

Article

Assessment of honey bees health in relation to varroa (Acari: Varroidae) infestation and morphometric analysis of the mite in two phytogeographic zones of Burkina Faso, West Africa

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Abstract

Varroa mite threatens honey bees worldwide by affecting larvae and adults and causing viral diseases associated with colony collapse. This study investigates its prevalence and infestation level, and morphometric traits in Southern Sudanese (SS) and Northern Sudanese (NS) phytogeographical zones of Burkina Faso. We visited 238 hives from 48 apiaries in 9 provinces. Phoretic varroa mites were detected through a 70% alcohol wash on approximately 300 worker bees. Once in the laboratory, 7 morphometric characters were measured on 1 to 10 varroa mites per hive. According to these measurements, the mites were identified as *Varroa destructor*, Anderson & Trueman, 2000. Data analysis reveals that 91.6% of colonies of the whole sample are infested with varroa. In NS zone, the provinces of Bazega and Zoundweogo show high infestation level (5.93% and 7.18% respectively), while in the SS zone, Nahouri and Ziro exhibit the highest level (8.19% and 9.00%) respectively. In terms of body length and body width (BL and BW), varroa mites from SS zone display averages of $1176.04 \pm 40.1 \mu\text{m}$ and $1765.14 \pm 49.2 \mu\text{m}$, while those from the NS zone have average values of $1167.44 \pm 40.8 \mu\text{m}$ and $1755.36 \pm 53.42 \mu\text{m}$. These morphological differences are statistically significant ($P \leq 0.05$), highlighting variability that may result from local adaptations or genetic variations. The morphological diversity of this parasite has implications for its biology, dispersion, and virulence towards bees. Future studies should explore genetic factors influencing parasitic dynamics and bee resistance for effective management strategies.

Keywords: *Varroa destructor*, Morphometry, *Apis mellifera*, variability, Burkina Faso

Introduction

Apis mellifera Linnaeus is the main insect used in beekeeping. It actively participates in the pollination of wild and cultivated plants, helping to increase agricultural yields and conserve biodiversity (Stein *et al.* 2017; Powney *et al.* 2019). However, many threats to beekeeping sustainability have been reported in the context of colony collapse disorder (Chagnon 2008; Kluser *et al.* 2010). Those include forest areas decrease, lengthening of dry season, use of pesticides in agriculture, bad beekeeping management, and recent observations of Varroa (Schweitzer *et al.*

2013). The varroa mite has been described as the greatest threat to honeybee colony health worldwide (Allsopp *et al.* 1997; Chen *et al.* 2004; Rosenkranz *et al.* 2010; Asma 2015). First and foremost, it has a direct impact on bees (Kralj & Fuchs 2006). These impacts include weight loss, reduced flight performance, reduced learning capacity and low levels of bee return to the hive (Duay *et al.* 2003; Kralj & Fuchs 2006). Varroa infestation is also associated with a reduction in the average lifespan of bees. Secondly, this parasite indirectly impacts bees by acting as a vector for viruses involved in bee Colony Collapse Disorder (Chen *et al.* 2004; Levin *et al.* 2016). Cases of bee mortality attributable to varroa mites have been reported in Europe and the USA (Kraus & Page 1995; Finley *et al.* 1996). All this has a negative impact on beekeeping, which not only contributes to economic development, but also helps maintain biodiversity by pollinating flowering plants (Bradbear 2005, 2010; Mall & Tiwari 2018). Over the past ten years, beekeeping has become a booming activity in Burkina Faso. In 2019, a study by the Ministry in charge of animal resources revealed that honey production rose from 35 to 500 tonnes between 2008 and 2018, contributing approximately 5 million USD to the national economy (STA 2019). It is now a subject of a national development strategy (MRAH 2019). In this national strategy, the management of bee diseases and parasites, including the varroa mite, occupies a prominent place. The first varroa infestations in sub-Saharan Africa were reported in South Africa in 1997 (Allsopp *et al.* 1997). In East and West Africa, it was first detected in early 2009 in Kenya, Tanzania and Ghana (Fazier *et al.* 2010). The level of infestation per colony (number of phoretic mites/100 adult worker bees) was around three times greater in colonies of European bees than in those of African bees (5.0 ± 1.4) (Nganso *et al.* 2017). In Burkina Faso, its presence was first mentioned in 2014 (Mutsaers *et al.* 2014). Since then, some work has been initiated to assess its infestation in certain localities of the country, without however including the variations that may exist according to phytogeographical zones (Aebi 2017; Kaboré *et al.* 2022). In this study, we focused on this mite. Our aim is to investigate its prevalence, infestation levels and the variability of its morphometric traits according to phytogeographical zones. Ultimately, the results could help decision-making and guide a possible parasite management program in Burkina Faso.

Materials and methods

Our study took place in the Northern Sudanese and Southern Sudanese phytogeographical zones of Burkina Faso (Figure 1). The Northern Sudanese is the most intensively cultivated region of the country. In this zone, rainfall varies from 700 to 900 mm per year. This is a savannah zone, with occasional large, stocky trees 10 to 20 m high. The densest forest formations in the country are found in the Southern Sudanese zone. Average annual rainfall ranges there from 900 to 1100 mm (Fontès & Guinko 1995; Nikiema *et al.* 2001).

The field phase of our study took place between February and March 2023. We inspected 238 hives (Fixed and mobile frames) from 48 localities and 9 provinces (Table 1). In each locality, a single apiary was selected for the study. The name of the locality is used here as the name of the apiary. According to phytogeographical zones, there were 18 apiaries in the northern Sudanese zone and 30 in the southern Sudanese one. Apiaries were selected with the consent of their owners. The sampling took place in daylight. In each apiary, a minimum of three hives were randomly selected.

