The systematic analysis of male and female genital structures of tribe *Carabini*, *Platynini*, *Sphodrini* and *Zabrini (Coleoptera, Carabidae)* species and their taxonomic importance

Carabini, *Platynini*, *Sphodrini* ve *Zabrini (Coleoptera, Carabidae)* tribusu türleri erkek ve dişi genital yapılarının sistematik analizi ve taksonomik önemleri

Research Article

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ABSTRACT

In this study, the structure of the male and female genitalia of fourteen species from the tribe *Carabini, Platynini, Sphodrini* and *Zabrini* have been examined. Aedeagus, parameres, hemisternites, basal and apical segment of styli have been analyzed and illustrated and systematic differences among them have also been discussed at the generic and species level in order to clarify their distinctive characteristics.

Key Words
Carabidae, Carabini, Platynini, Sphodrini, Zabrini, Male and female genital structure

ÖZET

Bu çalışmada, *Carabini, Platynini, Sphodrini* ve *Zabrini* tribusuna ait 14 türün erkek ve dişi genital organ yapıları çalışılmıştır. Erkek genitalyaya ait aedeagus ve paramerlerin, dişi genitalyadan hemisternite ve stylusun basal ve apical segmentlerinin yapısı analiz edilerek şekilleri çizilmiş, bu yapılara ait taksonomik karakterlerin gruplar arasındaki cins ve tür düzeyindeki farklılıkları tartışılmıştır.

Anahtar Kelimeler
Carabidae, Carabini, Platynini, Sphodrini, Zabrini, Erkek ve dişi genital yapı

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INTRODUCTION

The male genitalia of Carabidae family are rooted from aedeagus 10th abdominal segment and attached to the genital plate which is in the shape of a triangle that is formed by modification of the 9th segment of the genitalia. Inner sac is attached to the median lob apex, which is in the shape of a cylinder, to laterally apical edge, that is reversed in the vagina during the pairing period. In the inner sac lumen, there are armature sclerits with different shapes which create the opportunity to stick to female genitalia. Furthermore there is a pair of Paramere attached to median lob proximal and it carries a number of seta in its apical. Parameres are at equal size in primitive species. In developed ones, Parameres are varied in left and right sides or one of the parameres may be reduced in size [6]. In the studies on male genitalia, different points have already been analyzed in earlier studies: the shape of aedeagus [7,17,20]; pattern of parameres [29]; the structure and position of armatures in inner sac [1-3,11-15]. All of these characters have been analyzed together for tribe Lebiini as well [16].

Female genitalia is composed of hemisternites and stylus attached to it. Hemisternites occur as a result of the change in the 9th abdomen segment. Styli are in pair and made up of two segments. Basal segment is attached to hemisternites and the one is usually referred to as apical segment [28]. Several comprehensive studies have been carried out by Habu [9, 21-23]. In these studies, tribe Pterostichini and species of Trichochlaenius and Zabrus together with those of Oodinae were analyzed at the level of subfamily and genera. Additionally, some studies emphasized the systematical significance of styli of female genitalia [4,15]. Another significant study has analyzed hemisternite together with basal and apical segment of styli at the genera level and species in tribe Lebiini [16].

In this study, the structure of male and female genitalia of the tribe *Carabini,* including *Platynini, Sphodrini* and *Zabrini* have been analyzed and their shapes have been drawn. Also, all the parts with systematic significance, have been discussed at both levels of species and genus.

