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*Research Article*

# Anatomic Morphometrics of the "*Senene*" Tettigoniid *Ruspolia differens* Serville (Orthoptera: Conocephalidae) from North-West Tanzania

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The morphometrics of *Ruspolia differens* (order: Orthoptera; family: Conocephalidae), the longhorn grasshopper that is widely known as *senene* by its Kiswahili name, was largely unclear although the species serves broadly as a delicacy relish snack. In this study, the anatomic morphometrics of this insect was critically inferred based on the samples that were collected from North-west Tanzania in April-May 2009. *R. differens* was revealed to have a number of unique anatomic features that can essentially serve in its diagnosis. These include the paired male metathoracic flaps, finger-like prosternal protuberances, hind femoral spines, subequal tibial black markings, and an obvious male biased antennal dimorphism.

## 1. Introduction

Tettigoniid species (longhorn grasshoppers) are widely characterized based on their anatomic morphometrics [1, 2]. However, those of *Ruspolia differens* ("*senene*" by its Kiswahili name) are insufficiently understood despite various earlier efforts. Bailey and McCrae [3] and Bailey [4] analyzed the stridulatory apparatus of the left tegmen, but there is no reliable information on an equivalent organ on the right tegmen. The antennal length of this insect has been reported to be equal to its body length, ranging between 40–65 mm [4, 5]; however, there are no data of variation of the trait between sexes. Dearth of information of *R. differens* morphology makes it difficult to distinguish this insect from other tettigoniids. The present paper addresses the anatomic morphometrics of *R. differens* with a critical focus on the shapes, sizes, orientations, and markings of its salient external structures including the vertex, antennae, sternum, pronotum, metathorax, tympanum, leg segments, tibial markings, stridulatory apparati, terminal segments, and eggs.

## 2. Materials and Methods

The present morphometric analysis was based on a total of 180 *R. differens* specimens comprising 90 adult individuals per sex. These were collected in April-May 2009 using hands randomly from different bushes in three villages (Figure 1), namely, Nkindo, Makonge, and Rwagati of Bukoba Urban, Bukoba Rural, and Muleba districts, respectively, between 1.00° and 2.45°S, and 30.25° and 32.40°E in the north-western corner of Tanzania [6]. The districts were among the major East African zones with immense abundance of *R. differens* [4, 5]. The collection task was done based on standard procedures [7, 8]. The specimens were immediately sacrificed and preserved in 70% ethanol [9]. Morphological profiles were examined at the laboratory of the Department of Zoology and Wildlife Conservation, UDSM, using the naked eyes, hand lens, and binocular microscope, namely, ZEISS STEMI 2000 (Germany) fitted with a digital JVC camera (Model GR-D770, Japan) for photography.

Wings were analyzed according to the Comstock-Needham system [9]. Each of the right and left tegmina

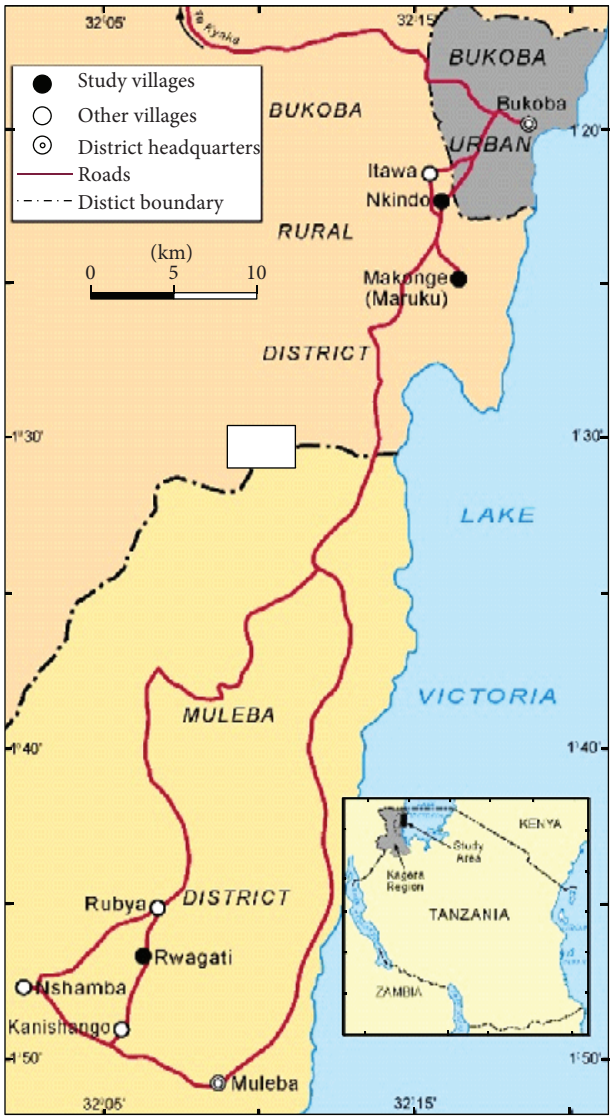


Figure 1: Areas in Bukoba and Muleba districts where *R. differens* samples were collected for the current analyses [6].

was found to comprise a stridulatory apparatus and thus both were studied in detail. The stridulatory ribs and pegs (teeth) and cubito-anal areas of both tegmina were analyzed mainly following the approach of Bailey [4] and Walker and Greenfield [10]. The pegs were counted serially and the file length was measured as a straight distance from the first tooth to the last. Characters of *terminalia* were inferred in fresh specimens mainly following the guide of Kjell and Tuxen [11]. Eggs were characterized upon removal from the gravid females after the abdomen was dissected longitudinally along the ventral median margin. Body length was measured from the fastigium to the abdominal tip. Vertex orientation in repose was characterized by measuring the frontodorsal fastigial angle (formed at fastigium by the frontoclypeal margin against the pronotal dorsum) as well as the interlateral fastigial angle (formed at fastigium by the anterior margins of vertex), following Naumann [9] and C. H. Lomer and C. J. Lomer [12]. Cerci lengths were measured from the dorsal abdominal abuttal to their distal ends while the lengths of the ovipositors were measured from the ventral abdominal abuttal to their distal ends [8]. All distances were first measured using a flexible ruler and then validated using a dissecting microscope (BOECO, Germany).

