



# Comparative Study on the Nymphal Stages of Two *Sphingonotus* Species (Acrididae: Oedipodinae)

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## ABSTRACT

Nymphal stages of two species of genus *Sphingonotus* Fieber viz. *S. savignyi* Saussure and *S. rubescens* (Walker) were studied exclusively from Sindh during the 2014-2016. Both species passed through six instars larvae. Emergence of larval instars in both species was started from the month of July just after monsoon rainfall, whereas, *S. savignyi* immature emerges earlier than *S. rubescens* and increases their density rapidly in open grounds and rocky areas. Immature stages were found exclusively geophiles in nature and usually giving two generation in a year but occasionally third generation of diapauses eggs of *S. savignyi* hatched in winter. A comparative key for immature stages of both species was constructed. Almost all immature stages occupied similar habitats as that of adults and their appropriate stages were differentiated through combination of characters i.e. coloration, morphometry, pronotum, femur bands, wing pad position and appearance of bands.

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## Authors' Contribution

RS and MSW conceived and designed the work and revised the manuscript FS performed the experiments, analyzed the data and wrote the manuscript.

## Key words

Nymph, Genus, Instar, Diapause, Geophiles, Habitat, Morphometry.

## INTRODUCTION

Subfamily Oedipodinae consists of notorious agricultural pest species. Their incidences are noted from all over Pakistan and particularly recorded from various localities of Sindh by Ahmed (1980), Wagan (1990), Baloch (2000) and Bughio (2012). Oedipodinae species are mostly polyphagous in nature and feed on wide range of food plants (Otte and Joern, 1976). Genus *Sphingonotus* is widely distributed in tropical and subtropical regions of the world (Mistchenko, 1936; Bughio *et al.*, 2011). They have higher survival tendency to combat harsh climatic conditions and are widely distributed in rocky and sandy areas with sparse traces of wild vegetation. The immature stages and adults of their insects also pose constant threat to main field crops near rain fed and irrigated areas of Sindh. Nymphal stages are more epidemic than adults; they have no functional wings to fly and all the time they are eating vigorously. They feed on blades of short grasses and seedlings of crops and rapidly consume large biomass. Higher temperature increases the rate of hatching and population density of these miniatures in the field. With reference of our previous paper (Soomro *et al.*, 2015) *Sphingonotus* species undergoes short or long winter

diapause in egg stage and hatching usually observed from spring to mid of July while, maximum emergence was noted in the month of August. Parihar (1987) reported that *Sphingonotus* species usually undergoes two to three generations in a year. The number of instars are variable in Oedipodinae species (Pfadt, 1988; Luong and Balanca, 1999). Identification of early stages of hoppers in the field is not an easy task, particularly in closely related species younger stages are more identical than adults. The reproductive areas of grasshoppers are found in moist gravel plain near cultivated field or wild vegetation of rain fed areas (Parihar and Pal, 1981).

There was no detailed work available on immature stages of Oedipodinae of this region except for some fragmentary work on biology by Baloch (1978). The present study is aimed at studying taxonomic characters of immature stages and to prepare identification key that would be useful for identification of pest species at any stage of their infestation. This would help in initiating control measure without disturbing eco-friendly fauna of insects.

## MATERIALS AND METHODS

### Sampling procedure and preservation

Various nymphal stages of genus *Sphingonotus* were captured from different districts of Sindh during the year 2014-2016. The immature stages of *Sphingonotus* were collected from wide varieties of vegetations such

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as agricultural crops, vegetables, grasses and wild vegetations. According to Luong and Balanca (1999) and Riffat and Wagan (2015), the focus was to collect first nymphal instars from field to identify their hatching time and exact number of nymphal stages. Collection was made first during their active period from 9.00 a.m. to 11.00 a.m. and second collection was made two to three hours before sun set to get maximum collection in short duration.

