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Morphometric structuring and diversity of ticks of the subgenus *Rhipicephalus (Boophilus)*, in the Savannah District, Côte d'Ivoire

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The existence of a biological barrier between *Rhipicephalus* (Boophilus) *microplus*, *Rhipicephalus* (Boophilus) *annulatus* and *Rhipicephalus* (Boophilus) *decoloratus*, which are considered species within the subgenus *Rhipicephalus* (Boophilus), is increasingly questioned due to observed hypothetical hybridization among them. To investigate this presumed hybridization, we conducted a morphometric characterization study of the tick population in the Savannah District. Ticks were collected from 74 farms, with an average of 16 cattle per farm. These collected ticks were then preserved in 70° ethanol, identified using a binocular magnifying glass and an identification key, and subsequently subjected to morphometric analyses. Only non-engorged adult individuals within the subgenus Rhipicephalus (B.) were analyzed using classical morphometry. This study revealed the presence of sexual dimorphism within ticks of the subgenus *Rhipicephalus* (Boophilus), with *Rhipicephalus* (Boophilus) females exhibiting significantly larger linear characteristics than males. Furthermore, this study demonstrated variation in morphological traits between different species. Classical morphometry, however, did not allow for the distinction between males of one species and those of another. In contrast, it was possible to differentiate *R.* (B.) *microplus* females from females of other species.

Key words: Variation, morphology, morphometry, ticks, *Rhipicephalus,* Côte d'Ivoire

INTRODUCTION

Ticks are obligatory and temporary hematophagous arthropods that attach themselves to the skin of their hosts (Socolovschi et al., 2008). They belong to a group of ectoparasites that are harmful to various animal species, including mammals, birds, reptiles, amphibians, and humans, due to their hematophagous mode of nutrition and their ability to transmit a wide variety of pathogenic agents, such as viruses, bacteria, and

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protozoa (Adehan et al., 2016). Ticks pose a significant challenge to the development of livestock farming in Africa and worldwide (Djakaridja et al., 2014). Approximately 80% of cattle worldwide are infested with ticks, resulting in substantial economic losses for farmers (Yeo et al., 2017).

Since 2007, the accidental introduction of the tick species *Rhipicephalus* (Boophilus) *microplus* to Côte d'Ivoire through cattle imports from Brazil has led to interspecific competition due to the invasive nature of this tick (Madder et al., 2011). Additionally, during personal communication, Madder et al. (2012) asserted that hybridizations occur between R. (B.) microplus and *Rhipicephalu*s (Boophilus) *annulatus,* as well as between *R*. (B.) *microplus* and *Rhipicephalu*s (Boophilus) d*ecoloratus* in West Africa. Kiffopan et al. (2019) identified hybrids resulting from the crossbreeding of R. (B.) annulatus and R. (B.) microplus based on morphological descriptors in the Savannah District of Côte d'Ivoire. Alongside hypothetical hybridization, there are also transboundary movements of herds through transhumance (Diaha-Kouame et al., 2017). All these factors contribute to modifying the tick population in Côte d'Ivoire (Biguezoton, 2016). Consequently, there is a pressing need for a better understanding of the morphological characteristics of species within the subgenus *Rhipicephalus* (Boophilus) in Côte d'Ivoire.

This study aims to confirm or invalidate the morphometric traits of the four species of ticks within the subgenus *Rhipicephalus* (Boophilus). Furthermore, it seeks to establish a structure based on tick morphometry in the Savannah District.

MATERIAL AND METHODS

Study site

The Savannah District is located in the North of Côte d'Ivoire between 8° and 11° north latitude and between 4 and 7° South longitude. The Savannah District has three regions namely Poro, Tchologo and Bagoué. The Poro region is made up of four departments (Dikodougou, Korhogo, M'Bengué and Sinématiali). The Tchologo region contains three departments (Ferkessedougou, Kong and Ouangolodougou). The Bagoué region is also composed of three departments (Boundiali, Kouto and Tengrela) (Figure 1). The climate of this District is Sudanian with two main seasons including one rainy and one dry. The rainy season goes from mid-April to October, with rainfall varying between 1000 and 1200 mm of water; whereas the dry season, goes from November to March (Le Guen, 2004). In addition to being a traditional breeding area, the Savannah District is, for reasons of its geographical location, a convergence zone for transhumant herds in the Sahelian zone. It has about 40% of the Ivorian livestock which is made up of 1.59 million cattle, 1.73 million sheep, 1.38 million goats, 360,000 pigs and 58.4 million poultry (Traoré et al., 2021).

