33%); neck and sternum (8%); anal and tail area (0%). For the prevalence of fleas in relation to tick anatomical locations in calves, the following rates were recorded: abdomen (27.5%); neck and sternum (25%); legs and pads (25%); head (excluding ears) (17.5%); auricular area (5%); udder or inguinal region (0%); anal and tail area (0%).

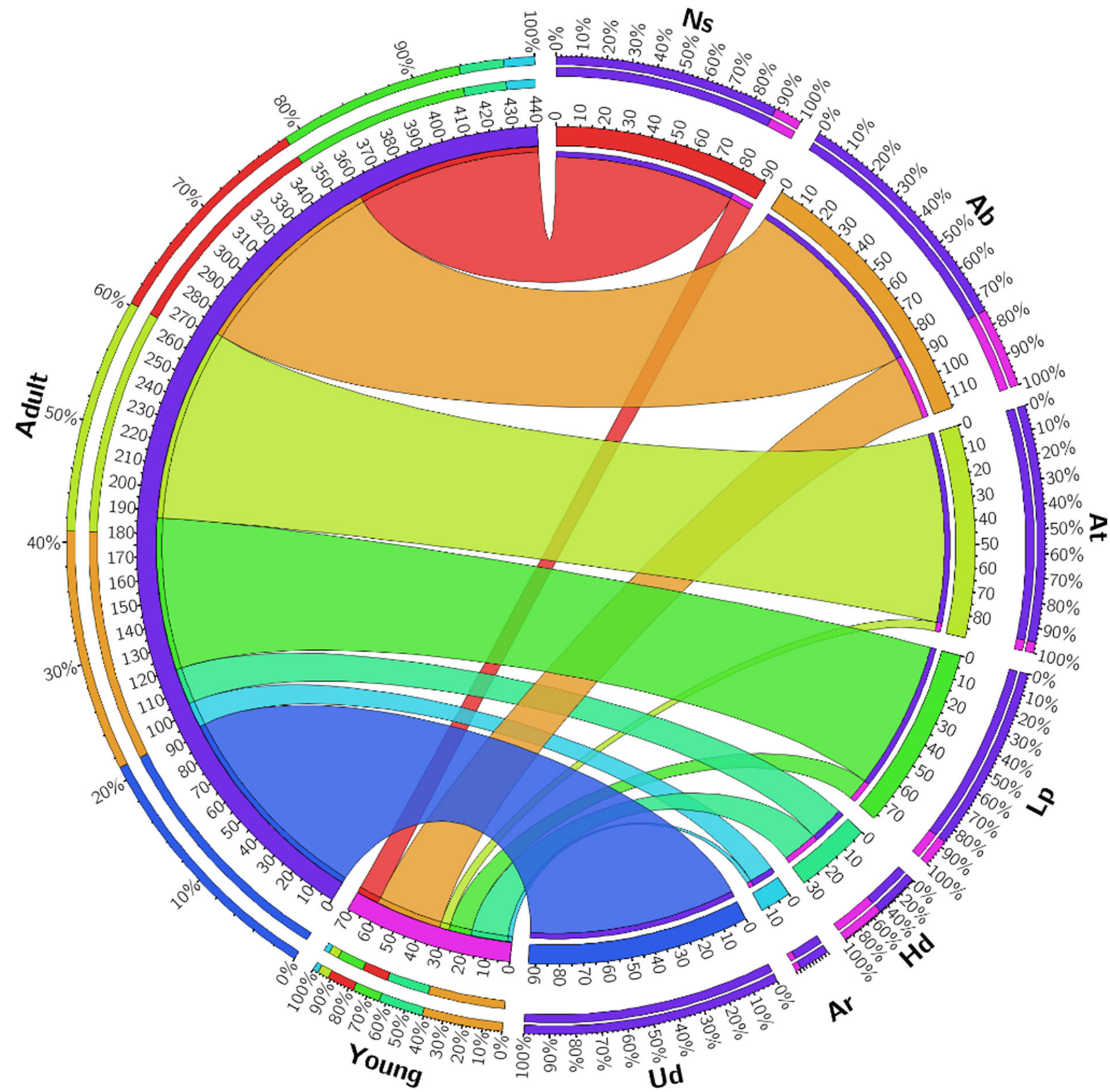

FIGURE 5 Chord diagramme illustrating the abundance-based distribution of ectoparasites across different affected body regions of the dromedary for young and adult camels from the region of Ouled Djellal, Northern Sahara Desert of Algeria (Parasitized body areas: Ab: Abdomen, Ar: Auricular area, At: Anal and tail area, Hd: Head except for ears, Lp: Legs and pads, Ns: Neck and sternum, Ud: Udder or inguinal region). Chord diagrammes visually represent relationships between entities using a circle divided into segments, with connections (chords) between them. The thickness of a chord indicates the strength or volume of the relationship between the connected entities. Larger arcs indicate larger values, and the visual flow of the diagramme reveals patterns and trends in the data.

Ectoparasite species distribution and overlap among sampling herds

The Venn diagramme representing the four sampling herds (CH1–CH4) illustrates the distribution and overlap of ectoparasite species across the different locations (Figure 7). CH1 exhibited the highest species richness, with six ectoparasites identified, while CH2, CH3 and CH4 contained four, two and two ectoparasite species, respectively. Notably, *H. dromedarii* was the only species found at all four locations. *H. marginatum* was present in CH1, CH2 and CH4, while *R. sanguineus* sensu lato was shared between CH1 and CH2. Additionally, *I. ricinus* was identified at both CH1 and CH3. Importantly, CH1 harboured two exclusive species, *S. scabiei* and *C. arabicus*, whereas CH2 had one unique species, *W. magnifica*. These findings underscore significant species overlap between the sites, with CH1 serving as a central hub of ectoparasite diversity.

Similarity patterns of ectoparasite communities across sampled herds

The heatmaps illustrating the values of similarity indices (two qualitative and two quantitative) among the four sampled camel herds (CH1-CH4) revealed significant patterns of similarity for ectoparasite