In each hive, around 300 bees from the brood chamber were collected in a jar. Varroa mites were detected by washing with 70% alcohol and then counted. At Laboratoire d'Entomologie Fondamentale et Appliquée (LEFA) of Université Joseph KI-ZERBO, biologically significant variables from 1 to 10 individuals from each hive were measured, i.e. a total of 1,641 varroa mites. The mites were first photographed in Petri dishes at a precise scale using Leica Application Suite

version 3.4.1. Image J software was then used to measure the variables (Figure 2). These variables included body length (BL), body width (BW), genital shield length (GSL), genital shield width (GSW), anal plate length (APL), anal plate width (APW) and lateral plate width (LPW). The ratio values of certain variables such as BL/BW, BW/BL, GSL/ GSW and APL/ APW were also calculated and included in the analysis. In the study of *Varroa* biology and description, the characters relating to body size, genitalia and sensory organs are significant (Rosenkranz *et al.* 2010).

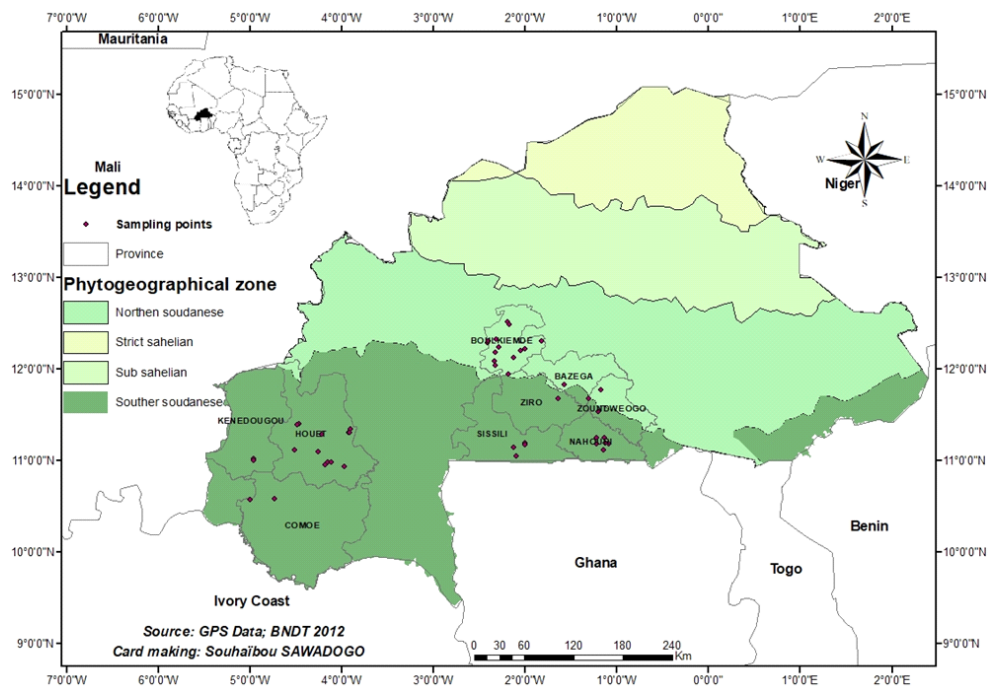


FIGURE 1. Map of Burkina Faso showing study area and varroa sampling points.

TABLE 1. Location of varroa collection sites in Burkina Faso.

N°	Phytogeographical zone	Province	Location/ Apiary
1	Northern Sudanese	Bazega	Silemba
2	Northern Sudanese	Boulkiemde	Bingo
3	Northern Sudanese	Boulkiemde	Bourkina
4	Northern Sudanese	Boulkiemde	Ipendo
5	Northern Sudanese	Boulkiemde	Koulnatenga
6	Northern Sudanese	Boulkiemde	Kunde
7	Northern Sudanese	Boulkiemde	La
8	Northern Sudanese	Boulkiemde	Nayalgue
9	Northern Sudanese	Boulkiemde	Poa
10	Northern Sudanese	Boulkiemde	Ramongo
11	Northern Sudanese	Boulkiemde	Sala
12	Northern Sudanese	Boulkiemde	Soaw
13	Northern Sudanese	Boulkiemde	Tatiou
14	Northern Sudanese	Boulkiemde	Tina

.....continued on the next page

TABLE1. (Continued)

N°	Phytogeographical zone	Province	Location/ Apiary
15	Northern Sudanese	Boulkiemde	Tiogho Mossi
16	Northern Sudanese	Comoe	Bounouna
17	Northern Sudanese	Comoe	Gouidougouni
18	Northern Sudanese	Comoe	Tangora
19	Southern Sudanese	Houet	Klesso
20	Southern Sudanese	Houet	Kofila
21	Southern Sudanese	Houet	Kokoun
22	Southern Sudanese	Houet	Kuakuale
23	Southern Sudanese	Houet	Missidougou
24	Southern Sudanese	Houet	Moamie
25	Southern Sudanese	Houet	Oualana1
26	Southern Sudanese	Houet	Oualana2
27	Southern Sudanese	Houet	Santidougou
28	Southern Sudanese	Houet	Soungalema1
29	Southern Sudanese	Houet	Soungalema2
30	Southern Sudanese	Houet	Yeguele
31	Southern Sudanese	Kenedougou	Lidaral
32	Southern Sudanese	Kenedougou	Lidara2
33	Southern Sudanese	Nahouri	Banon
34	Southern Sudanese	Nahouri	Pighiri
35	Southern Sudanese	Nahouri	Po_Secteur7
36	Southern Sudanese	Nahouri	Tambalo
37	Southern Sudanese	Nahouri	Tiakane
38	Southern Sudanese	Nahouri	Torem
39	Southern Sudanese	Nahouri	Yaro
40	Southern Sudanese	Sissili	Lame
41	Southern Sudanese	Sissili	Leo
42	Southern Sudanese	Sissili	Sissily1
43	Southern Sudanese	Sissili	Sissily2
44	Southern Sudanese	Sissili	Zoro
45	Southern Sudanese	Ziro	Gallo
46	Southern Sudanese	Zoundweogo	Kougressince
47	Southern Sudanese	Zoundweogo	Soanguin
48	Southern Sudanese	Zoundweogo	Tewaka

The data collected were used to calculate infestation levels and prevalences (Tibatá *et al.* 2021). The infestation level corresponds to the number of varroa mites per 100 bees. It was calculated for each hive. The calculation was made by dividing the number of varroa mites counted in the colony by 300 and multiplying the result by 100.

$$\text{Infestation level (IL, \%)} = \frac{\text{Number of varroa counted in a colony}}{300} \times 100$$