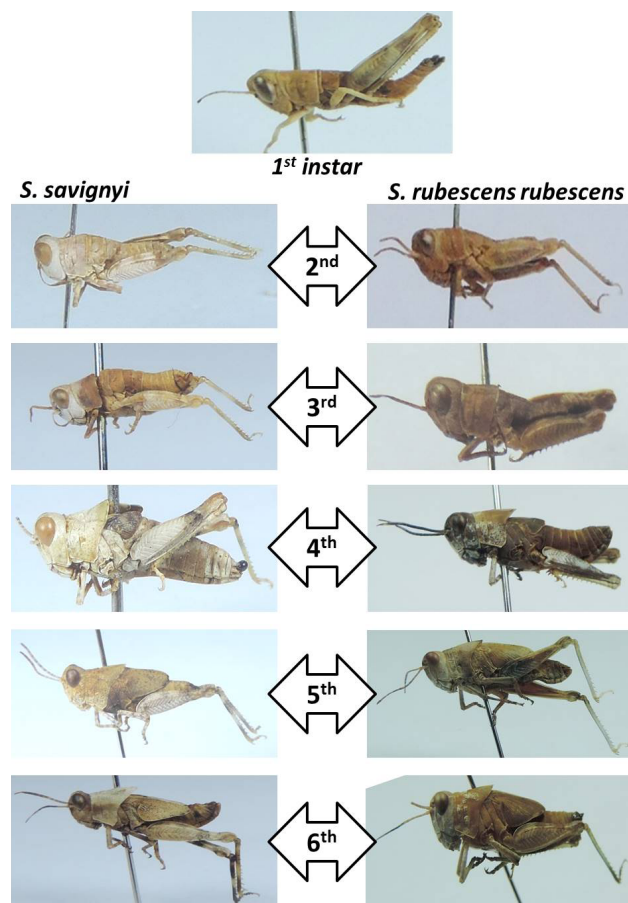


Fig. 1. Lateral view of different nymphal instars in genus *Sphingonotus*.

Specimens were captured through traditional insect net (8.60 cm in length and 55.40 cm in length) but more frequently by hand picking. It is important to retain them in condition near to live, for which the methods of Northcroft (1967), Brusven (1969) and Riffat *et al.* (2012) with slight modifications were adopted. For the illustrations, methodology of Guibord (1969) and Riffat and Wagan (2010) was followed.

#### Rearing techniques

For rearing first instars were immediately transferred

into small cage and fed on favorite food plants. During collection in the field cages were covered with moist muslin thin cloth. All nymphal stages were kept in different jars and cages for rearing. Earlier, immature stages (I-III) were shifted into 1 kg jam jars (11.5 cm diameter and 16.5 cm deep) while advance stages (IV-VI) were shifted to cages with wooden frame and metal gauge walls (47cm height and 32.5 cm width and length). Hygienic condition was maintained on daily basis and fecal material and dry food plants were removed daily. Cages and jars were kept under laboratory conditions (25°25' 0.7248" N, 68° 16' 27.5052" E) where temperature ranged between 28±2°C to 41±2°C and 26-71% relative humidity.

## RESULTS

#### Key for the Species of Immature Sphingonotus

1. Femur robust, wide, apical half with single grey band, tibia with pair of black ringlets alternatively arranged with white ringlets ..... *Sphingonotus savignyi*  
- Femur less-robust, narrow, apical half without band, tibia largely grey or blue in color ..... *S. rubescens rubescens*

#### Generalize key for the separation of nymphal instars of Sphingonotus species

1. Tegmina and Wing pads when presented directed downwards, not overlapping each other ..... 2  
- Tegmina and wing pads turned backwards, wing pads overlapping tegminal pads ..... 5
2. Tegmina and wing pads rudiments not developed .....  
..... **First instar**  
- Tegmina and wing pads rudiments developed ..... 3
3. Tegmina and wing pads rudiments appeared with rounded margin, directed downwards, not overlapping each other, antenna with 9-17 segments ..... **Second instar**  
- Tegmina and wing pads rudiments with angular margin, directed upwards, wing pad overlapping tegminal pad, antenna with 14-21 segments ..... 4
4. Wing pads triangular, directed downwards veination simple, external genitalia weakly marked ... **Third instar**  
- Wing pads leaf like, turned upwards cover dorsum up to one or one and half abdominal segment, veination complex, external genitalia well marked ..... **Fourth instars**
5. External genitalia thin, not much extended from supra-anal plate, Wing pads cover dorsum extended up to third or middle of forth abdominal segment, narrow, thin veination, antenna with 17 to more segments ..... **Fifth instar**  
- External genitalia thick, much extended from supra-anal plate, wing pads cover dorsum extended up to fifth or middle of sixth abdominal segments, antenna with 19 to more segments ..... **Sixth instar**