Collections and conservation of ticks

A total of 74 farms including 24 in the Poro region and 25 in each of the two other regions (Tchologo and Bagoué), were chosen for the ticks' collection. These farms were chosen based on their accessibility, breeder agreement to participate in the study and also to the size of the breeding herd (at least 20 cattle per farm). Ticks were collected from 15 randomly selected animals on each farm and conserved in ethanol (70%) in 50 ml bottles. Then, the numbers of the animal, the name of the farm as well as the name of the village were also mentioned on each bottle containing the sample of ticks collected. Finally, the geographic coordinates of these cattle farms were recorded using a Global Positioning System (GPS).

Morphological identification of tick species

The morphological identification of the genus and species of ticks was performed using OPTIKA brand binocular loup at 20X magnification, and dichotomous identification keys of Walker et al. (2003) and Meddour-Bouderda and Meddour (2006). The identification of the different genus and species of ticks was carried out by morphological characteristics. After this morphological identification only ticks of the subgenus *Rhipicephalus (Boophilus)* were selected for the characterization study.

Choice of specimens

This study was carried out on non-engorged adults because the engorgement state can influence the morphological variation of ticks. Larvae and nymphs were not analysed because it is more difficult to obtain a reasonable sample and their morphological characteristics are less developed for comparison. The study of classical morphometric characteristics, concerned 394 individuals, 60 males and 60 females: 60 males and 60 females *R. (B.) microplus*, 60 males and 60 females *R. (B.) decoloratus*, 34 males and 60 females *R. (B.) annulatus* and 60 females *Rhipicephalus (Boophilus) geigyi*.

Tick scanning

Digitization consists of capturing a precise image of each individual selected for the study. Indeed, each specimen was positioned on graph paper mounted under a digital magnifying glass (PCE-MM 200 microscope) which is connected to a computer at the same scale. An image was captured of the dorsal side of each specimen. The images of all specimens were captured at the same magnification (X100) and a resolution of 1600 dpi at the dimensions (0.30 cm in length and 0.25 cm in width). Finally, the images of each tick were saved in the JPEG (Joint Photographic Experts Group) image file format. The same technique was performed the digitization to reduce any instrumental error.

Measurements of the classic morphometric data

The measurements have been performed on the scanned tick images. Using the Image J software, nine quantitative parameters for males and 11 for females have been measured. These parameters are body length, idiosoma length, idiosoma width, scutum length, scutum width, capitulum base width, left palp length, right palp length, hypostome length, hypostome width and the number of rows of teeth. As for the variables, length of the scutum and width of the scutum are absent in the males. The values obtained from the measurement have been converted into millimetres (mm).