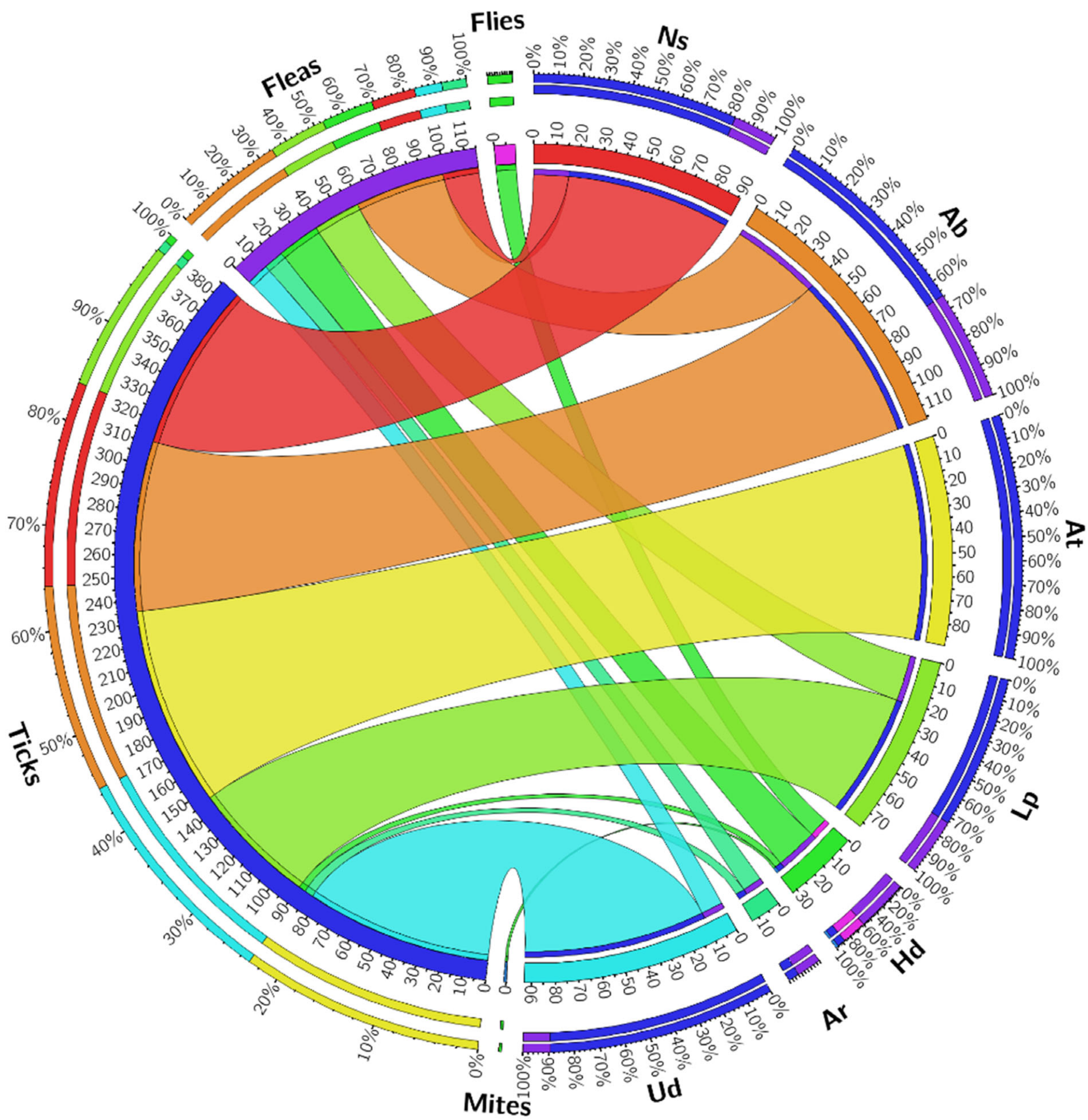

FIGURE 6 Chord diagramme illustrating the distribution of ectoparasite abundances for different parasite groups across affected body regions of the dromedary in the region of Ouled Djellal, northern Sahara Desert of Algeria. (Parasitized body areas: Ab: Abdomen, Ar: Auricular area, At: Anal and tail area, Hd: Head except for ears, Lp: Legs and pads, Ns: Neck and sternum, Ud: Udder or inguinal region.) Chord diagrammes visually represent relationships between entities using a circle divided into segments, with connections (chords) between them. The thickness of a chord indicates the strength or volume of the relationship between the connected entities. Larger arcs indicate larger values, and the visual flow of the diagramme reveals patterns and trends in the data.

species presence and abundance (Figure 8). For the Sorensen Classic index, the highest similarity values were recorded between CH2 and CH4, at 66.7%. The second highest similarity was observed between CH1 and CH2, at 60%. In contrast, the lowest similarity value of 33.3% was noted between CH3 and CH2. In the Jaccard Classic index, the most substantial similarity was again between CH2 and CH4, registering at 50%. The second highest value was observed between CH1 and CH2, at 42.9%. A lower similarity of 20% was noted between CH2 and CH3. The Morista-Horn index revealed a peak similarity of 95.1% between CH3 and CH4, with the next highest value of 90.4% between CH2 and CH4. Conversely, the lowest similarity of 36.6% was recorded between CH1 and CH3. Finally, in the Bray-Curtis index, the highest similarity value of 78.8% was found between CH3 and CH4, while the second highest similarity was noted between CH2 and CH4, at 42.9%. The lowest value of 32.5% was observed between CH2 and CH3. The similarity analysis employs