## 3. Results

*3.1. Body Size.* Body length of *R. differens* was taken as a direct function of total body size. It was found that the mean body length ($n = 30$) of males is 35.3 ± 0.8 mm and that of females is 38.0 ± 0.6 mm. Difference in body length between sexes was tested using Student's $t$-test. In this case, $P = 0.007$ hence $\ll 0.05$ inferring that females are significantly longer. Further, the males have slightly longer tegmina (i.e., 49.7 ± 0.8 mm versus 48.6 ± 0.6 mm).

*3.2. Cone.* The head of *R. differens* is produced into a rounded vertex projecting beyond the basal antennal segments (Figure 2). It is distinctly longer than wide, narrowing from base to apex. There is a caplike tubercle that is slightly rounded from the head dorsum to the face forming a characteristic conical lobe dorsoposteriorly. The fastigium is slightly extended in front of the eyes. The frons is slanted posteriorly forming an acute angle with the dorsum of pronotum. The antennae are inserted at the anterior margin of vertex just lateral to the vertex tubercle. The scape is pyramid shaped and the occiput notch (located between the anterior end of frons and the posterior end of vertex) is closed. The mean diameter of vertex tubercle of *R. differens* in repose ≈1.2 ± 0.2 mm ($n = 30$) and the species maintains a frontodorsal fastigial angle (between the frons and pronotal dorsum) of ≈50° and an inter-lateral fastigial angle (between lateral margins of the cone) of ≈40°. The fastigium is separated from the frons by a white interocular oval mark appearing like a median ocellus (simple eye) just posterior to the sulcus along the median carina (midway the two scapes). The longitudinal and lateral diameters of this mark are almost one-third of those of the compound eye. The compound eyes are oval longitudinally and each is located near the exterior lower arm of the scape along lateral margin of vertex. There is no difference between female and male cones.

*3.3. Antennae.* *R. differens* has long, filiform antennae. The male antennae are much longer (approximately 1.5 times) than those of the female. Whereas the distal tip of the female antenna lies at or near the hind knee joint, that of the male lies at or near the tegminal tip far beyond the hind knee joint. The male antenna is 58.8 ± 0.7 mm long and hence 1.7 times the mean body length (35.3 ± 0.8 mm) whereas the female antenna is 40.5 ± 0.3 mm long and hence 1.1 times the mean body length (38.0 ± 0.6 mm). Each sex has approximately 158 ± 0.8 mm segments.

*3.4. Prosternal Protuberances.* The study established a pair of finger-like prosternal protuberances located between the bases of the fore legs of *R. differens* (Figure 3). These protuberances are richly supplied with setae of various lengths

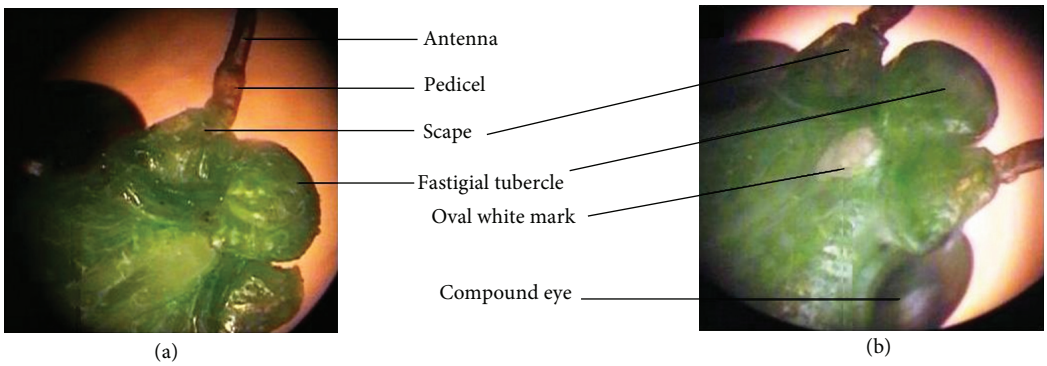


Figure 2: *R. differens* vertex showing main parts: (a) dorsal view and (b) ventral view.

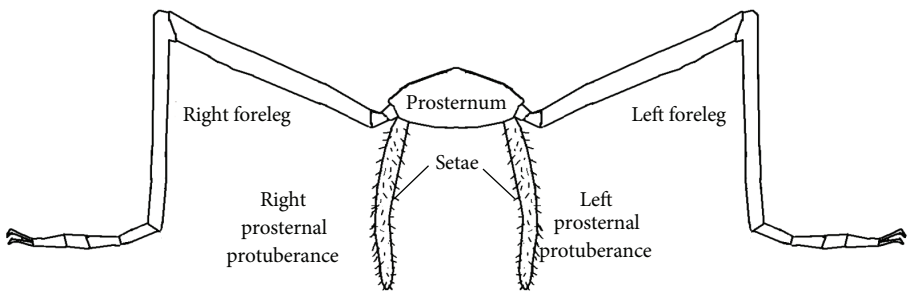


Figure 3: Generalized ventral view of the paired prosternal protuberances of *R. differens*.

and they are slightly inclined posteriorly and curved dorsally. Each prosternal protuberance measures approximately 3 ± 0.4 mm in length.

*3.5. Mesosternal and Metasternal Nodes and Mesosternal Interspace.* A reticulated mesosternal interspace was revealed between the bases of the median legs of *R. differens*. The mesosternum has a pair of roughly triangular lateral nodes and the metasternum has a pair of saclike lateral nodes.

*3.6. Pronotum.* The anterior margin of pronotum of *R. differens* is linear laterally. In addition, the pronotum has an obtuse lateral lobe ventrally and there is a rather right angled dorsolateral invagination just at the shoulders of the hind margin. The hind margin is slightly convex posteriorly (Figure 4). The mean length of *R. differens* pronotum along the median carina is 8±2 mm and its mean width is 4.5±1 mm with no significant variation between sexes. The mean mesopleural height is 7.0 ± 0.5 mm in males and 7.1 ± 0.5 mm in females ($n$ = 30) and hence almost consistent between sexes.

*3.7. Metathoracic Flaps.* At the dorsal side of the proximal base of the hind wing along the *Radius* vein (the strongest vein in the wing) there is a pair of active tongue-like male metathoracic flaps whereas the females were found to have a pair of budlike nodules appearing like the underdeveloped equivalents of the male flaps (Figures 5, 6, and 7). Each metathoracic flap has a broad and hairless foot that is tapered distally. The distal tip or apex comprises approximately one-quarter of the whole flap and it is rugose and highly flexible. In addition, the paired male metathoracicflaps are much protruded with a mean length of 2.8 ± 0.1 mm (range 2.1–3.3 mm) unlike the female equivalents, which are very undersized with a mean length of 0.4 ± 0.01 mm (range 0.2–0.5 mm). Prior to this study, the metathoracic flaps were unknown. However, their function remains unclear and hence requires to be investigated.