The prevalence refers to the proportion of hives with a positive varroa mite diagnosis. It was calculated by dividing the number of infested colonies by the total number of colonies sampled, then multiplying by 100.

$$Prevalence (\%) = \frac{Number\ of\ infested\ colonies}{Total\ number\ of\ colonies\ sampled} \times 100$$

Data were entered into Microsoft Excel 365 and analyzed using R Studio (R Core Team 2022). We compared varroa prevalences and infestation levels by phytogeographical zone and hive model, using proportion tests. Analyses were carried out also to present morphometric characteristics and investigate possible variability between populations in the 2 phytogeographical zones. To determine the significance of the differences between the means, Welch's t-tests were also used to compare varroa from the two phytogeographical zones. Pearson correlation coefficients were calculated between the variables. Additionally, we applied Principal Component Analysis (PCA) using the FactoMinerR and Factoextra packages to simplify and interpret the dataset. Following the PCA, we carried out an Ascending Hierarchical Classification (ACH) to identify the number of morphotypes among the mites based on their apiary of origin. All analyses were conducted with a 95% confidence level.

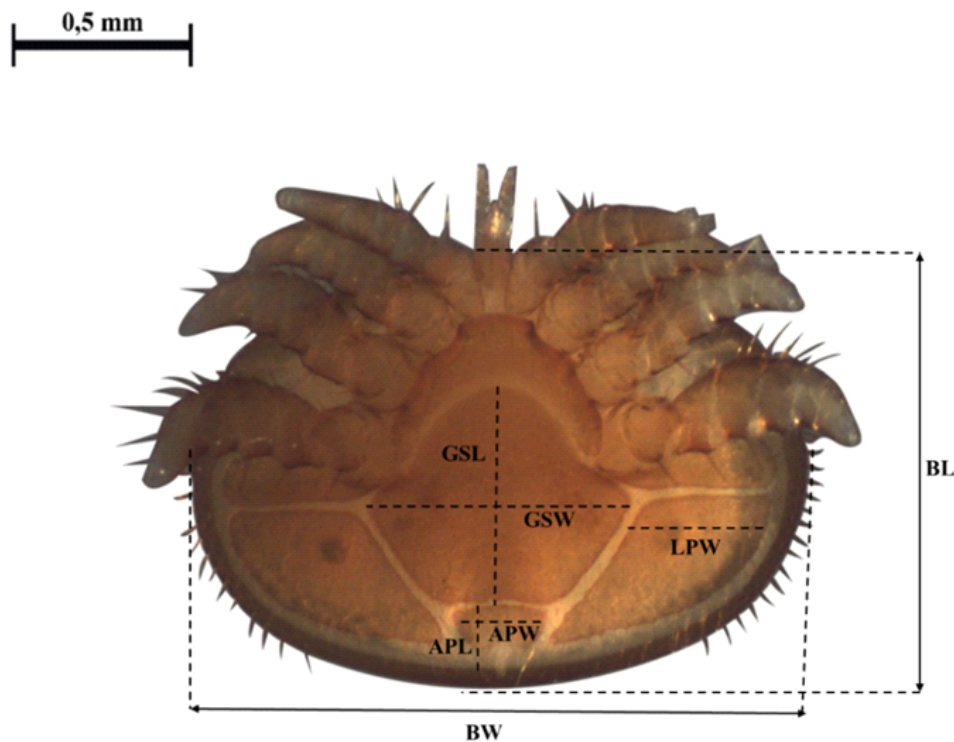


FIGURE 2. Morphometric variables measured. **BL:** Body length, **BW:** Body width, **GSL:** Genital shield length, **GSW:** Genital shield width, **APL:** Anal plate length, **APW:** Anal plate width, **LPW:** Lateral plate width.

Results

Diagnosis of varroa mites in beehives

The total number of hives we surveyed was 238. Of all these colonies, only 20 (i.e. 8.4%) were free of varroa infestation. Furthermore, the occurrence of varroa is higher in hives with mobile frames (94.0%) compared to fixed frames (68.2%) ($P < 0.05$). Regarding Varroa prevalence according to hive model, the results show that there were more infested mobile frames hives (94%) (Figure 3).

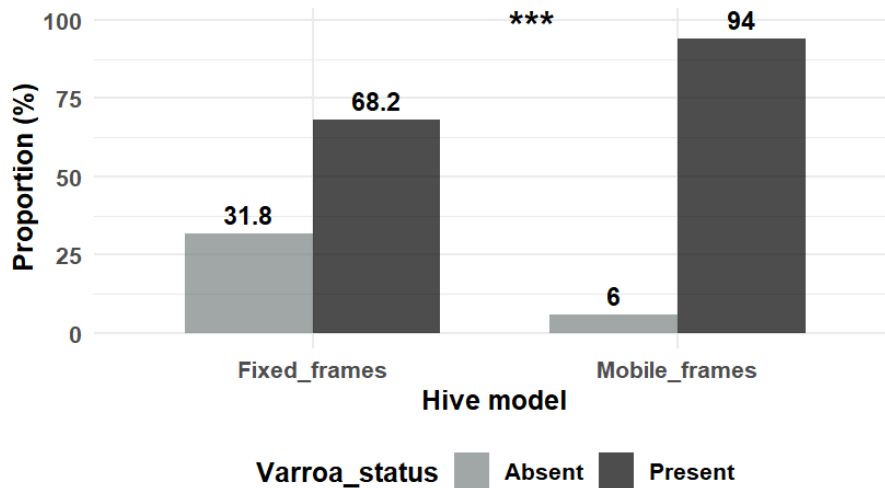


FIGURE 3. Varroa prevalence by hive model.

The results in Figure 4 show the distribution of varroa presence and absence in honey bee colonies belonging to the two phylogeographical zones. In the Northern Sudanese zone, 94.4% of bee colonies were infested with varroa, indicating a relatively high prevalence in this area. In the Southern Sudanese zone, 89.9% of hives were infested with varroa mites, showing similarly high prevalence. However, the differences between the two zones are not statistically significant ($P > 0.05$).

