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ENTOMON

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Note from the Chief Editor

Dear Entomologists, Scientists, Members, Academicians and Stake holders,

The Association for Advancement of Entomology (AAE) has been successful in publication of ENTOMON as per schedule. ENTOMON has gained wide acceptance among the members, readers, peer reviewers and other stakeholders.

After a long gap, ENTOMON regained the recognition of the National Academy of Agricultural Sciences (NAAS) in 2015. The NAAS rating of the journal improved steadily from 4.12 in 2015, to 4.42 in 2016 and to 4.69 in 2021.

The University Grants Commission, New Delhi has recognized ENTOMON by including the journal in the official list of scientific journals (UGC-CARE List Group I).

ENTOMON is included in CABI's full text repository. By including the scientific papers in the repository it is ensured that the research documents can be easily located by scientists and professionals throughout the world, both now and in the future. This would also be a valuable contribution of the journal for global users of CAB Direct and other related databases.

Entomon is also partnering with EBSCO for dissemination of papers published in the journal.

The Association follows the guidelines of the Committee on Publication Ethics (COPE) and ENTOMON has now joined – COPE, formally as a member.

Review of ENTOMON for inclusion in SCOPUS, Elsevier's abstract and citation database, has been completed successfully and indexing of the journal will begin shortly. The indefatigable efforts and hard work of the Secretary Dr. K. D. Prathapan in this endeavour is highly appreciated. Our relentless and steadfastness in striving for excellence has started yielding fruits. This is a moment to cherish and cheer our untiring efforts. Let us be proud of ourselves, who are rendering valuable service, purely on voluntary basis.

The service of our web site Manager Professor K. Madhavan Nair is gratefully acknowledged. The management and staff of SB Press, Thiruvananthapuram has been highly helpful in completing the printing of the journal as per schedule.

We are thankful to the National Academy of Agricultural Sciences (NAAS), UGC-CARE, CABI, the Committee on Publication Ethics, EBSCO and Scopus.

The continued support of peer reviewers, institutions and the universities, and contributors is duly acknowledged.

Presenting the first issue of ENTOMON 2021, 46 - 1.

Stay safe; follow COVID-19 Guidelines & Advisory.

Regards

Dr M.S. Palaniswami
Chief Editor

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SHORT COMMUNICATION

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On *Triteleia* Kieffer (Hymenoptera: Scelionidae) from India, with descriptions of two new species

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ABSTRACT: *Triteleia* Kieffer is a little known scelionid genus. Two species, viz., *T. flagellata* Abhilash and Rajmohana sp. nov. and *T. robusta* Abhilash and Rajmohana sp. nov. are described as new to science. Further *T. bengalensis* (Saraswat), the only species known under *Triteleia* in India, is redescribed and a dichotomous key to the three Indian species of *Triteleia* is provided.

KEY WORDS: Scelionid genus, *Triteleia flagellata, T. robusta, T. bengalensis, key*

INTRODUCTION

The genus *Triteleia* (Hymenoptera: Scelionidae) was erected by Kieffer (1906) based on the type species *Triteleia punctaticeps* Kieffer and are among the largest and elongate members of the family (Masner, 1976). This genus is very much similar to *Macroteleia* Westwood and *Habroteleia* Kieffer in size and body shape. But in *Macroteleia* Westwood, T6 in females is laterally compressed like a wedge and *Habroteleia* Kieffer lacks a postmarginal vein in their forewings. T6 in females is never compressed laterally, instead flat and triangular in *Triteleia*. In males, the postero-lateral corners of the apical tergite or tergite 7, are bispinose or at least pointed (Masner, 1976; Chen *et al*., 2013).

Of the 35 species reported worldwide, only 4 spp., are from the Oriental region viz., *Triteleia bengalensis* (Saraswat, 1978), *T. ladona* Kozlov and Le, 1995, *T. lagunica* Kozlov and Le, 1995 and *T. velicana* Kozlov and Le, 1995 (Cora and Johnson, 2017). In India, the genus is represented by a single species, *Triteleia bengalensis* (Saraswat, 1978) and the species was transferred from *Alloteleia* Kieffer (Talamas *et al*., 2017). Of the two species earlier described as *Triteleia* by Sharma (1981), *T. vindhiensis* Sharma is now *Baryconus vindhiensis* (Sharma) by generic transfer and *T. kotturensis* Sharma, has been synonymised under *Habroteleia flavipes* Kieffer (Chen *et al.,* 2018). Two species, *T. flagellata* Abhilash and Rajmohana sp. nov. and *T. robusta* Abhilash and Rajmohana sp. nov. are described here, along with a key to the Indian species. Data on hosts and biology of these egg parasitoids are scanty. However Popovici *et al.* (2011) reared *Triteleia peyerimhoffi* from the tettigonid (Orthoptera) eggs from Romania.

MATERIALS AND METHODS

The present study is based on specimens collected through Malaise traps, Yellow pan traps, and Sweep net from various localities in Kerala. Specimens

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were studied under a Leica M 205A stereomicroscope. Images were taken using Leica DFC 500 camera and processed using extended focus montage LAS software. The holotypes and other material examined are deposited at the Western Ghat Regional Centre, Zoological Survey of India, Kozhikode, Kerala (ZSI, WGRC), one specimen of *T. bengalensis* is deposited in ZSI, Kolkata (ZSIK). Terminology followed is based on Miko *et al.* (2007).

Abbreviations used

A1- A12- Antennal segments; EH- Eye height; HL- Head length; HW- Head width; IOS-Inter Ocellar length; L- Length; LOL- Lateral ocellar length; *m*- Marginal vein; MW- Mesosoma width; ML- Mesosoma length; OOL- Ocellocular length; OD- Ocellar diameter; *pm*- Post marginal vein; POL- Posterior ocellar length; SSS- Scutoscutellar sulcus; *stg*- Stigmal vein; T1- T2-Tergites of metasoma; W- Width.

RESULTS AND DISCUSSION

Key to species of the Genus *Triteleia* Kieffer from India (based on females)

1. Metasoma narrow, >2 × longer than head and mesosoma combined; T1-T5 longer than wide; T2 and T3 longitudinally striate, with areolate rugulae in interstices; A3 longer or as long as A2 2

- Metasoma <1.5 × combined length of head and mesosoma; T1-T5 transverse; T2 and T3 densely foveolate throughout (Figs. 17, 21); A3 not as long as A2 (Fig. 18) .....
... *T. robusta* Abhilash and Rajmohana sp. nov.

2. Setigerous foveae on frons scattered and small, separated by more than their own diameter; A3 elongate, >1.3 × longer than A2 and nearly 6 × as long as wide; T1 without a distinct anterior dorsal horn ……
T. flagellata Abhilash and Rajmohana sp. nov.

- Setigerous foveae on frons dense and large, separated by less than their diameter; A3 and A2 subequal in length, or A2 slightly longer than A3; A3 only 3.25 × as long as wide; T1 with an anterior dorsal horn ……
..... *T. bengalensis* (Saraswat)

Triteleia flagellata
Abhilash and Rajmohana sp. nov. (Figs. 1-8)

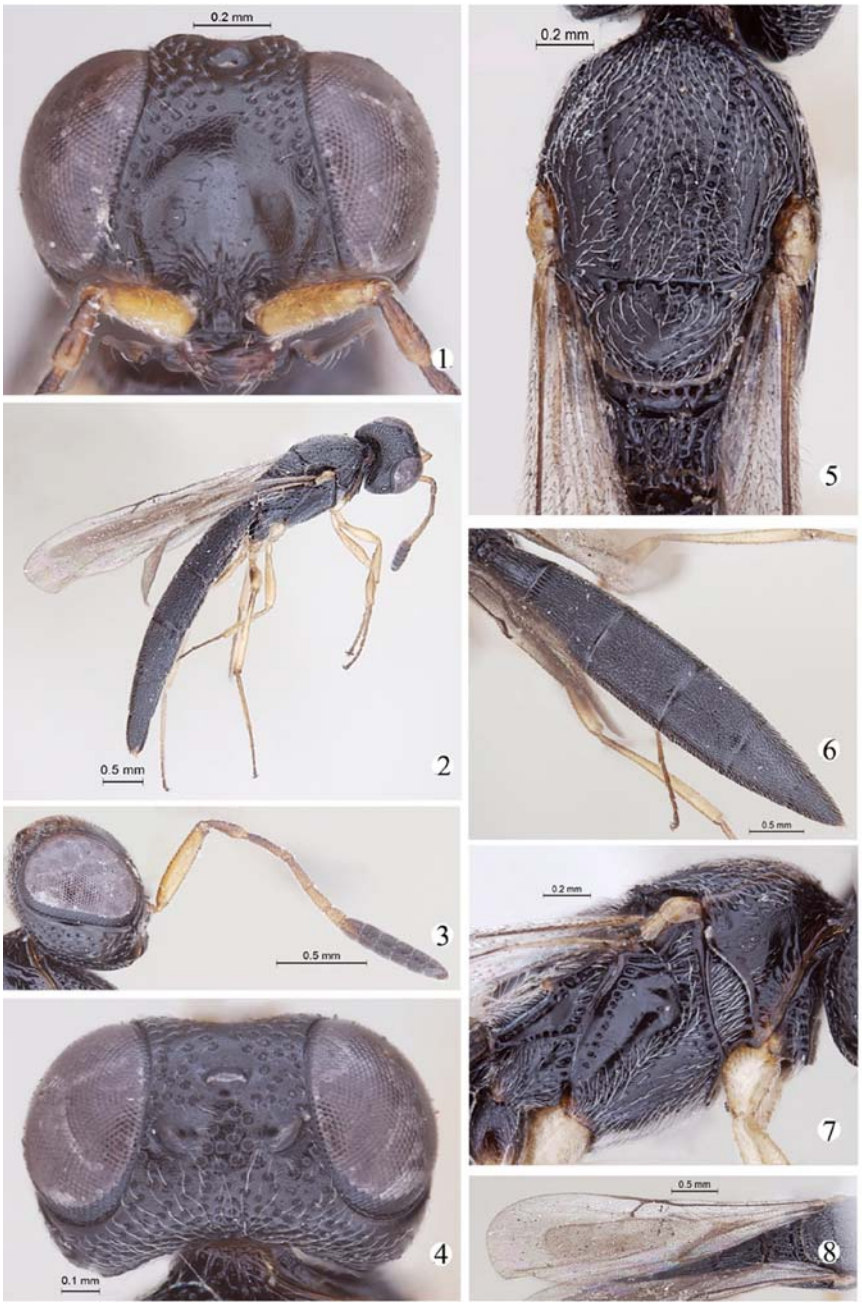
LSID urn:lsid:zoobank.org:act:83CB1118-D720-4D4C-9BBB-FFE6AC244160

Holotype: ♀. Length= 5.4 mm.

Body black; mandibles brown, teeth brownish black; legs pale brownish yellow except hind coxa brownish black; A1 yellow, A2- A6 pale brownish yellow, A7 brown, rest of antenna black; wings hyaline, veins brown.

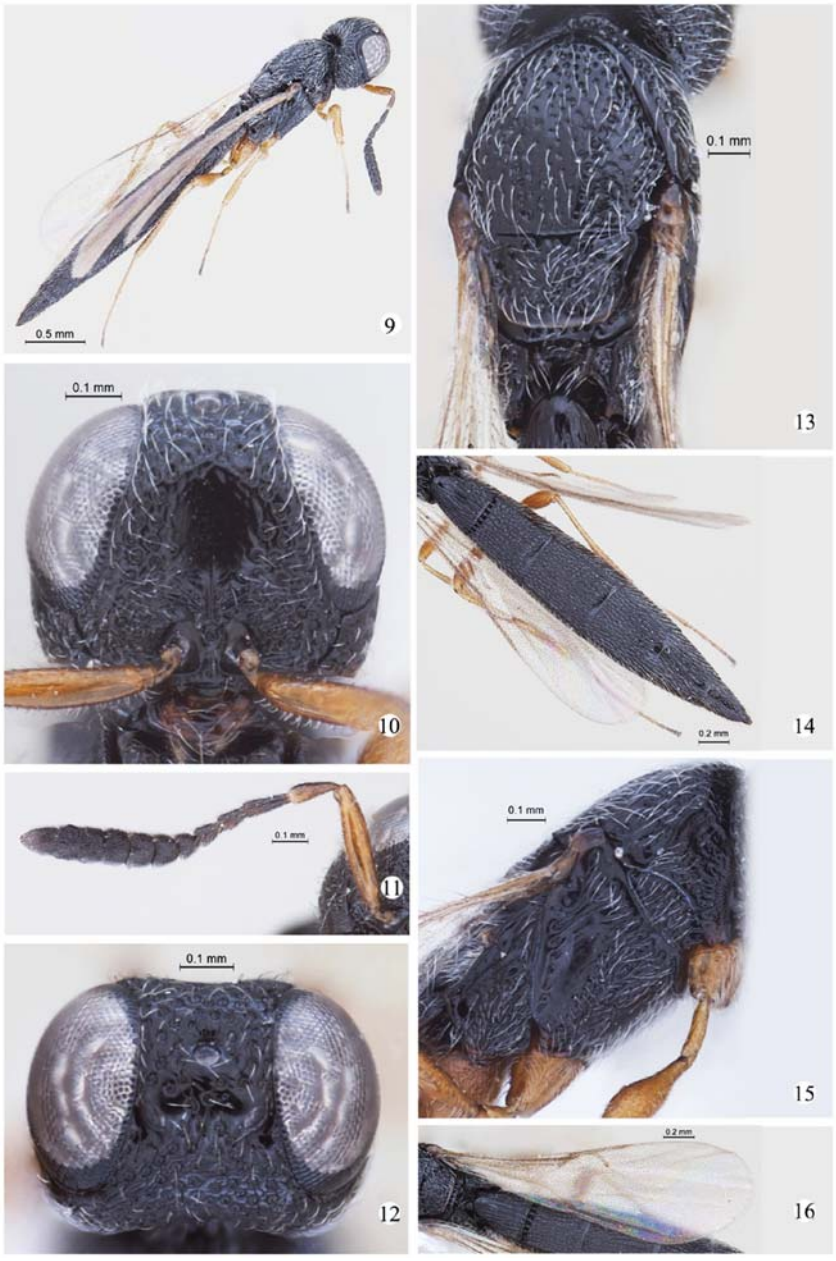
Head: In dorsal view transverse (HL: HW= 60: 108), 1.8 × as wide as long, hairy and with fine microsculpture; central keel absent, except for a trace at its base; minimal distance of IOS: EH = 41: 66; frons with scattered setigerous foveae, small and separated by more than their own diameter, foveae extremely sparse towards malar region; base of frontal depression with short stumps of striae; frons smooth medially; ventrolateral frons foveolate; frons below anterior ocellus foveolate, not contiguous; ocellar triangle foveolate and coriaceously sculptured; gena foveolate and hairy; lateral ocellus with inner orbits almost contiguous; LOL 4 × OOL; POL 1.6 × LOL; POL: LOL: OD= 20:12.2:3; malar sulcus prominent, running from lower margin of eye to mandibular articulation; clypeus small, semicircular without corners; mandible tridentate, teeth subequal in length; relative proportions of antennal segments (L: W) being: (53: 11); (23: 8); (29: 5); (20: 7); (16: 8); (11: 8); (11: 12); (11: 14); (10: 14); (10: 13); (10: 12); (14: 11).