*3.8. Tympanum.* In this study, it was found that the proximal base of the fore tibia of *R. differens* (just distal to the knee joint) is swollen to accommodate the tympanum. This has two longitudinal auditory slits located at the dorsolateral and ventrolateral margins of each fore tibia (Figure 8). These slits are accompanied by two pits (small cavities) with membranous walls that are connected to the auditory receptors. The two auditory pits are equal in length and they are slightly shorter than the entire tympanum and are slightly concave outwardly. The mean length of *R. differens* tympanum is 1.5 ± 0.01 mm (i.e., ≈1/4 of the length of the fore tibia). The two auditory pits are equal in length, each measuring approximately 1.0 ± 0.1 mm (i.e., almost 3/4 the length of the entire tympanum). No sexual difference was revealed in the tympanum. A combination of all these tympanal morphometrics largely characterizes *R. differens*.

*3.9. Leg Segments.* Each of the fore and mid femurs of *R. differens* was found to have a single, indented prolateral lobe at the inferior (lateroventral) margin (Figure 9). Each mid femur is armed with a single inferior prolateral spine at the inner margin. Each hind femur usually has 8 (rarely 9 or 10) inferior spines. The distal half of each fore tibia has 6 spines per each of the two inferior rows while that of the mid tibia

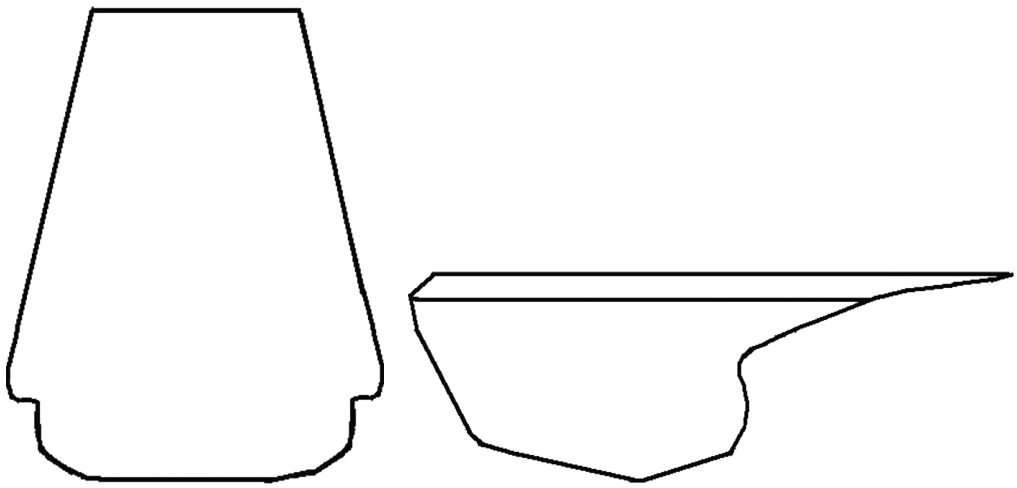


Figure 4: Morphological plan of *R. differens* pronotum in dorsal view (a) and lateral view (b).

Table 1: Number of spines in the respective legs of *R. differens*.

| | Lateroventral (inferior) margin | | Laterodorsal (superior) margin | |
|---|---|---|---|---|
| | Number of rows | Number of spines per row | Number of rows | Number of spines per row |
| Fore femur | 1 | 1 | — | — |
| Fore tibia | 1 | 6 | — | — |
| Mid femur | 1 | 1 | — | — |
| Mid tibia | 1 | 7 | — | — |
| Hind femur | 1 | Usually 8 (range 8–10) | — | — |
| Hind tibia | 2 | Usually 23 (range 20–25) | 2 | Usually 22 (range 20–25) |

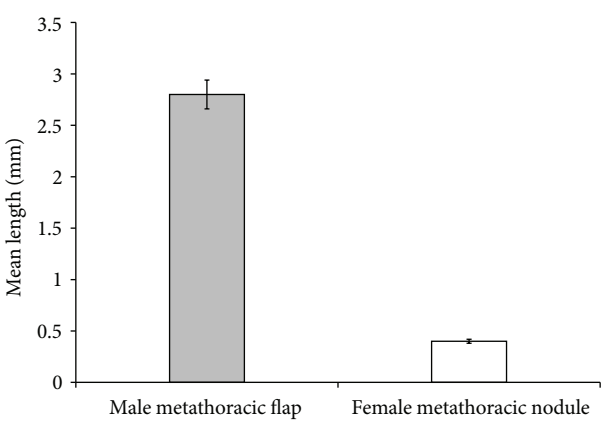


Figure 5: Comparative mean lengths between the male metathoracic flaps and female metathoracic nodules of *R. differens*.

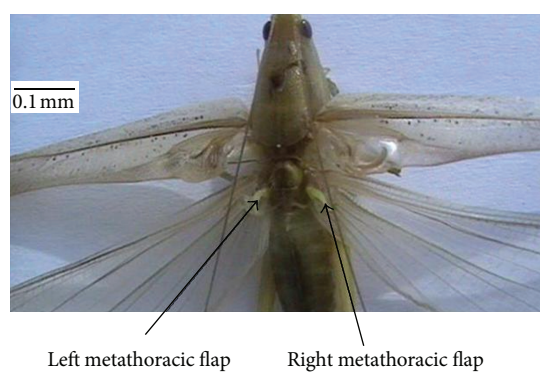


Figure 6: Dorsal view of male *R. differens* showing the paired metathoracic flaps.

has 7 spines (Table 1). The hind tibia has two inferior rows each usually with 23 spines (range 20–25) and two superior rows (on the laterodorsal margin) each usually with 22 spines (range 20–25). In addition, each hind tibia has 4 apical spurs, but the hind femur has no apical spine.