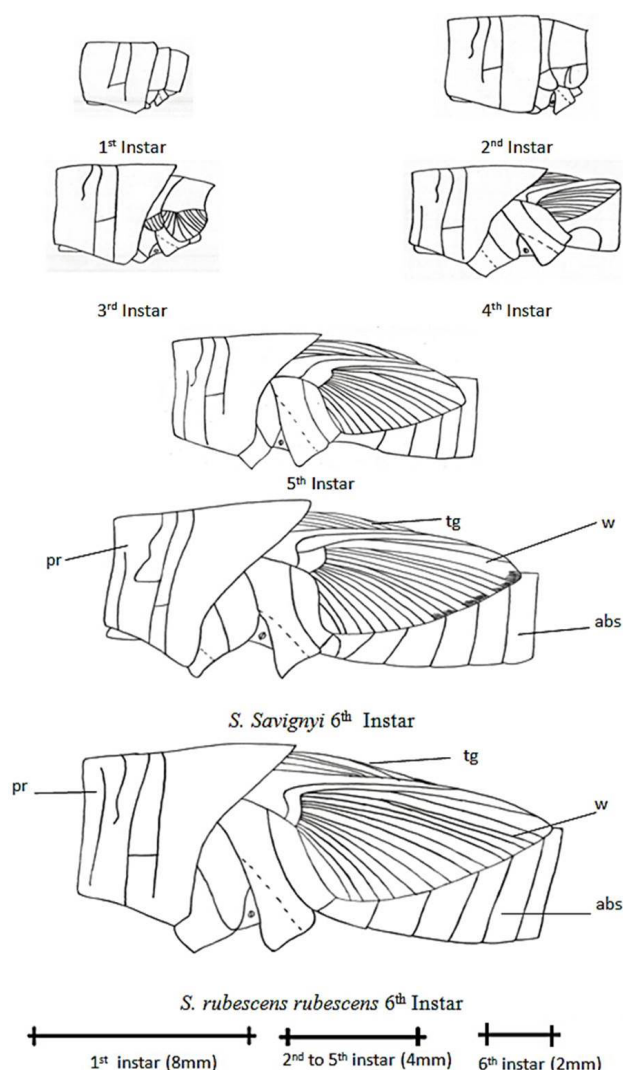


Fig. 2. Lateral view of wing pads in genus *Sphingonotus*. abs, abdominal segments; pr, pronotum; tg, tegmina; w, wing pad.

#### Morphological description of various nymphal stages of genus *Sphingonotus savignyi*

##### First instar

Body coloration light golden brown, largely whitish, without hairs, antenna filliform composed of 10-12 segments, integument smooth without spots, fastigium of vertex parallel. Pronotum cross by two sulci, median carina weakly present throughout, prozona as long as metazona, posterior margin invaginated towards anterior. Tegmina and wing pad not appeared.

##### Second instar

Body coloration become largely white towards dorsal and lateral sides, ventral side light golden brown, antennae

filliform with 13 to 15 segments in both sexes, light and dark ringlet appeared. Pronotum having third transverse sulci lightly appeared, prozona about one and half longer than metazona. Tegmina and wing pad lightly appeared laterally with rounded thick margin directed downwards. Hind femur thick, dorsally whitish, apical end with complete light grey band, ventral side widely yellow.

##### Third instar

Antennae with 16 to 18 segments in both sexes, pale and brown ringlet distinct, fastigium of vertex vase shape. Pronotum longer than head, prozona slightly constructed longer than metazona. Tegmina slightly curved backwards with rounded margin, wing pad having thick triangular apex directed downwards. Femur largely wide at base thin towards apex tibia with pair of black ringlet alternatively arranged with whitish ringlets.

##### Fourth instar

Antennae filliform with 18 to 20 segments in both sex, fastigium of vertex having minute punchers. Pronotum saddle shaped, integument patchy towards prozona, wing pads overlaps tegmina cover dorsum up to margin of first abdominal segment, leaf like in shape.

##### Fifth instar

Antennae with variable segments in ♀ 21 to 22 and ♂ instar 20 to 21, fastigium of vertex vase shape wide at base and narrow towards apex, wing pads reached 3 to 4 ½ abdominal segment, veins sparsely arranged having randomly scattered minute black spots.

##### Sixth instar

Body coloration light golden brown or largely whitish, antennae with 23-24 segments in ♀ and 22-23 segments in ♂. Pronotum with distinct median carina, metazona longer than prozona. Wing pads up to 5 or 6 abdominal segment in ♀ and 5 to 7 abdominal segment in ♂, apical area with traces of black transverse band. Hind femur broad thick towards basal joint, median carinulae sharp, ventral side largely dark brown, tibia with pair of black ringlets alternatively arranged with white ringlets.

