Trakia Journal of Sciences, No 4, pp 289-297, 2024

Available online at:
https://trakia-uni.bg

ISSN 1313-3551 (online) doi:10.15547/tjs.2024.04.001

Original Contribution

MORPHOLOGICAL AND BIOMETRICAL DESCRIPTION OF *LINOGNATHUS STENOPSIS* BURMEISTER, 1838 AND *BOVICOLA CAPRAE* GURLT, 1843 FOUND IN GOATS

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ABSTRACT

PURPOSE: The current study was performed to present a morphological and biometrical description of the sucking louse *Linognathus stenopsis* Burmeister, 1838 (Anoplura: Linognathidae) and the chewing louse *Bovicola caprae* Gurlt, 1843 (Ischnocera: Bovicolidae) found in goats. METHODS: A total of 100 male and 100 female lice of each species were subjected to morphological and biometrical identification. The key points used for identification were as follows: head length (HL), head width (HW), thorax length (TL), thorax width at the prothorax (TW), abdomen length (AL), abdomen width (AW), total body length (TBL), index of the head (IH = HL/HW), index of the body (IB = TBL/AW), last segment length (LSL), last segment width (LSW) and index of the last segment (ILS=LSL/LSW) as well as the ratio of the total body length to the head length (TBL/HL). RESULTS: The complete morphological description of the species *L. stenopsis* revealed that the TBL in females varies from 1.7 mm to 2.4 mm, while in males it ranges from 1.2 mm to 1.6 mm. The body length of female specimens of the species *B. caprae* ranges between 1.5–1.9 mm, and that of males between 1.0–1.4 mm. TBL in *L. stenopsis* is strongly influenced by AL. The analysis shows a distinctive connection between TBL and AW as well as in AL and AW of females. TBL in female *B. caprae* shows a strong correlation with AW and AL and in males between TBL and AL and TL. CONCLUSIONS: These morphological and biometrical descriptions could be used as a reliable marker for species identification.

Key words: goat phthirapterosis, morphological parameters, lice, *Linognathus stenopsis*, *Bovicola caprae*, correlation

INTRODUCTION

The lice (Insecta: Phthiraptera) are highly specialized permanent ectoparasites of birds and mammals. Throughout their life cycle, both adult lice and nymphal stages have direct and indirect effects on the host, causing a variety of local and systemic damages. In this regard, heavy infestations are usually associated with blood loss, inflammation and skin irritation, toxic effects and allergic response, restlessness, impaired food intake and rest, self-harm as a result of itching, etc. (1).

Depending on the food substrate used, Phthiraptera is divided into two groups - sucking lice (suborder Anoplura) and chewing lice (suborders Amblycera and Ischnocera). The most pronounced morphological differences between sucking and chewing lice are the structure of the mouth apparatus and the shape of the head (2). Anoplura have mouthparts adapted to pierce the skin of the host as they feed solely on blood. In contrast, the mouth apparatus of chewing lice consists of well-developed jaws, as they feed on hair, feathers, skin scales, and clotted blood. Also, the head of Anoplura is always narrower than the thorax, whereas the head of Amblycera and Ischnocera is wider than the thorax, or at least as wide as the thorax. Moreover, all lice possess a specific body hairiness which includes the density and arrangement of hairs on the different body parts e.g. located singly, diffusely or in rows, etc. (3). According to (4), the most common lice in goats in Bulgaria are *Bovicola caprae* Gurlt, 1843

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(Ischnocera: Bovicolidae) and *Linognathus stepopsis* Burmeister, 1838 (Anoplura: Linognathidae). There are species of lice morphologically close to the species mentioned. According to (5), *Linognathus africanus* Kellog and Paine, 1911 possesses prominent eye protuberances located behind the antennae, while in *L. stenopsis* the head is elongated. Also, the female gonapophysis of *L. africanus* are rounded and lack the "tooth-like" process described in *L. stenopsis* (6). In male *L. africanus*, the gonapophysis possess a pair of terminal tubercles with setae which are absent in *L. stenopsis*. Similarly, *B. caprae* и *Bovicola limbata* Gervais, 1844 may be differentiated by examining the genitalia (7). The male gonapophysis of both species are conical in shape. The conical gonapophysis of *B. limbata* have scattered long setae, while the posterior end of the gonapophysis of *B. caprae* are densely covered with short setae. A distinctive feature of *B. caprae* is the presence of two terminal flaps located near the genital opening.