Mesosoma: In dorsal view (ML: MW = 132: 97) 0.9 × width of HW, hairy and with microcoriaceous sculpture; epomial carina present; skaphion absent; mesoscutum foveolate; notauli present, narrow anteriorly and broad posteriorly, distinctly foveolate and carinate; SSS narrow medially and broad laterally; mesoscutellum transverse, sculpture same as that on mesoscutum, crenulate anteriorly, carinate and foveolate posteriorly; posterior rim smooth and unarmed; metascutellum transverse, carinate and foveolate; propodeum carinate and



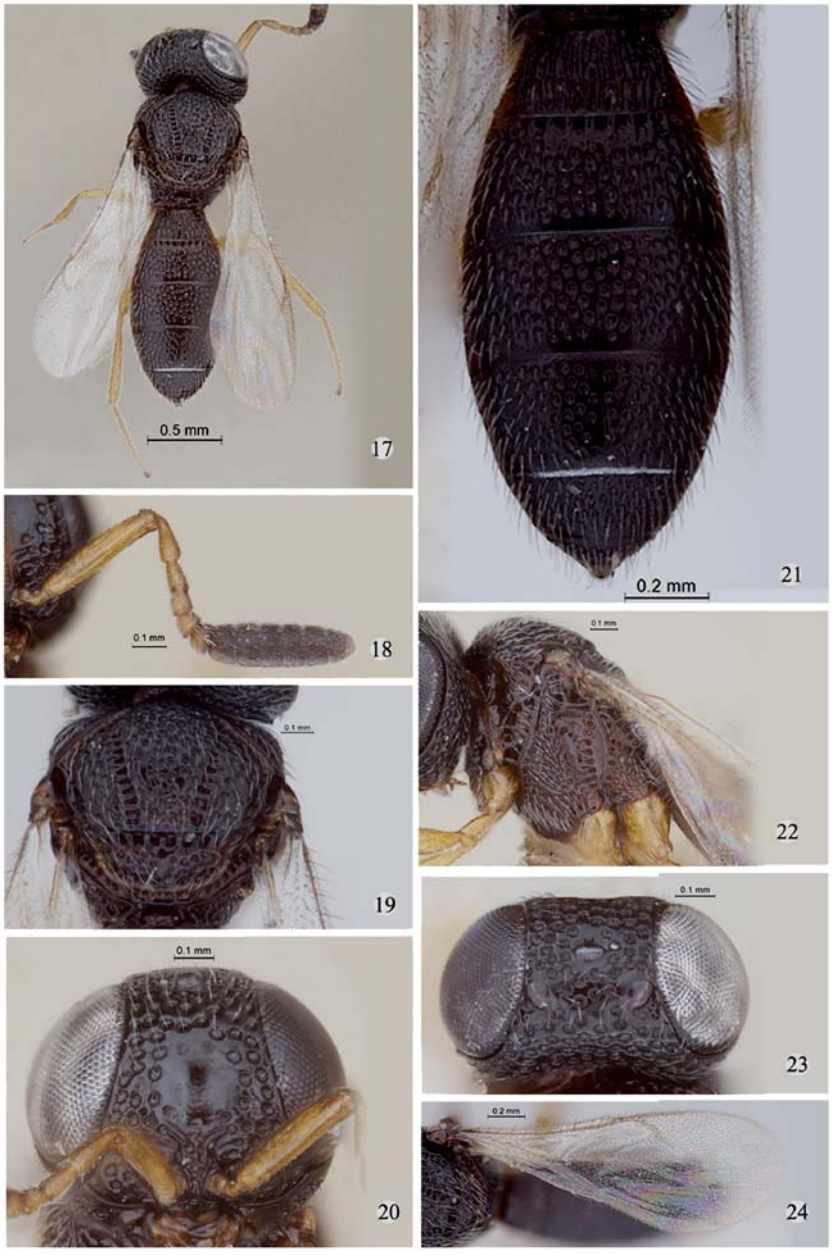
Figures 1-8. *Triteleia flagellata* Abhilash and Rajmohana sp. nov. Holotype - Female.

Fig. 1) Head- ventral; Fig. 2) Body profile; Fig. 3) Antenna; Fig. 4) Head- dorsal; Fig. 5) Mesosoma; Fig. 6) Metasoma; Fig. 7) Mesopleura; Fig. 8) Forewing venation



Figures 9-16. *Triteleia bengalensis* (Saraswat) - Female.

Fig. 9) Body profile; Fig. 10) Head- ventral; Fig. 11) Antenna; Fig. 12) Head- dorsal; Fig. 13) Mesosoma; Fig. 14) Metasoma; Fig. 15) Mesopleura; Fig. 16) Forewing venation



Figures 17-24. *Triteleia robusta* Abhilash and Rajmohana sp. nov. Holotype - Female

Fig. 17) Body profile; Fig. 18) Antenna; Fig. 18) Mesosoma; Fig. 20) Head- ventral; Fig. 21) Metasoma; Fig. 22) Mesopleura; Fig. 23) Head- dorsal; Fig. 24) Forewing venation

foveolate, excavate medially; cervical pronotal area hairy and coriaceously sculptured; dorsal pronotal area foveolate; lower pronotal area coriaceous anteriorly, indistinctly foveolate and carinate punctate; netrion hairy and foveolate; upper mesepisternum with a row of weak longitudinal carinae below subalar pit; speculum prominent, visible above femoral depression; mesopleural carina indistinct; sternaulus distinct; lower mesepisternum finely coriaceous and hairy with dispersed punctae; mesopleural depression smooth; metapleuron hairy; carinate and foveolate with speculum anteriorly and punctate posteriorly with lateral broad foveolae; forewing L: W= 390: 102; long not reaching tip of metasoma; *m* 0.68 × length of *pm*; *pm* 1.55 × longer than *stg*; *pm: stg: m* = 34: 22: 23.

Metasoma: In dorsal view (L: W= 401: 75), 2.09 × longer than head and mesosoma combined, depressed; T1 longitudinally striate medially, dorsal horn not distinct; T2 with basal fovea anteriorly; T2- T3 densely longitudinally striate with punctures and carina in interstices; T4 and T5 densely punctate; T1- T4 hairy laterally; T5 onwards hairy medially and laterally; length of T3 nearly as long as T2; T5 longer than wide; metasoma widest at T3; sublateral tergal carina present on T1- T3; relative L: W proportion of tergites T1 to T5 being (46: 48); (78: 69); (82: 75); (76: 73) (61: 60).

Male: Unknown.

Host: Unknown.

Etymology: This species is named 'flagellata', after its elongated A3, the first flagellar segment.

Material examined: Holotype. 1 ♀. INDIA, Kerala, Munnar IB, Idukki District, 8-vi-2012, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/ IR.INV.5982); Paratype: 1 ♀, INDIA, Kerala, Manalar, Idukki District, 7-iv-2013, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/ IR.INV.5983).

Discussion: Frons with scattered and widely placed setigerous foveolae and with fine coriaceous microsculpture, A3 1.3 × longer than A2 and nearly 6 × as long as its width, an elongate metasoma, which is >5.5 × as long as wide and no anterior metasomal horn on T1 are distinctive to *T. flagellata*. From *Triteleia bengalensis* (Saraswat), the closely resembling species, the proposed new species differs in the sculpture of the head region, the proportion of antennal segments as well as metasomal segments and also with regard to the dorsal metasomal horn on T1. Both the species can be well separated as per the key provided in this work. All the three Vietnamese species of *Triteleia* Kieffer, described by Kozlov and Le in 1995 (Lê, 2000), can be separated from *flagellata*, at once, their A2 and A3 being subequal in length like *T. bengalensis*, and also having a distinct dorsal metasomal horn on anterior T1.

Triteleia bengalensis (Saraswat), 1978
(Figs. 9-16)

Alloteleia bengalensis Saraswat, 1978, 18, 19. Original description in Saraswat and Sharma (1978).

Tritelia bengalensis (Saraswat, 1978), 211. Generic transfer, in Talamas *et al*. (2017).

Female. Length = 4.5 mm. Body black; mandible brown, teeth brown; legs pale brownish yellow; A1 and A2 brownish yellow, A3- A4 brownish black, A5- A12 black; wings hyaline, veins brown.

Head: In dorsal view, transverse (HL: HW= 43: 65), 1.51 × as wide as long, hairy; central keel weekly developed; IOS : EH =24: 37; frons not depressed; base of frontal depression obliquely strigose; medial frons smooth; ventrolateral frons foveolate rugose; frons below anterior ocellus rugosely foveolate, contiguous; ocellar triangle smooth or coriaceous with dispersed foveolae; gena with same sculpture as that on ventrolateral frons; POL: LOL: OD= 14: 10: 4; malar sulcus prominent, running from lower margin of eye to mandibular articulation; clypeus small, semicircular without corners; mandibles tridentate, teeth subequal in length; relative proportions of antennal segments (L: W) being: (34: 7); (14: 5); (13: 4); (7: 5); (7: 5); (5: 6); (6: 8); (6: 9); (6: 10); (6: 9); (6: 10); (10: 8).

Mesosoma: In dorsal view (ML: MW = 74: 58) 0.89 × width of HW, hairy and coriaceously sculptured; epomial carina present; skaphion

absent; mesoscutum foveolate notauli present narrow anteriorly and broad posteriorly, distinctly foveolate and carinate; SSS narrow medially; mesoscutellum transverse, sculpture same as that on mesoscutum; crenulate anteriorly, carinate and foveolate posteriorly; posterior rim smooth and unarmed; metascutellum transverse, carinate and foveolate; medial area slightly curved inward; propodeum, carinate and foveolate, excavate medially, propodeal flange with a pair of pointed spines; cervical pronotal area hairy and rugulose foveolate; dorsal pronotal area foveolate; lower pronotal area indistinctly foveolate rugulose; netrion hairy and foveolate; upper mesepisternum with a row of weak longitudinal carinae below subalar pit; speculum indistinct; mesopleural carina indistinct; sternaulus distinct; lower mesepisternum foveolate rugulose; mesopleural depression smooth; metapleuron longitudinally striate anteriorly and foveolate rugulose posteriorly, hairy; forewing L: W= 210: 67, apex extending from as far as posterior margin of T4 to middle of T5; *m* 0.65 × length of *pm*; *pm* 1.43 × longer than *stg*; *pm: stg: m* = 20: 14: 13.

Metasoma: In dorsal view (L: W= 264: 48), 5.5 × as long as wide and 2.26 × longer than length of head and mesosoma combined, depressed; T1 longitudinally striate, with a small anteriorly smooth dorsal horn; anterior basal fovea present on T2; T2- T4 densely longitudinally striate medially, with scattered punctures in interstices; T5 and T6 densely punctate; T1- T3 hairy laterally; T4 onwards hairy medially and laterally; length of T3 1.2 × length of T2;T5 longer than wide; metasoma widest at T3; sublateral tergal carina present on T1- T4; relative L: W proportion of tergites T1 to T6 being (39: 35); (45: 43); (54: 48); (49: 47); (39: 36) and (30: 20).

Male: Unknown.

Host: Unknown.

Material examined: 1 ♀, INDIA, Kerala, Tholpetty, Wayanad District, 10-x-2013, Coll. Abhilash Peter (ZSIK Regd. No. ZSI/WGRC/IR.INV.3708); 1 ♀, INDIA, Kerala, Gavi, Pathanamthitta District, 10-iv-2013, Coll. C. Bijoy (ZSIK Regd. No. ZSI/WGRC/IR.INV.5984); 1 ♀, INDIA, Kerala, Gavi (9.4404 N 77.1603 E), Pathanamthitta District, 10-iv-2013, Coll. P.M. Sureshan (ZSIK Regd. No. ZSI/WGRC/IR.INV.5985); 1 ♀, INDIA, Kerala, Gavi, Pathanamthitta District, 10-iv-2013, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/IR.INV.5986); 1 ♀, INDIA, Kerala, Gavi, Pathanamthitta District, 10-iv-2013, Coll. C. Bijoy (ZSIK Regd. No. ZSI/WGRC/IR.INV.5987); 1 ♀, INDIA, Kerala, Mullaperiyar, PTR, Palakkad District, 6-iv-2013, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/IR.INV.3712); 1 Female, INDIA, Kerala, Manomthora, Thenmala, Trivandrum District, 17-i-2014, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/IR.INV.3713); 1 ♀, INDIA, Kerala, Madakkimala, Kalpetta, Wayanad District, 09-i-2009, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/IR.INV.3714); 1 ♀, INDIA, Kerala, Parambikulam, Palakkad District, 12-xii-2013, Coll. Abhilash Peter (ZSIK Regd. No. ZSI/WGRC/IR.INV.3710); 1 ♀, INDIA, Kerala, Mangaladevi, PTR, Palakkad District, 5-iv-2013, Coll. Abhilash Peter (ZSIK Regd. No. ZSI/WGRC/IR.INV.3711); 1 ♀, INDIA, Kerala, Mannuthy, Thrissur District, 16-19-ix-2012 (Malaise Trap), Coll. Abhilash Peter (ZSIK Regd. No. ZSI/WGRC/IR.INV.5989); 1 ♀, INDIA, Kerala, Gavi, Pathanamthitta District, 10-iv-2013, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/IR.INV.3709); 1 ♀, INDIA, Kerala, Peruvayal, Kozhikode District, 2-i-2009, Coll. K. Rajmohana (ZSIK Regd. No. ZSI/WGRC/IR.INV.3715): 1 ♀, INDIA, Kerala, Thattekkad, Ernakulam District, 10-ii-2017, Coll. K. Rajmohana (NZC/H3 3709).

Discussion: Frons with large closely placed setigerous foveolae, A2 and A3 elongate, almost subequal in length, A5 not elongate, at the most 1.5 × as long as wide, metasoma elongate, which is > 5 × as long as wide, presence of an anterior metasomal horn on T1, metasomal segments never transverse and longitudinally striate, serve to diagnose *T. bengalensis*. The species was originally described as *Alloteleia bengalensis* by Saraswat (1978), but recently through generic transfer by Talamas *et al*. (2017), the species is now valid as *T. bengalensis* (Saraswat).

Triteleia robusta
Abhilash and Rajmohana sp. nov.

(Figs.17-24)

LSID urn:lsid:zoobank.org:act:83CB1118-D720-4D4C-9BBB-FFE6AC244160

Holotype: ♀. Length= 2.56 mm.

Body black; mandibles brown with yellow tinge, teeth brown; legs yellowish brown; A1 and A6 yellow with brown tinge, A7- A12 brownish black; wings hyaline, veins brown.

Head: In dorsal view transverse (HL: HW= 42: 77), 1.83 × wider than long, hairy; central keel reduced or weekly developed; IOS: EH = 33: 46; frons not depressed; base of frontal depression obliquely strigose; frons smooth medially, rest with setigerous contiguous foveolae; gena with same sculpture as that on vertex; ocellar triangle smooth towards ocelli; lateral ocelli touching orbital margin; LOL 3 × OD; POL: LOL: OD= 5:3:1; malar sulcus prominent; clypeus small; mandible tridentate, teeth sub equal in length; relative proportions of antennal segments (L: W) being: (39: 8); (13: 6); (8: 5); (7: 6); (5: 7); (5: 7); (8: 11); (7: 12); (6: 12); (6: 12); (6: 11); (8: 9).

Mesosoma: In dorsal view (ML: MW= 68: 72) width 0.94 × HW, hairy and foveolate to foveolate rugose; epomial carina present; skaphion absent; mesoscutum foveolate; notauli present uniformly wide throughout, foveolate; SSS narrow medially; mesoscutellum transverse, sculpture same as that on mesoscutum; crenulate anteriorly, carinate and foveolate posteriorly; metascutellum transverse, carinate and foveolate; propodeum, carinate and foveolate, excavate medially, flanges laterally with paired spines; cervical pronotal area smooth, glabrous; dorsal pronotal area foveolate, hairy; lower pronotal area smooth; netrion hairy, foveolate and carinate; upper mesepisternum with a row of weak longitudinal carinae below subalar pit; speculum indistinct; mesopleural carina indistinct; sternaulus distinct; lower mesepisternum foveolate; mesopleural depression smooth; metapleuron foveolate throughout, hairy posteriorly; forewing L: W= 192: 64, apex slightly surpassing posterior margin of T6; *m* 0.46 × length of *pm*; *pm* 1.71 × longer than *stg*; *pm: stg: m* = 24: 14: 11.

Metasoma: In dorsal view (L: W= 131: 65), 1.19 × longer than head and mesosoma combined, depressed; T1 longitudinally striate throughout, anterior dorsal horn indistinct; anterior basal fovea present on T2; T2- T6 densely foveolate throughout; T1 hairy laterally; T2 onwards hairy throughout; T3 longer than T2; metasoma widest at T3; sub lateral tergal carina absent on T1- T6; T6 extremely transverse, 2 × as wide as long; relative L: W proportion of tergites T1 to T5 being (21: 45); (27: 61); (29: 65); (28: 57) (17: 39).

Male: Unknown.

Host: Unknown.

Etymology: The species is named after its robust body.

Material examined: Holotype. 1 ♀, INDIA, Kerala, Medical College Campus, Calicut District, 21-xi-2012, Coll. A. Rameshkumar (ZSIK Regd. No. ZSI/WGRC/ IR.INV.5991); Paratype: 1 ♀, with same data as that of the holotype (ZSIK Regd. No. ZSI/WGRC/IR.INV.5992).

Discussion: *Triteleia robusta* Abhilash and Rajmohana sp. nov. with its peculiarly stout and broad metasoma can be compared best to the Australian species *T. valida* (Dodd, 1933). Both the species have T1-T5 rather transverse and A3 shorter than A2**.** But as per the images of the holotype of *T. valida*, available at (https://hol.osu.edu/index.html?id=5572), the terminal metasomal segments in Dodd's species are more tapering. Metasoma is 2.5 × as long as wide in *valida,* while it is only 2 × in *robusta*. T3 in *valida* is 1.5 × as wide as long, but more than 2 × as wide as long in *T. robusta*. As per the original description too, T6 in *T. valida* is as long as T5 and also as wide as its length, where as in *T. robusta*, this segment is highly transverse, about 0.6 of T5 length and almost 2 × as wide as long.