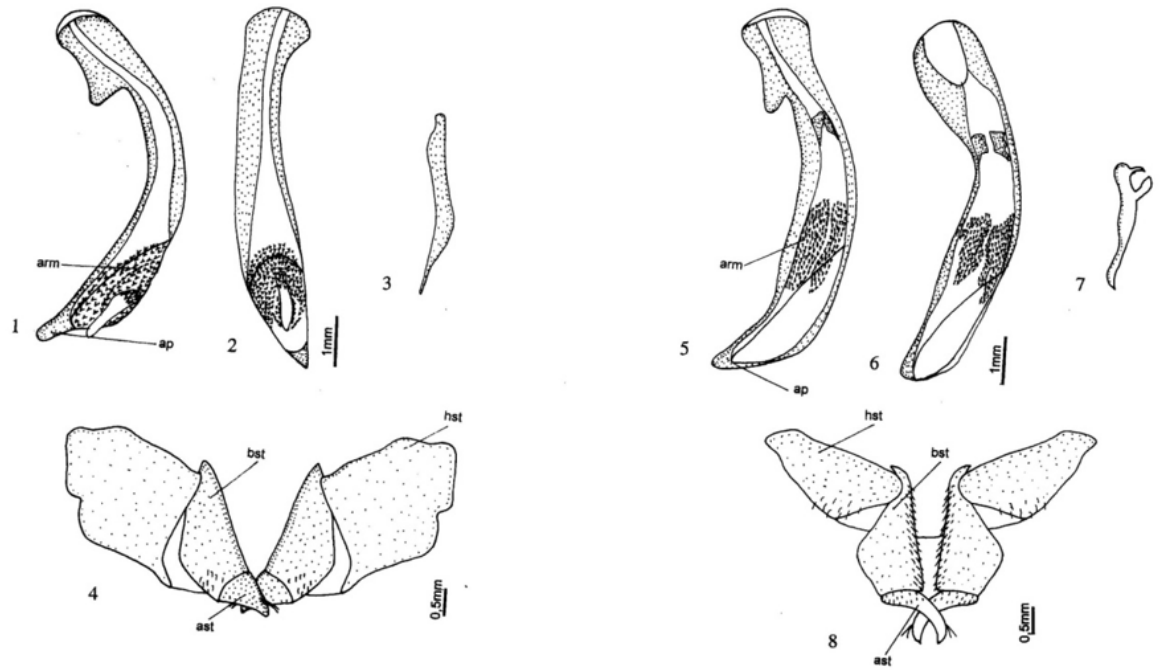
MATERIALS AND METHODS

For the preparation of male and female genitalia structure, Lindroth's [19] approach was employed. For the terminology, that of the Tuxen [28] was used. Those segments which are systematically significant in the structure of male and female genitalia (aedeagus, parameres, hemisternites, basal and apical segments of styli) are illustrated and defined. For drawings, Nikon SMZ-U stereoscopic microscope and drawing tools are used.

RESULTS

Tribe: Carabini Latreille, 1802
Genus: ***Calosoma*** *F. Weber*, 1801
Calosoma sycophanta **(Linneaus, 1758)**
Male genitalia- In lateral view aedeagus curved in ventral direction. In dorsal view its medial region broad, apical plate triangular; chitin plate located in the apical part of the inner sac and its basal part spined, surroundings of this chitin plate armed with small spines (Figures 1-2); parameres rectangular shaped and have the equal size, strongly narrowed from medio-apical to apical (Figure 3).
Female genitalia- Hemisternites almost trapezoid shape, their inner and outer margins straight and are slightly and apically sharply pointed; basal segment of styli narrowed basely, broad at medio-apical, inner margin hairy, outer distal surface with 9 setae; apical segment of styli triangular in shape, two setae on inner surface before apex, these setae protruding from a fovea (Figure 4).

Genus: *Carabus* Linneaus, 1758
Carabus chevrolati **Cristoforis et Jan, 1837**
Male genitalia- In lateral view aedeagus curved ventrally, ventral margin sinuate. In dorsal view its basal region broad, apical plate short and rounded; sclerits of inner sac located reciprocal proximally and two chitin plates almost rectangular shaped and also oval shaped with two spine groups medially (Figures 5-6); parameres have the same length, cylindrical basally and broader (Figure 7).
Female genitalia- Hemisternites triangular in shape, distal part with rare setae; basal segment of styli strongly narrowed basally and with a projection, medial region broad, inner margin hairy; apical segment of styli broad basally, strongly narrowed from proximal region, triangular in shape and curved apically, base hairy, apical of outer margin with two setae (Figure 8).



Figures 1-8. *Calosoma sycophanta* (Linneaus, 1758): aedeagus, lateral side (1), dorsal side (2), paramere (3), female genitalia (4); *Carabus chevrolati* Cristoforis et Jan, 1837: aedeagus, lateral side (5), dorsal side (6), paramere (7), female genitalia (8).arm:armature sklerites, hst: hemisternite, bst: basal sklerites, ast: apical sklerites.

***Carabus convexus Fabricius*, 1775**

Male genitalia- In lateral view aedeagus curved. In dorsal view aedeagus narrowed strongly at proximal, broad medially, apical plate narrow and triangular; armature of inner sac with two amorphous sclerites covered with spines at postero-medial, in addition to these sclerites with two spine groups one in medial and other in apical and cylindrical shaped (Figures 9-10); parameres have the same length, cylindrical at base, strongly narrowed apically (Figure 11).

Female genitalia- Hemisternites almost square, distal margin with setae; basal segment of styli narrow and triangular at base, strongly broad medially, outer margin hairy; apical segment of styli narrow slightly at proximal, apically cylindrical, dorsal surface hairy, with one seta situated on puncture at apex (Figure 12).