Each tarsus has 4 tarsomeres each with a distinct pulvillus underneath. The pulvillus of the anterior leg is divided into two equal bread-like sectors (i.e., rectangular with a rounded bottom) illustrating obvious remnants of a 5-tarsomere

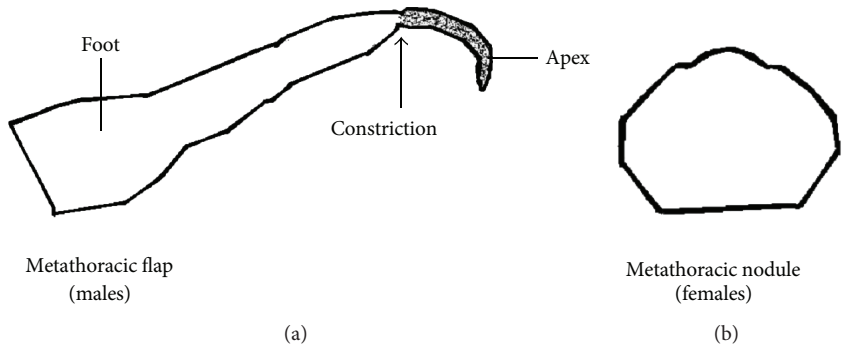


Figure 7: Morphological plans of the metathoracic flap (male) and nodule (female) of *R. differens* in dorsal views.

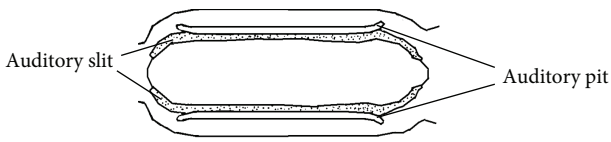


Figure 8: Morphological plan of *R. differens* tympanum in dorsal view.

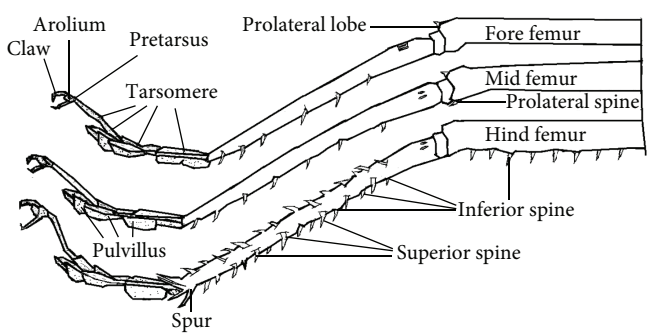


Figure 9: Dorsolateral views of *R. differens* legs showing the main morphological features diagrammatically.

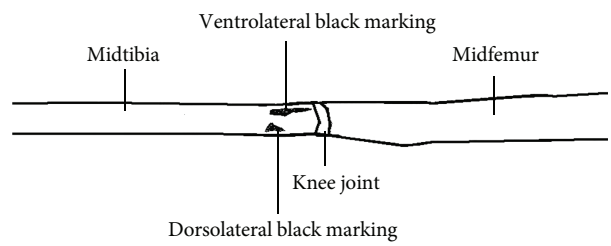


Figure 10: Dorsal view of *R. differens* mid tibia showing a pair of subequal ventrolateral and dorsolateral black markings.

pattern. That of the median leg is divided into two uneven flattened subsectors, namely, the proximal subsector that is apparently reduced in size, and the distal sub-sector that is slightly enlarged. The distal sub-sector of the first pulvillus of the posterior leg is excessively enlarged, but the proximal sub-sector is very much atrophied (by about 75%) and it is sunken and markedly pulled to the ventral periphery. One pulvilli of this tarsomere is almost lost to almost leaving the tarsus with only 4 clear tarsomeres.

*3.10. Mid Tibial and Hind Tibial Black Markings.* The study revealed unique paired black markings just distal to the proximal base of the mid tibia and hind tibia in *R. differens* (Figure 10). The position of these markings is quite analogous to that of the fore tibial tympanum and each comprises a pair of subequal members, namely, (by this study) ventrolateral tibial black marking (longer) and dorsolateral tibial black marking (shorter). A close microscopic examination revealed that the mean length of the ventrolateral marking was 0.7 ± 0.01 mm and hence almost half the length of the tympanum (i.e., 1.5 ± 0.01 mm) and almost two-times longer than the dorsolateral marking (0.3 ± 0.01 mm). Both these markings have never been described and their function is unknown.

*3.11. Stridulatory Apparati.* Each of the left and right male tegmina of *R. differens* was found to have a stridulatory rib formed as a modification of the *Radius posterior* vein. Both ribs are crescentic, but tapering slightly towards the anal margin than towards the axillary margin. The left rib is located on the tegmen's ventral surface (Figures 11 and 12). It is slightly convex distally and relatively thicker than the right rib (positioned at the tegmen's dorsal surface) and it is slightly concave distally. At the proximal edge of the mirror frame towards the axillary area of the left tegmen, there is a conspicuous groove that is accompanied by a ridge-like extension of the *Radius posterior*. Both these structures vary slightly among the individuals in terms of decorations and apical indentations. Near the anal margin of the right tegmen there is a well-developed scraper that functions to rasp over the file of the left tegmen during stridulation. The mirror frame (on the right tegmen) is D-shaped distally with a distinct V-shaped notch proximally along the *Radius* vein. Like other tettigoniids, the bases of the female fore wings are unmodified and hence lack any stridulatory organ. The mean rib length (Table 2) of the left tegmen is 3.5 ± 0.02 mm (range 3.0–4.0 mm) while the mean number of pegs in this tegmen is 86 ± 1 (range 74–94). On the other hand, the mean rib length of the right tegmen is 3.8 ± 0.01 mm (range 3.0–4.5 mm) and hence slightly longer, and the mean number of pegs in this tegmen is 76 ± 1 (range 70–80).

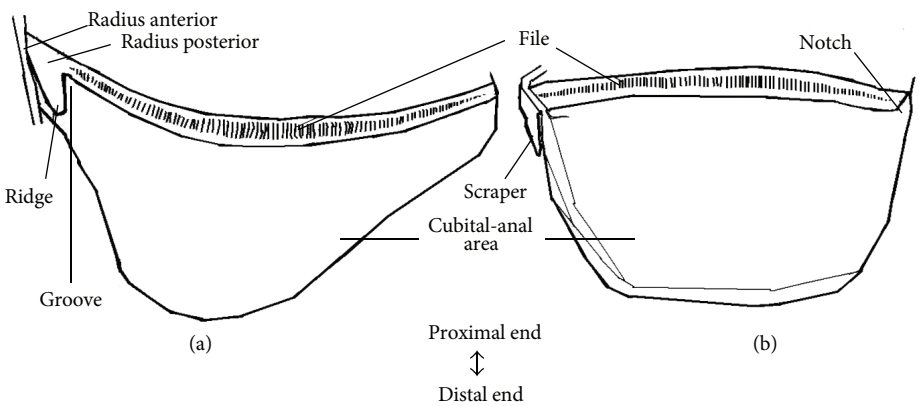


Figure 11: Left (a) and right (b) stridulatory apparatus of the male *R. differens* viewed from the dorsal aspect of tegmina.