The European species *Triteleia peyerimhoffi* (Kieffer, 1906) also has a broad metasoma, with T1-T5 transverse (Popovici *et al*., 2011). But unlike in *T. robusta*, in this species, A3 is elongate, and not smaller to A2. Further both the species have

different sculpture and length to width proportion of metasomal segments. T2 is almost 3 × as wide as long in *T. robusta*, whereas T2 is at the most only 2 × as wide as long in *T. peyerimhoffi*. In the former, the longitudinal striae is restricted to anterior margin of T2, whereas in the latter, longitudinal striae extend throughout T2. T3 is foveolate and without any longitudinal striae in *T. robusta,* while it is longitudinally striate as well as with areolate rugulae throughout in *T. peyerimhoffi*. In the European species, T6 is longer than wide, while it is extremely transverse in the proposed new species.

Though in *Triteleia*, generally *m* is elongate and longer than *stg* (Masner, 1976), at least in the species with broad metasoma, this is not always the case. In *valida, m* is only two third the length of *stg* (Dodd, 1933), while it is variable from 0.7 to 1.3 × length of *stg* in *T. peyerimhoffi* (Popovici *et al*., 2011) and in *T. robusta*, *m* is 0.8 × *stg*.

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Two-sex life table and host preference studies of *Bactrocera dorsalis* Hendel (Diptera: Tephritidae)

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ABSTRACT: Oriental fruit fly, *Bactrocera dorsalis*, is a serious invasive pest in tropical and subtropical countries. The stage-specific two-sex pooled life table of *B. dorsalis* on four different fruits (guava, water apple, rose apple and mango) were studied during 2018-2020. The life table showed that the survivorship of *B. dorsalis* falls in Type III with about 41.394-33.827per cent of the eggs successfully reached adult stage. The highest mortality recorded was in the egg and adult emergence stages with k_x of 0.045-0.113 and 0.032-0.192, respectively. The average potential fecundity (Pf) was 223-362 eggs female^{-1}. The intrinsic rate of natural increase (r_m) was 0.021-0.035 female^{-1} day^{-1} with mean generation time (T_c) of 194.058-148.710 days. The net reproductive rate (R_o) was 61.504-176.006 female offspring per female and the population doubling time (DT) was within 32.719-19.946 days. The population dynamics of *B. dorsalis* were significantly influenced by the host fruits due to their respective phytoconstituents in terms of host suitability or susceptibility (guava> water apple> rose apple> mango). Host preference of *B. dorsalis* was in the order of guava> water apple> rose apple. © 2021 Association for Advancement of Entomology

KEY WORDS: Oriental fruit fly, phytoconstituents, population dynamics, host preference

INTRODUCTION

Globally, fruit flies in the genus *Bactrocera* (Diptera: Tephritidae) are economically important pests of agricultural crops including fruits, vegetables and nuts (Drew and Raghu, 2002; Jiang *et al*., 2017; Liu *et al*., 2013, 2019). They have been reported to potentially infest more than 173 kinds of fruits and vegetables (White and Elson-Harris, 1992; Ekesi *et al*., 2016), where internal feeding by larvae causes premature abscission of fruit (Liu *et al*., 2013; Shinwari *et al*., 2015; Gu *et al*., 2019). The Oriental fruit fly, *B. dorsalis* (formerly known as *B. papayae*) infests more than 70 species of tropical and subtropical fruits and melons, representing 35 plant families, such as guava, water apple, rose apple, mango, cashew, cherry, orange, banana, etc. (Wee and Tan, 2005; Kunprom *et al*., 2015; Jiang *et al*., 2017; Zeng *et al*., 2019). In India, damage rates caused by *B. dorsalis* can reach 80 per cent, ranking it as the country's most serious fruit fly pest (Jalaluddin *et al*., 1999; Qin *et al*., 2015). Even today, management of such notorious pest, *B. dorsalis*, by applying broad-spectrum synthetic pesticide sand some bio-pesticides are the chief control strategy (Jiji *et al*., 2005; Carvalho, 2017; Rashmi *et al*., 2020). These result into secondary pest outbreak, pest resurgence and development of pesticide resistance as well as emergence of pest biotypes, which ultimately leads

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to both top down and bottom up regulatory complications in the agro ecosystem (Kim *et al*., 2017; Roy, 2019b, 2020).

In integrated pest management (IPM) programs, it is necessary to understand the basic and detailed information of pests can be derived through life table modelling (Yang *et al*., 1994; Chen *et al*.. 2017; Roy 2019b, 2020). Life table is a powerful tool for analysing and understanding the effect of different hosts on feeding, growth, survival and reproduction of an insect pest for their management (Southwood, 1978; Carey, 1993, 2001; Kakde *et al*., 2014; Roy, 2019b). The age-stage, two-sex life table can eliminate many of the inherent error characteristics of female-based traditional life tables (Chen *et al*.,2017; Mobarak *et al*., 2019; Roy, 2020). In other instances, host quality influences larval growth and development which are the key determinant of adult longevity, fertility, fecundity and survivability (Schoonhoven *et al*., 2005; Roy and Barik, 2012, 2013; Roy, 2017, 2018, 2020). Host primary metabolites (PMs) are used only for general vitality, growth and reproduction of the herbivores (Slansky and Scriber, 1985; Turunen, 1990; Roy and Barik, 2013) whereas, the secondary metabolites (SMs) have defensive role (Dicke, 2000; Howe and Jander, 2008; War *et al*., 2012). Moreover, host plant utilization is also influenced by the ability of insect to ingest, assimilate and convert food into their body tissues according to their metabolic as well as genomic regulations (Slansky and Scriber, 1985; Roy and Barik, 2013; Roy, 2019b). There is a range of innet reproductive capacity for individual of a population (Carey, 1993; Southwood, 1978; Roy, 2020) but the variation in available food quality always influence the growth, reproduction, longevity and survival of that population (Shobana *et al*., 2010; Roy and Barik, 2012; Roy, 2017). The effect of different food sources on population growth were observed in *Diacrisia casignetum* (Roy and Barik, 2013), *S. obliqua* (Mobarak *et al*., 2019), *Podontia quatuordecimpunctata* (Roy, 2015), *Epilachna vigintioctopunctata* (Roy, 2017), *Leptocorisaacuta* (Dutta and Roy, 2016) and many more on different host plants. Variation between the results of these studies could be attributed due to differences among nutritional (PMs) and anti-nutritional (SMs) factors present in their respective host plants (Awmack and Leather, 2002; Roy and Barik, 2013; Roy, 2014). Similarly, few biological studies have been reported on *B. dorsalis* with different pattern of development and growth depending on different artificial diets or natural hosts (Jaleel *et al*., 2017; Mohamed *et al*., 2019). Life table analysis is a solid theory to describe in details the survival, stage differentiation and reproduction of insects including fruit flies in order to develop a complete management system (Maia *et al*., 2000; Huang and Chi, 2013).

In other instances, trap cropping is an attractive remedy for pest management by natural enemies over artificial bio-control or other conventional means of pest control (Midega *et al*., 2011; Roy, 2018). Generally, crop polyculture always lead to less damage from pests and can enhance biological control by offering greater host capacity for natural enemies than monoculture within a given area (Shelton *et al*., 2006; Holden *et al*., 2012; Rhino *et al*., 2016). Trap cropping potentially attract pest natural enemies and reduce pest disperse into the main crop through predation and parasitism (Hokkanen, 1991). Considerable research has been conducted on different trap crops to develop improved pest management strategies and resulting in a substantial reduction in pesticides use throughout the world (Holden *et al*., 2012; Rhino *et al*., 2016). But, till date none of the studies has been performed with *B. dorsalis* on different fruit plants using age-stage, two sex life table or trap crop designing for climate smart agriculture (CSA). Therefore studies on basic information on the life stages and demographic parameters of *B. dorsalis* on different fruits were undertaken. Objectives are to find out the detailed information on biochemical basis of host preference of *B. dorsalis* and unfold the impact of different host plants on their population growth parameters.

MATERIALS AND METHODS

Host plants: Four well known economic fruit crops [guava (*Pisidium guajava* L.; Myrtaceae),

water apple (*Syzygium aqueum*; Myrtaceae), rose apple (*Syzygium jambos* L.; Myrtaceae) and mango(*Mangifera indica* L.; Anacardiaceae)] were selected in a field situated near Chinsurah Rice Research Center (CRRC), Chinsurah, 22°53' N, 88°23' E, 13m above sea level, Hooghly, West Bengal, India, in their growing season during 2018-2020. Intact mature fruits were collected separately for phytochemical analysis as well as provided as food for *B. dorsalis*. The plants were also identified and voucher specimens (Voucher No. ERU24-27) were kept in Department of Zoology, Ecology Research Unit, M.U.C. Women's College, Burdwan, West Bengal, India.

Phytochemical analysis: Intact mature ripen fruits (guava, water apple, rose apple and mango) were freshly collected from the selected plants. The fruits were initially rinsed with distilled water and dried under shade separately for phytochemical analysis as in Roy (2019b, 2020). Different primary and secondary metabolites (PMs and SMs) were extracted and estimated by various standard biochemical analysis protocols (Harborne, 1973) as in Roy (2019b, 2020). Determination of each biochemical analysis was repeated for three times and expressed in dry weight basis accordingly.

Insect collection, culture and rearing: The initial populations of *B. dorsalis* adults were collected from each fruit (guava, water apple, rose apple and mango) crop separately by special type of baited traps from the cultivated fields near CRRC, Chinsurah, Hooghly, West Bengal, India during summer season (June-August) in 2018-2020. The traps were suspended at a height of 1-1.5 m above the ground. Within one hour the flies was capture from the field then transfer carefully in laboratory condition (28± 2°C temperature and 70±5% relative humidity with 14:10 [L: D] photoperiod) for rearing. The selected fruits in slices were placed in the rearing cages (40×30×30 cm^3) separately for egg laying. The culture was maintained until adult emergence as described by Jaleel *et al.* (2019).

Fecundity, developmental duration and survivorship determination: Five pairs of newly emerged *B. dorsalis* adults from the stock culture were sexed and released into a new adult rearing cage (40×30×30 cm^3). The adults were fed with mixture of yeast extract and sugar in water at ratio 3:1. The eggs of *B. dorsalis* were collected when the age of adult flies from above cultures reached 3 weeks old. Fruit domes were used as egg collection device by cutting the fruits in thin slices leaving little flesh as possible on the skin and placed in Petri dishes (15 cm diameter). The outer skin of domes was pierced 30- 50 times with an entomological pin as oviposition holes. The fruit domes were placed inside the cage and the flies were allowed to oviposit for 24 hours and new fresh fruits slices were supplied every day for oviposition. After 24 hrs of exposure, the eggs were collected using fine hair brush and counted daily under a stereo microscope (Olympus-i20) with micro-photographic attachment. Eggs laid by each female were counted and recorded daily until the death of all individuals. The pre-oviposition periods (POPs), oviposition periods (OVPs) and fecundity of females and adult longevity of females and males of *B. dorsalis* adults were recorded. For each cohort (n=100), the eggs were then divided into 10 groups with 10 eggs per group for survivorship observation. Each group of eggs was placed on 20 g of each fruit pulp diet (in Petri dish 6 cm in diameter). To ensure the eggs remain moist, the Petri dish was covered and sealed with parafilm for the first 3 days. After egg hatching, the larval developmental time was measured as time in days within each stage. The larvae of *B. dorsalis* were reared on the selected fruits as pulp diet instead of the whole fruit to facilitate the daily calculation of survival and mortality of larvae. The eggs and early instar larvae were observed under the stereo microscope to record egg hatch and the survival of the first instar larvae until they reached the third larval instar. The third instar larvae which can be identified by their jumping behaviour were transferred from rearing Petri dish using a fine pair of forceps to plastic cups containing 0.5 cm sterilized fine sand as pupation medium. After 3 days of incubation, the pupae were sieved from sand and placed individually in small plastic cups (3.5 cm height, 6 cm diameter) layered with moistened tissue paper for adult emergence. The developmental durations

(days), survival (%), accumulate survival (AS %) and mortality (%) of eggs, larvae, pupae and adults were observed and recorded.

Life table study: The data on survival, developmental duration and oviposition of all individuals on the selected four fruits (guava, water apple, rose apple and mango) were analyzed separately based on age-stage, two-sex life table (Chen *et al*., 2017; Mobarak *et al*., 2019). It includes several parameters, which were calculated with the formulae of Carey (1993, 2001) and Southwood (1978). These parameters include probability of survival from birth to age x (l_x), proportion of dying (d_x), mortality rate (q_x) and survival rate (s_x) per day per age class from egg to adult stages. Using these parameters, the following statistics like total individuals at age x and beyond k (T_x), average population alive in each stage (L_x), life expectancy (e_x), exponential mortality or killing power (k_x), total generation mortality (K or GM), generation survival (GS), gross reproductive rate (GRR or m_x), net reproductive rate (NRR or R_0), mean generation time (T_c), doubling time (DT), intrinsic rate of population increase (r_m), Euler's corrected r (r_c), finite rate of population increase (λ), weekly multiplication rate (λ^7), increase rate per generation (λ^{Tc}), were also computed, using Carey's formulae (1993). Some other population parameters like potential fecundity (Pf), total fertility rate (F_x), mortality coefficient (MC), population growth rate (PGR), population momentum factor of increase (PMF), expected population size in 2nd generation (PF_2), Hypothetical females in 2nd generation (HFF_2), expected females in 2nd generation (RFF_2), general fertility rate (GFR), crude birth rate (CBR), reproductive value (RV), vital index (VI) and trend index (TI) were also determined by using well defined formulae (Carey, 1993; Southwood, 1978; Roy, 2019b, 2020).

Statistical Analysis: Experimental data of different phytoconstituents of the selected fruits (guava, water apple, rose apple and mango) and the pest (*B. dorsalis*) population parameters were subjected to one-way analysis of variance (ANOVA) and Tukey's (HSD) test (Zar, 1999). All the statistical analysis was performed by using SPSS, version 16.0 (Roy, 2019a, 2019b, 2020).

RESULTS

Host phytochemicals: The chemical constituents of the selected fruits (guava, water apple, rose apple and mango), all the PMs and SMS, varied significantly ($F_{3,8} \geq 3.821$, $P \leq 0.024$) in the fruits and they were present in reverse order with each other with few deviations (Fig.1). Among the PMs, total carbohydrate and protein contents were 86.573±1.161, 34.286±1.581, 60.506±1.477, 72.361±1.257 and 12.822±0.561, 8.128±0.448, 9.344±0.501, 11.777±0.212 µg/mg dry weight, respectively, in the selected fruits. Total lipids and amino acids in guava, water apple, rose apple and mango were 2.473±0.960, 1.292±0.316, 1.868±0.525, 2.256±0.167 and 5.705±0.360, 2.037±0.183, 3.594±0.549, 4.696±0.123µg/mg dry weight, respectively. From the SMs, total phenol and flavonoid were11.206±0.561, 12.271±0.560, 14.596±0.487,17.129±0.251 and 10.070±0.524, 13.432±0.452, 13.115±0.504, 15.393±0.214µg/mg dry weight, respectively, in the selected fruits (guava, water apple, rose apple and mango), respectively. Total tannin and alkaloid content in guava, water apple, rose apple and mango were 5.571±0.486, 4.106±0.344, 7.246±0.521, 8.514±0.177 and 7.209±0.412, 5.317±0.195, 9.383±0.546, 11.019±0.126µg/mg dry weight, respectively. Ultimately, the ratio of PMs to SMs was significantly ($F_{3,8} \geq 5.772$, $P<0.022$) varied in the selected fruits and they can be arranged in the order of guava> rose apple> water apple>mango (Fig 1).