***Carabus coriaceus* Linneaus, 1758**

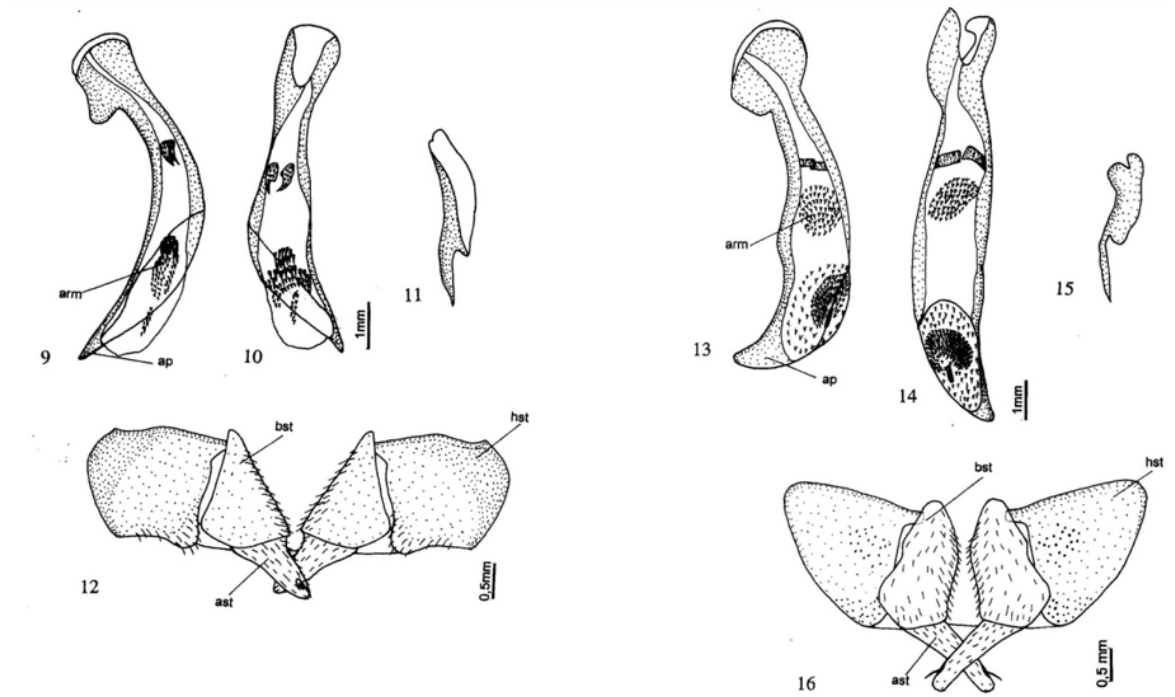
Male genitalia- In lateral view aedeagus curved, ventral margin sinuate, basal part broad. In dorsal view narrowed proximally, apical plate curved left side, ovoid at apex; armature of inner sac with two almost rectangular sclerites covered with spines at proximal, with sparsely located spines form a ovoid spine group at postero-medial, with one more ovoid spine group at apex, also with two spine groups, one is semi circle shaped and other is cylindrical (Figures 13-14); parameres equal size, basally emarginated, medially strongly narrowed, almost rectangular (Figure 15).

Female genitalia- Hemisternites at proximal edge triangular, its medial and distal parts pointed; basal segment of styli broader apically, outer margin more densely hairy; apical segment of styli cylindrical, outer margin with one big seta on fovea (Figure 16).

***Carabus graecus* Dejean, 1826**

Male genitalia- In lateral view aedeagus curved, latero-ventrally sinuate, apical plate curved. In dorsal view aedeagus narrow at proximal, apical plate curved; armature of inner sac with two crescent shape chitinous plates at proximal part, these plates located reciprocally, square-shaped two spin groups attached to these plates, in addition with a conic spin group at medial, also with a tooth like amorphous sclerite covered with spins and almost oval-shaped spin group at medio-apical (Figures 17-18); parameres have equal size and strongly narrowed from medio-apical to apical (Figure 19).

Female genitalia- Hemisternites almost square shape, distal margin setaceous; basal segment of styli conical and broad at medio-apical, outer margin



Figures 9-16. *Carabus convexus* Fabricius, 1775: aedeagus, lateral side (9), dorsal side (10), paramere (11), female genitalia (12); *Carabus coriaceus* Linneaus, 1758: aedeagus, lateral side (13), dorsal side (14), paramere (15), female genitalia (16). arm:armature sklerites, hst: hemisternite, bst: basal sklerites, ast: apical sklerites.

hairy; apical segment of styli almost cylindrical, ovoid at apex, apex of outer margin with two setae on fovea (Figure 20).

Tribe: Platynini Bonelli, 1810
Genus: *Agonum* Boneli, 1810
***Agonum marginatum* (Linneaus, 1758)**

Male genitalia- In lateral view aedeagus strongly curved, apical plate narrow. In dorsal view lateral sides of aedeagus sinuate, apical plate ovoid at apex; armature of inner sac with small spines extending from proximal to apical, in addition to these spines with five teeth at medio-apical (Figures 21-22); parameres ovoid shape, right paramere 1,2 times longer than to left paramere (Figures 23-24).

Female genitalia- Hemisternites with a process at proximal edge, proximal margin concave, distal margin with long setae forming two rows; basal segment of styli cylindrical, with two setae medio-apically and six setae apically; apical segment of styli strongly narrowed at apical part, triangular at apex, with two big spin at medio-ventral (Figure 25).

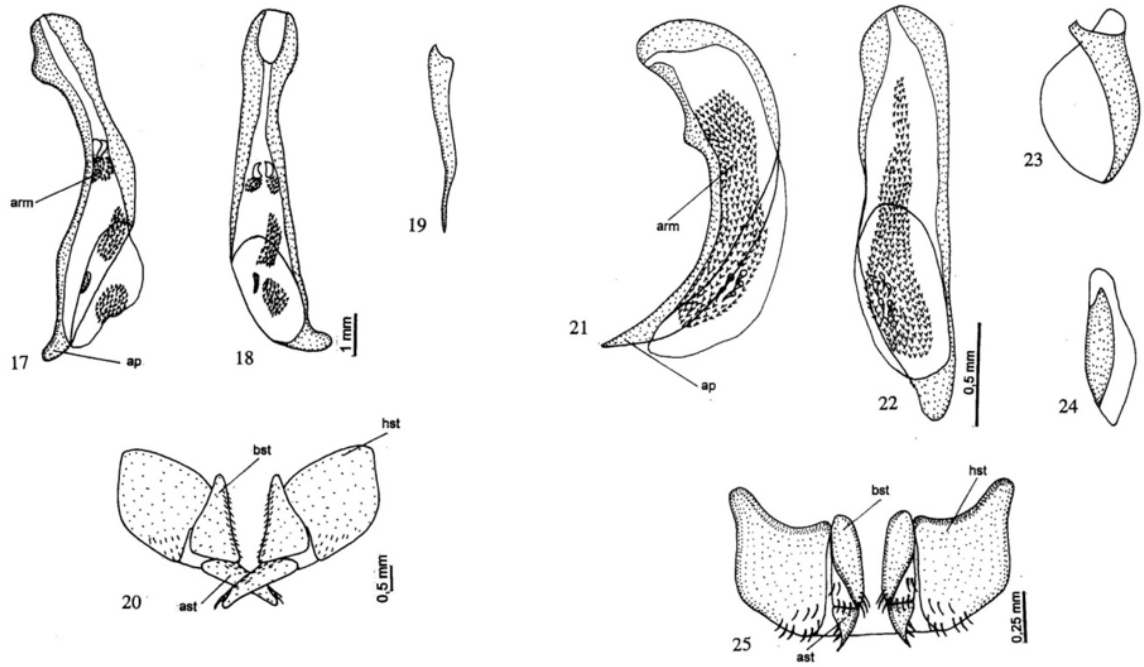
***Agonum viridicupreum* (Goeze, 1777)**