Statistical analysis

The data obtained from the classic morphometry were recorded on

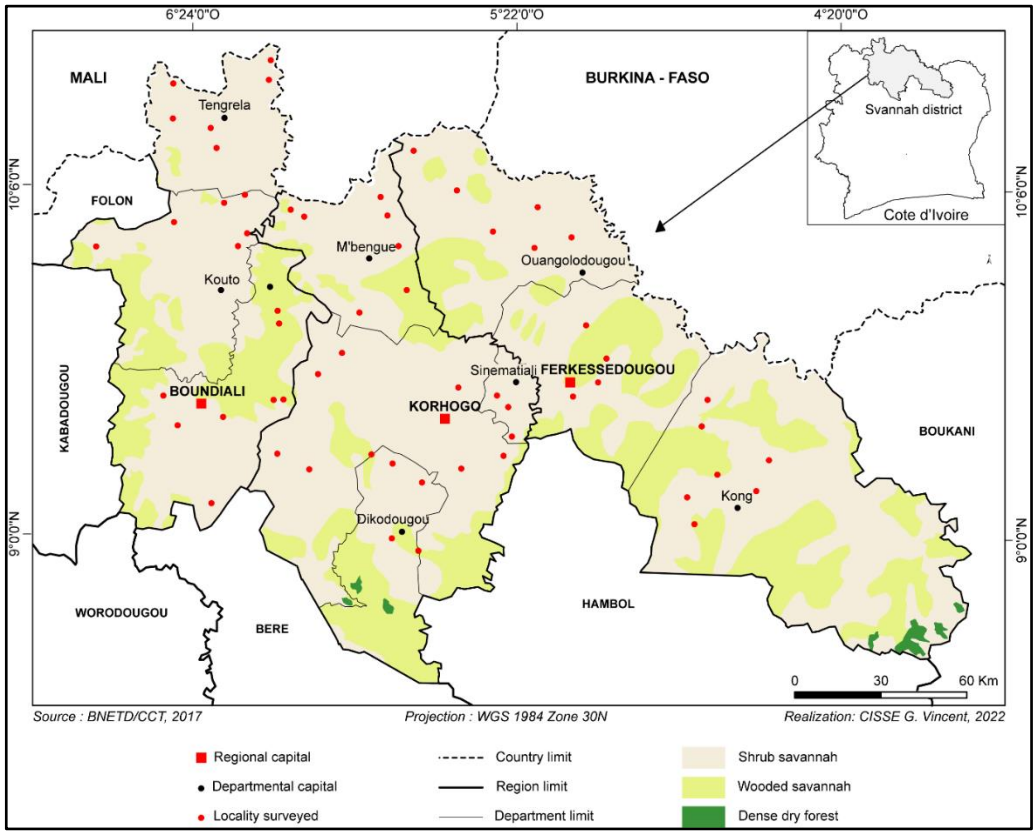


Figure 1. Map of the Savannah District showing tick collection sites.

the Microsoft Excel spreadsheet and analyzed with the R-4.2.2 software. After exploratory data analysis, Bartlett's test of homogeneity of variances and the Shapiro-Wilk test of normality have been performed. The effect of sex and species was tested on the measured variables using multivariate analysis of variance (MANOVA) to know the variation factors of these morphometrical data. The significance of the differences observed between the means generated by MANOVA was tested by the Kruskal Wallis test and complemented by this one of Wilcoxon-Mann-Whitney at the 5% threshold. To identify the most prominent variables in the phenotypical variability and to visualize the distribution of ticks according to the species in a graphical space (factorial map), the collected data have been submitted to the principal component analysis (PCA). To this purpose, the data were firstly evaluated by the Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests to ensure that the data could be submitted to the multivariate factorial analyses.

RESULTS

Ticks identified in the Savanes District

In total, 11408 ticks were identified in the Savanes District, including 5324 *R. (B.) microplus*, 895 *Amblyomma variegatum*, 857 *Hyalomma truncatum*, 1125 *R. (B.) geigyi*, 421 *R. (B.) decoloratus* and 2786 *R. (B.) annulatus*.

Effects of Influencing factors on tick phenotypic descriptors

The results of the multivariate analysis of variance (MANOVA) are reported in Table 1. These results show that the sex and the species have significant effects on the variables measured. The comparison of the means revealed that the females *R. (B.) decoloratus*, *R. (B.) microplus* and *R. (B.) annulatus* have a bigger morphology ($p<0.05$) than this one the males (Table 2). Therefore, sex significantly affects the morphology of ticks of the subgenus *Rhipicephalus (Boophilus)*.

Interspecific comparisons of four species of ticks of the subgenus *Rhipicephalus (Boophilus)* for their morphometrical characters are presented in Tables 3 and 4. Table 3 reveals that the males of the three species of ticks from the subgenus *Rhipicephalus (Boophilus)* did not differ significantly in body length. However, the length and the width of the idiosoma of the males *R. (B.) annulatus* and *R. (B.) microplus* did not show any significant difference but both are statistically lower than those of the males *R. (B.) decoloratus*. Regarding the rostrum, the males of the three species did not differ statistically in the width of their hypostome. However, *R. (B.) microplus* and *R. (B.) decoloratus* males showed similar left and right palp lengths, which have been

Table 1. The effects of sex and species on the morphology of ticks of the subgenus *Rhipicephalus (Boophilus).*

Qualitative factors	Trace of Pillai	Fischer's approximation	Number of variable	df	Probability	Residual	Significance
Sexes	0.699	107.9	11	385	$2.2*10^{-16}$	392	***
Species	1.828	35.74	11	687	$< 2.2*10^{-16}$	236	***

***: significant difference at the 5% of threshold; df: degree of freedom.

Table 2. Comparison of linear characters (mm) of ticks according to sex.