Population dynamics: The stage-specific two-sex pooled life tables of *B. dorsalis* were investigated in the laboratory with three replications on ripen fruits (guava, water apple, rose apple and mango) and showed four distinct stages (i.e., egg, larva, pupa and adult) with three larval instars. The population parameters like, l_x, L_x, T_x and e_x of *B. dorsalis* were gradually decreased throughout their developmental stages on the selected fruits and they always produce type-III survivorship curve like most of the insects. Whereas, the q_x and k_x were varied in different developmental stages and comparatively higher in

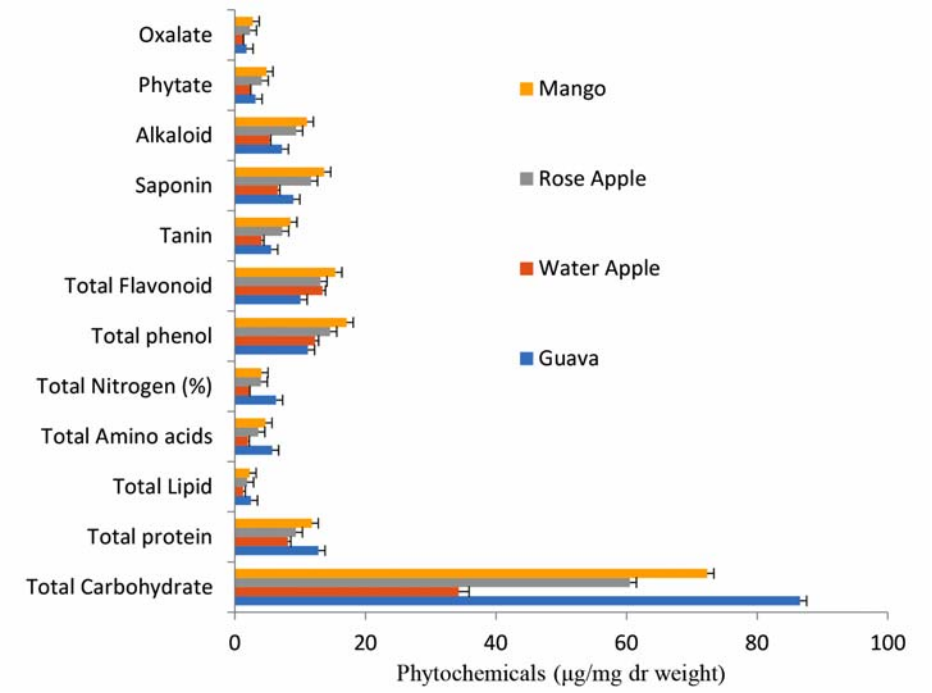

Fig. 1. Phytochemical variations (Mean ± SE, n=3) of four selected fruits (guava, water apple, rose apple and mango) observed during summer season in 2018-2020. All the estimated chemicals were significantly different at P<0.05 by Tukey (HSD) test

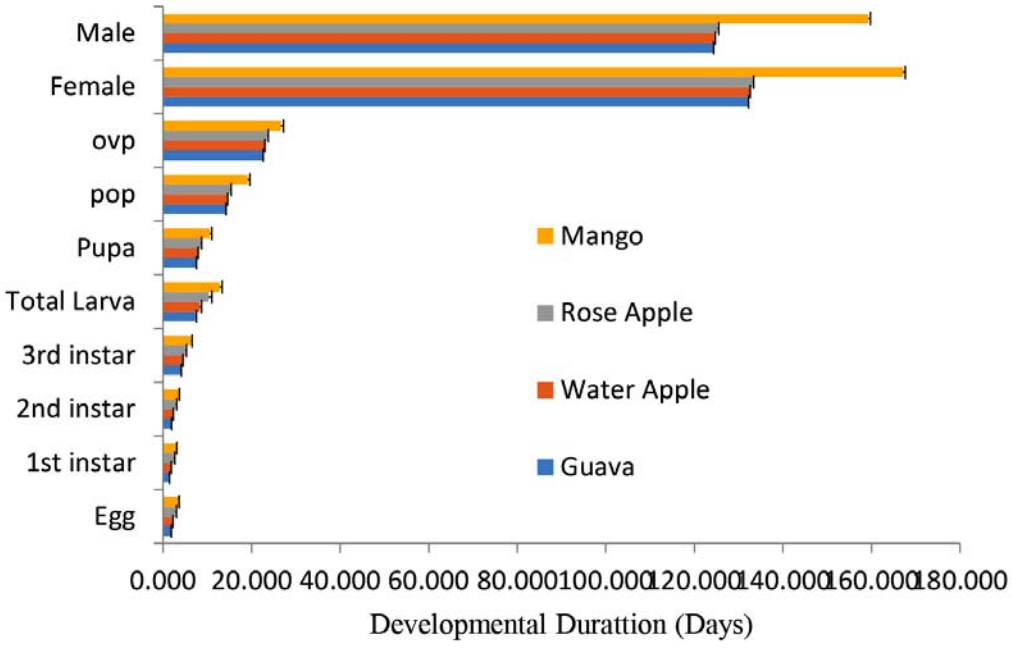

Fig. 2. Developmental duration (Mean ± SE, n=3) of *B. dorsalis* on four selected fruits (guava, water apple, rose apple and mango) observed during summer season in 2018-2020. All the estimated developmental durations were differed at P<0.001 by Tukey (HSD) test

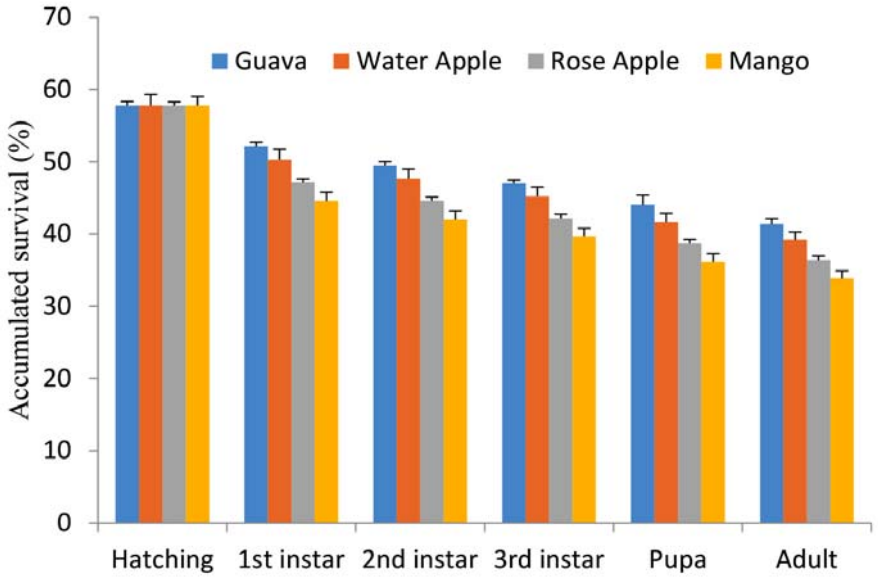

Fig. 3. Accumulated survival (Mean ± SE, n=3) of *B. dorsalis* on four selected fruits (guava, water apple, rose apple and mango) observed during summer season in 2018-2020. All the estimated accumulated survival values were different at P<0.001 by Tukey (HSD) test.

egg and 1st instar larval stage with a rapid surge during adult stage on the selected fruits. The l_x and k_x of adult *B. dorsalis* were 0.716±0.008, 0.679±0.011, 0.630±0.006, 0.585±0.011and 0.032±0.008, 0.074±0.010, 0.131±0.012, 0.192±0.012 individual^{-1}, respectively on guava, water apple, rose apple and mango the adult e_x of *B. dorsalis* on guava, water apple, rose apple and mango were 1.430±0.017, 1.343±0.020, 1.240±0.021, 1.143±0.019 day^{-1}, respectively (Table 1). ANOVA results of the life table parameters on the selected crop cultivars were showed more or less same pattern (guava>water apple>rose apple>mango)with significant ($F_{5,18}$=77.148-641.86; P<0.0001) variations(Table 2) due to host phytoconstituents as well as their metabolic utility by the pest.

The average Pf were 362.000±12.530, 320.667±8.988, 273.000±12.490 and 223.000±9.866 eggs/female, respectively on the selected fruits (guava> water apple> rose apple> mango) with significant ($F_{3,8}$=29.363; *P*<0.001) variations. The F_x, GRR and NRR or R_0 of *B. dorsalis* were also significantly ($F_{3,8} \geq$ 33.316; *P*<0.001) differed on the fruits in the order of guava> water apple> rose apple> mango. Average T_c for the fruits (guava, water apple, rose apple and mango) were 148.710±0.433, 150.614±0.882, 154.627±1.512 and 194.058±7.452 days, respectively (Table 3) with significant ($F_{3,8}$=31.489; *P*<0.001) variations. Similarly, the average DT were 19.946±0.208, 21.332±0.342, 23.692±0.603 and 32.719±1.236 days, respectively on the selected fruits (guava< water apple< rose apple< mango) with significant ($F_{3,8}$=64.326, *P*<0.001) variations. The r_m and ë of *B. dorsalis*were0.035±0.001, 0.033±0.001, 0.029±0.001, 0.021±0.001 and 1.035±0.001, 1.033±0.001, 1.030±0.001, 1.021±0.001 individuals female^{-1}day^{-1}, respectively on the selected fruits (guava> water apple> rose apple> mango) with significant ($F_{3,8}$≥83.214; *P*<0.001) variations. The average GS, PGR, PMF, CBR, RV, VI and TI of *B. dorsalis* were also significantly ($F_{3,8}$=5.402-33.316; *P*≤0.025-0.001) differed on the fruits in the order of guava> water apple> rose apple> mango. All the vital parameters like, GRR, NRR or R_0, r_m, T_c, DT and ë including other dependent parameters such as PGR, PF2, HF2, RF2, RV, VI and TI were higher on guava followed by water apple, rose apple

Table 1. Stage-specific pooled life table (Mean ± SE, n=3) for 3 cohorts (n=100) of *B. dorsalis* on four selected fruits (guava, water apple, rose apple and mango) observed during summer season in 2018-2020

Host: Guava						
Stage	l_x	q_x	L_x	T_x	e_x	k_x
Egg-0	1.000±0.000	0.098±0.005	0.951±0.003	4.883±0.030	4.883±0.030	0.045±0.003
lnst- I -1	0.902±0.005	0.051±0.001[a]	0.880±0.005	4.265±0.026	4.726±0.003	0.023±0.001[b]
lnst- II-2	0.857±0.005	0.050±0.001[a]	0.835±0.005	3.385±0.021	3.951±0.004	0.022±0.001[b]
lnst- III-3	0.814±0.005	0.064±0.012	0.787±0.009	2.550±0.016	3.134±0.004	0.029±0.006[c]
Pup-4	0.761±0.014	0.059±0.018	0.739±0.008	1.763±0.007	2.316±0.032	0.027±0.008[c]
Adult-5	0.716±0.008	0.070±0.017	0.691±0.001	1.024±0.002	1.430±0.017	0.032±0.008
Host: Water Apple						
Stage	l_x	q_x	L_x	T_x	e_x	k_x
Egg-0	1.000±0.000	0.130±0.015	0.935±0.007	4.663±0.072	4.663±0.072	0.061±0.007
lnst- I -1	0.870±0.015	0.052±0.001[d]	0.847±0.014	4.014±0.074	4.613±0.016	0.023±0.001[e]
lnst- II-2	0.825±0.013	0.051±0.001[d]	0.804±0.013	3.167±0.060	3.840±0.017	0.023±0.001[e]
lnst- III-3	0.782±0.013	0.079±0.001	0.752±0.012	2.363±0.047	3.020±0.018	0.036±0.001
Pup-4	0.721±0.012	0.059±0.001	0.700±0.011	1.611±0.035	2.235±0.019	0.026±0.001
Adult-5	0.679±0.011	0.157±0.020	0.626±0.015	0.912±0.025	1.343±0.020	0.074±0.010
Host: Rose Apple						
Stage	l_x	q_x	L_x	T_x	e_x	k_x
Egg-0	1.000±0.000	0.185±0.005	0.908±0.003	4.350±0.035	4.350±0.035	0.089±0.003
lnst- I -1	0.815±0.005	0.054±0.001[f]	0.793±0.005	3.675±0.041	4.506±0.024	0.024±0.001[g]
lnst- II-2	0.771±0.005	0.054±0.001[f]	0.751±0.005	2.881±0.036	3.735±0.022	0.024±0.001[g]
lnst- III-3	0.730±0.005	0.082±0.001	0.700±0.005	2.131±0.031	2.918±0.022	0.037±0.001
Pup-4	0.670±0.005	0.061±0.001	0.650±0.006	1.431±0.026	2.135±0.021	0.027±0.001
Adult-5	0.630±0.006	0.260±0.021	0.548±0.012	0.781±0.020	1.240±0.021	0.131±0.012
Host: Mango						
Stage	l_x	q_x	L_x	T_x	e_x	k_x
Egg-0	1.000±0.000	0.229±0.012	0.886±0.006	4.083±0.062	4.083±0.062	0.113±0.007
lnst- I -1	0.771±0.012	0.057±0.001[h]	0.749±0.012	3.386±0.062	4.391±0.019	0.026±0.001[i]
lnst- II-2	0.727±0.012	0.057±0.001[h]	0.706±0.012	2.637±0.050	3.626±0.018	0.025±0.001[i]
lnst- III-3	0.686±0.012	0.087±0.001	0.656±0.011	1.930±0.039	2.815±0.018	0.040±0.001
Pup-4	0.626±0.011	0.065±0.001	0.605±0.011	1.275±0.028	2.037±0.018	0.029±0.001
Adult-5	0.585±0.011	0.357±0.019	0.481±0.011	0.669±0.018	1.143±0.019	0.192±0.012

Within the column means followed by same letter(s) are not significantly different at $P<0.05$ by Tukey (HSD) test.

Table 2. ANOVA result of stage-specific pooled life table (Mean ± SE, n=3) for the 12 cohorts (n=100) of *B. dorsalis* on four selected fruits (guava, water apple, rose apple and mango) observed during summer season in 2018-2020

Parameters	Sum of Squares	df	Mean Square	F	Sig.
l_x	87.124	5,18	17.425	487.405	<0.001
q_x	80.235	5,18	16.047	641.862	<0.001
L_x	52.005	5,18	10.401	551.773	<0.001
T_x	29.581	5,18	5.916	428.651	<0.001
e_x	14.843	5,18	2.969	303.240	<0.001
k_x	4.174	5,18	0.835	77.148	<0.001

and mango while, GM, GFR and DT were in reverse (guava< water apple< rose apple< mango) order (Table 3).

Their average developmental durations of *B. dorsalis* on the selected fruits were differed significantly ($F_{3,8} \geq 83.214$; $P<0.001$) like T_c with few deviations within the developmental stages. The average POPs and OVPs were 14.135±0.078, 14.455±0.146, 15.122±0.252, 19.181±0.445 and 22.535±0.076, 22.855±0.149, 23.522±0.242, 26.581±0.618 days, respectively on the selected fruits (guava< water apple< rose apple< mango) with significant ($F_{3,8}$=5.643, P=0.023) variations (Fig. 2). The AS (%) of *B. dorsalis* in different developmental stages ($F_{5,18}$=436.351; P<0.001) on the selected fruits (guava> water apple> rose apple> mango) were varied significantly like l_x (Fig. 3). Thus, the population growth and reproductive parameters of *B. dorsalis* were significantly affected by their hosts (fruits) in respect to their phytoconstituents (Fig. 1) which support the host superiority or susceptibility (guava> water apple> rose apple> mango) to the notorious pest. According to host preference the three fruits (guava> water apple> rose apple) plant can be used in trap cropping for mango as main crop.