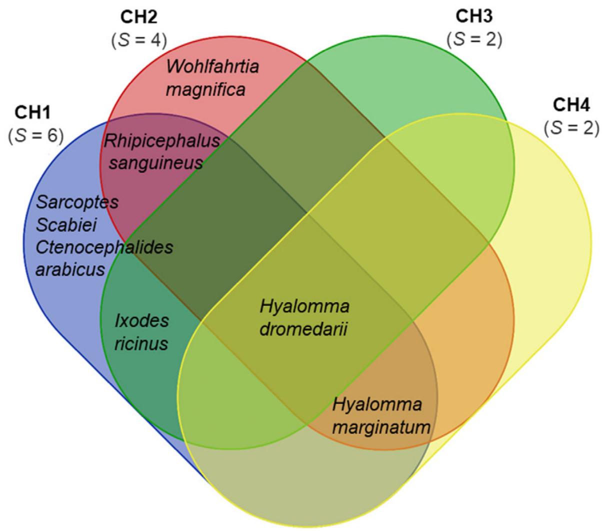

FIGURE 7 Four-set Venn diagramme displaying the distribution of ectoparasite species among the sampling herds (CH1–CH4) of dromedary camels (*C. dromedarius*) in the region of Ouled Djellal, northern Sahara Desert of Algeria.

qualitative indices such as the Sorensen and Jaccard, as well as quantitative indices including the Morista-Horn index and Bray–Curtis index.

DISCUSSION

The present cross-sectional study aimed to investigate the prevalence, dominant species and infestation levels of ectoparasites in *C. dromedarius* herds reared in northern Algeria's Sahara Desert, as well as factors that influence their prevalence and distribution. In four *C. dromedarius* herds in northern Algeria, the current study examined the prevalence and infestation of ectoparasites, that include: ticks, fleas, mites and flies. In herds of various types and municipalities, factors like the hosts' age and sex were taken into account.

Regarding the abundance of ticks in this study, *H. dromedarii* comprises 45.21% of the total ectoparasites identified (Table 3). The dominance of *H. dromedarii* was also reported in camels of the Algerian Sahara Desert by Bouhous et al. (2008), with a prevalence of 79.31%, and by Ouchene-Khelifi et al. (2020) with a prevalence of 83.98%. Also, this dominance was shown on a worldwide scale by Alanazi et al. (2020) in Saudi Arabia (76.4%); Champour et al. (2013) in Iran (85.5%); and Moshaverinia and Moghaddas (2015) in Iran (70.76%). Conversely, in Iran, *H. dromedarii* exhibited lower dominance in camels from Sabzevar City, with dominance of *Hyalomma anatolicum anatolicum* Koch (Ixodida, Ixodidae) (Shamsi et al., 2020). The persistence of *H. dromedarii* may be attributed to its adaptation to the harsh climatic conditions of the Saharan regions (Khan et al., 2022; Walker et al., 2003).

Hyalomma marginatum accounted for 18% of the total ectoparasites identified in this study (Table 3). By contrast, it was observed in various ruminant species in Pakistan (Khan et al., 2022). Champour et al. (2013) reported a lower prevalence of 2.9% for *H. marginatum* in camels from northeastern Iran. However, it was not detected in Iran by Moshaverinia and Moghaddas (2015) and Shamsi et al. (2020), nor in camels from the Oued Souf region (Ouchene-Khelifi et al., 2020) and Saudi Arabia (Alanazi et al., 2020).

In the present study, *R. sanguineus* sensu lato (brown tick dog) accounted for 7.63% of the total ectoparasites identified. However, lower levels of infestation by *R. sanguineus* sensu lato have been reported in camels from the Oued Souf region (0.32%) by Ouchene-Khelifi et al. (2020) and from the Adrar region (0.03%) by Bouhous et al. (2008). Matallah et al. (2013) found *R. sanguineus* to be the only ectoparasite species present in the dogs of the Souk-Ahras region (northeastern Algeria), whereas in the El-Kala region, it constituted 77% of the ticks collected, emphasizing the zoonotic risk posed by these dogs. Khan et al. (2022) from Pakistan and Abdallah et al. (2017) from China elucidated the cross-species transmissibility of *R. sanguineus*. The *Rhipicephalus* genus is the most common in the Mediterranean Basin among ticks (Defaye et al., 2022); however, it is less common among various genera of ectoparasites (17.17%) in Ethiopia (Endris et al., 2021). For the present study, it was noted that the camel breeders typically rear sheep and goats alongside camels. They also often have several guard dogs, and their herds overlap with those of small ruminants on pastureland. According to Defaye et al. (2022), certain species of ticks from the *Rhipicephalus* and *Ixodes* genera exhibit a tropism for pets and livestock, facilitating high transmissibility of pathogens between different animal species, and significantly impacting human and other animals' health. Elati et al. (2021) attributed the presence of *R. sanguineus* in camels to their cohabitation with small ruminants and dogs.