Parameter	Females	Males	SIG
Body descriptors (idiosoma)			
Body length	$3.81±0.94^a$	$2.12±0.17^b$	*
Idiosoma length	$3.47±0.98^a$	$1.78±0.17^b$	*
Idiosoma width	$2.21±0.59^a$	$1.11±0.16^b$	*
Scutum length	0.89±0.25	-	-
Scutum width	0.90±0.15	-	-
Rostrum descriptors (gnathosoma)			
Capitulum base length	$0.54±0.15^a$	$0.42±0.08^b$	*
Left palp length	$0.27±0.09^a$	$0.18±0.05^b$	*
Right palp length	$0.68±0.43^a$	$0.18±0.04^b$	*
Hypostome length	$0.25±0.09^a$	$0.18±0.05^b$	*
Hypostome width	$0.24±0.08^a$	$0.18±0.04^b$	*
Number of row of teeth	$3.75±0.43^a$	$3.61±0.49^b$	*

On the same line, the means with different superscript letters are significantly different at the 5% level. SIG: significance *: significant.

Table 3. Comparison of linear characters of the male ticks according to species.

Parameter	*R. (B.) annulatus*	*R. (B.) microplus*	*R. (B.) decoloratus*	SIG
Body descriptors (idiosoma)				
Body length	2.1±0.22	2.12±0.13	2.16±0.15	NS
Idiosoma length	$1.73±0.19^b$	$1.79±0.16^b$	$1.83±0.14^a$	*
Idiosoma width	$1.06±0.14^b$	$1.13±0.17^b$	$1.17±0.12^a$	*
Rostrum descriptors (gnathosoma)				
Capitulum base width	$0.42±0.07^b$	$0.38±0.06^c$	$0.48±0.09^a$	*
Left palp length	$0.16±0.05^b$	$0.19±0.04^a$	$0.19±0.05^a$	*
Right palp length	$0.17±0.06^b$	$0.19±0.04^a$	$0.20±0.001^a$	*
Hypostome length	$0.18±0.06^b$	$0.17±0.05^b$	$0.20±0.05^a$	*
Hypostome width	0.18±0.05	0.18±0.04	0.18±0.03	NS
Number of row of teeth	$4.00±0.00^a$	$3.00±0.00^b$	$4.00±0.00^a$	*

On the same line, the means with different superscript letters are significantly different at the 5% level. SIG: significance, R.: Rhipicephalus, B.: Boophilus, *: significant (measurements are in cm).

significantly longer than those of the males *R. (B.) annulatus.* Male *R. (B.) decoloratus* have a base of the capitulum which is significantly wider than this of male *R. (B.) annulatus* and narrower than that of *R. (B.) microplus.* The length of the hypostome of the males *R. (B.) annulatus* and *R. (B.) microplus* which does not differ significantly from each other, is shorter than this one of the males *R. (B.) decoloratus*. Male *R. (B.) decoloratus* have three teeth rows, while the males *R. (B.) annulatus* and *R. (B.) microplus* have four. Table 4 presents the females of the four species of ticks of the subgenus *Rhipicephalus (Boophilus)* differ significantly from one species to another by their body morphology.

The average body length and the parameters of the

Table 4. Comparison of linear characters of female ticks according to species.

Parameter	*R. (B.) decoloratus*	*R. (B.) annulatus*	*R. (B.) geigyi*	*R. (B.) microplus*	SIG
Body descriptors (idiosoma)					
Body length	3.92±0.58^{b}	3.62±0.42^{c}	4.98±0.52^{a}	2.68±0.25^{d}	*
Idiosoma length	3.61±0.59^{b}	3.33±0.42^{c}	4.68±0.50^{a}	2.27±0.27^{d}	*
Idiosoma width	2.42±0.29^{b}	2.23±0.39^{c}	2.78±0.36^{a}	1.41±0.16^{d}	*
Scutum length	0.97±0.31^{b}	0.72±0.14^{c}	0.86±0.14^{b}	1.02±0.24^{a}	*
Scutum width	0.84±0.17^{b}	0.97±0.11^{a}	0.86±0.12^{b}	0.96±0.14^{a}	*
Rostrum descriptors (gnathosoma)					
Capitulum base length	0.61±0.11^{b}	0.37±0.07^{d}	0.56±0.11^{c}	0.64±0.13^{a}	*
Left palp length	0.31±0.12^{a}	0.29±0.07^{a}	0.23±0.08^{b}	0.26±0.08^{b}	*
Right palp length	0.29±0.08^{b}	0.28±0.07^{b}	0.23±0.08^{c}	1.91±12.86^{a}	*
Hypostome length	0,28±0.09^{a}	0.25±0.07^{a}	0.21±0.09^{b}	0.27±0.08^{a}	*
Hypostome width	0.26±0.09^{a}	0.21±0.05^{b}	0.23±0.06^{b}	0.28±0.10^{a}	*
Number of row of teeth	3.00±0.00^{b}	4.00±0.00^{a}	4.00±0.00^{a}	4.00±0.00^{a}	*