DISCUSSION

Modern agriculture includes integrated crop management (ICM) as well as integrated pest management (IPM) for eco-friendly, sustainable and smart agriculture (Cook *et al*., 2007; Chávez *et al*., 2018; Anuga *et al*., 2019). Despite this, it also relies primarily on habitat manipulation through farm scaping, trap cropping and other biological control practices to avoid detrimental effects of chemical insecticides on the total environment (Cook *et al.,* 2007; Holden *et al*., 2012). On the other hand, trap cropping by habitat manipulation is an attractive option to reduce dependency on conventional pest management practices through insecticides (Satarkar *et al*., 2009; Rhino *et al*., 2016). The study of pest population dynamics are widely useful technique in insect pest management (Southwood, 1978; Kakde *et al*., 2014; Roy, 2015, 2018). The development of immature insect pests is known to fluctuate with various abiotic and biotic factors (Roy 2014, 2015; Chen *et al*., 2017). Thus, host plant availability and quality in terms of their phytochemicals play a vital role on pest ecology (Awmack and Leather, 2002; Roy, 2014, 2015). The PMs (carbohydrates, proteins, lipids, amino acids including moisture content) are used for their general growth and reproduction like other animals (Turunen 1990). Whereas, consumption of SMs (phenols, flavonoids, tannin, alkaloids, phytate, etc.) are responsible for reducing their adult longevity, fecundity and retardation of larval growth (Schoonhoven *et al.,* 2005; Roy, 2017, 2019b) due to higher metabolic costs (War *et al.,* 2012). The polyphenols are a common and widespread group of defensive compounds which provide host resistance by antibiosis mechanism against any invading organisms (Bhonwong *et al.,* 2009). Even, oxidation of phenols by polyphenol oxidase or peroxidase produces quinones and it binds covalently with proteins and inhibits its utilization

Table 3. Population dynamics and reproductive table (Mean ± SE, n=3) of the 12 (3 cohorts/host) cohorts (n=100) of *B. dorsalis* on four selected fruits (guava, water apple, rose apple and mango) observed during summer season in 2018-2020

Population parameters	Guava	Water Apple	Rose Apple	Mango	$F_{3,8}$	Sig.
Potential fecundity (Pf)	362.000±12.530	320.667±8.988	273.000±12.490	223.000±9.866	29.363	<0.001
Total fertility rate (F_x)	17600.571± 735.166	13426.596± 834.302	9319.930± 782.561	6150.441498.946	47.182	<0.001
Gross reproductive rate (GRR)	246.025±12.698	197.679±10.315	147.854±11.023	104.986±7.674	33.316	<0.001
Net reproductive rate (NRR or R_0)	176.006±7.352	134.266±8.343	93.199±7.826	61.504±4.989	47.182	<0.001
Generation time (T_c)	148.710±0.433	150.614±0.882	154.627±1.512	194.058±7.452	31.489	<0.001
Doubling time (DT)	19.946±0.208	21.332±0.342	23.692±0.603	32.719±1.236	64.326	<0.001
Intrinsic rate of increase (r_m)	0.035±0.001[a]	0.033±0.001[a]	0.029±0.001	0.021±0.001	83.161	<0.001
Finite rate of increase (ë)	1.035±0.001[b]	1.033±0.001[bc]	1.030±0.001[c]	1.021±0.001	83.214	<0.001
Weelkly multiplication rate ($ë^7$)	1.275±0.003	1.256±0.005	1.228±0.007	1.160±0.007	83.423	<0.001
Increase rate per generation ($ë^{Tc}$)	176.005±7.352	134.266±8.343	93.199±7.826	61.504±4.989	47.182	<0.001
Generation mortality (GM)	0.177±0.003	0.243±0.016	0.332±0.016	0.425±0.016	59.556	<0.001
Mortality coefficient (MC)	0.135±0.004	0.130±0.002	0.125±0.001[d]	0.123±0.001[d]	5.402	0.025
Generation survival (GS)	0.794±0.007	0.780±0.001	0.772±0.002	0.759±0.002	12.581	0.002
Population growth rate (PGR)	2.314±0.041	1.863±0.094	1.368±0.087	0.801±0.049	83.016	<0.001
Population momentum factor of increase (PMF)	31.744±1.449	26.893±1.120	21.703±1.203	16.710±0.854	30.493	<0.001
Population size in 2nd generation (PF_2)	2114.773± 113.351	1543.615± 115.045	1015.707± 95.324	631.437± 54.830	43.594	<0.001
Hypothetical F_2 females (HFF_2)	31086.103± 2641.626	18166.561± 2223.198	8808.591± 1504.924	3832.582± 616.075	39.449	<0.001
Realised F_2 females (RFF_2)	1543.784±82.746	1126.839±83.983	741.466±69.587	460.949±40.026	43.594	<0.001
General fertility rate (GFR)	7.446±0.209	7.678±0.105	8.019±0.070	8.108±0.085	5.641	0.023
Crude birth rate (CBR)	4.451±0.177	4.098±0.095	3.738±0.145	3.252±0.128	13.530	0.002
Reproductive value (RV)	492.049±25.395	395.358±20.629	295.708±22.046	209.972±15.349	33.316	<0.001
Vital Index (VI)	0.184±0.005	0.178±0.002	0.171±0.001[e]	0.169±0.002[e]	5.402	0.025
Trend index (TI)	216.405±11.337	177.101±8.142	139.918±10.030	103.323±7.385	27.000	<0.001

Within the rows means followed by same letter(s) are not significantly different at P<0.05 by Tukey (HSD) test along with *F* values (ANOVA)

by the herbivores (Howe and Jander, 2008). The complex mixture of other SMs in many plants may provide effects in defence against a range of pests (Dicke, 2000; Schoonhoven *et al*., 2005). Never the less feeding on nutritionally poor host plants causes lower fecundity and survivability (Roy, 2014, 2017, 2020). Thus, phytoconstituents of the host plants would help to understand the mechanisms of host suitability or susceptibility as it affects larval survival, fecundity, growth and development (Awmack and Leather, 2002; Mobarak *et al.,* 2019). In this study, host suitability or susceptibility (guava> water apple> rose apple> mango) of *B. dorsalis* was also affected by the phytoconstituents (PMs and SMs) in their population parameters.

Several studies have described the biology of *Bactrocera* species on different artificial diets (Ekesi *et al*., 2007, 2016, Waseem *et al*., 2012; Mir *et al*., 2014; Aslam *et al*., 2019). Jaleel *et al*. (2019) described the two-sex life table parameters of four species in the genus *Bactrocera* e.g., *B. correcta, B. dorsalis, B. cucurbitae* and *B. tau* fed on semi-artificial diet. Only a few studies having focused on the two sex life table traits of *B. cucurbitae* on cucumber and *B. dorsalis* on mango as a natural host plant (Huang and Chi, 2014; Mohamed *et al*., 2019). The suitability of a host for larval development was determined by the nutritional elements, texture of the fruit pulp and chemical composition (Jaleel *et al*., 2019). According to Gomina et al. (2014), the differences of fecundity observed in *Bactrocera* species mainly affected by the diet provided to the larvae. In this instance, the larval development, survival and fecundity of *B. dorsalis* was also affected by the selected fruit diets. The development time of their immature stages and pre-oviposition period of their females was also varied with food resource like *B. cucurbitae* (Waseem *et al*., 2012; Huang and Chi, 2012). *B. dorsalis* was showed almost similar life-history attributes like *B. cucurbitae* and *B. correcta*on the selected fruit diets (Liu *et al*., 2013; Mir *et al*., 2014; Gu *et al*., 2019). The GRR, NRR or R_0, r_m, T_c, DT and λ are fundamental ecological parameters to predict the pest population growth to evaluate the performance of an insect on different host plants as well as their resistance (Roy, 2017, 2019b; Mobarak *et al*., 2019). Further, these are influenced by several factors like development time, survivorship and fecundity rate of an insect which states the physiological status of an insect in relation to its capacity to increase (War *et al*., 2012; Roy, 2019b, 2020). The r_m is an important population parameter in insect development and survival, because it explains the age, sex ratio, survivorship, and fecundity of insect population (Southwood, 1978; Dicke, 2000). The R_o is an indicator of rate of population increase, where the highest rate of population increase is dependent on the fecundity, development and survival of insect pests (Huang and Chi, 2012). Variations in the host plants directly affect potential and achieved development and growth of *B. dorsalis* as in other insects (Awmack and Leather, 2002; Roy and Barik, 2013; Roy, 2014, 2015). The survivorship (l_x) of *B. dorsalis* observed in the twelve cohorts recorded high mortalities during early instar larvae and low mortality during later life stages indicated type III survivorship as in other insect pests (Carey, 1993; Roy, 2017). In general, short developmental time and high reproduction rate are presumed reflect the adaptability of the species. In this study, the life table results displayed that this particular *B. dorsalis* species shows high R_o and λ with lower DT on guava followed by on the other fruits (guava> water apple> rose apple> mango). This showed that the population of *B. dorsalis* has rapid build-up in short period of time on guava than the other fruit diets. In addition, based on the results of life table study, we could better understand when (and why) their populations suffer high mortality. Trap cropping system in different agronomic situations will be greatly enhanced if future research works are conducted with cropping patterns including other ecological concepts (Shelton *et al*., 2006; Holden *et al*., 2012). According to host preference the three fruits (guava> water apple> rose apple) plant can be used as trap cropping system for mango as main crop. Even, sustainable management of *B. dorsalis* can be obtained through judicious control measures at most vulnerable stage(s) by using their life tables for each fruit crop in both mono and poly culture system in near future.

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An appraisal of post flood dengue vector *Aedes albopictus* Skuse (Diptera: Culicidee) surveillance in a coastal district of Kerala, India

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ABSTRACT: Alappuzha coastal district was worst affected by floods due to the heavy rainfall in August 2018. *Aedes albopictus* survey carried out in the post flood/ disaster areas covering 1,140 households revealed maximum larval positivity in plastic/leather followed by metal and earthen containers. The House index ranged from 1.75 to 12.28 per cent whereas the container index ranged from 1.73 to 20.51 per cent. Breteau index ranged from 3.5 to14.3. As dengue is endemic in the district, there exists a potential outbreak of the vector borne disease.

KEY WORDS: Vector borne disease, *Stegomyia* indices, *Aedes*, container index

INTRODUCTION

Vector-borne diseases (VBDs) pose a significant global human threat today, with a number of old diseases resurging in recent decades alongside newly emerging infectious diseases (Smolinski *et al.*, 2003). Dengue is one of the most widespread mosquito-borne viral diseases worldwide. At present dengue is a major public health concern in 128 countries and is still expanding (WHO, 2012, 2020a). The incidence of dengue has grown drastically around the world in recent decades. One of the recent modeling estimates that 390 million dengue virus infections occur annually, with 96 million clinical manifestation and 5,00,000 hospitalization (Bhatt *et al*., 2013). Southeast Asia is the most impacted region with highest incidence of dengue in the world (Undurraga *et al.,* 2013). Dengue is caused by a virus of the family Flaviviridae and there are four distinct, but closely related, serotypes of the virus that cause dengue (DENV-1, DENV-2, DENV-3 and DENV-4). Recovery from infection is considered to provide lifelong immunity against that serotype. But, cross-immunity to other serotypes after recovery is only partial, and temporary. Succeeding infections by other serotypes increase the risk of developing severe dengue. Dengue virus is mainly transmitted by female *Aedes aegypti* (L.) mosquitoes and to a lesser extent, *Aedes albopictus* Skuse. These

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mosquitoes are also vectors of chikungunya, yellow fever and zika viruses. *Aedes aegypti* mosquito is considered to be the major vector of DENV and it breeds mostly in man-made utensils and containers. *Ae. albopictus*, a secondary dengue vector is also known as Asian tiger mosquito and, is highly adaptive and its geographical spreads is largely due to its tolerance of colder conditions, as egg and adult (Romi *et al*., 2006).

Kerala experienced an abnormally high rainfall and received an excess of 96% rainfall during the period from 1st to 30th August 2018. During this period, Alappuzha district in Kerala received 608.2 mm rainfall which is 77% more than the normal rain fall (343.1 mm). The peak spell of rains that led to severe flood in Kerala began on 8th August 2018 and continued up to 17th August 2018. Floods can potentially increase the spread of water and mosquito-borne diseases. Floods may indirectly lead to an increase in VBDs especially mosquito-borne diseases due to the expansion of numerous mosquito breeding habitats. This enhances the possibility of getting exposure to vector mosquitoes in the flood-affected population and pave for the rapid spread of mosquito-borne diseases such as malaria, dengue (WHO, 2019). Dengue fever (DF) was first reported in Alappuzha district in 2003 and since then it is a major public health issue. In the district, dengue cases were reported throughout the year with more number during monsoon and post monsoon seasons. Even in extreme summer season, DF cases are reported in Alappuzha district due to summer rains. Every year hundreds of DF cases are reported and thus Alappuzha became an endemic area for dengue. As per the report of Integrated Disease Surveillance Project (IDSP-DSU, 2016-2018), Alappuzha, the number of DF cases reported in 2016 was 832 with no death; in 2017 it was 1375 with 08 deaths. The dengue fever cases reported in Alappuzha district in 2018 (flood year) was 149 with 1 death. The present surveillance work was done in post flood period in Alappuzha district, one of the coastal districts of Kerala, to determine the major breeding sites of vector mosquitoes and to identify high density vector infested areas so that appropriate and timely vector control activities could be initiated.

MATERIALS AND METHODS

Mosquito larval survey was done by house to house visit in rural and urban areas of Alappuzha district during the post flood period from1st to 30th September 2018. The survey was carried out in 22 rural Panchayaths spread over nine Community Development (CD) Blocks and two urban (Municipality) areas. *Aedes* larval survey was done in 22 Panchayath areas spread over 9 Community Development (CD) Blocks. The areas are Purakkad and Ambalappuzha North (Ambalappuzha Block), Mararikkulam South and Mannancherry (Aryad Block), Thakazhi, Champakkulam, Kainakary and Edatua (Chambakkulam Block), Budhanoor and Pandanad (Chenganoor Block), Cheruthana, Kumarapuram, Pallippad, Veeyapuram and Haripad (Haripad Block), Thaneermukkom and Kanjikuzhi (Kanjikuzhi Block), Vayalar and Ezhupunna(Pattanakkad Block), Thycattussery and Chennam-Pallippuram(Thycattussery Block) and Kavalam (Veliyanad Block). In addition to this the larval survey was also done in 2 urban areas namely Alappuzha and Cherthala Municipal areas. 50 houses each from 21 areas and 30 houses each from 3 areas were selected by random sampling. Thus a total of 1,140 houses were selected from 24 areas in Alappuzha district. For larval survey, house or premise was taken as the Basic Sampling Unit (BSU) and each house/premise was thoroughly searched for water holding containers. All the accessible water holding containers/habitats in and around the houses were checked for the presence of immature stages of mosquitoes and recorded. Larvae/pupae from each positive container were collected separately. The immature stages of mosquitoes from small containers (less than 10 litre capacity) were collected using appropriate Steiner. Larvae and pupae were collected from large containers using modified larval dipper. The larvae/ pupae collected from each container were kept in separate vials labeled with date of collection, name of the locality, house number and breeding source (container type/ habitat). The immature kept in separate vials were placed in rearing jars filled with 150ml freshwater and were covered with fine piece of mosquito net. All larvae were fed with larval diet (prepared by mixing 12.5 g of tuna meal, 9.0 g

of bovine liver powder, and 3.5 g of Yeast, in 100 ml of distilled water). Larvae and pupae were reared until the emergence of adults and the mosquitoes were identified using standard key (WHO, 2020b). *Aedes* larval indices - House index (HI), Container index (CI), Breteau index (BI) and the Breeding Preference Ratio (BPR) of vector mosquitoes were analyzed.

RESULTS AND DISCUSSION

During the survey a total of 1,258 containers were checked for larval presence. In addition to this, fridges (12 nos.) and wells (15nos.) were inspected for mosquito larvae. None of the fridges have immature but mosquito larvae/ pupae could be collected from 13 % of the wells from the survey area (Fig. 1). Of the total 1,258 breeding sources examined, maximum positivity was found in plastic/ leather (39.03%), followed by metal containers (25.70%), earthen (mud pots, mud jars, flower pots) containers (17.80%) and glass bottles (6.12%).

In most of the houses in Kuttanad area, supply of water is only twice in a week. This forced the households to store the water in the available containers; most of them were without proper lid/ covering. This leads to breeding of *Aedes* mosquitoes in these containers. A total of 116 water stored containers without proper covering were checked for larval presence; 24 (20.68%) of them were having mosquito larvae. Many discarded/dry containers were seen scattered in the peridomestic area. House index ranged from 1.75- 12.28 percent. Container index (CI) ranged from 1.73 -20.51 percent. CI was minimum (1.73%) in Cherthala Municipal area (Ward No.13) and it was maximum in Ward No.4 of Ezhupunna Panchayath (20.51%). Breteau index (BI) noted was minimum in Ward No.1 of Kainakary Panchayath (3.5) while maximum (14.03) BI was noted in Ezhupunna Panchayath area (Fig. 2).

The larvae and pupae collected from each survey area were reared under laboratory conditions and the emerged mosquitoes were identified. Of the total 115 adult mosquitoes emerged, 85 (73.91%) were *Aedes albopictus*, 4 (3.48%) were *Aedes vittatus*, 15 (13.04%) were *Culex quinquefasciatus* and 11 (9.57%) were *Armigeres subalbatus* mosquitoes. Of the total *Aedes* mosquitoes emerged, 95.5% were *Ae.albopictus.* This indicates *Ae. albopictus* is the predominant *Aedes* mosquitoes prevalent in Alappuzha district.

The location and type of water holding containers seen scattered in the house premises may influence site selection of *Aedes* mosquitoes for oviposition. Study related to the breeding preference of *Ae. albopictus* mosquitoes in post flood situation is meager. Hence an analysis has been done to find out the most preferred breeding sources of *Ae. albopictus* in post flood situation in Alappuzha district (Fig.3). The Breeding Preference Ratio (BPR) was found to be more in cement tanks (5.0) and overhead tanks (5.0) followed by grinding stones (4.0) and tires (2.0).

Kerala received heavy monsoon rainfall in mid-August 2018 that resulted in severe flood in almost all districts. Floods are one of the natural disasters occurring worldwide which have a wide range of health impacts. Flood can increase the transmission of water borne and air borne diseases. In addition to this, flood can intensify the transmission of vector borne diseases such as West Nile Fever (WNF) and Dengue fever (Babaie *et al.,* 2015). Climate change scenario is coincided with the emergence and re-emergence of *Aedes* borne diseases such as dengue, chikungunya and zika. The rapid urbanization, travel, trade, demographic changes, globalization, global warming, and inadequate water supplies are key factors favoring the spread of *Ae. aegypti* and *Ae. albopictus* mosquitoes, the vectors of dengue.