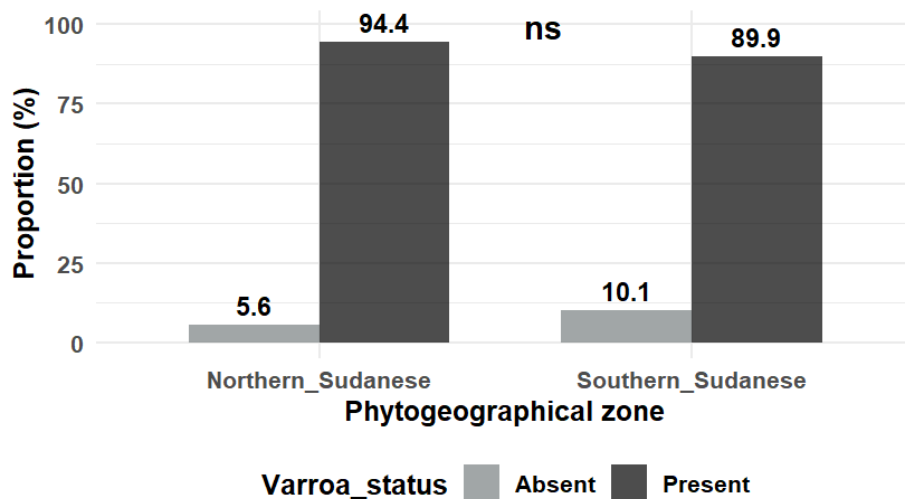


FIGURE 4. Varroa prevalence by phylogeographical zone.

The Kruskal-Wallis test shows a statistically significant difference between infestation levels in fixed-frame and mobile-frame hives ($P < 0.05$). Indeed, fixed frame hives show a low mean infestation level ($1.24 \pm 1.69\%$), with a median of 0.67% and limited dispersion (min = 0% , max = 5.67%), underlining the relatively low variability in this group. In contrast, mobile frame hives had a much higher mean infestation level ($5.5 \pm 7.02\%$), with a median of 3.33% and a wider distribution of values (min = 0% , max = 58.7%) (Figure 5).

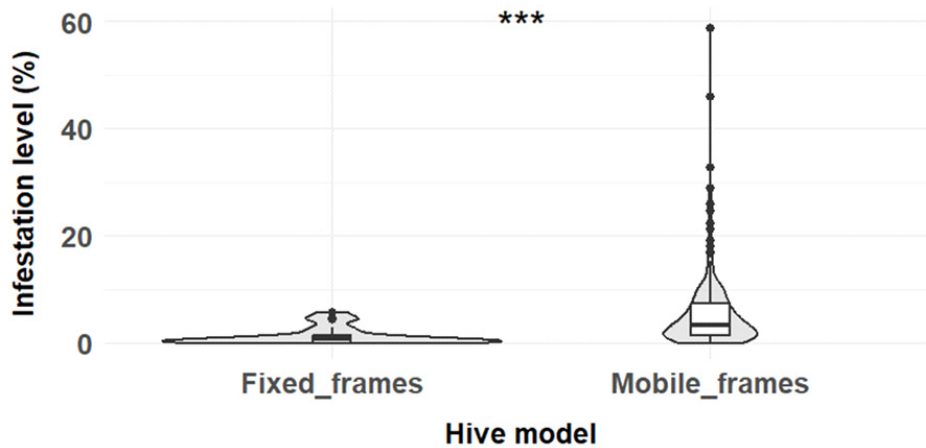


FIGURE 5. Varroa infestation level by hive frame type.

The results of analyses of infestation levels by phytogeographical zone reveal a mean of 3.89% (standard deviation 4.86) for the Northern Sudanese zone, while the Southern Sudanese zone shows a significantly higher mean of 5.84% (standard deviation 7.69) ($P < 0.05$). The respective median values are 2.33% for the northern zone and 4.00% for the southern zone, indicating also a variation in data between these zones (Figure 6).

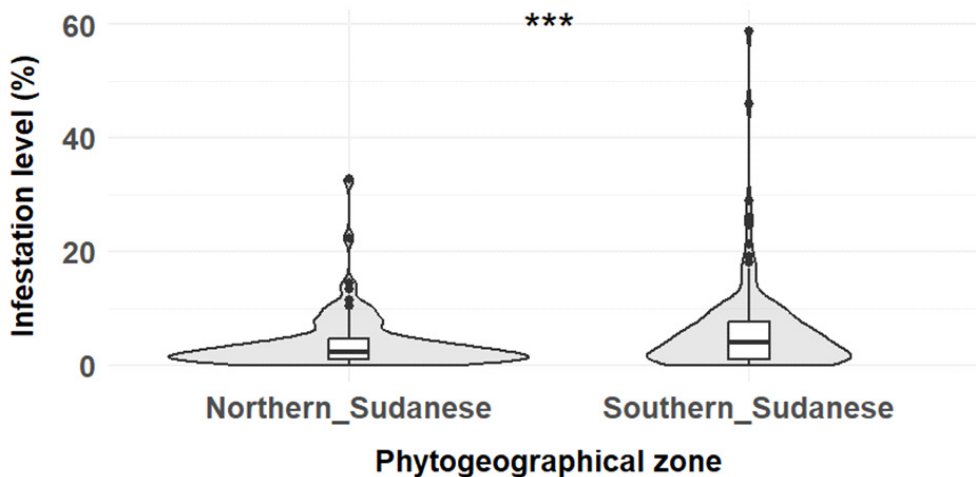


FIGURE 6. Varroa infestation levels by phytogeographical zone.

The provinces of Nahouri (8.19%) and Ziro (9.00%) had the highest infestation levels, indicating significant parasite pressure in these areas ($P < 0.05$). In contrast, the province of

Kenedougou had the lowest infestation level, at just 1.7%. Other provinces, such as Bazega (5.93%), Houet (6.63%), and Zoundweogo (7.18%), show intermediate infestation levels, suggesting variability in parasite prevalence. The statistical test reveals that Nahouri and Ziro differ significantly from the other provinces, while the infestation levels of Boulkiemde (3.04%), Comoe (4.73%), Sissili (2.55%), Bazega, Houet and Zoundweogo show no significant differences between them ($P < 0.05$). We can therefore conclude that the severity of *Varroa* infestation of hives by province highlights geographical disparities (figure 7).