Ixodes ricinus comprises 4.9% of the total ectoparasites identified in this study. In Mediterranean basin countries, *I. ricinus* has been found to carry 34 tick-borne pathogens. *I. ricinus* is ubiquitous and can inhabit mammals, reptiles and avifauna. It is primarily recognized for its role in transmitting the causative agent of Lyme disease in humans (Defaye et al., 2022). In Africa, *I. ricinus* is primarily restricted to the cooler and more humid areas of the Mediterranean climatic region, and it is present in Tunisia, Algeria and Morocco (Walker et al., 2003).

During the present study, only one case of *S. scabiei* infestation was identified near the nostrils of an adult female camel in the Gharbaa region (CH1), representing 0.002% of the total ectoparasites. This low incidence may be attributed to seasonal factors; as camel mange is generally more prevalent in winter. *S. scabiei* var. *cameli* poses a significant threat to camel health and production due to its highly contagious nature (Sazmand et al., 2019). In comparison, Ahmed et al. (2020) reported that 47.6% of camels in Egypt harboured sarcoptic mange infections. Furthermore, they identified age, sex and sampling season as the most significant risk factors associated with the disease. In Morocco, Kamili et al. (2019) found that *S. scabiei* lesions primarily affected the neck (51%), legs (35%), abdomen (34%) and head (15%) of camels.

Ctenocephalides arabicus comprised 22.31% of the total identified ectoparasites in the present study. Literature indicates that *C. arabicus*