On the same line, the means with different superscript letters are significantly different at the 5% level. SIG: significance, R.: Rhipicephalus, B.: Boophilus, *: significant (measurements are in cm).

shape of the idiosoma (length and width) differ significantly, with the highest averages in *R. (B.) geigyi* followed by *R. (B.) decoloratus*, *R. (B.) annulatus*, and *R. (B.) microplus*. A comparison of mean scutum length revealed that the females *R. (B.) decoloratus* and *R. (B.) geigyi* showed no significant difference in scutum length. These averages are statistically lower than those obtained in *R. (B.) microplus* females but statistically higher than those of *R. (B.) annulatus* females by this organ. The females *R. (B.) microplus* and *R. (B.) annulatus* have statistically the same means for scutal width, while *R. (B.) decoloratus* and *R. (B.) geigyi* are statistically similar for this parameter. However, the mean scutal widths of *R. (B.) microplus* and *R. (B.) annulatus* females are statistically superior to those of *R. (B.) decoloratus* and *R. (B.) geigyi* females. At the level of the gnathosoma, *R. (B.) microplus* has the longest base of the capitulum followed by *R. (B.) decoloratus*, *R. (B.) geigyi* and *R. (B.) annulatus*. The lengths of the right and left palp are statistically similar in females *R. (B.) decoloratus* and *R. (B.) annulatus* on the one hand and in females *R. (B.) geigyi* and *R. (B.) microplus* on the other hand. *R. (B.) geigyi* females have a significantly longer right palp than that of *R. (B.) decoloratus* and *R. (B.) annulatus* females, which have a left palp length statistically greater than that of the females *R. (B.) microplus* and *R. (B.) geigyi.* However, the females *R. (B.) decoloratus*, *R. (B.) annulatus* and *R. (B.) microplus* are statistically similar by their hypostom length, which is significantly inferior to those of the females *R. (B.) geigyi*. The hypostome widths of *R. (B.) decoloratus* and *R. (B.) microplus* females are statistically similar but they are significantly larger than those of the females *R. (B.) geigyi* which no differ with *R. (B.) annulatus* females by this character. *R. (B.) decoloratus* females have three rows of teeth, whereas the females of the other species have four rows.

Multivariate description of the species ticks of the subgenus *Rhipicephalus (Boophilus)*

The KMO (Kaiser-Meyer-Olkin) index is 0.74 in males and 0.64 in females. These indices as well as the Bartlett sphericity test ($p<0.001$) were obtained from the analysis of the measured variables (Table 5). These values indicate that the data can be subjected to multivariate analyses.

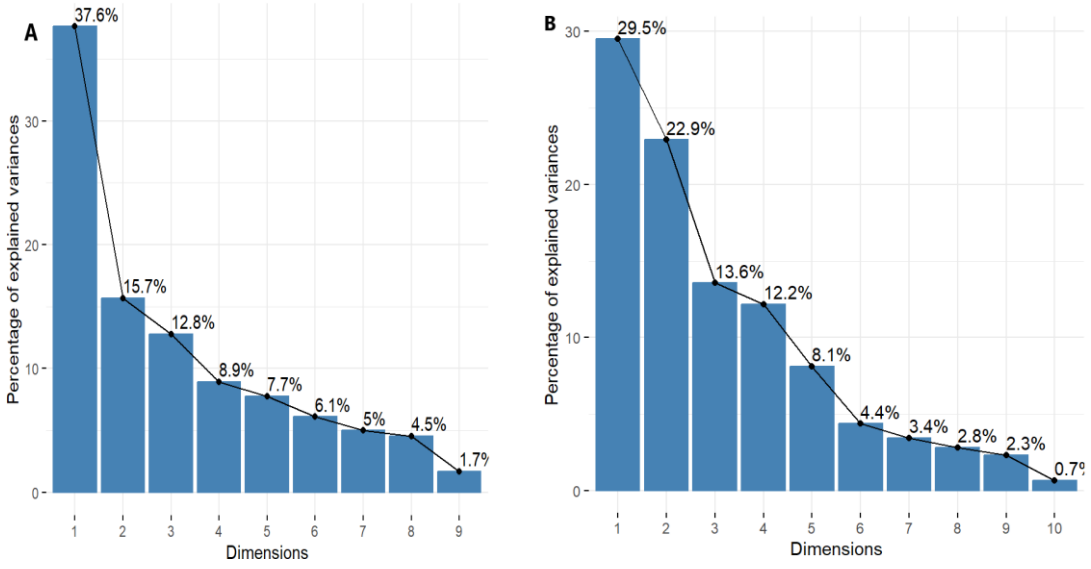
Principal component analysis (PCA)