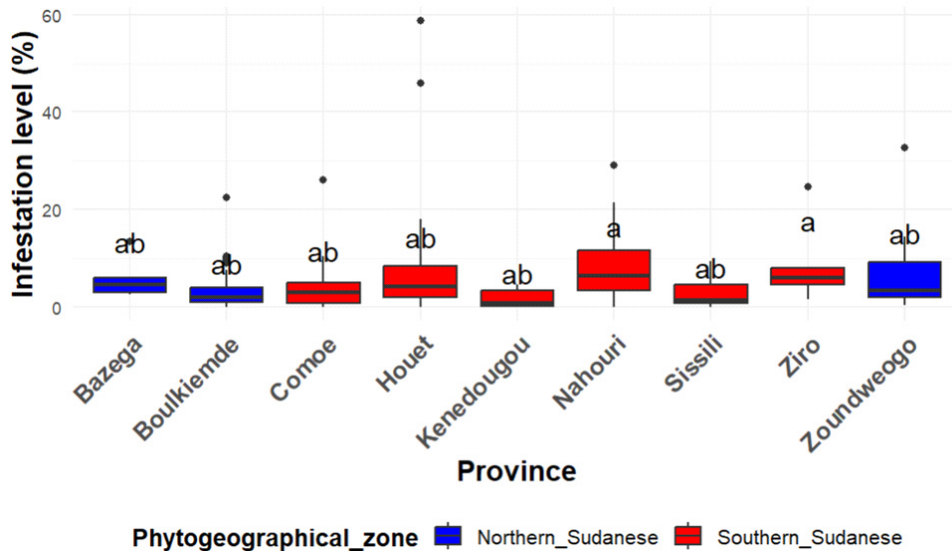


FIGURE 7. *Varroa* infestation levels by province and phytogeographical zone.

The violin and box plot illustrates the distribution of IL into three groups (Figure 8). The asymmetrical distribution of the violins indicates an asymmetry in the distribution of IL ($P < 0.05$). The most predominant group is represented by class 1, where hives have IL below 2%. This class includes most of the beehives, with an average IL of 1.66%. Another group is class 3, representing hives with IL of 5% or more. Although this class has fewer hives than the first one, IL are considerably higher, sometimes reaching as high as 58.67%. Between these two extreme groups lies class 2, with IL ranging from 2% to 5%. Although fewer in number than class 1, these hives show moderate levels of infestation, with an average of 3.72%.

Table 2 shows the distribution of *varroa* IL in each phytogeographical zone. It shows that 74.70% of colonies in the Southern Sudanese zone have an IL of 5 *varroa* mites or more per 100 bees, compared with 25.30% in the Northern Sudanese zone.

TABLE 2. Frequency of infestation levels by phytogeographical zone.

IL	Northern Sudanese		Southern Sudanese	
	Number of colonies	Frequency (%)	Number of colonies	Frequency (%)
IL < 2%	43	45.26	52	54.74
2% ≤ IL < 5%	26	43.33	34	56.67
5 ≤ IL	21	25.3	62	74.7

Morphometric characterization of varroa mites

The morphometric characteristics of the varroa population studied are shown in Table 3. Mean values \pm standard deviation is given, as well as minimum and maximum values. All measurements are in micrometers (μm), except for ratio values. The average length of the mite body is $1172.91 \pm 40.56 \mu\text{m}$, with a range from $1000 \mu\text{m}$ to $1297 \mu\text{m}$, while its average width is $1761.59 \pm 50.98 \mu\text{m}$, varying from $1520 \mu\text{m}$ to $1931 \mu\text{m}$. All other dimensions are presented with their central trends and dispersions. Morphometric ratios are also given, providing clues to the relative proportions of these characters.

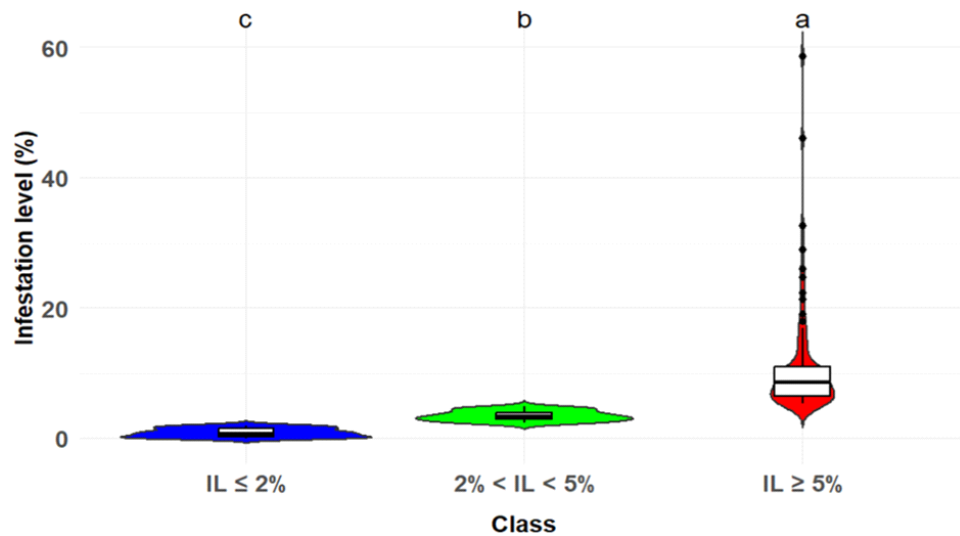


FIGURE 8. Breakdown of varroa infestation levels into 3 classes.

TABLE 3. Mean and standard deviations, minimum and maximum values of morphometric characteristics of the varroa sampled.