#### Morphological description of various nymphal stages of genus *Sphingonotus rubescens rubescens*

##### First instar

Body coloration light golden brown in color or largely whitish, antennae filliform with 10 to 11 segments, other features more liked with first instar of *S. savignyi*.

##### Second instar

Body coloration become radish brown tinged with

grey color from head to abdomen, antennae with 13 to 15 segments in both sexes. Pronotum with smooth integument, apical margin flat, prozona narrow, metazona wide slightly raised towards median carinae, posterior margin flat. Wing pads lightly appeared rounded directed downwards. Hind femur thin, chevron dorsally dark brown ventrally pale, bands not appeared.

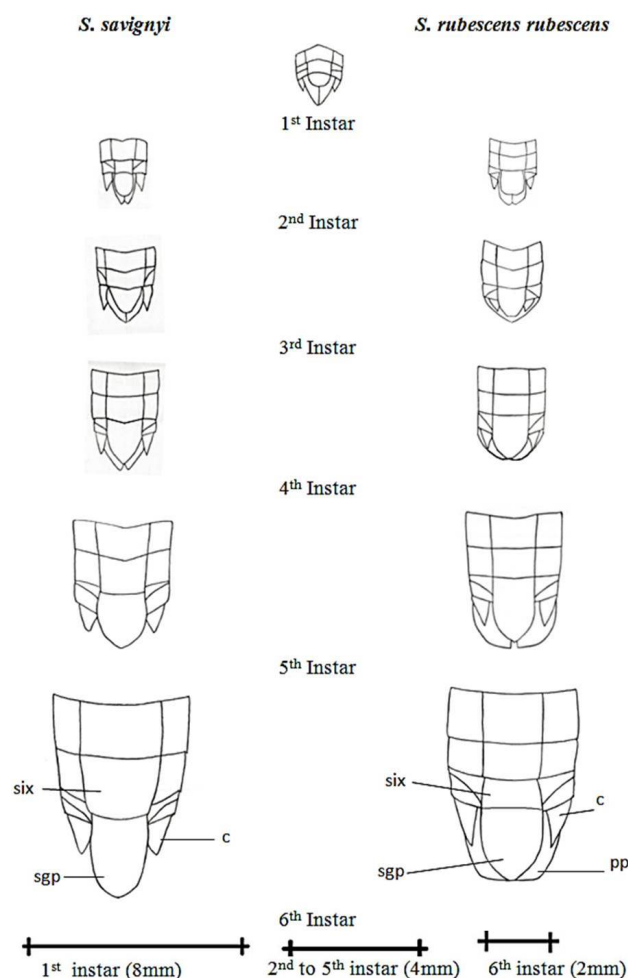


Fig. 3. Male ventral view of posterior abdominal sternites of different immature stages in genus *Spbingonotus*. c, cerci; pp, paraproct; sgp, sub-genital plate; six, sternite nine.

#### Third instar

Body coloration same as previous instar, antennae filliform with 16 to 17 segments in both sex, basal segment elongated, apical segment short thin, grey and brown ringlets present throughout, fastigium of vertex vase shape, flat, with scattered minute brown spots, fastigial foveolae narrow lightly visible. Pronotum with slightly raised median carinae towards posterior margin, crossed

by three sulci. Hind femur narrow, apical area with two light grey incomplete bands towards upper half, tibia with apical grey ringlet.

#### Fourth instar

Antennae with 18 to 19 segments in ♂ and 19 to 20 segments in ♀, Eye with oval dark brown spot appeared toward vertex. Prozona cross by three transverse sulci, fourth sulci slightly indicated from lateral side, apical margin slightly produced in angular manner, wing pads covered dorsum up to first abdominal segment, leaf like, with thick intercalary veins. Basal joint of tibia with black spot, inner side grey or bluish in color

#### Fifth instar

Body coloration light radish brown, antennae with 20-21 segments in ♂ and 20-22 segments in ♀, antennae as long as head and pronotum, segments evenly elongated and thin. Metazona smooth longer than prozona, median carinae distinct raised towards metazona only.