Table 2: Relative morphometrics of the stridulatory ribs of the left and right tegmina of male *R. differens*.

| | Left tegmen | | | Right tegmen | | |
|---|---|---|---|---|---|---|
| | Rib length (mm) | Number of pegs | Peg packing density (number per mm) | Rib length (mm) | Number of pegs | Pegs packing density (number per mm) |
| Range | 3.0-4.0 | 74–94 | 22–28.7 | 3.0–4.5 | 70–80 | 17.3–24.3 |
| Mean | 3.5 | 86 | 24.7 | 3.8 | 76 | 20.4 |
| SD | 0.4 | 5 | 1.9 | 0.4 | 3 | 1.8 |
| SE | 0.1 | 0.9 | 0.4 | 0.1 | 0.6 | 0.3 |

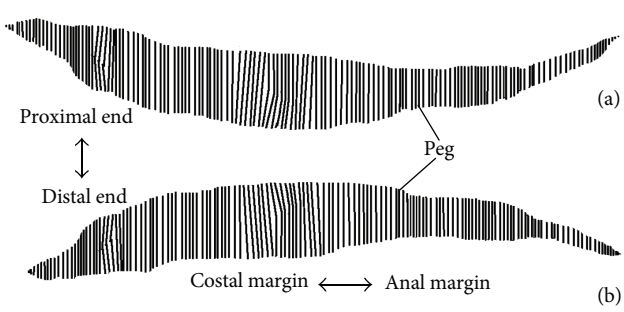


Figure 12: Diagrammatic representation of the left (a) and right (b) male stridulatory files of *R. differens* in dorsal views.

The difference between the stridulatory pegs of the left tegmen and those of the right tegmen was analyzed based on the profiles of their packing density (number of pegs per mm of rib length) using Student's *t*-test. It was observed that $P < 0.001$ hence $\ll 0.05$. Therefore, the null hypothesis was rejected and it was concluded that the packing density of the stridulatory pegs of the left tegmen was higher than that of the right tegmen.

*3.12. Terminalia.* The margin of the supraanal plate (epiproct) of the male *R. differens* is concave posteriorly. Cerci are bilobed dorsoventrally and each lobe is bent internally and has a pair of obliquely curved, subequal spines radiating from the middle. The subgenital plate (formed by the 9th sternite) between styli is concave apically and it is fairly rugose. Styli are slightly conical and short. In females, the apical margin of the supraanal plate is evenly bilobed and medially emarginated. Cerci are unarmed, unbranched, and slightly curved dorsally and indented apically. The subgenital plate is triangular apically; its base is almost as broad as long and contains a deep fissure medially. The ovipositor is somewhat sword shaped.

Detailed examination of the lobes of each male cercus of *R. differens* established that diagnostically the ventral (superior) lobe is almost twofold longer than the dorsal (inferior) lobe. The ventral lobe has a correspondingly larger spine than that of the dorsal lobe. On the other hand, female cerci are unbranched and unarmed and are much more protruded than the male cerci (Figures 13 and 14). The margin of the male supraanal plate is concave posteriorly whereas the female supraanal plate is evenly bilobed in which both lobes are separated by a V-shaped invagination anteriorly and each is angulate at its distal end.

The apical margin of the male subgenital plate between the two titillators is concave posteriorly and the styli are relatively conical and short. The female subgenital plate is roughly triangular and it is divided into a pair of concavities by a distinct fissure medially. The titillators are at the bases of the cerci internally and are slightly curved dorsally and hence parallel to the cerci. The ovipositor (females) is long, slender and somewhat straight. Diagnostically, it is roughly as long as the hind femur, hind tibia, or the combined thoracic and abdominal lengths. The mean length of this ovipositor is $24 \pm 0.1$ mm (range 20–25 mm) and its tip lies behind the tegminal tip by approximately $4 \pm 0.1$ mm. Each male titillator is almost

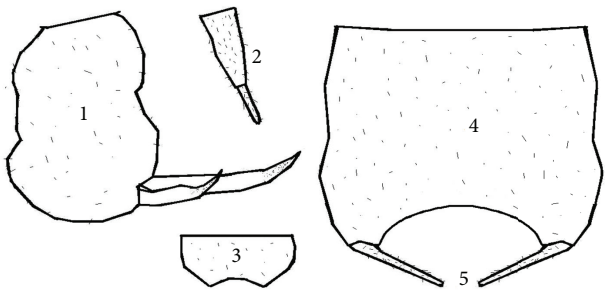


Figure 13: Genital segments of male *R. differens* in bottom view: 1= Cercus, 2 = Style, 3 = Supraanal plate, 4 = Subgenital plate, and 5 = Titillators.

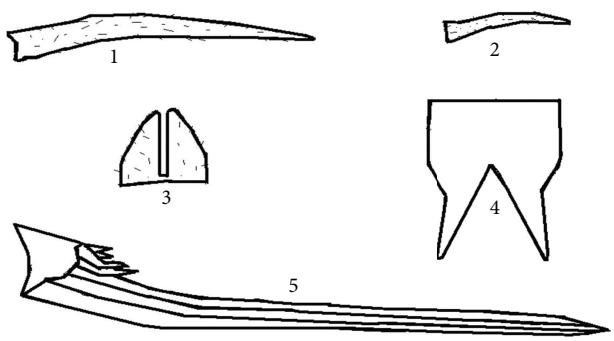


Figure 14: Genital segments of female *R. differens*: 1 = Cercus, 2 = Titillator, 3 = Subgenital plate, 4 = Supraanal plate, and 5 = Ovipositor.

as long as the cercus (2 ± 0.1 mm). Male style is 1 ± 0.1 mm in length hence almost half the length of the titillator or the cercus. The distance (interlobular) between the proximal bases of the two lobes of the male cercus is around 3 ± 0.2 mm. Each female titillator length is 1.5 ± 0.2 mm, which is roughly half the length of the cercus (3 ± 0.1 mm).

*3.13. Eggs.* The eggs of *R. differens* were found to be slender, cone shaped with rounded basal ends and tapering apical ends and are slightly curved. When inside the oviduct, the base of each egg is directed posteriorly notably for facilitating smooth oviposition (Figure 15). The mean length ($n = 30$) of *R. differens* eggs was found to be 6.0 ± 0.1 mm (range 4.5–6.5 mm) with the mean width of 1.1 ± 0.04 mm (range 1–1.5 mm).