Morphometric characteristics	Mean \pm standard deviations	Minimum	Maximum
BL (μm)	1172.91 ± 40.56	1000	1297
BW (μm)	1761.59 ± 50.98	1520	1931
GSL (μm)	584.9 ± 23.82	496	650
GSW (μm)	732.51 ± 26.62	661	801
APL (μm)	171.16 ± 14.37	115	207
APW (μm)	269.7 ± 15.42	200	315
LPW (μm)	389.93 ± 21.41	301	449
Ratio_1 (BL/ BW)	0.67 ± 0.02	0.57	0.8
Ratio_2 (BW / BL)	1.5 ± 0.05	1.26	1.76
Ratio_3 (GSL/ GSW)	0.8 ± 0.04	0.68	0.94
Ratio_4 (APL/ LPW)	0.64 ± 0.06	0.41	0.86

BL: Body length, **BW:** Body width, **GSL:** Genital shield length, **GSW:** Genital shield width, **APL:** Anal plate length, **APW:** Anal plate width, **LPW:** Lateral plate width.

Table 4 compares morphometric characteristics by phytogeographical zone. For almost all the variables measured, there are statistically significant differences between zones ($P < 0.05$), except for APL, Ratio 1 and Ratio 2.

TABLE 4. Means, standard deviations, minimum and maximum values for varroa body characteristics in the two phytogeographical zones.

Characters	Northern Sudanese				Southern Sudanese				Pr(>F)	Signif_codes
	Mean	sd	Min	Max	Mean	sd	Min	Max		
BL (μm)	1167.44	40.8	1007	1269	1176.04	40.1	1000	1297	3.513E-05	***
BW (μm)	1755.36	53.42	1520	1931	1765.14	49.2	1530	1901	0.0001811	***
GSL (μm)	582.39	24.35	496	649	586.34	23.39	509	650	0.0012353	**
GSW (μm)	723.83	25.75	661	789	737.46	25.84	662	801	4.097E-24	***
APL (μm)	171.65	14.24	115	207	170.89	14.45	122	207	0.2988616	
APW (μm)	267.54	15.12	221	315	270.93	15.46	200	315	1.797E-05	***
LPW (μm)	386.11	21.81	301	449	392.12	20.87	321	449	3.975E-08	***
Ratio_1	0.67	0.02	0.57	0.73	0.67	0.02	0.58	0.8	0.3139401	
Ratio_2	1.5	0.05	1.37	1.76	1.5	0.05	1.26	1.71	0.2964163	
Ratio_3	0.81	0.04	0.68	0.94	0.8	0.04	0.68	0.94	2.782E-07	***
Ratio_4	0.64	0.06	0.41	0.86	0.63	0.06	0.43	0.82	0.0004217	***

Sd= Standard deviation; Min= Minimum value; Max= Maximum value

Significance. codes: '***': $P < 0.001$; '**': $P < 0.01$; '*': $P < 0.05$; '.' : $P < 0.1$; ' ': $P \geq 0.1$

BL: Body length, BW: Body width, GSL: Genital shield length, GSW: Genital shield width, APL: Anal plate length, APW: Anal plate width, LPW: Lateral plate width

Figure 9 shows the correlation between the different morphometric characteristics measured on varroa mites. The correlation coefficients shown are all statistically significant ($P < 0.05$). The correlation between BL and BW is 0.49, indicating a moderate positive correlation. Between BW and GSW, the correlation is stronger at 0.54, suggesting a stronger positive relationship. Some variables, such as APL and GSW, show weak or near-zero correlations (0.11 and -0.01 respectively).

The apiaries were plotted according to the morphometric character measurements of the varroa mites collected (Figure 10). The coordinates of each location indicate its position defined by the Principal Component Analysis (PCA). Thus, individuals from the Southern Sudanese zone appear to be long and characterized in most cases by high values for all morphometric characteristics measured.

The classification of varroa mites according to apiaries revealed four classes, which were formed without distinction of province or phytogeographical zone (Figure 11). Class 1 includes varroa from Ipendo, Poa, etc. with reduced values for the variable APL. Meanwhile, class 2 comprises individuals from Lidara2, Missidouyou, Moami, Oualana2, Santidouyou, Soungalema and Soungalema2, distinguished by high values for the variables BL, LPW, GSL, BW, GSW, APW and APL. Class 3 is made up of individuals belonging to Sissily2 apiary, distinguished by significantly high values for the variable APL, while they present relatively low values for the variables GSW, LPW, and BL. Finally, class 4 is made up of individuals coming from apiaries including La, Nayalgue, Bourkina, Soaw, Tina, Banon, Tambolo and Torem, characterized by low values for the variables BW, GSL, BL, LPW, GSW and APW.

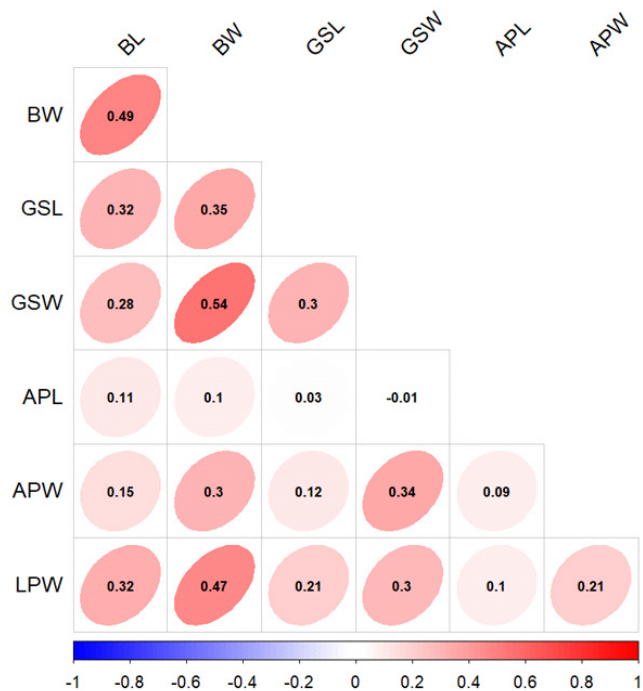


FIGURE 9. Correlation between morphometric characteristics measured on the varroa mite. **BL:** Body length, **BW:** Body width, **GSL:** Genital shield length, **GSW:** Genital shield width, **APL:** Anal plate length, **APW:** Anal plate width, **LPW:** Lateral plate width.