Male genitalia- In lateral view aedeagus strongly curved. In dorsal view aedeagus broad basally, lateral sides parallel, apical plate ovoid at apex; armature of inner sac with spins forming a crescent shaped group and extending from medial to apical (Figures 26-27); right paramere about 1,6 times length to left paramere, lateral sides sinuate and ovoid shape, left paramere spatula shaped (Figures 28-29).

Female genitalia- Hemisternites concave at proximal margin, outer margin sinuate, distal part with long setae forming two rows; basal segment of styli cylindrical, deeply emarginated, truncate apically, with long setae at inner and outer edge at apex; apical segment of styli triangular, ovoid at apex, with two spins at medio-ventral (Figure 30).

Genus: *Anchomenus* Boneli, 1810
***Anchomenus dorsalis* (Pontoppidan, 1763)**

Male genitalia- In lateral view aedeagus strongly curved. In dorsal view aedeagus broad basally, lateral sides parallel, apical plate ovoid at apex; armature of inner sac with two amorphous sclerites covered with spins, one in medio-apical and other in apical (Figures 31-32); parameres same length, right paramere prominent at the joining part to aedeagus and oval shaped, with setae at lateral sides, left paramere indented at base, triangular, with setae



Figures 17-25. *Carabus graecus* Dejean, 1826: aedeagus, lateral side (17), dorsal side (18), paramere (19), female genitalia (20); *Agonum marginatum* (Linneaus, 1758): aedeagus, lateral side (21), dorsal side (22), right paramere (23), left paramere (24), female genitalia (25). arm:armature sklerites, hst: hemisternite, bst: basal sklerites, ast: apical sklerites.

sparsely medially (Figures 33-34).

Female genitalia- Hemisternites strongly concave at proximal margin, outer margin sinuate, distal part prominent, with setae forming two rows; basal segment of styli with a process at basal part, broad at apical, inner edge with four and outer edge with three setae at apex; apical segment of styli narrowed at apex, gently curved, inner margin with three and outer margin with one setae (Figure 35)

Tribe: Sphodrini Laporte, 1834

Genus: *Calathus* Boneli, 1810

***Calathus fuscipes* (Goeze, 1777)**

Male genitalia- In lateral view aedeagus not curved, apical plate curved. In dorsal view aedeagus broad medially, apical plate ovoid at apex; armature of inner sac with spines extending from medial to apical, densely in apical part (Figures 36-37); right paramere two times as long as left paramere, triangular and forming an evident hook, left paramere ovoid and punctured at medial (Figures 38-39).

Female genitalia- Hemisternites sinuate at outer margin, almost triangular, inner margin with short and dense setae; basal segment of styli strongly broadened at apical, without puncture and setae; apical segment of styli narrow from medial to apical, with two large spins one at inner margin and other at outer margin and also with one seta on fovea at medio-dorsal (Figure 40).