Dengue is a major public health concern in Alappuzha since 2003. It has been found that among the *Aedes* mosquitoes, *Ae. albopictus* was the most predominant species prevalent in Alappuzha (Sheela Devi, 2011; Rajendran *et al*., 2020). After the flood, mosquito borne viral diseases such as dengue fever especially in endemic areas can increase. Standing water after overflow from different natural and man-made water sources could act as breeding sites of mosquitoes. Thus,

one may naturally expect a sudden increase of mosquito borne diseases such as dengue in the flood affected areas of Alappuzha district.

The report of IDSP, Alappuzha showed that there was less number of dengue cases in 2018 in comparison to the number of cases reported in 2016 and 2017 in the district (IDSP-DSU, 2016-2018). This is possible because the flood had swept away most of the immature stages of mosquitoes. Many of the small and medium sized containers might have swept away due to heavy downpour. Of the 22 rural areas surveyed, nearly 45% of the areas were from Kuttanad region (Champakkulam, Haripad and Veliyanad Blocks) of Alappuzha district. Kuttanad is well known for its vast lowland, flooded and single crop seasonal paddy fields. The region has the lowest altitude in India, and is one of the few places in the world where agricultural farming is carried on in 4-10 feet lowland below mean sea level. This is a backwater area formed by confluence of four major rivers-Pampa, Meenachil, Achankovil and Manimala prior to final emptying in to the Arabian Sea. This area is unique with vast network of backwaters, the Vembanad Lake and lagoons criss-crossing the land.

Area wise data on communicable diseases in Alappuzha district during the last 10 years (IDSP-DSU, 2010-2019) indicates that the number of dengue fever cases in Kuttanad area were less when compared with other areas. This is mainly related to the attitude of the local inhabitants. Kuttanad being a water-logged area, most of the houses are on the bank of the river/canal. After cleaning the house premises, the households usually strew the things including the small and medium sized containers into the nearby water bodies. Hence the chance of mosquito breeding especially *Aedes* mosquitoes in these areas is very less. Because of this reason, in each year only very few dengue fever cases have been reporting from Kuttanad area. The team locating only on an average 1.04 containers per house in this area substantiates the aforesaid contention.

The traditional indicators of vector surveillance are House index (HI), Container index (CI) and Breteau index (BI) and continue to be the main surveillance tool to predict and prevent *Aedes*-borne diseases. The *Stegomyia* indices have been developed as quantitative indicators to predict the impending outbreak of dengue. However the reliability of these indices in assessing the epidemiological situation and vector control operations is still a debatable point. The HI has been most widely used for measuring the larval infestation level. But it does not give the number of positive containers per positive house. The CI provides information only on the proportion of water-holding containers that are positive. It does not take in to account the productivity of the containers (Focks, 2003). The BI establishes a relationship between positive containers and houses. Thus BI is considered to have some relevance in assessing the risk of dengue infection in an area. As the container productivity is not taken in to account, BI could not serve as a potential Risk Assessment Index (RAI) but remains only a Guiding index (GI).

In the present study, maximum *Aedes* larval positivity was found in plastic/leather (39.03%), followed by metal containers (25.70%), earthen containers (17.80%) and glass bottles (6.12%). In a study related to the post flood vector surveillance in Ernakulam district (Samuel *et al.*, 2019) reported a similar observation. However the vector borne disease surveillance in Malappuram district after 2018 flood, it has been found tires, plastic and earthen containers are the most preferred *Aedes* breeding habitats (Lalthazuali *et al*., 2020). The container positivity reflects only the number of containers positive in an area and it does not give the number of larvae/pupae in these containers. For instance, in some small water holding containers, there may be enough larvae, on the other hand in containers with more volume of water, the number of *Aedes* larvae may be less and vice versa. The field observations indicate that the most common containers are often not the most productive (Focks and Alexander, 2006).

In the post flood situation, due to severe disruption of ecosystem, the availability of breeding sources of mosquitoes may also differ. Sometimes due to lack of proper habitats in nearby resting places, the

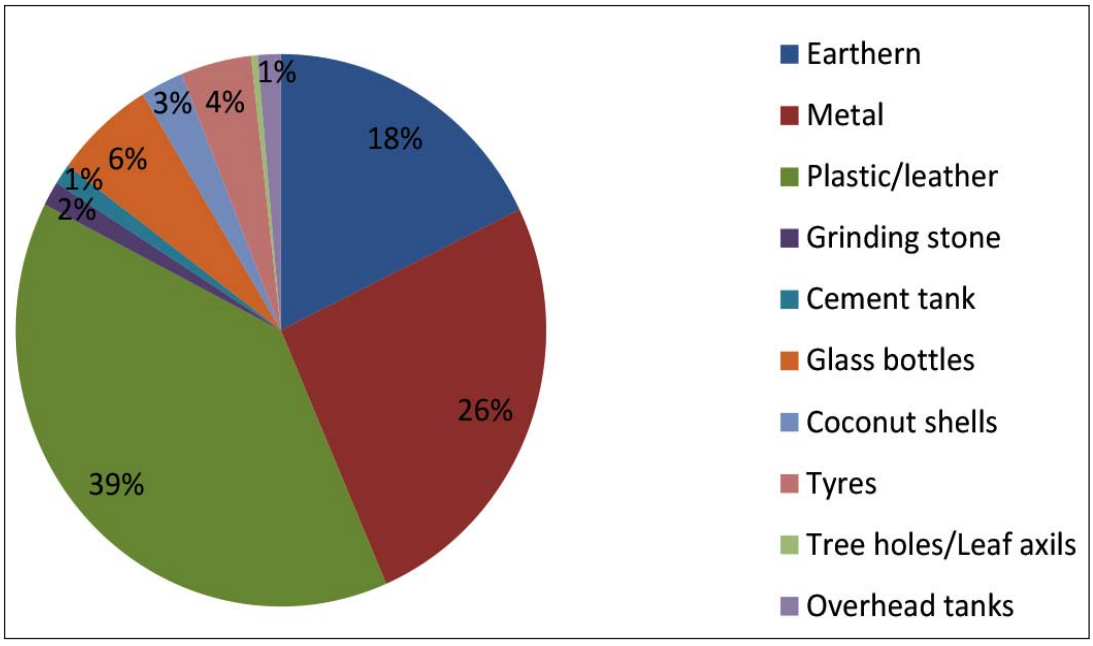

Fig. 1. Different types of containers/habitats checked in 24 localties (n = 1258) in Alappuzha District (%)

mosquitoes may force to fly in areas in search of suitable oviposition sites. In short, due to the changes in the environment, the behavior of the mosquitoes may also differ. Study related to the breeding preference of *Ae. albopictus*, the vector of dengue, in post flood situation is meager. Hence an analysis has been done to find out the most preferred breeding source of *Ae. albopictus* in post flood situation in Alappuzha district. The Breeding Preference Ratio (BPR) was found to be more in cement tanks and overhead tanks followed by grinding stones and tires. In an earlier study in Alappuzha district showed that the most preferred breeding sites of *Ae.albopictus* mosquitoes were tires followed by plastic containers (Rajendran *et al*., 2020). Due to unprecedented flood, almost all small and medium sized containers might have washed away. The cement tanks, overhead tanks and grinding stones remain as such. In the absence of most suitable breeding sites in the flood affected area, *Ae. albopictus* preferred to lay eggs in tanks and grinding stones. This is a classic example to illustrate the high adaptability of these mosquitoes. This also indicates that even breeding preference of *Ae. albopictus* may differ in tune with the changing environmental conditions. Therefore caution must be taken while referring breeding preference of *Aedes* mosquitoes in any locality.

Normally, in *Aedes* survey only those containers checked and positive for larvae/pupae are taken in to account leaving the actual number for calculating indices. The rate of emergence of adult mosquitoes from each type of container may likely to differ depending upon the number of immature stages of mosquitoes present. Hence for localities with similar larval indices and having different container profiles, the number of adult mosquito emergence may differ. This may create difficulty in assessing the transmission potential or epidemiological link of *Aedes* borne diseases.

The *Aedes* larval indices such as HI, CI and BI are commonly used to determine priority areas to determine vector control interventions. Generally, a HI greater than 5% and/or a BI greater than 20 for any locality are an indication that the locality is dengue sensitive. Earlier, *Aedes* larval indices were proposed to prevent outbreaks of yellow fever (YF). HI, 1% or less, BI, 5 or less has been considered to prevent dengue transmission because of the

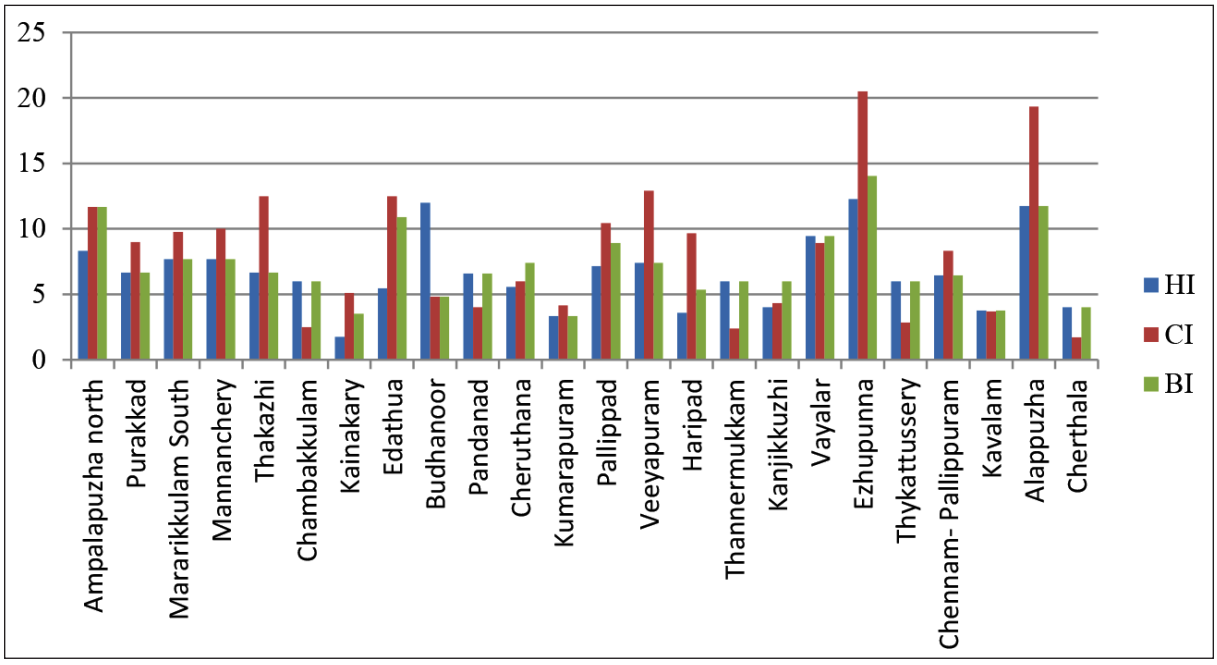

Fig. 2. Area-wise *Aedes* larval indices in Alappuzha district

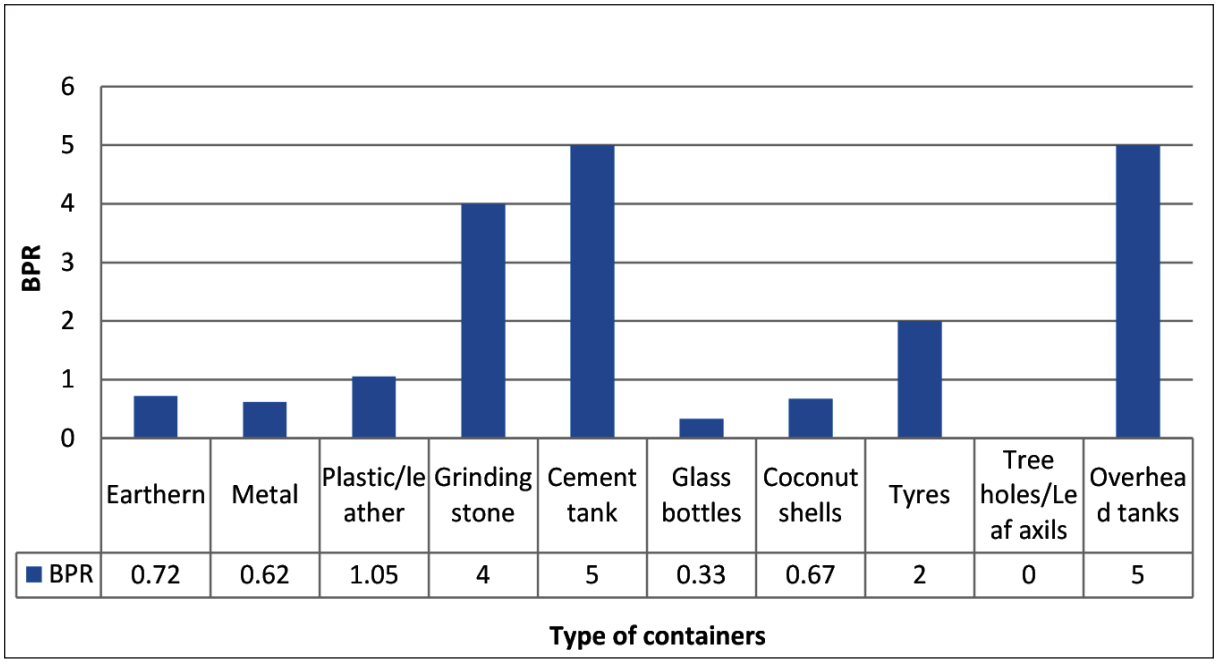

Fig. 3. Breeding Preference Ratio (BPR)

epidemiological similarities of both DF and YF (Kuno, 1995). But as per the Pan American Health Organization (1994), the dengue transmission can be assessed with the help of 3 levels of risk factors – low (HI<0.1%), medium (0.1% -0.5%) and high (HI >5%). The reliability and sensitivity of these indices in assessing *Aedes* borne diseases in different localities are yet to be ascertained (Cromwell *et al*., 2017; Garjito *et al*., 2020). Critical vector density as a risk factor in predicting dengue transmission is always a topic of much debate and conflicts.

In the present study, the predominant *Aedes* mosquitoes prevalent in Alappuzha district were noted as *Ae. albopictus*. As dengue is endemic in this district, there exists a potential threat of disease transmission. Normally one should expect an increase in vector-borne diseases such as dengue in flood affected areas. This is because of rapid increase in numerous mosquito breeding habitats. But the number of DF cases reported in Alappuzha district in the post flood period (September to December 2018) was 67. However in 2017, during the same period, the number of DF cases reported in the district was 246 ie, 3.7 times more than that of 2018. This clearly indicate that there was a significant reduction in dengue cases in 2018 post flood period when compared to the previous year. This is because of the devastating flood might have destroyed the immature and adult mosquitoes. Another major contributory factor for the reduction of dengue cases in post flood situation may be attributed to the vector control measures taken by the Local Self Governments (LSGs) and local health centers with the advice of central and state health teams.

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Tyrophagus putrescentiae (Schrank) (Astigmata: Acaridae) as natural enemy for wood boring pest, *Psiloptera fastuosa* F. (Coleoptera: Buprestidae) in tropical tasar

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ABSTRACT: In tasar silkworm culture the stem-boring jewel beetle *Psiloptera fastuosa* Fabr. (Buprestidae: Coleoptera) is considered as a major pest of tasar plant (*Terminalia arjuna*, Combretaceae) cultivation. The grubs of *P. fastuosa* often damage the *Arjuna* stem by causing dieback. *Tyrophagus putrescentiae* Schrank (Acari: Acaridae) infested buprestid eggs up to 15% and caused egg mortality up to 9%. The mite predation on the buprestid beetle is reported for the first time. The mite seeps the newly-laid egg-fluids causing the egg mortality suggesting that tasar plant stem-boring pest (*P. fastuosa*) can be partially controlled by the mite as a natural enemy.