The interactions between the different measured variables were analyzed through the two-dimensional scatter plot (Figures 2 and 3). The first two principal components of the PCA graph of the male individuals contributed 53.30% of the total variability while those of the females grouped together 52.42% of the total inertia (Figure 2). In this factorial plan, most of the variability was carried by six variables (the length of the body, the length of the idiosoma, the width of the idiosoma, the length of the right palp, the length of the left palp and the width of the base of the capitulum). Among these variables, body length, idiosoma length, idiosoma width, right palp length and left palp length were positively and strongly correlated (>0.6) to the first dimension which capitalized 37.60% of the variability (Table 6; Figure 3A). The width of the capitulum's base was positive with the second dimension, which expressed 15.70% of the morphological variability of the males. However, in the population of female ticks of the subgenus *Rhipicephalus (Boophilus)*, only five variables accounted for most of the variability

Table 5. Result of the Bartlett sphericity test.

Populations	df	chisq	P-value
Male	36	457.31	1.93*10-74
Female	36	720.97	2.39*10-128

df: degree of freedom.



A-Population of males B-Population of females

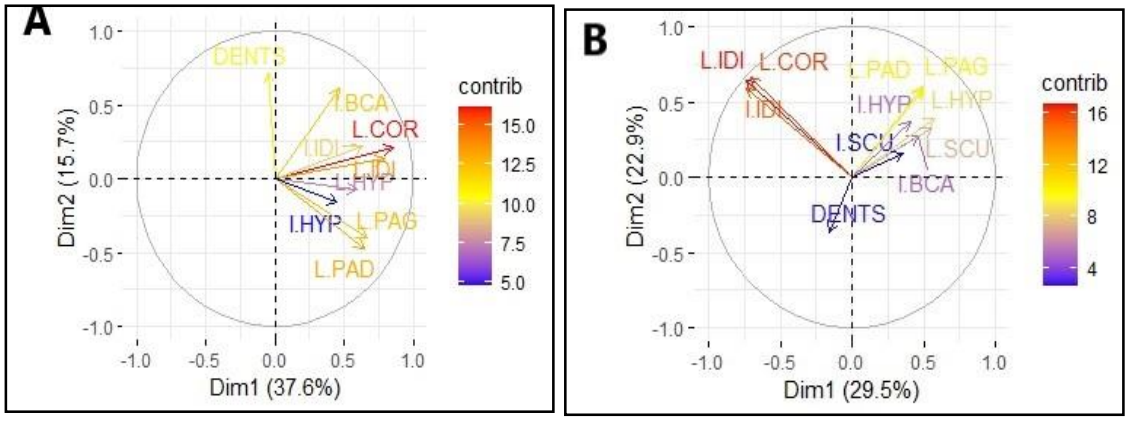
Figure 2. PCA scree plot made on ticks of the subgenus *Rhipicephalus (Boophilus).*

(body length, idiosoma length, idiosoma width, the length of the right palp and the length of the left palp). Body length and idiosoma width were negatively and strongly correlated (>-0.6) to the first dimension. The length of the idiosoma was positively and strongly correlated (>0.6) to the first dimension. This dimension represented 29.52% of the morphological variability of female individuals (Table 6; Figure 3B). Finally, the length of the right palp and the length of the left palp were positively and strongly correlated (>0.6) to the second dimension which capitalized 22.90% of the morphological variability of female ticks.

The projection of male individuals in the factorial plane of the three (3) species *R. (B.) decoloratus*, *R. (B.) annulatus* and *R. (B.) microplus* is shown in Figure 4A, show overlap individuals of the three species. Thus, no morphological distinction of the different species of ticks within the males is possible. On the other hand, in the population of females, the projection of individuals in the factorial plane of the four species (*R. (B.) geigyi*, *R. (B.) decoloratus*, *R. (B.) annulatus* and *R. (B.) microplus*) exhibits an overlap of three species *(R. (B.) geigyi*, *R. (B.) decoloratus*, and *R. (B.) annulatus)* and a distinction of individuals from *R. (B.) microplus* of these three species (Figure 4B). *R. (B.) microplus* females are therefore characterized by low values for body length, idiosoma length and idiosoma width. However, *R. (B.) geigyi*, *R. (B.) decoloratus*, *R. (B.) annulatus* and *R. (B.) microplus* females are characterized by high values for these three parameters.