#### Sixth instar

Antennae with 22 to 24 segments in ♂ and 23-25 segments in ♀, with distinct light brown ringlets, fastigium of vertex vase shaped, apex flat slightly compressed, minute black spots and hairs sparsely present towards vertex. Pronotum twice longer than head, metazona twice longer than prozona, rough, constructed, third transverse sulci invaginated in v-shape towards median carina, posterior margin with regular brown spots, obtusely angular, wing pads up to 6 ½ abdominal segments in ♂ and 5 to 6 abdominal segments in ♀. Hind femur with two incomplete grey bands towards basal area, tibia with bluish coloration towards inner side.

#### Sex differentiation

The sex and nymphal stages are identified on the basis morphological changes of the external genitalia (Fig. 3). In the *Spbingonotus* species appendages appeared on eight and ninth sternites not differentiated in to male and female sex. Pair of paraproct more than two third longer and wider than ninth sternite. At the second instar of *S. savignyi* male ninth sternite bear clear D-shape projection of sub-genital plate covered by paraprocts. The third instar bears a slightly longer conical sub-genital still shorter than paraprocts. At the fourth stage it becomes more elongated reached up to the tip of paraprocts. At the fifth instar it become thick and darkens in color. At the sixth and final stage sub-genital plate become elongated with conical apex, outstrips the abdomen tip. While in *S. rubescens rubescens* second instar male having slightly wider sub-genital plate with flattened apex covered by paraprocts (Fig. 4).



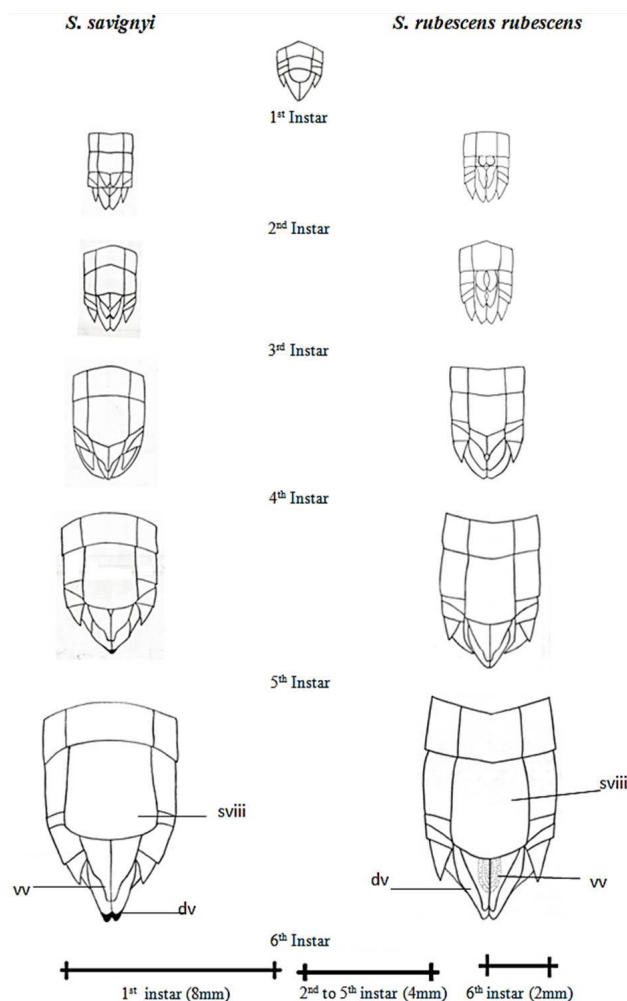


Fig. 4. Female ventral view of posterior abdominal sternites of different immature stages in genus *Sphingonotus*. dv, dorsal ovipositor valve; sviii, sternite eight; vv, ventral ovipositor valve.

While second and third instar are identical except tip sub-genital plate have rounded apex. At the fifth instar sub-genital plate not surpasses the paraprocts tip. At the sixth instar sub-genital plate thick elongated as long as abdomen tip with conical tip possess minute hairs. The female instars are identified through size and shape of the ventral and dorsal ovipositor valves. Second instar of *S. savignyi* shows triangular valves touch's the margin of ninth sternite, slightly shorter triangular dorsal vales projecting from apical tip of ninth sternite. At the third instar apex of eight sternite indented ventral valve touches lower half of dorsal valve. Dorsal valve leaf shape indented in center making space with pointed apices. At the fourth instar eight sternite elongated with rounded margin, ventral valves rhombus shape not exceed from dorsal valves. At

the fifth instar ventral and dorsal valve extended beyond the paraprocts while they become thick and apices of dorsal vae become darker and pointed at the sixth instar. However, second instars of *S. rubescens rubescens* dorsal valves are elongated leaf like and ventral vales are rounded and shorter than dorsal valve. At the third instar ventral valve elongated indented in middle completely overlapped the ninth sternite, dorsal valves are leaf like as long as ventral valves with pointed apex. At fourth instar margin of eight sternite become angular bear ventral valves wide at base and pointed at apices and dorsal valves not extended from paraproct. Whereas, they do at fifth and definitely at the sixth instar. Ventral valves possess perforated integument with thin pointed apices near to touch the thick dorsal valves. The sex ratio in the instars of both species was quite in the favor of advance stages and particularly for the females (Fig. 5).