KEY WORDS: Tasar culture, mite-predation, buprestid eggs, biological control

INTRODUCTION

Tropical tasar silkworm culture is one of the major agricultural industries in central Indian provinces providing business and employment. Among non-mulberry silks, tasar silk is considered the second largest cash-crop from the tropics. *Antheraea mylitta* (Lepidoptera: Saturniidae) produces of this natural-protein-rich silk (Kundu *et al*., 2012). The tasar silkworms usually consume leaves from two plant species from Combretaceae family viz., *Terminalia arjuna* (Arjuna) and *Terminalia tomentosa* (Asan). Therefore, *Terminalia* species are considered as primary food plants for tasar silkworms (Ojha *et al*., 2009; Manabendra and Minu, 2013). Nearly 10-15 million hectares of land are being used for tasar plant cultivation (*T. tomentosa*) from central Indian provinces, but due to systematic denudation and destruction of forest, large areas of naturally-grown Tasar plantation (*T. tomentosa*) have been lost in forest fringes during the last couple of years (Sinha and Srivastava, 2002). To compensate the loss of naturally-grown *T. tomentosa*, large scale plantation of fast-growing *T. arjuna* plants were done in the affected zones. But extensive monoculture of such raised plantations has also made these plants vulnerable to various pest attacks (Singh and Saratchandra, 2002 and Singh *et al*., 2004) and among them buprestid insects are predominant.

The newly-grown Arjuna plants (*T. arjuna*) are mainly infested by a metallic green folivorous stem-boring insect, *Psiloptera fastuosa* (Fabricius,1775)

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(Coleoptera: Buprestidae) (Singh *et al.,* 1987, 1989; Mandal, 2007). The grubs of *P. fastuosa* often girdle inside the stem of young Arjuna and restrict translocation of plant nutrients and retard plant growth and development. As a result, the infested plants die (Dhar *et al*., 1989; Mandal and Singh, 1990; Tirkey *et al*., 2019). The stem-boring coleopteran is considered as a major pest for primary tasar food plant, *T. arjuna* (Reddy *et al.,* 1996). To control this pest, chemical pesticides though applied in some occasions but due to crypto-biotic nature of *P. fastuosa* grub, no effective measures have yet been successful. Therefore, the scope of biological control of this notorious pest is important. The absence of information regarding biotic check for buprestid beetles and its grubs by natural enemies makes it more challenging to monitor and control in changed habitats. Published literature also lacks in information on its natural enemies except for a few instances where the importance of buprestid natural enemies has only been reported so far (Mandal, 2007). Therefore, we conducted our investigation aiming to find out existence of any biological control agent for *P. fastuosa* and second, we paid attention to examine how egg mortality of *P. fastuosa* varied upon the parasitic/predatory intervention of that controlling agent.

MATERIALS AND METHODS

Field Study

Buprestid egg-masses were randomly collected from young Arjuna plants (7±2 years, mean ± SD) from four tasar plantation sites of Pali, Chhattisgarh, India (22.37° N, 82.32° E) during the breeding season of the beetles (September to October) for a period of three consecutive years (2016 to 2019). Study sites were maintained and managed by Central Tasar Research & Training Institute (CTRTI), Ranchi, Government of India. Average aerial distance between two sites was 5±2 km and each site was surrounded by mixed deciduous degraded forest vegetation. During field collection environmental temperature (25±3°C) and relative humidity (70±5% RH) were moderate without any incidence of rainfall. Beetle infested plants were spotted by observing yellowish scares on Arjuna shoot. The spotted plants were ribbon-marked for the year and selected for egg-mass collection. Throughout the survey, 1025 egg-masses were collected by digging the bark of the plant (0.2-1.2 cm) for three consecutive years (year I; n=278; year II; n=351; year III; n=396). Excavated egg-masses were transported to the laboratory and numbers of eggs per egg-mass were counted accordingly.

Microscopic study

Out of 1025 egg masses, a portion (n=205) of egg-mass was transferred to FAA (formaldehyde-acetic acid-alcohol) medium (Talbot and White, 2013) for taxonomic identification and the remaining portion (n=820) was kept in moist aerated test tubes so that the eggs were remained alive until further experiment. Mouths of test tubes were tightened with distilled-water-soaked-cotton-balls to keep it humid. Therefore, 205 randomly selected egg-masses were considered for mite identification (year I: 52; year II: 72, and year III: 81) under microscope (Leica, Wild M8). During this process of identification, if any mite was noticed, they were isolated and counted year-wise and thereafter identified taxonomically. The remaining portion of egg-masses (n=820) were separated again into two groups, a) non-infested egg-mass, where egg-masses were free from any mite attack, and b) infested egg-mass, where presence of any mite was recorded. During this separation, some adult alive mites (both males and females) were isolated from infested egg-masses in moistened test tubes.

Egg mortality assay of *P. fastuosa* by mite attack

Non-infested egg-masses were used for egg mortality assay. Non-infested egg-mass was kept in glass Petri-dish (8 mm diameter) and covered by a fine cotton mesh to prevent any contamination. Two groups of experimental sets (Set A and Set B) were prepared from these egg-masses. In Set A, 20 Petri-dishes were prepared and in each of which only one non-infested egg-mass was placed (control). Similarly, in Set B, another 20 replicates were prepared with non-infested egg-masses, but in each of which 3 to 4 adult mites were inoculated

(treatment). The number of eggs per egg-mass was counted for each replica. Both the 'control' (n=20) and 'treatment' (n=20) Petri-dishes were kept at BOD incubator (25±3°C and 70±5% RH) for 21 days. During this period, each Petri-dish was observed daily to notice any nymphal emergence. When the eggs hatched out from a replica, either from 'control' or 'treatment', the number of emerged nymphs were counted accordingly. Similar to a few earlier reports we also noticed that mites generally seep the egg-fluids and as a result the egg dies (Moser, 1975; Brust and House, 1988; Canevari *et al*., 2012). After 21 days, total numbers of emerged hatchlings were pooled together. Numbers of non-hatched eggs from both sets (control and treatment) were also counted separately. Egg mortality (%) was calculated based on non-hatched eggs by the formula: number of non-hatched eggs / number of eggs taken for experiment × 100 (Hughes, 1959; Colloff, 1987). Egg mortalities were analysed and compared between 'control' and 'treatment' sets using SPSS software (ver. 25).

RESULTS AND DISCUSSION

During the field investigation buprestid eggs were found infested with mites and it was identified as *Tyrophagus putrescentiae* Schrank (Acari: Acaridae). It showed predation of *P. fastuosa* egg-masses in several occasions. Infestation incidence of *T. putrescentiae* on buprestid eggs has never been reported before. However, *T. putrescentiae* was earlier reported as a common store-grain-product pest (Eaton and Kells, 2011; Freitag and Kells, 2013) and usually attacked coccid eggs (Collins, 2006; 2012).

Buprestid beetles used to lay eggs inside the barks of *Terminalia* plants from late September to late October, but the mite finds its way and attacked buprestid eggs inside the bark. Like a few previous records it was observed that *T. putrescentiae,* the mould mite oviposit its eggs on Buprestid egg masses; usually seeps the newly-laid egg-fluids and as a result the eggs die (Moser, 1975; Brust and House, 1988; Canevari *et al*., 2012). Moreover, the mite passed rest of its life-stages (larva to adult) on the beetle's egg-mass by consuming the eggs maintaining their ovivorous feeding habit (Balazy and Kielczewski, 1965). Among the studied 205 buprestid egg-masses from three successive years, an average of nearly 12% egg-mass (range, 9-15%) was noticed predated by the mite (Table 1). Egg mortality of *P. fastuosa* was recorded 53±14.14% (mean±SD) for non-infested eggs (in control sets), but due to mite-predation egg mortality of *P. fastuosa* significantly increased to 62±15.87% (mean±SD) (ANOVA, $F_{1, 38}$ =7.02; p=0.012) (Fig. 1).

Several natural enemy complexes have been reported so far by numerous authors as controlling agents for several buprestid beetles across the world (Carlson and Knight, 1969; Loerch and Cameron, 1983, Bauer *et al*., 2005; Sallé, 2016; Wang *et al*., 2016; Zang *et al*., 2017; Abell *et al*., 2020). Mortality studies of buprestid eggs were mainly caused by parasitoids, however, pathogens and

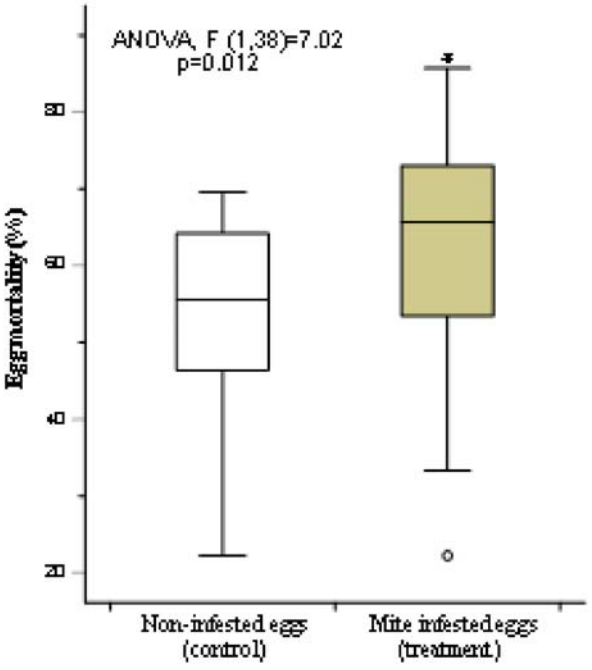

Fig. 1. Egg mortality % of *P. fastuosa* due to mite infestation (treatment) compared to non-infested eggs (control) at laboratory conditions. Each box represents 20 mortality assays (total assay, n=40). * indicates ANOVA (one way) result was statistically significant (p<0.05), transects in interquartile range indicate median value scaled in Y-axis, the circle indicates potential outlier

Table 1. Occurrence frequency of eggs per egg-mass of beetle (*P. fastuosa*) and mite (*T. putrescentiae*) infestation frequency to beetle's eggs

	P. fastuosa		***T. putrescentiae***	
	Egg mass observed/ Collected egg mass	Eggs counted/ Observed egg mass	Mites observed/ Counted eggs	% of eggs infested by mite
Year I	52/278	339/52	51/339	15.04
Year II	72/351	491/72	44/491	8.96
Year III	81/396	634/81	74/634	11.67
Total/Mean ± SD	205/1025	1464/205	169/1464	11.54±3.05

predators were also described in a few occasions (Oliveira *et al*., 2003). Most of the buprestid egg parasitoids were reported from hymenopteran insects from families Encyrtidae, Braconidae and Ichneumonidae. For example, natural enemies of Willow wood-borer, *Agrilus fleischeri* (Coleoptera: Buprestidae) were the parasitic non-stinging wasp, *Oobius* sp. (Hymenoptera: Encyrtinae) (Zang *et al*., 2017), where natural enemies for emerald ash borer, *Agrilus planipennis* were reported 3 species from braconids, 1 species from chalcid and an eupelmid parasitic wasp (Bauer et al, 2005). Another survey describes a complex of natural enemies including eight hymenopteran insects damage buprestid eggs (Zhang *et al*., 2003; Abell *et al*., 2020). Besides these, ichneumonid wasps were also reported on several occasions as potential parasitoids for buprestid beetles. At least 2 ichneumonid species along with 2 braconids and 1 chalcid established parasitoid on the sap-borer, *Trachypteris picta* (Kenis and Hilszczanski 2004). Solians (1974) has described several species of parasitoids (braconid and ichneumonid) for the Oak-borer buprestid, *Coraebus florentinus* larval instars. However, there was no report of any acarine parasite or predator record on buprestid eggs.

In most of the instances egg mortality of buprestid beetles varied approximately from 10 to 50%, though in some instances much lower value was observed. Variation of buprestid egg-mortality was described as an outcome of several reasons like varied geographic occurrence of the beetle, changes of sampling season, variation of forest plantation etc. (Bauer *et al*., 2005; Wang *et al*., 2016; Sallé, 2016; Zang *et al*., 2017; Abell *et al*., 2020). Mite infestations to a few coleopteran beetles, except buprestid, were reported. For example, a large number of *Caloglyphus* mites parasitized on Cranberry white grub, *Phyllophaga anxia* (Scarabaeidae) (Jarvis, 1964); the ovivorous mite, *Tarsonemoides gaebleri* fed spruce bark beetles, *Ips typographus* (Scolytidae) (Balazy and Kielczewski, 1965); the water mite, *Eylais* sp parasitized a variety of aquatic coleopterans beetles like *Dineutus nigrior* (Fairn *et al*., 2008) etc. Mites from several genera were reported as controlling agent for several coleopteran borers like *Sternochetus lapathi* (Curculionidae), *Pseudopityophthorus minutissium* (Scolytidae), and *Aphanisticus cochinchinae seminulum* (Buprestidae) (Berry and Bretz, 1966; Hall *et al*., 2005). The straw itch mite, *Pyemotes tritici* (Acari: Pyemotidae) was discovered parasitizing the gold spotted oak borers, *Agrilus auroguttatus* in the USA, and *Agrilus coxalis* in Mexico (Loghmani *et al*., 2014). Parasitizing mites, *Pyemotes* (Acarina: Pyemotidae) parasitoid on jewel beetle, *Ovalisia festiva*, and maintained a biological relationship (Ruseva *et al*., 2020).

The mite caused significant additional mortality to beetle's eggs up to 9% (mite-infested egg mortality: 62%) than its natural death (53%). Our result agrees with the observation of Canevari *et al*. (2012) where the authors noticed predation of *T. putrescentiae* on tobacco pest larvae, *Lasioderma serricorne* (Fabricius, 1792) (Coleoptera: Anobiidae) varied from 54 to 78%, depending on the larval stage.

Under laboratory trials the mite, *T. putrescentiae* showed a significant predatory activity to the beetle's eggs and therefore, the mite can be treated as a natural enemy for tasar plant stem boring pest, *P. fastuosa.*

Mites belonging to genus *Tyrophagus* have though been reported as parasitizing agent (Brust and House, 1988; Kumar, 1997) or predator for some insect groups such as beetles (Papadopoulou, 2006; Canevari *et al*., 2012), flies (Serpa *et al*., 2004), and bees (Maggi 2011; Texeira *et al*., 2014), but surprisingly no report has yet been available on *Tyrophagus* attack to any buprestid beetle. *Tyrophagus putrescentiae* (Schrank, 1781) is reported for the first time as an egg predator to buprestid beetle, *P. fastuosa.*

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Bio-efficacy of *Millettia pinnata* oil soap in the suppression of brinjal fruit and shoot borer, *Leucinodes orbonalis* Guenee

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ABSTRACT: A field experiment to evaluate the efficacy of pungam (Millettia/Pongamia) oil soap at four different concentrations against brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* Guenee and its effect on spiders of brinjal field revealed that application of 3% pungam oil soap brought down fruit damage to minimum level (12.94% on 7 days after third spray) followed by chlorantraniliprole 18.5% SC (0.3 mL/L), 2, 1 and 0.6% pungam oil soap and neem oil soap 0.6%. Efficacy of chlorantraniliprole persisted up to 14th day of spray followed by pungam oil soap. None of the botanical or chemical pesticides found to influence the spider population until seven days. After 14 days of application soap solution either alone or with pungam oil increased spiders over the control whereas 14 DAS it was minimum in standard check.

KEY WORDS: BFSB, pongamia, botanicals, spiders, chlorantraniliprole

INTRODUCTION

Brinjal, *Solanum melongena* L. is one of the principal vegetables crops in the country. India ranks second in brinjal production with 12.80 MT of production (NHB, 2018). The destructive pest of brinjal is fruit and shoot borer (BFSB), *Leucinodes orbonalis* G. (Lepidoptera: Crambidae) which causes enormous yield loss. As high as 70-92 per cent yield loss has been reported in India (Rosaiah, 2001). The pest is also reported to cause 47.6-85.8 per cent fruit damage and 3.3-68.9 per cent flower damage in India (Patnaik, 2000). Rising concerns on adverse impact of insecticides necessitates the development of environmentally safe and sustainable pest control. Pongam/karanj oil is one such eco-friendly biocide which can be used against wide range of pests. Pungam/pongam/Indian beech/ karanj, *Millettia pinnata* (L.) Pierre is a multipurpose tree, particularly valued for its oil which is derived from their seeds (27 - 40% oil). The toxicity of karanj oil against pests is mainly attributed to furanoflavones such as karanjin, pongapin, kanjone, diketone pongamol *etc*. (Bringi, 1987). A field experiment was undertaken to evaluate the efficacy of pungam (Millettia/ Pongamia) oil soap at four different concentrations against brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* Guenee and its effect on spiders.

MATERIALS AND METHODS

Pungam oil soap was made as per the technology used for 'Ready To Use neem oil garlic soap', the botanical released by KAU (Varma, 2018). To

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prepare the pungam oil soap, 55 g of caustic soda mixed in 100 ml of water and kept for 4 h was blended thoroughly in to solution made of 55g soap stone powder mixed in one litre pungam oil and kept for solidification. pH of the pungam oil soap solution prepared was 10.5 and the saponification value of the oil was 194 mg KOH/g of oil. Neem oil soap 0.6% and two new generation insecticides were also included as treatments to compare the results of pungam oil soap.