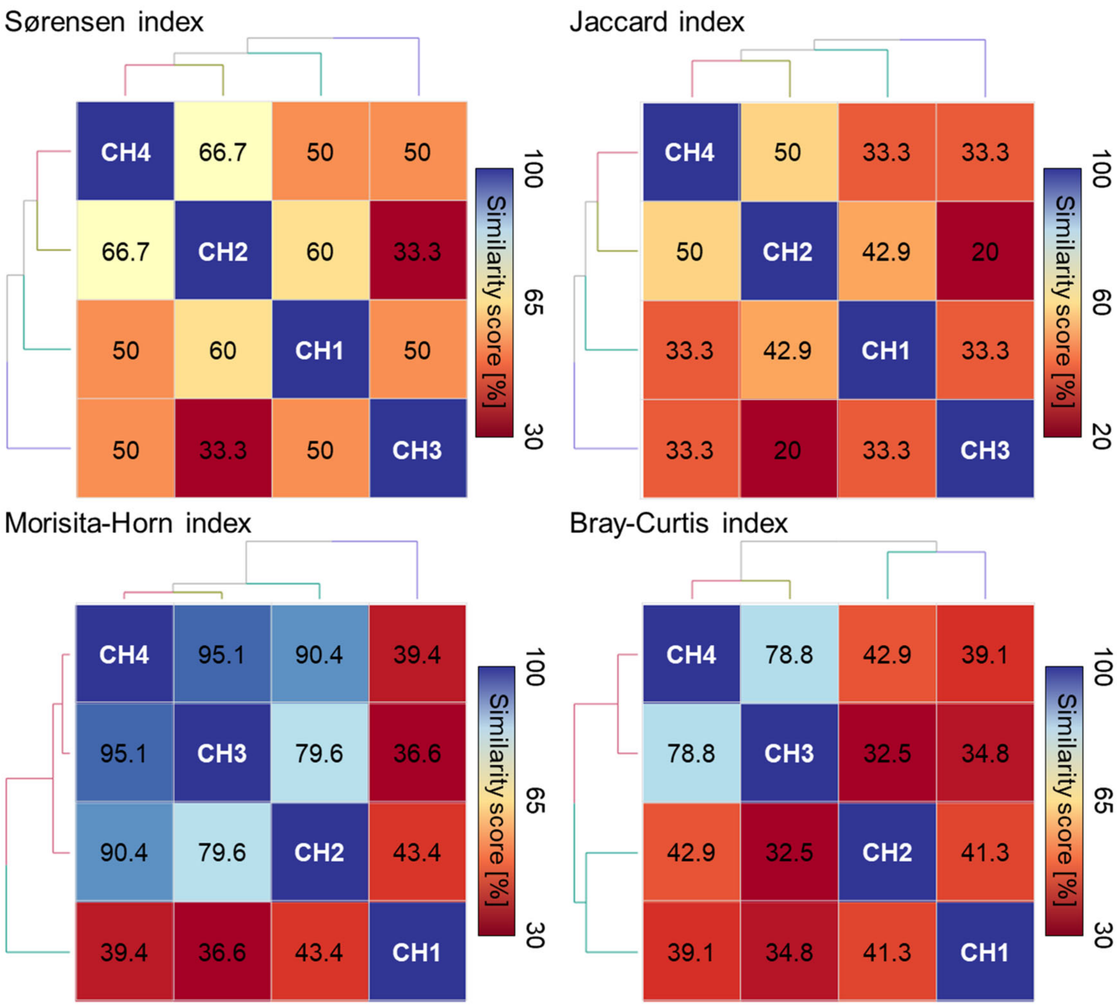

FIGURE 8 Heatmaps, with two-way clustering analysis (Ward's method), displaying the matrices of similarity of ectoparasite species parasitizing dromedary camels at four sampling regions (CH1-CH4) in the region of Ouled Djellal, northern Sahara Desert of Algeria. The similarity analysis employs qualitative indices such as the Sorensen and Jaccard, as well as quantitative indices including the Marisita-Horn index and Bray–Curtis index. Similarity scores were mapped and scaled proportionally to colour intensity, where colder colours (blue) indicate higher similarity values, while hotter colours (red) represent lower similarity of ectoparasite species between camel herds.

is associated with the genus *Meriones*. Morsy et al. (2001), in the Najran District of Saudi Arabia, found *C. arabicus* in *Meriones rex* (king jird) Yerbury & Thomas (Rodentia, Muridae) among several tick species. It is noteworthy that jirds are prevalent in this study area and often take shelter in the burrows they dig under thorny and halophytic vegetation grazed by dromedary camels.

Nine cases of myiasis caused by *W. magnifica* were identified during the present study, accounting for 1.76% of the total ectoparasites recorded. In Pakistan, Qamar et al. (2018) reported a higher prevalence of *W. magnifica* (16.67%) than of the other two fly species examined: *Chrysomyia* spp. (10%) and *Cephalopina titillator* Clark (Diptera, Oestridae) (1.11%). Alnaqeb (2024) reported that *W. magnifica* is attracted to small lesions, which are often caused by tick bites. *W. magnifica* is active from May to October, and thrives during the sunny, warm hours of the day (Farkas & Hall, 1998). As myiasis is not easily detected through routine examinations, clinicians should remain vigilant regarding its potential presence in various parts of the body (Kheirabadi et al., 2014). Li et al. (2022) reported that *W. magnifica* is the sole parasite responsible for causing vaginal myiasis in Bactrian camels on the Mongolian plateau.