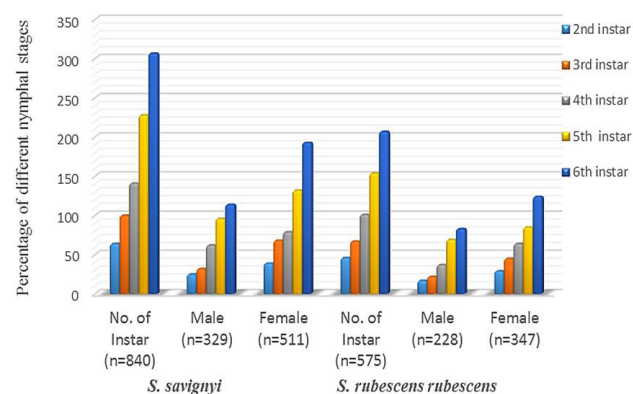


Fig. 5. Sex ratio of different nymphal stages in genus *Sphingonotus*.

### Morphometry

Morphometric means of the various instars of genus *Sphingonotus* shows that there was significant difference in the measurement of different body parameters except first instar of both species were only varying in the number of antennal segments only (Table I). However, measurement of body parameters of second instar of *S. savignyi* male and female shows significant difference in the length femur and total body length. The third instar male was considerably smaller in the length of pronotum and total body length from female instar. As for as fourth instar is concerned female possess more number of antennal segment than that of male along with greater length of femora and body as well. Apart from the other parameters fifth and sixth instar was also shows remarkable difference in the length of tegmina and wing pads. Total body length of female instars was usually longer than male instars.

Table I.- Morphometry of different nymphal stages in genus *Sphingonotus* (n=15 each).

Parameters (mm)	1 <sup>st</sup> instar		2 <sup>nd</sup> instar		3 <sup>rd</sup> instar		4 <sup>th</sup> instar		5 <sup>th</sup> instar		6 <sup>th</sup> instar	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
<i>S. savignyi</i>												
Antennal segment	10.86±0.21	13.66±0.21	14.13±0.19	16.46±0.13	16.53±0.13	18.46±0.13	19.40±0.13	20.53±0.12	21.26±0.11	23.06±0.20	23.46±0.25	
Antennal length	1.68±0.04	2.11±0.07	2.86±0.07	3.19±0.06	3.96±0.07	4.02±0.04	4.38±0.06	5.96±0.06	5.75±0.11	7.37±0.17	7.81±0.17	
Pronotal length	0.74±0.02	0.94±0.02	1.19±0.03	1.77±0.06	2.27±0.06	2.29±0.05	3.25±0.05	3.19±0.05	4.31±0.05	4.05±0.06	5.07±0.05	
Tegminal length	-	0.59±0.02	0.71±0.02	0.83±0.03	0.98±0.03	2.41±0.04	2.73±0.04	5.16±0.05	6.19±0.08	6.90±0.11	8.07±0.07	
Wing pad length	-	0.71±0.02	0.86±0.02	1.02±0.02	1.21±0.04	2.15±0.03	2.40±0.05	4.90±0.09	5.94±0.10	5.97±0.09	7.76±0.05	
Femoral length	2.74±0.03	2.92±0.06	4.05±0.07	4.19±0.04	4.84±0.06	4.97±0.07	6.58±0.12	7.02±0.11	8.07±0.08	8.17±0.08	9.11±0.07	
Total body length	4.27±0.09	5.71±0.07	6.69±0.09	7.54±0.13	9.54±0.13	9.56±0.12	10.96±0.11	12.66±0.10	14.22±0.21	16.79±0.09	18.15±0.23	
<i>S. rubescensrubescens</i>												
Antennal segment	10.11±0.13	13.73±0.20	14.06±0.18	16.33±0.12	16.66±0.12	18.53±0.13	19.53±0.13	20.53±0.13	21.26±0.18	23.00±0.21	23.86±0.19	
Antennal length	1.20±0.06	1.58±0.04	1.72±0.05	3.03±0.03	3.14±0.05	4.15±0.04	4.91±0.05	5.78±0.06	6.09±0.06	6.63±0.11	6.87±0.09	
Pronotal length	0.88±0.04	1.02±0.03	1.12±0.03	1.34±0.03	2.06±0.04	2.58±0.05	3.24±0.05	3.61±0.04	4.43±0.06	4.48±0.07	5.35±0.06	
Tegminal length	-	0.59±0.01	0.66±0.01	0.90±0.03	1.02±0.02	2.46±0.03	3.10±0.03	5.03±0.05	6.61±0.05	6.84±0.05	7.75±0.06	
Wing pad length	-	0.68±0.01	0.73±0.02	1.10±0.02	1.22±0.03	1.99±0.05	2.73±0.02	4.52±0.04	6.13±0.04	6.04±0.05	6.83±0.05	
Femoral length	2.55±0.03	2.84±0.06	3.52±0.06	4.10±0.04	4.80±0.04	6.56±0.05	6.97±0.07	7.08±0.08	8.14±0.05	8.07±0.06	8.91±0.0	
Total body length	3.87±0.07	5.15±0.09	6.02±0.07	7.85±0.06	8.91±0.07	10.74±0.08	12.13±0.10	13.34±0.08	14.86±0.06	14.85±0.05	16.20±0.06	