***Calathus melanocephalus* (Linneaus, 1758)**

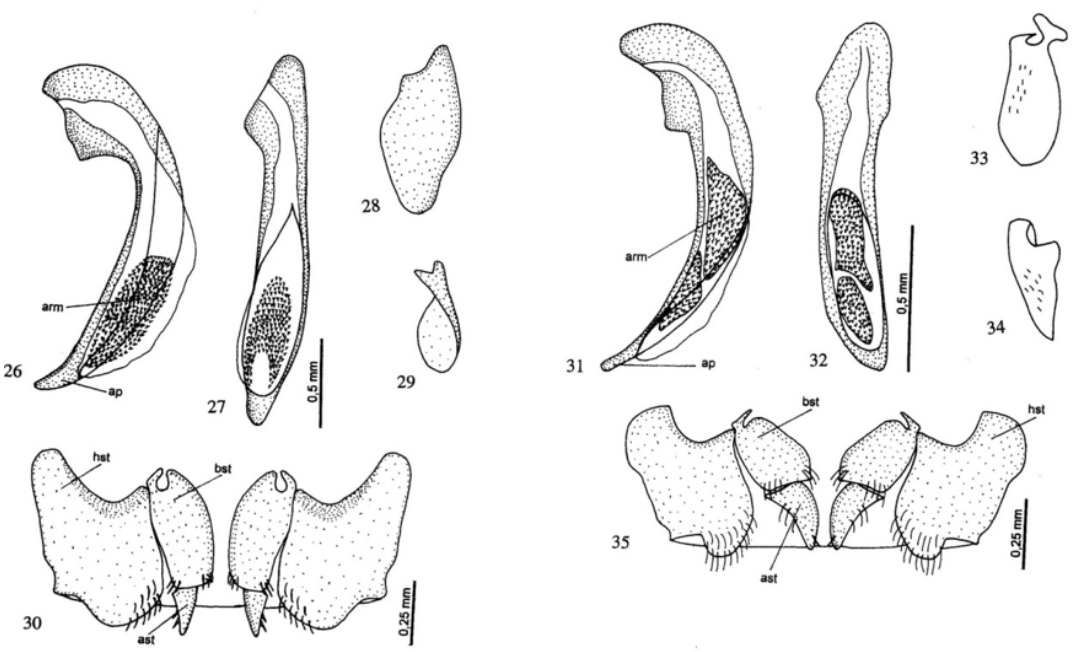
Male genitalia- In lateral view aedeagus slightly curved, apical plate expanded dorso-ventrally. In dorsal view aedeagus broad medially, apical plate expanded at apex; armature of inner sac with spines extending from medial to apical, densely in lateral sides (Figures 41-42); right paramere 1,8 times length to left paramere, narrow, long and with a hook at apex, left paramere bilobed at base, ovoid shape, with setae densely at medial (Figures 43-44).

Female genitalia- Hemisternites indented at outer margin, proximal margin concave, distal margin with five setae; basal segment of styli conic, outer margin with setae sparsely; apical segment of styli sickle-shaped, strongly narrowed at apex, inner margin with two large spines, outer margin with one large seta (Figure 45).

Genus: *Dolichus* Boneli, 1810

***Dolichus halensis* (Schaller, 1783)**

Male genitalia- In lateral view aedeagus strongly curved at medio-apical, apical plate expanded ventral side and curved. In dorsal view aedeagus



Figures 26-35. *Agonum viridicupreum* (Goeze, 1777): aedeagus, lateral side (26), dorsal side (27), right paramere (28), left paramere (29), female genitalia (30); *Anchomenus dorsalis* (Pontoppidan, 1763): aedeagus, lateral side (31), dorsal side (32), right paramere (33), left paramere (34), female genitalia (35). arm:armature sklerites, hst: hemisternite, bst: basal sklerites,ast:apicalsklerites.

narrow at apex proximally, apical plate triangular; armature of inner sac with spines extending from medial to apical, densely in medially (Figures 46-47); right paramere two times as long as left paramere, broad at base, narrow from proximal and apical and cylindrical, left paramere almost cylindrical and inner margin sinuate (Figures 48-49).

Female genitalia- Hemisternite concave at proximal margin, lateral margins sinuate, narrow at distal part, with setae sparsely at medial; basal segment of styli with a process at basal part, with setae sparsely at medial; apical segment of styli strongly narrowed from medial to apical, narrow and triangular at apex, with two large spins at latero-medial, with one seta at apex (Figure 50).

Tribe: Zabrini Bonelli, 1810

Genus: *Zabrus* Clairville, 1806

***Zabrus corpulentus* Schaum, 1864**

Male genitalia- In lateral view aedeagus gently curved at apical part, lateral margin sinuate. In dorsal view aedeagus slightly narrow proximally, apical plate ovoid; armature of inner sac with an oval shaped spin group between medio-apical and apical (Figures 51-52); right paramere broad at base, narrowed towards apical, curved like a hook at apex, two times longer spatula shaped left paramere (Figures 53-54).

Female genitalia- Hemisternites sinuate at proximal margin, distal margin long, narrowed proximally and with setae; basal segment of styli broad medially, outer margin with setae densely; apical segment of styli narrow at base, ovoid at apex, dorsal surface dense hairy, medio-apical of outer margin with two setae situated on same puncture (Figure 55).