DISCUSSION

Species of ticks of the subgenus *Rhipicephalus (Boophilus)* are those that most parasitize cattle in Côte d'Ivoire (Toure et al., 2014; Tuo et al., 2021; Sylla et al., 2022). Although the immature stages of tick species play an important role in the distribution of ticks and tick-borne diseases, the identification mainly depends on the adult stage. Therefore, the present study attempts to identify the morphological characteristics specific to adult ticks of each species of *Rhipicephalus (Boophilus)* by classical morphometry.



A-Projection of male individuals B-Projection of female individuals

Figure 3. Projection of all the variables in the circles of correlations formed by axes 1 and 2. L.COR: body length, L.IDI: idiosoma length, I.IDI: idiosoma width, L.SCU: scutum length, I.SCU: scutum width, I.BCA: capitulum's base width, L.PAG: left palp length, L.PAD: right palp length, I.HYP: hypostome length, DENTS: number of row of teeth.

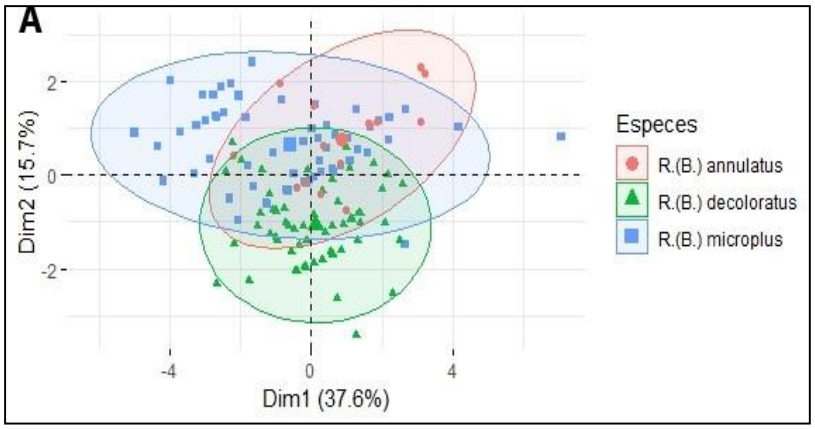
Table 6. Correlation of variables in the construction of the first two principal components.

Sexes	**Male**		**Female**	
Parameters	CP1	CP2	CP1	CP2
Proportions of variations	37.60%	15.70%	29.52%	22.90%
Body Descriptors (idiosoma)				
Body length	0.85	0.21	-0.71	0.66
Idiosoma length	0.79	0.13	0.74	0.64
Idiosoma width	0.63	0.22	-0.74	0.59
Scutum length	-	-	0.56	0.32
Scutum width	-	-	0.35	0.16
Rostrum Descriptors (gnathosoma)				
Capitulum base width	0.47	0.61	0.46	0.27
Right palp length	0.64	-0.47	0.49	0.60
Left palp length	0.66	-0.39	0.50	0.60
Hypostome length	0.59	-0.07	0.58	0.39
Hypostome width	0.45	-0.16	0.41	0.37
Number of row of teeth	0.05	0.70	-0.16	-0.36

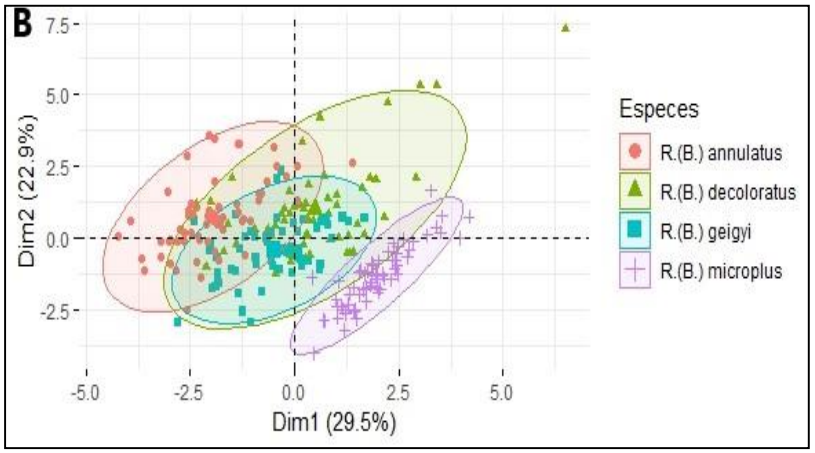
CP: Principal Component, %: percentage, the values in bold are strongly correlated (>0.6).