The present literature review highlights the existence of detailed morphological descriptions of lice by authors working across different periods. This underscores the importance of understanding the morphology of these species to determine their systematic classification and species identification. The aim of the present study is to provide new, more in-depth studies on their anatomical structure would facilitate easier recognition of these ectoparasites

MATERIALS AND METHODS

Clinical study

A total of 34 herds of goats were examined from May 2018 to November 2019. The insects found (preimaginal and imaginal stages) were collected individually with tweezers and were stored in containers with 70° ethanol. The lice were gathered from 7 body parts measuring 10 cm^2 (shoulder, brisket, neck, flank, thigh, groin and abdomen) from one side of the body (8).

Lice identification

In laboratory the lice were additionally fixed with 70° ethanol for 24h and dried up on filter paper before further preparation including clearing in xylene for 5-10 min and mounting on slides in Canada balm. Microscopic evaluation and photography were performed on a DMi1 S/M 424790 Leica ® microscope (Leica Microsystems CMS GmbH), equipped with a Leica MC120 HD photo camera. A total of 100 male and 100 female unharmed lice of each species were subjected to morphological identification, according to the criteria described by (3).

Biometrical description

Biometrical measurements according to (9) were also conducted, including head length (HL), head width (HW), thorax length (TL), thorax width at the prothorax (TW), abdomen length (AL), abdomen width (AW), total body lenght (TBL), index of the head (IH = HL/HW), index of the body (IB = TBL/AW). Apart from these parameters it was also measured last segment length (LSL), last segment width (LSW) and index of the last segment (ILS=LSL/LSW), as well as the ratio of the total body length to the head length (TBL/HL).

Statistical analysis

The biometrical parameters were analysed by means of a frequency analysis and standard methods of descriptive statistics with IBM® SPSS® Statistics 26.0 software.

RESULTS AND DISCUSSION

The collected specimens were identified as *L. stenopsis* and *B. caprae*. *Linognathus stenopsis* has a big and elongated body easily seen with an unarmed eye **(Figure 1 and 2).** The colour of the body is golden-yellow to orange and the abdomen is brown. The head is slender, elongated, cone shaped and round at the front. Compared to the body it is relatively small. The antennae consist of 5 segments. The first segment is the widest and has a trapezoidal shape. The posterio-lateral margins of the head are slightly convex. Eyes are absent. The thorax is short and four-angled, wider or equal to the width of the head, slightly prominent compared to the abdomen. The last has nine segments, oval in shape, widest at the region of IV segment and in both sexes has a stripe of bristles and long hairs on the side edge. The hetotaxia is well displayed. The stigmata are barely visible. The limbs are well developed ending in a massive curved nail. The tibia of the last pair of legs is best developed.

Figure 1. *Linognathus stenopsis* Burmeister, 1838, male, dorsally - rounded last segment.

Figure 2. *Linognathus stenopsis* Burmeister, 1838, female, dorsally - angular notch on the last segment

The structure of the parts of the head, thorax and abdomen (from I to VIII abdominal segment) does not show signs of sex dimorphism. An important morphological feature that is significant for the description and the differentiation of the species, and serves as a sign of sex dimorphism is the structure of the last abdominal segment. In male specimens it is round with a penis resembling an arrowhead while in females there is quadrangular in shape and has a tooth-like projection close to the posterio-lateral margin. The results from biometrical measurements of *L. stenopsis* are shown in **Table 1**. TBL in females varies between 1.7 mm to 2.4 mm and the average size is 2.0 mm. In males it is between 1.2 mm to 1.6 mm with an average size of 1.4 mm. Apparently, the females are much larger than the males ($p<0.001$).