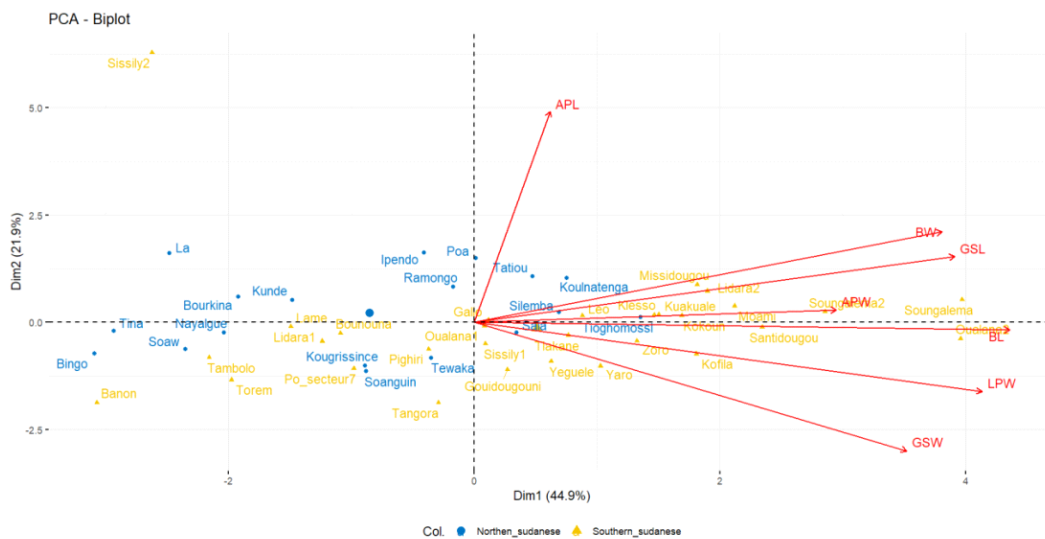


FIGURE 10. 1:2 factorial plane of the PCA showing apiaries in relation to the morphometric characteristics of their varroa. **BL:** Body length, **BW:** Body width, **GSL:** Genital shield length, **GSW:** Genital shield width, **APL:** Anal plate length, **APW:** Anal plate width, **LPW:** Lateral plate width.

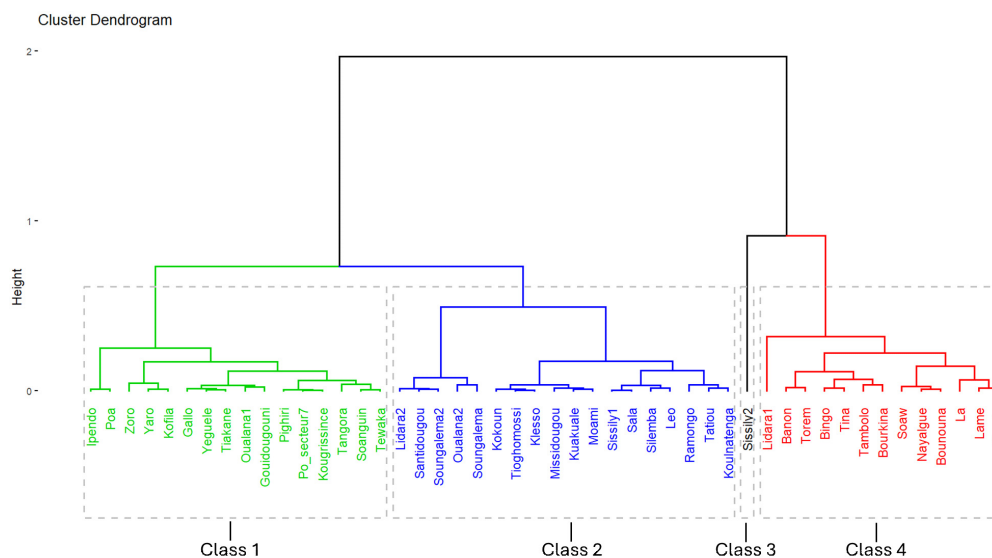


FIGURE 11. Grouping of varroa mites from different apiaries based on similarity of morphometric characteristics studied.

Discussion

The honey bee mite varroa is globally distributed and represents the greatest threat to bee health and apiculture (Rosenkranz *et al.* 2010). In this study, we described the spatial epidemiology of its infestation in the Northern Sudanese and Southern Sudanese phytogeographical zones of Burkina Faso. Of the 238 hives of various types examined, only 8.4% showed no sign of varroa infestation. This indicates its very high prevalence in the bee colonies, with 91.6% of hives affected. By phytogeographical zone, the proportion of infested hives was higher (albeit not significantly) in the Northern Sudanese zone (94.4%) than in the Southern Sudanese one (89.9%). In some apiaries belonging to the Northern Sudanese zone, Aebi (2017) found a prevalence of 100% infestation in 81 modern hives. In Mondon, a village located in the Southern Sudanese zone, Kaboré *et al.* (2022) found a prevalence of $91.7 \pm 7.9\%$. These spatial variations in varroa distribution suggest potential differences in environmental conditions or beekeeping practices that could influence them (Boecking & Genersch 2008; Rosenkranz *et al.* 2010; Giacobino *et al.* 2014).

Varroa was first reported in Burkina Faso in 2014 (Mutsaers *et al.* 2014). The rapid spread and wide distribution of the mite in the country can be attributed to the displacement of wild colonies. In Africa in general and Burkina Faso particularly, hives are colonized from wild swarms and swarming can be a source of varroa dispersal (Wilde *et al.* 2005). Infestation levels, representing the number of varroa mites per 100 bees, were 3.89 ± 4.86 and 5.84 ± 7.69 , respectively in the Northern and Southern Sudanese zones. Cases of infestation were more recurrent and more severe in mobile-frame hives than in fixed-frame hives. Differences in infestation levels had been noted in Ethiopia between local hives ($2.6 \pm 5.9\%$) and frame hives ($5.0 \pm 0.9\%$) (Gela *et al.* 2023). This could be explained by the fact that the former are easier to search thoroughly and reach the brood combs where varroa mites are concentrated. The mite is also influenced by bioclimatic conditions in terms of occurrence and distribution (Giliba *et al.* 2020). Environmental conditions are cited as a predominant factor, with infestation levels higher in humid regions (Giacobino *et al.* 2017). However, the Southern Sudanese zone of Burkina Faso has the highest average annual rainfall in the country (Fontès & Guinko 1995;