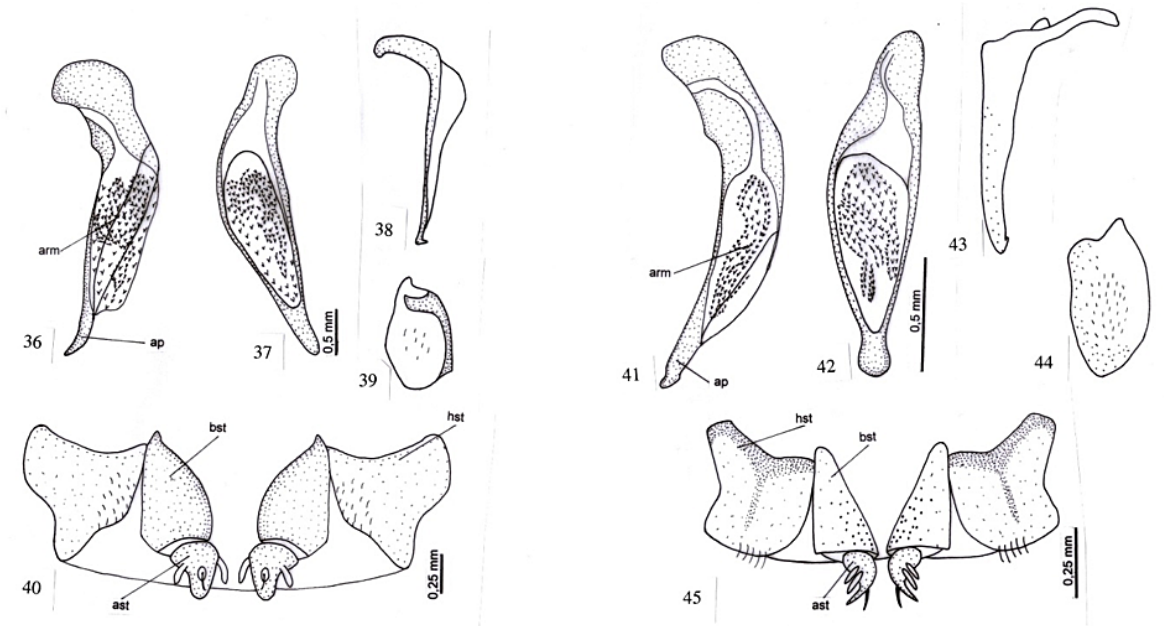
***Zabrus spinipes* (Fabricius, 1798)**

Male genitalia- In lateral view aedeagus strongly curved. In dorsal view lateral sides of aedeagus parallel, apical plate triangular; inner sac covered with spines from postero-medial to apical sparsely (Figures 56-57); right paramere broad at base, narrow from proximal to apical; with small hook at apex and two times longer triangular shaped left paramere (Figures 58-59).

Female genitalia- Hemisternites elongated oval shaped, with dense setae at distal margin; basal segment of styli broad at medial, outer margin with setae densely between medial and apical; apical segment of styli almost cylindrical, dorsal surface hairy, apex of outer margin with two setae situated on same puncture (Figure 60).

***Zabrus tenebrioides* (Goeze, 1777)**

Male genitalia- In lateral view aedeagus strongly curved. In dorsal view aedeagus weakly broad at



Figures 36-45. *Calathus fuscipes* (Goeze, 1777): aedeagus, lateral side (36), dorsal side (37), right paramere (38), left paramere (39), female genitalia (40); *Calathus melanocephalus* (Linneaus, 1758): aedeagus, lateral side (41), dorsal side (42), right paramere (43), left paramere (44), female genitalia (45). arm:armature sklerites, hst: hemisternite, bst: basal sklerites, ast: apical sklerites

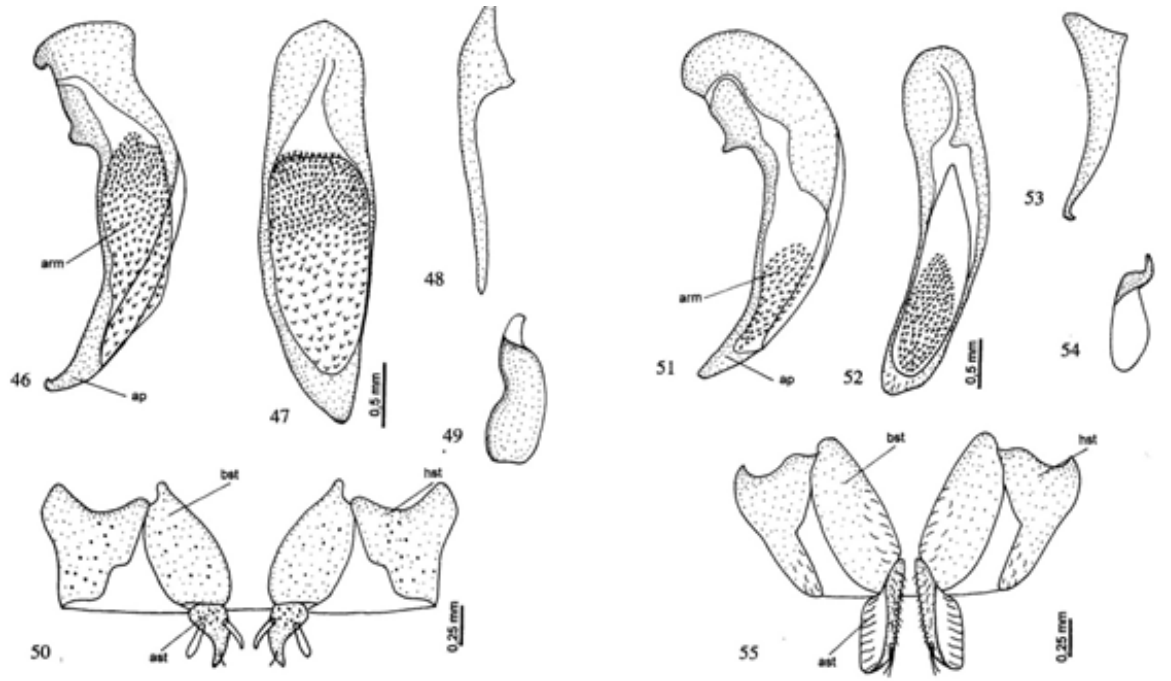
proximal, narrowed towards apical, apical plate cylindrical and ovoid at apex; armature of inner sac with two spin groups, sickle shaped group at medial, triangular group at apical (Figures 61-62); right paramere broad basally, narrow at apex and with a small hook, left paramere 1, 7 times shorter than right paramere and oval shaped with a node at medial (Figures 63-64).