The published data concerning the TBL of *L. stenopsis* showed that the females measure 2 mm and males 1.5 mm (10); TBL of both sexes is 3.5 mm (11); 2.2-3 mm for females and 1.7-2.1 mm for males (3, 12); TBL of both sexes 2-3.5 mm (13); 2.5-3 mm for females and 1.5-2 mm for males (4). As seen, most of authors published higher values of TBL in male and female specimens. Our data are in general

agreement with the results reported by (10). The possible cause for the difference in the published data might be the different climate and geographical differences of the area, as well as the specimen characteristics of the host bred in these conditions. The analysis of current results and the available scientific data show that the TBL of *L. stenopsis* considerably varies which gives an opportunity for this value to be used for species identification and sex differentiation. Our data on the metrical values of the head **(Table 1)** shows that its length surpasses the width ($p<0.001$). IH value is 1.4 in males and 1.3 in females. The ratio between TBL and HL is 4.4 in males and 6.3 in females which shows that the head of females is much smaller than the body. In this sex, about 3/4 of the body length is due to the abdomen.

The length of the thorax in both sexes is bigger than its width ($p<0.001$). The abdomen in males is significantly narrower than in females ($p<0.001$). This feature does not lead to a difference in the index of the body since the males are much shorter than the females. In them, BI is averagely 2.43 and in females - 2.72 ($p<0.001$). The last abdominal segment in both sexes is bigger in width than in length ($p<0.001$). Also, its length is 0.121 mm in males and 0.100 mm in female specimens.

Table 1. *Basic biometrical indicators of the species Linognathus stenopsis Burmeister, 1838.*

Parameter	Male (n=100)		Female (100)	
	Min-max (mm)	**Mean ± SEM (mm)**	**Min-max (mm)**	**Mean ± SEM (mm)**
Total body length	1.168 - 1.561	1.392 ± 0.080***	1.698 - 2.407	2.072 ± 0.133
Head length	0.252 - 0.374	0.317 ± 0.024**	0.242 - 0.389	0.326 ± 0.023
Thorax length	0.207 - 0.386	0.265 ± 0.027***	0.264 - 0.410	0.342 ± 0.029
Abdomen length	0.615 - 0.976	0.815 ± 0.076***	1.077 - 1.699	1.406 ± 0.119
Head width	0.170 - 0.262	0.222 ± 0.017***	0.206 - 0.342	0.247 ± 0.020
Thorax width	0.216 - 0.311	0.268 ± 0.019***	0.251 - 0.395	0.310 ± 0.030
Abdomen width	0.429 - 0.670	0.575 ± 0.042***	0.593 - 1.058	0.767 ± 0.091
Index of the body	2.103 - 3.074	2.431 ± 0.198***	2.13 - 3.79	2.72 ± 0.227
Index of the head	1.185 - 1.710	1.434 ± 0.121***	0.907 - 1.559	1.32 ± 0.123
Total body length/head length	3.584 - 5.746	4.402 ± 0.356***	4.365 - 9.946	6.37 ± 0.653
Head width/thorax width	0.669 - 0.983	0.830 ± 0.063**	0.619 - 1.056	0.803 ± 0.080
Last segment length	0.060 - 0.174	0.121 ± 0.020***	0.057 - 0.149	0.100± 0.018
Last segment width	0.185 - 0.396	0.293 ± 0.034***	0.228 - 0.438	0.336 ± 0.035
Index of the last segment	0.261 - 0.771	0.416 ± 0.068***	0.166 - 0.462	0.302 ± 0.055

IB – index of the body (IB=total body length/abdomen width); IH – index of the head (IH=head length/head width); ILS – index of the last segment (ILS= last segment length / last segment width); *** - $p < 0.001$; ** - $p < 0.01$; * $p < 0.05$; $p > 0.05$ between both sexes.