## 4. Discussion

The present study has demonstrated that the male antennae of *R. differens* are exceptionally much longer than those of the females indicating sexual dimorphism. This characterizes *R. differens* since no close relative has been reported to possess such a trait. Diagnostically, each male antenna is as long as the combined lengths of the tegmen and mid tibia whereas the female antenna is as long as the tegminal length minus the mid tibial length ((1) and (2)):

$$\begin{aligned}\text{Male antennal length} &= \text{Tegminal length } (50\,\text{mm}) \\ &\quad + \text{Mid tibial length } (8\,\text{mm}) \\ &\approx 58\,\text{mm},\end{aligned} \tag{1}$$

$$\begin{aligned}\text{Female antennal length} &= \text{Tegminal length } (49\,\text{mm}) \\ &\quad - \text{Mid tibial length } (8\,\text{mm}) \\ &\approx 41\,\text{mm}.\end{aligned} \tag{2}$$

A number of tettigoniid species have been reported to have prosternal spines that may be very short as in *Ruspolia brevipennis* Scudder or very long as in *Orchelimum nigripes* (Scudder) [13]. Most tettigoniids have no prosternal processes (spine or protuberance) as in *Scotodrymadusa philbyi* [14], *C. nigropleurum* [15], and *Daedalellus* spp. [13]. The paired finger-like prosternal protuberances observed in *R. differens* (this study) are an unfamiliar trait among tettigoniids and thus the feature largely characterizes this insect. The protuberances compare very well with those of *Deinacridopsis connectens* Ander, which is a single species belonging to a rather primitive family, namely, Rhaphidophoridae (cave and camel crickets) of the superfamily Rhaphidophoridae syn. Gryllacrididae [16–20]. The function of these structures is unknown, but the presence of the hairy tips suggests that they might be playing some role in sensing certain conditions or resources.

Shapes and dimensions of mesosternal lobes and interspaces are useful characters in telling apart certain species and subfamilies. For instance, the characters are widely used to distinguish the two-striped grasshopper, *Melanoplus bivittatus* (Say) (Acrididae), from the rest of the other species of its genus [21]. Rather, *R. differens* may be differentiated from its nearest relatives based on its reticulated mesosternal interspace (located between the bases of the median legs), triangular mesosternal nodes, and saclike metasternal nodes. No other species of the genus *Ruspolia* has been reported to have the comparable combination of characters.

The lateral view of *R. differens* pronotum complies well with how it was illustrated by Bailey [22], but the invaginated lateral lobe of pronotum is roughly right angled. Thus it differs significantly from that of *R. nitidula*, which is acute angled [22]. The mean pronotal length of *R. differens* is roughly as long as the mid tibia (≈8 mm). The mean mesopleural height is as long as the fore tibia or mid femur (≈7 mm).

It has long been difficult to separate sexes of the East African sympatric coneheads on anything else than the phonoresponse [5, 23]. Inheritable characters that are conditioned by the sex of an individual are called sex-influenced characters and these are determined by genes that act differently in both sexes and the usual result is that a given trait predominates in one sex [24, 25]. The metathoracic flaps identified in *R. differens* for the first time by this study typically qualify as a sex-influenced trait as they develop

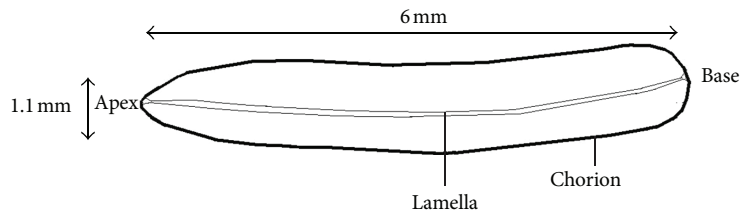


Figure 15: Morphological outline of the fresh *R. differens* egg.

only in the males, but retaining the undersized equivalents in the females. The function of the male metathoracic flaps is not clearly understood, but since females only develop the vestigial counterparts, the flaps appear to be a secondary sexual character that may be playing some role in courtship.

The position and morphology of *R. differens* tympanum (situated at the base of fore tibia and with a pair of longitudinal auditory slits and pits in each case) have demonstrated that this insect is a typical tettigoniid. However, this tympanum of *R. differens* does not differ significantly from that of other coneheads hence it does not qualify as a reliable diagnostic feature.

*R. differens* tarsi provide useful taxonomic information particularly with regard to the evolutionary transformation from the primitive 5-segmented tarsi to the 3-segmented tarsi typically of the Acrididae through 4-segmented tarsi typically of the *Tettigoniidae*. From the fore leg towards the hind leg through mid leg there is a sequential degeneration of the proximal sub-sector of the first pulvillus and this is accompanied by a sequential enlargement of the distal sub-sector. The species clearly demonstrates a sequential transformation from the paired pulvilli in the first tarsomere (a conspicuous remnant of primitive 5-tarsed life form) to a state of unity (closely affording a 4-tarsed life form well known as advanced). The first pulvillus of the fore leg is evenly divided into two nearly merged sectors, but the hind leg has almost lost one of its two tarsal sectors. All these are very useful evolutionary and taxonomic traits. Further, an anomalous set of 8 hind femoral spines revealed by this study in *R. differens* demonstrates a taxonomic specificity since tettigoniids are universally known to lack any femoral spine.

The relationships among lengths of segments of *R. differens* legs provide the general formula referred by this study as the "*Leg Lengths Coding Rule*" of this insect (3):

$$\begin{aligned}\text{Fore femoral length} &= \text{Fore tibial length} - 1\,\text{mm}\\ &= \text{Mid femoral length} - 1\,\text{mm}\\ &= \text{Mid tibial length} - 2\\ &= 0.25\times\ \text{Hind femoral length}\\ &= 0.25\times\text{Hind tibial length} \approx 6\,\text{mm}.\end{aligned} \tag{3}$$

From (4), it is also apparent that (4)-(5):

$$\text{Fore tibial length} = \text{Mid femoral length} \approx 7\,\text{mm}, \tag{4}$$

$$\text{Hind femoral length} = \text{Hind tibial length} \approx 24\,\text{mm}. \tag{5}$$

The above three formulae can be used for coding the lengths of the respective leg segments of this species interchangeably.