Female genitalia- Hemisternites almost rectangular, distal margin covered with short setae; basal segment of styli broad at apex, inner margin sinuate, outer margin with setae densely; apical segment of styli broad proximally, ovoid at apex, dorsal surface hairy, apex of outer margin with two short setae, with one seta on medio-ventral (Figure 65).

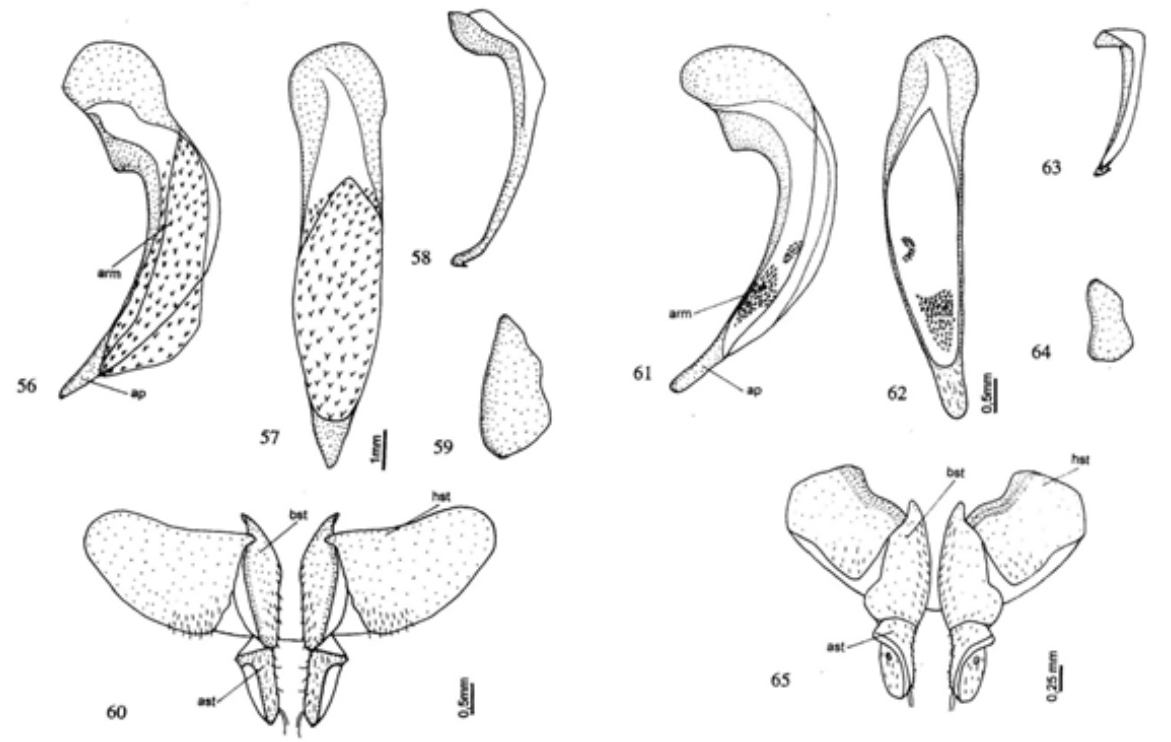
CONCLUSIONS AND DISCUSSION

Male and female genitalia of fourteen species belonging to the tribe Carabini, Platynini and Sphodrini were analyzed in terms of their genital structure. Specifically, aedeagus, inner sac armatures, apical plate and parameres in male genitalia and hemisternite, basal and apical segments of styli in female genitalia were examined and the differences between the number of setae and positions on basal and apical segment of styli were identified. With this study it was established that the paramers of male genitalia and the hemisternits with the styli of female genitalia can be used as discriminating characters for systematic studies.

With regard to the male genitalia of the three tribes, it was found that basal orifice of aedeagus is in the form of posterior and parameres do not differ in terms of shape and size. This finding is consistent with that of Casale [5]. Furthermore, in this subfamily the existence of chitin area in inner sac show some differences at the generic level. In *Calosoma*, this area in inner sac does not exist. In *Carabus* there is a chitin area and in some species it is covered by spines. *C. convexus* and *C. coriaceus* belonging to *Carabus* have apical plate curved left. This finding is parallel to that of Casale [5,24,25,27,30] emphasize the significance of this character in the same genus. Chitin plate in inner sac proximal is quadrangle in *C. chevrolati* and *C. coriaceus*, whereas it is oval in *C. convexus* and *C. graecus*. Chitin plate is covered by spines in *C. convexus* and *C. coriaceus*. Furthermore type and distribution of inner sac armatures significantly differ in these species. Although *C. chevrolati* and *C. coriaceus* are similar in terms of having two lobes paramere basal, *C. coriaceus, C. convexus* and *C. graecus* are different in that in *C. coriaceus*, these lobes are in lateroproximal; in both



Figures 46-55. *Dolichus halensis* (Schaller, 1783): aedeagus, lateral side (46), dorsal side (47), right paramere (48), left paramere (49), female genitalia (50); *Zabrus corpulentus* Schaum, 1864: aedeagus, lateral side (51), dorsal side (52), right paramere (53), left paramere (54), female genitalia (55). arm:armature sklerites, hst: hemisternite, bst: basal sklerites, ast: apical sklerites