The results regarding the variation analysis of the metric characteristics of *L. stenopsis* are presented in **Table 2**. Most of the parameters are strongly variable and have a coefficient of variation (V%) greater than 5. Therefore, species identification should be based on both biometric data and morphological characteristics of *L. stenopsis*. In contrast, V % of TBL was much lower in females compared to male specimens. The strongest variations were observed in TL of males and AW of females.

Table 2. *Coefficient of variation (V%) of the main biometric parameters in male (n = 100) and female (n = 100) specimens of the species Linognathus stenopsis Burmeister, 1838.*

	TBL	HL	TL	AL	HW	TW	AW	IB	IH
M	5.7	7.5	10.1	9.3	7.6	7.0	7.3	8.1	8.4
F	6.2	7.0	8.4	8.4	8.0	9.6	11.8	8.3	9.3

The values of the correlation coefficient (r) between some metrical parameters of *L. stenopsis* are presented in **Table 3**. In both sexes, the highest level of correlation is observed between TBL and AL. Also, TBL has a strong dependency on AW especially in female specimens as well as a milder dependency on HL and TL ($p<0.05$). Correlation was also observed between HW and TW ($p<0.05$).

Table 3. *Correlation coefficient (r) between some main biometric parameters in male (n = 100) and female (n = 100) specimens of the species Linognathus stenopsis Burmeister, 1838.*

	TBL/HL	TBL/TL	TBL/AL	TBL/AWHL/HW	TH/TW	AH/AW	WH/WT
M	0.36*	0.08	0.93*	0.36*	0.43*	- 0.03	0.27*	0.51*
F	0.08	0.42*	0.95*	0.74*	0.19	0.37*	0.70*	0.31*

* - $p < 0.05$.

Bovicola caprae is yellow-orange in colour, with the head being darker **pigmented (Figure 3 and 4).** Compared to the body, the head is relatively big. It has a rounded tetragonal shape, with relatively equal length and width and possesses a cut-out in the front. Dorsally there are a few bristles. The jaws are brown in colour and are located close to the frontal head edge. The antennae are composed of 3 segments, they are curved back and are partially located in the antennae pits. They show signs of sex dimorphism. In males, the second segment is longer than the basal one, whereas in females such a difference has not been noticed. Maxillary palps are absent. In front of the antennae there are darkly pigmented eyes. The head is widest at the temporal region. The thorax is short and its three segments are narrower than the head **(Table 3 and 4).** The prothorax is short, narrow and is the smallest part of the body. The meso- and metathorax are fused into a pterothorax.

Figure 3. *Bovicola caprae* Gurlt, 1843, female, dorsally - rounded last segment.

Figure 4. *Bovicola caprae* Gurlt, 1843, male, dorsally - last segment with a conical shape.

Table 4. *Basic biometrical indicators of the species Bovicola caprae Gurlt, 1843.*

Parameter	Male (n=100)		Female (100)	
	Min-max (mm)	Mean ± SEM (mm)	Min-max (mm)	Mean ± SEM (mm)
Total body length	1.012 - 1.499	1.268 ± 0.097***	1.548 - 1.967	1.784 ± 0.082
Head length	0.264 - 0.399	0.327 ± 0.024***	0.338 - 0.491	0.422 ± 0.018
Thorax length	0.148 - 0.237	0.192 ± 0.022***	0.191 - 0.283	0.236 ± 0.019
Abdomen length	0.559 - 0.902	0.752 ± 0.068***	0.918 - 1.807	1.138 ± 0.095
Head width	0.267 - 0.406	0.369 ± 0.018***	0.435 - 0.578	0.494 ± 0.022
Thorax width	0.225 - 0.291	0.257 ± 0.013***	0.294 - 0.405	0.345 ± 0.019
Abdomen width	0.469 - 0.629	0.541 ± 0.032***	0.655 - 0.886	0.797 ± 0.049
Index of the body	1.930 - 2.957	2.350 ± 0.227***	2.089 - 2.465	2.240 ± 0.081
Index of the head	0.749 - 1.232	0.889± 0.076***	0.0007 - 0.849	0.854 ± 0.247
Total body length/head length	2.762 - 4.246	3.880 ± 0.247***	4.365 - 4.946	4.857± 0.653
Head width/thorax width	1.027 - 1.676	1.435 ± 0.086	1.247 - 3.312	1.452 ± 0.204
Last segment length	0.062 - 0.126	0.097 ± 0.014***	0.078 - 0.345	0.117 ± 0.027
Last segment width	0.049 - 0.248	0.165 ± 0.023***	0.331 - 0.432	0.373 ± 0.019
Index of the last segment	0.416 - 1.776	0.601 ± 0.141***	0.209 - 0.878	0.316 ± 0.068