Sazmand et al. (2019) reported that various ticks and flies associated with camels serve as biological and mechanical vectors for several zoonotic agents, including Crimean-Congo hemorrhagic fever virus (CCHFV), Alkhurma hemorrhagic fever virus, Dhori virus, Sindbis virus, Kadam virus and Toghoto virus, along with bacteria such as *Coxiella burnetii* Derrick (Legionellales, Coxiellaceae), *Rickettsia* spp. (Rickettsiales, Rickettsiaceae), *Bartonella* spp. (Hyphomicrobiales, Bartonellaceae), *Anaplasma phagocytophilum* Foggie (Rickettsiales, Ehrlichiaceae), and *Borrelia burgdorferi* Johnson (Spirochaetales, Spirochaetaceae). Defaye et al. (2022) reported that in the Mediterranean Basin, five tick genera were found to be positive for tick-borne pathogens from various domestic hosts: *Argas*, *Haemaphysalis*, *Hyalomma*, *Ixodes* and *Rhipicephalus*.

In the case of camels in the Sahara Desert of Algeria, Temani et al. (2025) detected CCHFV Africa 1 lineage in *H. dromedarii*.

Accordingly, Degui et al. (2024) found an overall seroprevalence of 94.79% (95% CI = 92.14–97.45) in serum samples which were positive for CCHFV-specific IgG antibodies. Kernif et al. (2012) identified *Rickettsia africae* Kelly (Rickettsiales, Rickettsiaceae) from *H. dromedarii*. Hamlili et al. (2022) reported that *H. dromedarii* harboured *Coxiella burnetii* and *Anaplasma* sp., closely related to *Anaplasma platys* Dumler et al. (Rickettsiales, Ehrlichiaceae). Benredjem et al. (2014) identified *Borrelia garinii* Baranton et al. (Spirochaetales, Borreliaceae) and *Rickettsia monacensis* Simser et al. (Rickettsiales, Rickettiaceae) in *I. ricinus*.

Regarding preferential attachment sites of ticks on camels, based on our field observations and the findings of previous studies (Bouhous et al., 2008; Elati et al., 2021; Elias et al., 2020; Gharbi & Darghouth, 2014; Khan et al., 2022), it can be suggested that they depend on the breed of the animal, which influences hair distribution, density and length; the thickness of the skin, which affects accessibility to blood vessels; the selection of anatomical regions that are more vascularized and less exposed to sunlight; and the genus and species of the parasite. In the present study, the udder was found to be the most heavily parasitised area of the camel's body by ticks, followed by the legs and pads. The auricular area and head were the body parts least affected by tick infestation. Elati et al. (2021) found that the sternum and anus, followed by the udder and inner thigh, were the preferred tick attachment sites. Bouhous et al. (2008) observed that *H. dromedarii* was found on all body regions, while *H. marginatum* was collected in the perianal and perivulvar regions.

In the four herds examined, females exhibited a higher level of parasitism than males, although this was not statistically validated. A notable limitation of the present study is that the composition of camel herds is usually characterized by a high proportion of adult females, as breeders typically select a small number of high-performance breeding males to ensure effective reproduction, then they sell or slaughter the remaining males. This selection strategy accounts for the observed discrepancies in the sex ratios within this study's sample. Elati et al. (2021), noted that female camels in Tunisia were more infested with ticks than their male counterparts, supporting the hypothesis that lactation and pregnancy may increase females' susceptibility to tick infestation. Similar to our findings, Elias et al. (2020) did not find any statistical correlation regarding sex differences in tick infestation.

The Chi-squared test revealed a highly significant association between the ectoparasitic groups and the age classes of dromedaries, with increased ectoparasitism observed in older camels. Similarly, Khan et al. (2022) and Bouhous et al. (2008) observed that the degree of tick parasitism increased with the age of camels. Swai et al. (2005) linked the frequency of ectoparasites in adult cattle to their larger body surface area.