It revealed that sex significantly affects the morphology of ticks of the subgenus *Rhipicephalus (Boophilus)* through the significant differences in mean size between males and females.

This size difference reflects the sexual dimorphism within the subgenus *Rhipicephalus (Boophilus)* tick species. These results are consistent with the morphological characteristics listed by Walker et al. (2003) to differentiate male *Rhipicephalus (Boophilus)* females. They meant that the females are larger than the males of the subgenus *Rhipicephalus (B.).* In addition to the effect of sex, the study also showed that the species significantly affects the morphology of species of the subgenus *Rhipicephalus (Boophilus).* The characters' averages vary from one species to another within the female and male populations except for the length of the body and the width of the hypostome which are identical in the males. This morphological variation reveals the interspecific diversity within the subgenus *Rhipicephalus (Boophilus)* tick species. The study also showed the



A- Male individuals



B- Female individuals

Figure 4. Projection of all male and female individuals in the factorial plane.

overlap of male *R. (B.) microplus, R.(B) annulatus* and *R. (B.) decoloratus*.

This attests to the difficulty of distinguishing the males of the three species based solely on classic morphometry (Yousseu et al., 2022). These results are consistent with those of Barker and Walker (2014). These authors claimed that it is often difficult to tell the difference between males of one species from another of the subgenus *Rhipicephalus (Boophilus)* based on certain morphological characteristics. The difficulty of distinguishing species of the subgenus *Rhipicephalus (Boophilus)* was also found in females. This ambiguity is presented by an overlap of female ticks *R. (B.) geigyi, R. (B.) annulatus* and *R. (B.) decoloratus* at the principal component analysis (PCA) level. On the other hand, *R. (B.) microplus* females differ morphologically from other females. This distinction of *R. (B.) microplus* females is justified by their small size among other females of the same genus (Berry, 2017). Thus, *R. (B.) microplus* females are distinguished from other females by low values of body length, idiosoma length and idiosoma width. The overlapping of female ticks *R. (B.) geigyi, R. (B.) annulatus* and *R. (B.) decoloratus* could be justified either by a strong resemblance in terms of morphological characters or by the presence of hybrids from the crossing between these species. Because the hybrids resulting from crossing *R. (B.) microplus* and *R. (B.) annulatus* were reported from northern Côte d'Ivoire and characterized morphologically by Kiffôpan et al. (2019). Unfortunately, no study has yet confirmed the presence of hybrids resulting from the cross between *R. (B.) microplus* and *R. (B.) decoloratus*. They could therefore be present in our tick samples.

The results of this study have shown that classic morphometry does not correctly distinguish all tick species of the subgenus *Rhipicephalus (Boophilus).* Therefore, it made it possible to distinguish only the females *R. (B.) microplus* from other females. Since it is

only interested in the study of distance measurements of morphological characters (Perrard, 2012; Mitteroecker et al., 2004). However, the study of the morphological diversity of tick species is not limited to the study of the distance of morphological characters but also to the study of the shape by geometric morphometry (Clabaut et al., 2007; Durango et al., 2020).

Morphometry is, therefore, an approach to comparative biology described as “revolutionary” by Adams et al. (2004), thus opening interesting perspectives for the study of tick populations (Estrada-Peña et al., 2012). The proof is that it was used to present the variation of morphology between species of ticks from metric characters and able to provide indirect information of order genetic and environmental effects on natural populations (Dujardin, 2011; Hosseini et al., 2011; Dupraz et al., 2016). Diaha-Kouame et al. (2017) used classical morphometry and geometric morphometry simultaneously to study the intra-specific diversity of *R. (B.) microplus* on the Ivoiro-Burkinabe transhumance corridor.

Conclusion

The classical morphometric characterization study confirmed the presence of sexual dimorphism within tick species of the subgenus Rhipicephalus (Boophilus), with males exhibiting less pronounced morphological characteristics compared to females. It also revealed that tick species within the subgenus Rhipicephalus (Boophilus) display morphological variations from one species to another. However, classical morphometry was only able to distinguish R. (B.) microplus females from females of other species. Consequently, it appears that classical morphometry does not consistently provide clear morphological differentiation for all tick species within the subgenus Rhipicephalus (Boophilus). Therefore, geometric morphometry can be considered as a novel and complementary technique to classical morphometry for characterizing tick species within the subgenus Rhipicephalus (Boophilus). To better understand the results of this study, it would be necessary to conduct further research involving geometric morphometric characterization and molecular investigations of the ticks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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