IB – index of the body (IB=total body length/abdomen width); IH – index of the head (IH=head length/head width); ILS – index of the last segment (ILS= last segment length / last segment width); *** - $p < 0.001$; ** - $p < 0.01$; * $p < 0.05$; $p > 0.05$ between both sexes.

The limbs are relatively poorly developed. They are five-segmented and end with a sharp, thin and long claw. The species is more agile than bloodsucking lice in goats.

The abdomen is 9-segmented and has the shape of an elongated oval, narrowed at the back. It is widely oval in females **(Figure 3)** and egg shaped in males **(Figure 4)** and has median pigmented stripes and side pigmented spots. Each abdominal segment is covered with a row of short bristles. In both sexes, the third abdominal segment is wider than the others. The last segment is especially important for sex determination. In males, it is cone shaped and densely covered with short bristles. Two terminal valves near the genital opening are also observed. In females it is rounded and has a fine vertical cut-out medially, which is covered with bristles on its inside margin.

According to (14), *B. caprae* has an subquadrangular head with few setae on its dorsal surface **(Figure 5).** In females, the setae on the inner margin of the gonapophysis are restricted to lobe **(Figure 6).**

Figure 5. *Bovicola caprae* Gurlt, 1843, head with a rounded-quadrangular shape.

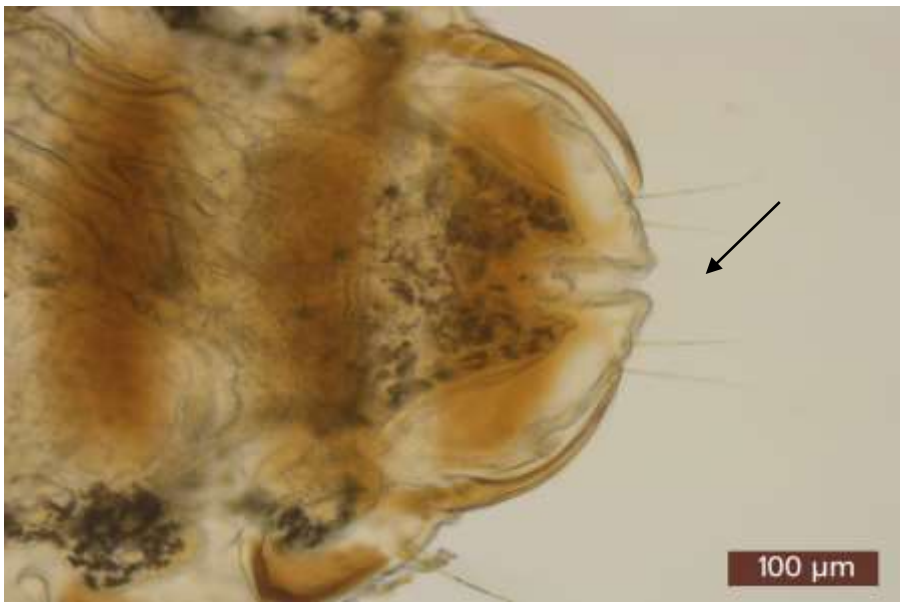

Figure 6: *Bovicola caprae* Gurlt, 1843, female- last segment with a fine notch.