It is noteworthy that camels raised in the peri-urban intensive system of the Bir Nâam (CH3) and Doucen (CH4) regions carried fewer ticks than those reared in the semi-extensive system of the Chaîba region (CH2) and the extensive system of the Gharbaa region (CH1). This difference could be attributed to the fact that camels reared in semi-extensive and extensive systems are more exposed to contact with certain steppe vegetation that hosts parasitized rodents or lagomorphs, as well as ectoparasites that may cling to their leaves and branches. Due to the small size of the study sample, the breeding system and region are confounded and have only been replicated once, which limits the conclusions that can be drawn about these variables. In other studies from the Algerian Sahara Desert, Bouhous et al. (2008) reported an exceptionally high tick infestation level of 99.41% in camels. Additionally, Al-Salihi et al. (2018) documented heavy tick infestations among camels in the Sahara Desert of Iraq under extensive breeding conditions. Also, regional differences have been reported for camel ectoparasitism, with variations in prevalence and associated risk factors being observed across different regions. In this context, Elias et al. (2020) reported the impact of several factors on ectoparasitism in camels, including temperature, rainfall, humidity, vegetation, landscape and altitude. Nuttall (2021) highlighted that elevated temperatures can differentially impact the survival of various tick life stages.

The elevated parasitological indices observed in some of the herds surveyed (CH1 and CH2) may be attributed to variations in breeding management practices among camel herders, particularly regarding the control of ectoparasites through the regular application of acaricides, also to the lack of adequate veterinary services. Bouhous et al. (2008) attributed the high levels of tick infestation to the nomadic nature of camel husbandry, which supports our findings. Moreover, the substantial population of camels in the Gharbaa (CH1) and Chaîba (CH2) regions is likely a critical factor in the amplification of ectoparasite infestations, which aligns with Charles Nicolle's epidemiological hypothesis (Schultz & Morens, 2009).

CONCLUSION

This study revealed that the one-humped camel (*C. dromedarius*) reared in Ouled Djellal Province in the Sahara Desert of Algeria is infested by four tick species, one flea species, one mite species and one fly species. The overall parasite prevalence reached 61.76%, with a load of up to 10 ectoparasites per infested camel. These findings underscore a significant ectoparasitic challenge facing camel populations in the drylands of Algeria, an area with limited prior research on camel ectoparasites. The identification of multiple ectoparasite species in camels raises concerns about their potential role as vectors of zoonotic diseases. Ticks, in particular, are known to transmit pathogens that could pose significant public health risks, not only to herders and their families but also to other animals sharing the same environment. Monitoring the prevalence of these ectoparasites can help anticipate and mitigate possible outbreaks of tick-borne diseases in the region.

The implications of this study are critical, as high ectoparasite prevalence can lead to decreased animal health and productivity, potentially impacting the livelihoods of camel herders. Future research should focus on elucidating the specific risk factors contributing to ectoparasite persistence not only in camel herds but also in other livestock that may interact with camels. Understanding these dynamics is vital for predicting zoonotic disease outbreaks associated with ectoparasites. Moreover, enhancing health prophylaxis in camel breeding within the northern Algerian Sahara is essential. This could be achieved through organized extension conferences led by entomologists and veterinarians, along with intensified veterinary inspections of camel herds. Effective control strategies for haematophagous arthropods, particularly ticks, will necessitate comprehensive knowledge of species identification, their ecological niches and ongoing monitoring of treatment efficacy.

AUTHOR CONTRIBUTIONS

Badreddine Attir: Conceptualization; formal analysis; data curation; supervision; writing – original draft; resources; investigation; methodology. **Adel Mammeri:** Conceptualization; methodology; data curation; investigation; formal analysis; writing – original draft. **Abdelhamid Baa:** Data curation; investigation. **Madjed Aggouni:** Methodology. **Safia Zouaid:** Methodology; investigation; writing – original draft. **Mebarka Basli:** Methodology; writing – original draft; investigation. **Haroun Chenchouni:** Formal analysis; visualization; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets used and/or analysed during the current study are available on the Dryad Digital Repository from: https://doi.org/10.5061/dryad.37pvmcvvv.

ETHICS STATEMENT

The present study was approved by the scientific committee of the Faculty of Natural and Life Sciences and then by the committee of members of the Laboratory of Genetics, Biotechnology, and Valorization of Bioresources (LGBVB), University Mohamed Khider of Biskra, Algeria.

STATEMENT OF ANIMAL RIGHTS

All the animal studies were conducted with the utmost regard for animal welfare, and all animal rights issues were appropriately observed. No animal suffered during the course of the experiment.

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