Nikiema *et al.* 2001). This could explain the higher infestation levels in this area. The average varroa infestation level was 4.97% (i.e. around 5 varroa per 100 bees) throughout the sample. Although a large proportion of the hives sampled have infestation levels below 2%, there are still some with higher levels, up to 58.67%. Across Africa, high levels of varroa mites have also been observed in healthy *A. mellifera* colonies (Allsopp 2006; Muli *et al.* 2014; Mumbi *et al.* 2014). For the time being, beekeepers are not carrying out acaricide treatments against this hive pest in Burkina Faso. Despite this, dramatic colony losses attributable to varroa mites have not yet occurred in Africa, unlike in Europe (Pirk *et al.* 2014; Strauss *et al.* 2015). Several studies have shown the lack of impact of varroa mites on the strength and productivity of bee colonies on the continent (Muli *et al.* 2014; Strauss *et al.* 2015; Chemurot *et al.* 2016). Indeed, African bee colonies can resist varroa infestation via grooming of infested adult bees, elimination of infested pupae and physiological resistance mechanisms (Rosenkranz *et al.* 2010). To these characteristics can be added a specificity of African bees and beekeeping, which is swarming and desertion behavior, as well as the lack of chemical control (Fries 1989; Wilde *et al.* 2005; Allsopp 2006). Another reason for the varroa tolerance of African honey bees could be the high ratio of wild to managed colonies, which allows wild populations to adapt to new parasites/pathogens without human interference (Pirk *et al.* 2017). Any initiative to protect bees against varroa mites in Burkina Faso should therefore consider this context.

Morphometry is an easy and good way of identifying varroa species (Anderson & Trueman 2000). When we analyzed morphometric characters, we found that all mites averaged $1172.91 \pm 40.56 \mu\text{m}$ long by $1761.59 \pm 50.98 \mu\text{m}$ width. These measurements were $1176.04 \pm 40.1 \mu\text{m}$ and $1765.14 \pm 49.2 \mu\text{m}$ respectively, then $1167.44 \pm 40.8 \mu\text{m}$ and $1755.36 \pm 53.42 \mu\text{m}$ in the Southern Sudanese and Northern Sudanese zones. In Benin, studies determined a body length and width of $1115.1 \pm 15.33 \mu\text{m}$ and $1639.9 \pm 12.48 \mu\text{m}$ respectively (Kelomey *et al.* 2016). Anderson and Truman identified mites measuring $1167.3 \pm 26.8 \mu\text{m}$ long by $1708.9 \pm 41.2 \mu\text{m}$ wide as *Varroa destructor* (Anderson & Trueman 2000). The average body size ratio we measured was 1.5 in both Northern Sudanese and Southern Sudanese phytogeographical zones. According to some data, when this value is greater than 1.4, *Varroa destructor* is present. Our results therefore suggest that the mite specimen examined in the two phytogeographical zones of Burkina Faso is *Varroa destructor*. This result is in line with those of Yougbaré (2022) who identified also the same species. Molecular analyses carried out in Burkina Faso's neighboring country Benin have confirmed the presence of this Varroa species in the West African sub-region (Kelomey *et al.* 2017). We further confirm the findings that *A. mellifera* is infested solely by *V. destructor* subspecies in Africa, Europe and the USA (Anderson & Trueman 2000). Significant differences were detected for most traits according to phytogeographical zones ($P < 0.05$). As a result, all the varroa mites studied fell into four statistically distinct groups, based on ascending hierarchical classification. These results testify to the heterogeneity of varroa populations in Burkina Faso. The same number of morphotypes had already been found in Benin (Kelomey *et al.* 2016). These morphotypes reached 17 in countries such as Iran, Argentina and Ukraine (Akimov *et al.* 2004; Maggi *et al.* 2009; Dadgostar & Nozari 2018). Indeed, within a single population of *V. destructor*, there is wide phenotypic plasticity (Akimov & Zaloznaya 1996). These morphometric variations could be explained by differences in climatic and geographical factors (Maggi *et al.* 2009). However, there are differences in temperature, humidity, precipitation and vegetation between the two phytogeographical zones of the country in which the varroa mite has been collected and measured (Fontès & Guinko 1995). Knowing that there has always been coevolution between a parasite and its host, it has been shown that variations affecting bee ecotypes can influence the body dimensions of the Varroa mites that infest them (Giménez *et al.* 2017). A study is currently underway to assess the morphometric diversity of honeybees in different parts of the country. These yet unpublished data attest to the fact that there is indeed significant variability in the physical traits of bees across ecotones. Future studies should not only establish the

relationship between body dimensions of *A. mellifera* and *V. destructor*, but also consider climatic constants and beekeeping practices in the apiaries. This morphological variation must be considered in varroa control, as a positive correlation has been detected between body dimensions and resistance to acaricides (Maggi *et al.* 2012; Loeza-Concha *et al.* 2018). The spread of *V. destructor* involves both vertical and horizontal transmission. To better understand the biogeography and evolution of varroa populations in Burkina Faso, it would be interesting to study its population genetic structure within and between honey bee colonies.

Conclusion

The vast majority of bee colonies in Burkina Faso are infested by *V. destructor*. Its distribution and infestation levels vary according to phytogeographical zones. These results underline the importance of considering phytogeographical variations in understanding the dynamics of its infestation. The morphometric characteristics of the strain implanted in the country are also known. However, morphometric identification needs to be complemented by molecular studies. Further research is also needed to explore the real impact of the parasite on the health and productivity of local honeybees, to devise an optimal management strategy.

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Authors contribution

SS: Conceptualization; Methodology; Software; Formal analysis; Investigation; Data Curation; Writing—Original draft; Writing—Review and Editing. BHR: Conceptualization; Methodology; Validation; Formal analysis; Data Curation; Writing—Review and Editing; Supervision. OGD: Investigation; Data Curation. SZ: Writing—Review and Editing; Project administration. MB: Writing—Review and Editing; Project administration. AA: Writing—Review and Editing. ZI: Conceptualization; Methodology; Validation; Formal analysis; Investigation; Data Curation; Writing—Review and Editing; Supervision.

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