Body markings are widely used to tell apart many tettigoniid species and sexes. Significant variations among the markings may serve as a taxonomic basis for identifying different species. Presence in *R. differens* of five white spots on the pronotum has earlier been reported to distinguish this species from other coneheads, but the spots are sporadic and hence cannot be a reliable diagnostic feature [26]. The present study has identified unequal tibial black markings in *R. differens.* These markings have never been reported in any of its relatives and thus they can be a reliable diagnostic feature. If present in any close relatives, the mid and hind tibial markings might be of different characters.

The ventral stridulatory file of *R. differens*, located at the surface of left tegmina, had previously been only partially described [23] and there was no clear information on the counterpart structure in the right tegmina. In addition, most tettigoniids were known to have only one stridulatory rib commonly located on the left tegmen [7, 9]. The right stridulatory apparatus identified in this studyis built on the same plan as that of the left side and each is almost the mirror image of the other with several variations. Earlier, it had been reported that the left stridulatory file of *R. differens* is bulbous [22]; however, the present study has demonstrated that both stridulatory ribs are crescentic, but tapering narrower towards the anal marginthan towards the axillary margin. The right stridulatory file is relatively thinner, concave distally and it is located at the dorsal surface of tegmen whereas the left stridulatory apparatus is thicker, convex distally and is located on the ventral surface of tegmen. Only the left stridulatory file showed the potential for stridulating since the left tegmen lacks scraper for rubbing the file of the right tegmen. The right stridulatory file appears to be vestigial or it might have assumed another role apart from stridulation. The functions of the *Radius posterior* ridge and the groove (in the left tegmen) are also unknown, but their morphology and orientation reflect that they are probably used for locking the scraper temporarily when not in use. The stridulatory files, ridges, and grooves of *R. differens* largely correspond to

those of *R. flavovirens, R. basiguttata*, *R. ruthae,* and *R. paraplensia* [22] inferring that all these tettigoniids share a close ancestry.

Mirror frame is a circular patch of wing membrane which acts as a resonant loud speaker to amplify the insect's song [27]. In this study, it has been found that both female tegmina of *R. differens* lack mirror frame as most other tettigoniids. However, the present study has demonstrated that the right mirror frame is D shaped distally, has a distinct V-shaped notch proximally along the *Radius* vein, and has a diameter of 5 ± 0.5 mm in adults. All three aspects were not reported by any worker although they largely characterize *R. differens*. Previous reports were probably based on insufficient examination. Obviously, the shape of the mirror frame of *R. differens* is quite distinct and hence can be used diagnostically to distinguish this insect from its relatives. Based on the D-shaped mirror, a V-shaped notch, and a distally concave proximal margin, it is apparent that *R. flavovirens, R. basiguttata,* and *R. ruthae* are closely related to *R. differens*.

The range of number (74–94) of stridulatory pegs on the left tegmina of *R. differens* compares well with that (70–97) previously reported by [22]. Nevertheless, the species evidently conforms to the generalization that it has less than 100 stridulatory teeth [3]. Prior to this study, there was no information of the presence and characteristics of the stridulatory apparatus of the right tegmen of *R. differens.* The present study has successfully shown that the right tegmen of this insect has 70–80 ± 1 (mean 76) stridulatory pegs with a significantly lower packing density than that of the left tegmen. Since there are a number of other species with less than 100 stridulatory pegs, it is better to characterize *R. differens* based on the two stridulatory organs (one per each tegmen) containing 70–100 teeth each.

The female subgenital plate of *R. differens* is triangular apically and it is divided into two central concavities as that of *Zealandosandrus fiordensis* and *Z. gracilis* (Salmon), *Z. marculifrons* (Walker) [16], and *Parapholidoptera willemsei* [14]. However, the concavities of *R. differens* are separated from each other by a distinct fissure medially while those of the other mentioned species are separated by a brief apical excision at the centre. The character can be used to identify this species.

*R. differens* from the Ethiopian range has been reported to have a consistently rounded supraanal plate whereas *R. nitidula* and a number of other Palaearctic cone-headed species have been reported to have variable supraanal plate in which the individuals may have either a rounded or angled profile independent of sex [26]. In this study, however, the *R. differens* males from Tanzania have been shown to have rounded supraanal plate whereas that of the females is angled and evenly bilobed. Thus, one can proclaim that *R. differens* individuals from East Africa and Ethiopia are heterotypic in which the two sets can be distinguished based on the profiles of their supraanal plate. Bailey [26] speculated that the angled supraanal plate could have developed among the Palaearctic coneheads through a degree of isolation. The present findings verifies that the angled supraanal plate among the Palaearctic coneheads might have evolved from the females of the ubiquitous *R. differens* and not necessarily a result of isolation forces among the Palaearctic species as previously conceived.

Compared with other reported coneheads, *R. differens* has an exceptionally long ovipositor, which is as long as the hind femur, hind tibia, or the combined lengths of the thorax and abdomen:

$$\begin{aligned}\text{Ovipositor length} &= \text{Hind femoral length}\\ &= \text{Hind tibial length} = \text{Thoracic length}\\ &\quad + \text{abdominal length} \approx 24\,\text{mm}.\end{aligned} \tag{6}$$

Comparatively, the ovipositor of *Orchelimum gladiator* Brunner (family Gryllacrididae) has been reported to be 1/2 to 2/3 length of hind femur while in *O. concinnum* Scudder and *O. campestre* Blatchley it is less than 1/2 the length of the hind femur [15]. The ovipositor of the genus *Hemiandrus* (Ander) is extremely short as it can hardly be as long as the styli. However, the ovipositor of the genus *Zealandosandrus* (Salmon) may be as long as or relatively longer than the abdomen and hence can be compared with that of *R. differens* [15].

Each insect species produces eggs that are morphologically and genetically distinct; these may be stalked, spherical, ovate, conical, sausage shaped, barrel shaped, torpedo shaped, and so forth [7, 9]. According to the this study, *R. differens* eggsare characteristically conical and slightly curved with the mean length of $6 \pm 0.1$ mm and width of $1.1 \pm 0.04$ mm. Its egg length compares well with its fore femoral length (≈6 mm):

$$\text{Egg length} = \text{Fore femoral length} \approx 6\,\text{mm}. \tag{7}$$

The present morphometric analysis has demonstrated that of *R. differens* exhibits sex dimorphism by which it can be identified (Table 3). The males are relatively shorter with slightly longer tegmina and much longer antennae. Further, the males have a distinct pair of metathoracic flaps that are lacking in the females. The margin of the male supraanal plate is concave posteriorly, while that of the female has angulate bilobes that are separated by a V-shaped invagination anteriorly.