However, second and third instar of *S. rubescens rubescens* females were significantly longer in the total body length than that of males. At the fourth stage female possess more number of antennal segments as well as length of femur and wing pad were considerably longer than male. As for as fifth and sixth instar is concerned length of pronotum was significantly longer in female instar as compared to male.

## DISCUSSION

There was no any significant work on the nymphal stages of Oedipodinae species was carried out from subcontinent, particularly Sindh, Pakistan. Except Riffat and Wagan (2010) on subfamily Hemiacridinae they mainly relied on position of wing pads for the separation of nymphal instar. While, Chesler (1938) identified the nymphal stages on the basis of the length of body, hind femur, antenna and wing pads. Similarly, Albrecht (1955) preferred the position of tegmina and wing pads only for the determination of instar stage. However, Guibord (1969) and Crozier (1977) relied on antennal segments, external genitalia and wing pads for determination of the stage of various instars in Oedipodinae species. In the present investigation we use combination of characters for the determination of various developmental stages. However, wing pad position, femur length and antennal segments were found more reliable. But for the identification of sex of instar modification in the external genitalia is more authorized. Moreover, for the identification of the first instar we consider body coloration along with antennal segments in closely related species. The result of present investigation shows that there was significant difference in the morphometry of different developmental stages as well as in the male and female instars of both species. Parihar (1987) worked on immature stages of few species of Acrididae from Rajasthan India he, ambiguously describe five to six nymphal stages in *S. rubescens rubescens*. However, during this study we have confirmed the six nymphal stages in the both sex of this species as well as in the *S. savignyi*. The hopper stages were also confirmed through laboratory rearing. Moreover, sex ratio was exclusively in the favor of female instars. Identification keys, detailed description and illustration are being presented here for the first time. The results obtained are important for better understanding about economic importance of this genus. This study also helps out to initiate control measures at appropriate time.

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## Statement of conflict of interest

The authors have declared no conflict of interest.