Figures 56-65. Zabrus spinipes (*Fabricius*, 1798): aedeagus, lateral side (56), dorsal side (57), right paramere (58), left paramere (59), female genitalia (60); *Zabrus tenebrioides* (Goeze, 1777): aedeagus, lateral side (61), dorsal side (62), right paramere (63), left paramere (64), female genitalia (65). arm:armature sklerites, hst: hemisternite, bst: basal sklerites, ast: apical sklerites

C. convexus and *C. graecus* paramere basals form a weak recess. The shape of aedeagus, chitin plate in inner sac and the position of spines as well as the shapes of parameres are the distinctive features of species. Molecular studies support the male genital organ data that *C. chevrolati* and *C. coriaceus* are similar to each other, whereas *C. convexus* and *C. graecus* are different from them but similar to one another (26).

Species belonging to tribe Carabini were analyzed in terms of female genitalia, and it is found that there is no distinctive feature on generic level. *Carabus genus, C. chevrolati* and *C. coriaceus* have triangular hemisternite and are different from *C. convexus* and *C. graecus* that their hemisternites are square-shaped. All species have setae in distal parts of hemisternites except for *C. coriaceus*. Basal segment of styli are triangular in all species but it is circular in *C. coriaceus*. Apical segment of styli in *C. chevrolati* is in the shape of sickle. In other species it is cylindrical. *C. chevrolati* and *C. graecus* have two setae in apical of apical segment of styli. It is only one in *C. coriaceus and C. convexus*. In *Carabus genus*, it is thought that the shape of hemisternites, distribution of setae, the shape of basal and apical segment of styli, the number of setae in apical segments are the species' distinctive features.

In tribe Platynini, *Agonum* and *Anchomenus* genera differ from Zabrini in terms of having equal size of parameres. Right paramere in *Calathus, Dolichus* and *Zabrus* genera is extended. In genus *Calathus* the basal area is wide. Furthermore in *Dolichus* genus there is no hook in right paramere apical. But in *Zabrus* genus, there is a hook in same region. *Agonum, Calathus* and *Dolichus* genera have spines in apical segment of styli. Anchomenus and *Zabrus* genera have setae; thus, they are different. The existence of setae in *Zabrus* genus is also reported by Ortuno [23].

In *Agonum* genus, *A. viridicupreum* has spines across inner sac armature. *A. marginatum* has tooth in addition to spines. It is found that the structure and distribution of inner sac armatures vary among species. In this genus, it has been concluded that the structures, positions and number of setae in basal segment of styli can be seen as the general distinctive features in genus level.

As Jeannel [10] stated, *Anchomenus* genus differs from *Agonum* genus only in terms of having wider apical plate in male genitalia. Additionally, the spines in parameres are also feature of male genitalia. Since only one species is analyzed, the discussion of male and female genitalia for *Anchomenus* genus cannot be provided.

In *Calathus* genus, apical plate in *C. fuscipes* is curved ventrally, in *C. melanocephalus* it is widened both dorso-ventrally and laterally. In both species, an inner sac armature is formed by spines but there are differences in terms of the positions of spines. In *C. fuscipes*, the right paramere is narrowing in apical and hook is very evident. In *C. melanocephalus*, apical is wide and hook is very small. In *C. melanocephalus,* hemisternites are in shape of square and it is triangular in *C. fuscipes*. Setae are in the outer part and numerous in *C. fuscipes*. They are in distal part (a total of five setae) in *C. melanocephalus*. Apical segment of styli is in the shape of sickle in *C. melanocephalus*. There are two big spines in the outer margin and one seta in inner margin apical. Apical segment of styli is triangle, in *C. fuscipes*. There are big spines on lateral regions and is one seta in medio-dorsal part. The structure of aedeagus, the shape of right paramere apical and the distribution of spines in inner sac are the distinctive features of male genitalia on species level. The shape of hemisternites and the position of setae on it as well as the distribution of spines in apical segment of styli are the distinguishing factors of female genitalia.

For *Dolichus* genus, the distinctive features of male genitalia are that right paramere and aedeagus have nearly the same length and that there is no hook in apical. Distinguishing factors of female genitalia are that hemisternites have no setae and that there are big spines in apical segment of styli. In *D. halensis*, apical plate in ventral part is curved ventrally, as stated by Jeannel [10]. But it is not two-layered in dorsal part.

In *Zabrus* genus, male genitalia inner sac is covered by spines from postero-medial to apical in *Z. spinipes*. In *Z. corpulentus* it forms an oval cluster from distal to apical. In *Z. tenebrioides,* there is a spine cluster in the shape of triangular in apical in addition to the spine cluster in medial. The hook in

right paramere apical is small in *Z. spinipes* and *Z. tenebrioides*. This hook is bigger in *Z. corpulentus*. Hemisternites are triangular in *Z. corpulentus,* elongated and oval in *Z. spinipes,* quadrangle in *Z. tenebrioides*. Apical segment of styli is wide in apical in *Z. corpulentus*. It is wide in basal in *Z. spinipes*. In *Z. tenebrioides* basal and apical parts have the same width. All species have apical segment of styli with two setae. The distinguishing factors for male genitalia are the structure of right paramere and the distribution of spines in inner sac. The shape of hemisternites and the structure of apical segment of styli seem to be the distinguishing features for female genitalia.

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