The results from biometrical measurements of *B. caprae* are shown in **Table 4**. TBL in females exceeds significantly the minimal and maximal (1.5-1.9 mm), as well as average (1.7 mm) values of those in males, accordingly 1.0-1.4 mm and average value-1.2 mm. HL is smaller than HW ($p<0.001$) in both females (HL-0.42 mm, HW-0.49 mm) and males (HL-0.32 mm and HW-0.36 mm). TW is smaller than HW in both sexes (0.25 mm for males and 0.34 mm for female specimens).

According to data published in some scientific reports, TBL of *B. caprae* reaches 1.3 mm in males and 1.6 mm in females (4, 10, 15). Other researchers reported that the TBL varies between 1.4-1.5 mm in males and 1.8-2.0 in female specimens (12, 13). The difference in size between male and female specimens suggests the possibility that this parameter can be used for sex differentiation, however, the TBL is not is not determinative for species identification, as *B. caprae* is not the only biting louse specific to goats.

The metric parameters of the last abdominal segment show that in both sexes it is more wide than long - 2 fold in males and almost 3 fold in females, which explains the substantial difference in ILS between the two sexes. All sex differences found for this parameter show a high level of statistical significance ($p<0.001$).
The results regarding the variation analysis of the basic biometric values of *B. caprae* are presented in **Table 5**. It is obvious that in both sexes the coefficient of variation is highest in TL, followed by AL, TW and AW. It is also notable that the values for female specimens vary within narrow limits, while those for males are more variable e.g., the coefficient of variation of HL in females is 4.2 vs 7.3 in male specimens.

***Table 5**: Coefficient of variation (V%) of the main biometric parameters in male (n = 100) and female (n = 100) specimens of the species Bovicola caprae Gurlt, 1843.*

	TBL	HL	TL	AL	HW	TW	AW	IB	IH
M	7.6	7.3	11.4	9.0	4.8	5.0	5.9	9.6	8.5
F	4.5	4.2	8.0	8.3	4.4	5.5	6.1	3.6	5.8

The results of the correlation analysis **(Table 6)** shows that in both sexes the strongest dependency is between TBL and AL, with TBL changing in favour of AL ($p<0.001$). Furthermore, in females, TBL correlates closely with AW, which is not observed in males. The same correlation was noticed when comparing the AL/AW in both sexes. The level of correlation between HW and TW is relatively high and comparatively permanent in both sexes.

***Table 6.** Correlation coefficient (r) between some main biometric parameters in male (n = 100) and female (n = 100) specimens of the species Bovicola caprae Gurlt, 1843.*

	TBL/HL	TBL/TL	TBL/AL	TBL/AW	HL/HW	TH/TW	AH/AW	WH/WT
M	0.59*	0.67*	0.95*	0.05	0.27*	0.34*	0.05	0.32*
F	0.24*	0.64*	0.75*	0.83*	0.30*	0.29*	0.68*	0.40*

* - $p < 0.05$.

The correlations between the morphological parameters of *B. caprae* that are presented could help with its unmistakable identification.

CONCLUSION

This study provides a detailed morphological and biometric analysis of two louse species infesting goats in Bulgaria. The research highlights key distinguishing features of these ectoparasites, offering insights into their identification, sex differentiation, and potential for species-specific diagnosis. The biometric variability observed underscores the need for combining morphological and metric criteria for accurate species identification and differentiation. This research contributes

valuable data to the taxonomy of goat lice and offers a practical framework for their identification, benefiting both veterinary practice and parasite management programs.

ABBREVIATIONS

HL - head length
HW - head width
TL - thorax length
TW - thorax width at the prothorax
AL - abdomen length
AW - abdomen width
TBL - total body length
IH - index of the head
IB - index of the body
LSL - last segment length
LSW - last segment width
ILS - index of the last segment

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