## REFERENCES

- Ahmed, F.U., 1980. *Survey of grasshopper in arid and semiarid region of Pakistan*. Final Report, PL-480, No. P.K-ARS-20 (FG-Pa-212), pp. 1-500.
- Albrecht, F.O., 1955. La Densite des population et la croissance chez *Schistocerca gregaria* (Forsk) et *Nomadacris septemfasciata* (Serv), la mue d Adjustment. *J. Agric. Trop. Bot. Applic.*, **2**: 109-192. <https://doi.org/10.3406/jatba.1955.2212>
- Baloch, A.A., 1978. Some studies on the nymphs of *Aiolopus thalassinus* F. *Yet. Tek. BitKor. Bull.*, **2**: 115-123.
- Baloch, N., 2000. *Survey and taxonomy of grasshoppers belonging to family Acrididae (Orthoptera) of Punjab*. Ph.D. thesis, University of Sindh, Jamshoro, Sindh, Pakistan.
- Brusven, M.A., 1967. Differentiation, ecology and distribution of immature slant faced grasshoppers (Acridinae) in Kansas. *Tech. Bull. Kansas Agric. Exp. Stat.*, **149**: 1-59.
- Bughio, B.A., Wagan, M.S. and Riffat, S., 2011. A new species of genus *Sphingonotus* (Oedipodinae: Acrididae: Orthoptera) from Pakistan. *Sindh Univ. Res. J. (Sci. Ser.)*, **43**: 195-198.
- Bughio, B.A., 2012. *Taxonomy of the band winged grasshoppers (Oedipodinae: Acrididae: Acridoidea: Orthoptera) of Pakistan*. Ph.D. thesis, University of Sindh Jamshoro, Sindh, Pakistan.
- Chesler, J., 1938. Observation on the biology of some South African Acrididae. *Entomol. Soc. Lond.*, **87**: 313-351. <https://doi.org/10.1111/j.1365-2311.1938.tb00720.x>
- Crozier, L.M., 1977. *Identification of the immature stages of grasshoppers (Acrididae) of Quebec*. Master's thesis, McGill University, Montreal, Canada.
- Guibord, M.O.C., 1969. *A study of the immature stages of some grasshoppers (Orthoptera: Acridoidea) in Quebec*. Master's thesis, McGill University, Montreal, Canada.
- Luong, S.M.H. and Balanca, G., 1999. *Bryophyma debillis* (Karsch, 1986) Nymphal instars (Orthoptera: Acrididae: Cyrtacanthacridinae). *J. Orthop. Res.*, **8**: 110-118. <https://doi.org/10.2307/3503434>

- Mischehnko, L.L., 1936. Revision of *Paelearctic* species of the genus *Sphingonotus* Fieber (Orthoptera: Acridoidea). *Eos. Rev. Esp. Ent.*, **12**: 65-282.
- Northcroft, M.A., 1967. *The immature stages of Phaulacri diummarginale (Walker) and Sigaust campestris (Hutton) (Orthoptera: Acrididae)*. Master's thesis, University of Canterbury, New Zealand.
- Parihar, D.R. and Pal, S.K., 1981. Development of arid zone and its ecological effects in their insect fauna. In: *Seminar on development of Desert and Drought Prone-Areas*, Vol. I. HCM State Institute of Public Administration, India.
- Parihar, D.R., 1987. *Grasshopper pests of grazing land vegetation and their management in Indian desert*. Technical Report: Central Arid Zone Research Institute, Jodhpur, India, p. 1-56.
- Pfadt, R.E., 1988. *Field guide to common western grasshoppers*, 2<sup>nd</sup> ed. Wyoming Agricultural Experiment Station Bulletin 912. Available at: <http://www.uwyo.edu/entomology/grasshoppers/fieldgde.htm> (accessed on 14 March, 2019).
- Otte, D. and Joern, A., 1976. On feeding patterns in desert grasshoppers and the evolution of specialized diet. *Proc. Acad. Nat. Sci. Philadelphia*, **128**: 89-126.
- Riffat, S. and Wagan, M.S., 2009. Comparative study on the morphology of egg pods, egg development and hatching of three *Hieroglyphus* species (Acrididae: Orthoptera). *Pakistan J. Zool.*, **41**: 143-148.
- Riffat, S. and Wagan, M.S., 2010. Comparative study on the immature stages of three *Hieroglyphus* species (Acrididae: Orthoptera) from Pakistan. *Pakistan J. Zool.*, **42**: 809-816.
- Riffat, S., Bughio, B.A., Waheed, A.P. and Haji, K., 2012. Studies on the immature stages of *Oxya velox* (Fabricius) a rice grasshopper from district Jamshoro. *FUUAST J. Biol.*, **2**: 57-62.
- Riffat, S. and Wagan, M.S., 2015. *Grasshoppers and locusts of Pakistan*. Higher Education Commission, Government of Pakistan, Islamabad, pp. 1-180.
- Soomro, F., Riffat, S., Wagan, M.S., Abbasi, A.R. and Solangi, B.K., 2015. Studies on immature stages of *Aiolopus thalassinus thalassinus* (Fabricius) (Oedipodinae: Acrididae: Orthoptera). *Sindh. Univ. Res. J. (Sci. Ser.)*, **47**: 267-274.
- Wagan, M.S., 1990. *Grasshopper (Acrididae) of Sindh*. Pakistan Science Foundation Islamabad, Pakistan, pp. 1-110.