## 5. Conclusion

*R. differens* has a number of unfamiliar morphological characters that are useful for distinguishing this insect from other species and explicating its taxonomy. These are mainly associated with the vertex profile, antennal lengths, metathoracic male flaps and female nodules, prosternal protuberances, mesosternal and metasternal interspace and nodes, mid tibial and hind tibial black markings, pronotum, tympanum, left and right stridulatory apparatuses, leg segments, *terminalia* and eggs. A number of body characters of this species have demonstrated sexual dimorphism and these include the strikingly male-biased antennal lengths and paired metathoracic flaps which have, for the first time, been reported by this study. The traits can serve to distinguish this insect from the rest of the other coneheaded species. Various morphometric relationships among *R. differens* structures

Table 3: Data matrix of sex dimorphism of *R. differens* from Tanzania ($N$ = 3,000).

| | Male (♂) | | | | Female (♀) | | | | Intersex Deviation $P$ value | Inference |
|---|---|---|---|---|---|---|---|---|---|---|
| | Range (mm) | Mean (mm) | SD | SE | Range (mm) | Mean (mm) | SD | SE | | |
| Antennal length | 54–64 | 58 | 3.7 | 0.7 | 38–43 | 41 | 1.6 | 0.3 | <0.0001 | ♂ ≫ ♀ |
| Antennal segment length | — | 0.37 | — | — | — | 0.26 | — | — | — | ♂ > ♀ |
| Body length | 30–42 | 35.3 | 4.3 | 0.8 | 33–42 | 38 | 3 | 0.6 | 0.007 | ♀ > ♂ |
| Tegminal length | 42–57 | 50 | 4.6 | 0.8 | 43–54 | 49 | 3.3 | 0.6 | <0.001 | ♂ > ♀ |
| Metathoracic flap length | 2.1–3.3 | 2.8 | 0.3 | 0.1 | — | — | — | — | — | ♂ trait |
| Metathoracic nodule length | — | — | — | — | 0.2–0.5 | 0.4 | 0.1 | 0 | — | ♀ trait |
| Supraanal plate | Concave posteriorly | | | | The apical margin is evenly bilobed and it is emarginated by a V-shaped invagination medially | | | | — | ♂ ≠ ♀ |

are governed by definite formulae that can serve as useful shortcuts for characterizing this species and expressing its taxonomic affiliation.

## Key Characters of Identification of *R. differens*

(i) A tendency to form swarms strikingly during wet seasons.

(ii) Existing in at least six sympatric colour forms, that are green (predominantly females), brown (predominantly males and with black speckled tegmina), purple striped green (rare), purple suffused green (very rare), purple suffused brown (very rare), and purple striped brown (extremely rare).

(iii) Face is slanted and it lies at the acute angle of approximately 50° with respect to the pronotal dorsum in repose.

(iv) Cone is distinctly longer than wide, narrowing from base to apex and forming an acute angle of around 40° anteriorly between the lateral sides in repose.

(v) Vertex of cone does not extend beyond the basal antennal segments.

(vi) The anterior of vertex has a slightly rounded tubercle with dorsal and ventral conical endings posteriorly.

(vii) The fastigium of vertex is slightly extended in front of the eyes in profile.

(viii) An interocular oval white mark that appears like a simple eye.

(ix) Oval compound eyes that may be black or grey.

(x) Each of the left and right male tegmina has a stridulatory organ with a crescentic rib; the left rib has 74–94 pegs (usually around 86 pegs) and it is positioned on the ventral aspect and is convex distally and it lacks a scraper. The right rib has 70–80 (usually around 76) pegs, it is positioned on the dorsal aspect, it is concave distally, and it has a scraper.

(xi) The right stridulatory mirror frame is roughly D shaped with a distinct V-shaped notch proximally along the *Radius* vein.

(xii) A pair of finger-like prosternal protuberances.

(xiii) A pair of active male metathoracic flaps with a corresponding pair of vestigial female metathoracic nodules.

(xiv) Paired subequal black markings on the mid and hind tibia.

(xv) Tympanum is situated at the base of fore tibia and has paired longitudinal auditory slits and pits.

(xvi) Male antenna is almost 1.5-times longer than female antenna (filiform in both).

(xvii) Tympanal length is approximately one-quarter as long as the fore tibia.

(xviii) Wings are held roof-like in cross-section. The hind wing is slightly longer (by around 3 mm) than the fore wing.

(xix) Tarsi are 4-segmented with obvious remnants of the 5th segment (tarsomere).

(xx) Hind femur is as long as hind tibia, each being 4-fold longer than fore femur.

(xxi) Each fore and mid femur has a single, indented prolateral lobe at the inferior (lateroventral) margin.

(xxii) Each mid femur is armed with a single inferior prolateral spine at the inner margin. Hind femur has 8 (rarely 9 or 10) inferior spines; hind tibia has two inferior rows each usually with 23 (range 20–25) spines, two superior rows (i.e., on laterodorsal margin) each usually with 22 (range 20–25) spines, and 4 apical spurs; mid femur is armed with a single inferior prolateral spine; foretibia and mid tibia have 6 and 7 spines, respectively, per each of the two inferior rows.

(xxiii) Male cercus <1/4 length of hind femur or hind tibia and it is subequally bilobed in which the ventral

(superior) lobe is almost twofold longer than the dorsal (inferior) lobe; the spine of the ventral lobe is almost twofold larger than that of the dorsal lobe; female cerci are unbranched and unarmed and they are much more protruded than the male cerci.

(xxiv) The apical margin of the male subgenital plate (the ninth abdominal tergite) between the two titillators is concave posteriorly; the female subgenital plate is triangular apically and it is divided into 2 concavities that are separated by a distinct median fissure.

(xxv) The margin of the male supraanal plate is concave posteriorly; female supraanal plate is equally bilobed and the two lobes are separated by a medial V-shaped invagination anteriorly with a lobe that is angulate at its distal end.

(xxvi) A reticulated mesosternal interspace; a pair of triangular mesosternal nodes and a pair of saclike metasternal nodes between the bases of the median legs.

(xxvii) The ovipositor is as long as the combined lengths of the hind femur and hind tibia, or of the thorax and abdomen.

(xxviii) Eggs are slender (approximately $6.0 \times 1.1$ mm) and slightly conical and curved.

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