The experiment was carried out on brinjal variety 'Surya' under randomised block design (RBD) with eight treatments (Table 1) and three replications at Instructional farm II, Karuvachery, College of Agriculture, Padannakkad. Brinjal seeds were sown in pro trays and one-month old seedlings were transplanted in a plot of 3.4 X 2.8m^2 size each with the spacing of 60 X 60 cm. The treatments imposed in the experiment include; chlorantraniliprole 18.50% SC (Spray I and III) and thiamethoxam 25% WG (Spray II) (T_1); pungam oil soap 3% (T_2); pungam oil soap 2% (T_3); pungam oil soap 1% (T_4); pungam oil soap 0.6% (T_5); neem oil soap 0.6% (T_6); soap solution 0.5% (T_7) and control (T_8).

The pungam oil soap at 30, 20, 10 and 6g per litre were used to prepare 3, 2, 1 and 0.6% oil soap solutions and knapsack sprayer was used for spraying. Three sprays were given at 28th January, 25th February and 15th April 2020 during morning hours to avoid drift. Five representative plants (among 12 plants) were selected and tagged for taking observations. Fruit infestation by BFSB was recorded as per cent fruit damage and spiders was recorded as population count (per five plants) at

Table 1. Fruit damage by BFSB, *Leucinodes orbonalis* in different treatments

Treatments	Mean % of infested fruits *					
	First application		Second application		Third application	
	7 DAS	14 DAS	7 DAS	14 DAS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 0.3 ml/l - 1st & 3rd application & Thiamethoxam 25 WG 0.2g/l - 2nd application	16.92 (24.17) ^{c}	18.38 (25.37) ^{b}	38.14 (37.60) ^{cd}	64.23 (53.27) ^{bc}	30.36 (33.32) ^{cd}	34.49 (35.92) ^{de}
Pungam oil soap 3%	15.66 (23.25) ^{c}	16.28 (23.49) ^{b}	22.17 (28.04) ^{d}	32.77 (34.82) ^{d}	12.94 (20.93) ^{e}	30.95 (33.76) ^{e}
Pungam oil soap 2%	15.77 (23.38) ^{c}	20.36 (26.80) ^{b}	29.52 (32.86) ^{cd}	38.06 (38.09) ^{d}	24.91 (29.77) ^{d}	37.54 (37.77) ^{de}
Pungam oil soap 1%	20.51 (26.88) ^{c}	21.81 (27.49) ^{b}	30.63 (33.60) ^{cd}	40.30 (39.42) ^{d}	31.53 (34.12) ^{cd}	39.73 (39.07) ^{cd}
Pungam oil soap 0.6%	22.64 (28.29) ^{bc}	25.26 (29.83) ^{b}	42.61 (40.72) ^{bc}	49.10 (44.48) ^{cd}	38.98 (38.57) ^{c}	47.84 (43.76) ^{c}
Neem oil soap 0.6%	29.78 (32.85) ^{b}	57.71 (49.70) ^{a}	61.64 (51.81) ^{a}	80.51 (64.76) ^{ab}	67.51 (55.36) ^{b}	85.94 (68.29) ^{b}
Soap solution 0.5%	31.25 (33.98) ^{b}	44.90 (42.03) ^{a}	57.04 (49.08) ^{ab}	76.18 (61.19) ^{ab}	70.27 (57.26) ^{b}	85.08 (67.51) ^{b}
Control	46.52 (43.00) ^{a}	60.03 (50.82) ^{a}	64.22 (53.36) ^{a}	84.26 (68.24) ^{a}	82.77 (65.70) ^{a}	93.57 (75.37) ^{a}
C.D.(*P*=0.05)	8.78	17.80	17.00	17.20	12.80	6.91

* Mean of five observations; Means superscripted by same letters are not significantly different at 0.05
Figures in parentheses indicates arc sine transformed values; DBS- Day Before Spray; DAS- Days After Spray

weekly intervals after spray (7th and 14th day). The data on per cent fruit damage were analysed after arc sine transformation (angular transformation) and the spider population count was analysed after square root transformation by analysis of variance (ANOVA). Web Agri Stat Package (WASP) software was used to analyse the data.

RESULTS AND DISCUSSION

BFSB damage was significantly reduced by the application of pungam oil soap 3% with only 15.66 per cent fruit damage on seven days after first spray (DAFS) (Table 1) which was on par with pungam oil soap 2% (15.77%), chlorantraniliprole 18.5 SC @ 0.3 ml/l (standard check) (16.92%) and pungam oil soap 1% (20.51%). Pungam oil soap at 0.6% showed 22.64 per cent fruit damage which was significantly different from neem oil soap 0.6% and soap solution 0.5%. The lowest BFSB infestation was observed in pungam oil soap 3% on 14 DAFS also followed by standard check, 2, 1 and 0.6% pungam oil soap. The efficacy of neem oil 0.6% decreased on 14th day of application which was on par with soap solution 0.5% and control.

During second spray also, application of pungam oil soap 3% resulted in minimum of 22.17 per cent fruit damage followed by pungam oil soap 2%, 1%, standard check- (thiamethoxam 25 WG) and pungam oil soap 0.6% at 7 DASS (days after second spray). The efficacy of neem oil soap 0.6% started to decrease from second spray onwards which was on par with control and soap solution 0.5%. Pungam oil soap 3% remained effective in reducing BFSB infestation on 14 DASS followed by pungam oil soap 2%, 1% and 0.6%. Control suffered maximum fruit damage. Neem oil soap 0.6% and soap solution 0.5% had damage on par with control. Standard check (thiamethoxam) showed 64.23 per cent mean fruit damage which was statistically on par with pungam oil soap 0.6%, soap solution 0.5% and neem oil soap 0.6%.

The per cent fruit damage was effectively reduced to 12.94% by pungam oil soap 3% on seventh day after third spray (DATS) which was followed by pungam oil soap 2%, standard check (chlorantraniliprole) and pungam oil soap 1%. Pungam oil soap 0.6% was on par with pungam oil soap 1% and standard check while standard check and pungam oil soap 1% were at par with pungam oil soap 2%. Neem oil soap was on par with soap solution. At 14 DATS, pungam oil soap 3% remained statistically superior over other treatments followed by standard check and pungam oil soap 2%. The highest BFSB infestation was recorded in control (93.57%). Pungam oil soap 1 and 0.6% were found to be statistically on par with each other. Soap solution and neem oil soap were less effective at 14 DATS.

Pungam oil soap at 3% reduced the fruit damage significantly in all the three sprays at seventh and fourteenth days after treatment application followed by 2, 1 and 0.6% pungam oil soap. Similar findings were given by Sahana and Tayde (2017) in which, next to the spinosad 0.1 ml/l (6.38%) and neem oil soap 3% (9.66%), pongamia oil 3% recorded minimum fruit infestation of 10.28. In the study conducted by Sureshsing and Tayde (2017), 3% pongamia oil was effective against BFSB in reducing the fruit damage with the mean fruit infestation of 11.57 and 12.40 per cent during second and third spray respectively. The present study can also be supported by the findings of Thomas and Sreekumar (2019) in which pongamia oil soap 2% reduced the bhindi shoot and fruit borer, *Earias vitella* incidence significantly followed by 1 and 0.6% pongamia oil soap in okra. Pongam oil soap 2% recorded highest efficacy against cowpea aphid, *Aphis craccivora* followed by 1% while neem oil soap 0.6 and pongamia oil soap 0.6% were on par with each other in vegetable cowpea (Sajay *et al*., 2020).

The major spider species observed in brinjal ecosystem were *Oxyopes assamensis, Peucetia viridana, Olios* sp. and *Thomisus projectus*. The spiders count was uniform in all the treatments at pre count as well as post counts except on fourteenth day after spray. Pungam oil soap at 0.6, 1, 2 and 3% and neem oil soap 0.6%, chlorantraniliprole and thiamethoxam were statistically uniform in harbouring spider population up to 7th day after treatment while on 14th day significant difference was observed during all the

Table 2. Relative abundance of spiders during field evaluation of pungam oil soap

Treatments	Number of spiders/ 5 plants								
	First application			Second application			Third application		
	1 DBS	7 DAS	14 DAS	1 DBS	7 DAS	14 DAS	1 DBS	7 DAS	14 DAS
Chlorantraniliprole 18.5 SC 0.3 ml/l - 1st & 3rd application & Thiamethoxam 25 WG 0.2g/l - 2nd application	1.33 (1.34)	1.67 (1.28)	1.00 (1.00) c	2.33 (1.47)	3.67 (1.91)	3.33 (1.73) e	3.67 (1.86)	3.33 (1.82)	3.67 (2.04) c
Pungam oil soap 3%	0.67 (1.05)	2.00 (1.38)	2.33 (1.52) ab	3.33 (1.82)	4.00 (1.99)	7.33 (2.71) d	3.33 (1.76)	3.67 (1.91)	4.00 (2.12) bc
Pungam oil soap 2%	1.00 (1.22)	2.33 (1.49)	1.33 (1.14) bc	4.00 (1.89)	5.33 (2.28)	7.67 (2.77) cd	6.33 (2.47)	4.00 (1.99)	4.67 (2.27) abc
Pungam oil soap 1%	1.00 (1.22)	1.33 (1.14)	2.00 (1.38) bc	1.67 (1.28)	5.33 (2.23)	9.00 (3.00) bc	4.67 (2.00)	3.33 (1.82)	4.00 (2.12) bc
Pungam oil soap 0.6%	1.00 (1.22)	1.00 (1.00)	2.00 (1.38) bc	2.67 (1.48)	5.67 (2.26)	9.67 (3.11) ab	3.67 (1.91)	4.00 (1.99)	6.00 (2.55) a
Neem oil soap 0.6%	1.00 (1.22)	2.33 (1.49)	2.33 (1.52) ab	2.33 (1.47)	5.67 (2.35)	7.67 (2.76) cd	3.67 (1.75)	4.67 (2.15)	5.00 (2.34) ab
Soap solution 0.5%	1.33 (1.22)	2.33 (1.47)	4.00 (1.99) a	2.67 (1.58)	5.00 (2.19)	10.67 (3.21) a	6.33 (2.50)	3.67 (1.91)	4.33 (2.20) bc
Control	1.67 (1.46)	2.67 (1.58)	2.00 (1.38) bc	3.00 (1.67)	7.33 (2.70)	8.00 (2.82) cd	6.33 (2.50)	3.67 (1.91)	5.00 (2.32) abc
C.D.(*P*=0.05)	NS	NS	0.50	NS	NS	0.27	NS	NS	0.29

Means followed by similar alphabets do not differ significantly @ 0.05; Figures in parentheses denote square root transformed values; DBS- Day Before Spray; DAS-Days After Spray; NS – Non significant

three sprays (Table 2). The maximum spider population was recorded on 14 DAT in plots applied with soap solution 0.5% during first and second spray with 4.00 and 10.67 spiders per 5 plants respectively and on third spray, spider population was high in pungam oil soap 0.6% with 6.00/5 plants. Chlorantraniliprole on first and third spray (1.00 and 3.67 per plant) and thiamethoxam on second spray (3.33/plant) could support the lowest numbers of spiders when compared to botanicals however these treatments were also on par with control up to 7th day of spray. From the present study, pungam and neem oil soap found to be statistically on par with untreated control plot and soap solution in sustaining the spider population facilitating for a conclusion that pungam oil soap has no negative consequences on spider population even at 3% (Table 2).

Kumar *et al*. (2019) suggesting the safety of biopesticides on spiders including pungam oil reported non-significant difference between botanicals and chemical check in sustaining spider numbers with pongamia oil + detergent powder (10 ml/l) showing 1.3 per plant while the crude neem oil and control with 0.9 and 1.7 spiders/plant. Study conducted by Bhatt *et al*. (2018) in okra revealed that thiamethoxam 25%WG @ 25g a.i./ha and chlorantraniliprole 18.5% SC @ 25g a.i./ha were harmless to the spiders and resulting in 2.30 and 2.69 spiders/plant at spray I and 2.69 and 3.03 spiders/plant at spray II respectively.

The highest yield marked in standard check treated plants with 2058.44g/plant followed by pungam oil soap 3%, 2%, 1% and 0.6% with 1919.04, 1809.02, 1661.29 and 1507.75g /plant respectively. Reduced

leaf lamina size (phytotoxicity) was noticed in pungam oil soap 3% treated plants after second spray when the temperature reached 32-34^0 C however no change in yield was recorded.

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Ultra structure of second instar larva of *Hemipyrellia ligurriens* (Wiedemann) (Diptera: Calliphoridae), a forensically important blow fly species from India

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ABSTRACT: Ultra structural characters of second instar larvae of *Hemipyrellia ligurriens* are elucidated through micrographs (Scanning Electron Microscope). Morphological details of maxillary palpi, antennae, oral cirri, facial mask, labial lobe, spinulations, and papillae of anal segment are described. Oral cirri are ten in number, arranged bilaterally on each side of the functional mouth opening and gently curved medially. The labial lobes are distinctively demarcated with fleshy projections antero–ventrally and have a characteristic shape. Thoracic spines have a bulbous base, slender sharp tips and are directed backwards. Prominent dorsal and ventral anal papillae with projected tips and broad conical base were present surrounded by microtrichia. The ultrastructure details of *H. ligurriens* would help in the rapid and accurate identification of the species in forensic investigations and to estimate time since death in medico legal cases. This is the first report on the ultra-structural features of *H. ligurriens.*

KEYWORDS: *Hemipyrellia ligurriens,* identification, micrograph, scanning electron microscope

Forensic examinations involving decomposed dead bodies need a careful scrutiny of the entomological evidence as the latter being very significant in calculating time of death when the natural postmortem signs of body hold no significance beyond certain level of putrefaction. Studies on insects of forensic significance is very much rudimentary in India except for a few reports on selective species (Bala and Singh, 2015; Bharti and Singh, 2003; Kulshrestha and Chandra, 1987; Rao *et al.,* 1984). *Hemipyrellia ligurriens* (Calliphoridae: Luciliinae) seems to be a synanthrope found in close association with human habitats, garbage dumps, decaying animal bodies and cadavers. The adult flies are generally considered as the vectors of many enteric pathogens (Sinha and Nandi, 2007). Kano and Sato (1952) reared this species on raw fish in Japan and described the larval stages. Ishijima (1967) described the third instar larvae of *H. ligurriens* while Bunchu *et al.* (2012) studied the morphological characters of larval stages of the species using light and stereo microscopy.

The oldest descriptions about all the three larval instars of *H. ligurriens* were provided by Tao (1927) and Knipling (1939). The keys provided in these works were of limited application owing to lack of species specific details. In recent works, blowfly species were identified based on the

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structure of antennae, maxillary palpi, cirri, spines and anal papillae/tubercles (Bunchu *et al.,* 2012; Sukontason *et al.,* 2008). The need for identification of larvae becomes significant especially during forensic investigations when larval specimens are presented. Studies suggest that rapid and more accurate identification of the species is possible through detailed examination of the ultra structural features of the larvae (Liu and Greenberg, 1989; Mendonca *et al.,* 2013).

Blowflies are normally the first insects to infest dead bodies (Smith, 1986). Their larval stages can be aged using knowledge of their developmental rates, and this can then be used to calculate time of death (Erzinclioglu, 1989). Morphological studies of larvae using light microscopy do not provide species specific details and hence larvae should be reared till adult fly emerges. Therefore scanning electron microscopic (SEM) examination of ultra structural details of larvae is very important and would help to identify the species rapidly and accurately (Liu and Greenberg, 1989; Mendonca *et al.,* 2013). SEM studies of larvae of few species of *Luciliinae* have been done by different workers in different parts of the world (Sukontason *et al.,* 2008; Sandeman *et al.,* 1987; Klongklaew *et al.,* 2012; Szpila *et al.,* 2013). However similar studies are lacking in India. Hence the ultra-structural features of *H. ligurriens* in the region was studied for the rapid and accurate identification of this species in forensic investigations to estimate time since death

Second instar larvae of *H. ligurriens* were collected from the outdoor rearing facility for blow flies in Kolangattukara, Thrissur, Kerala (10.5808°N, 76.1875°E). Adult females of *H.ligurriens* were trapped and isolated in the rearing cabinet with decomposing bovine meat as bait. The adult flies were identified using the morphological keys provided in standard literature (Senior-White *et al.,* 1940). Molecular diagnosis of the species was done based on Cytochrome oxidase Subunit I (COI) gene. The DNA sequencing was done at Regional Facility for DNA Fingerprinting (RFDF), Rajiv Gandhi Centre for Biotechnology, Thiruvananthapuram, Kerala, India. Sequence similarity was searched using NCBI BLAST. The sequence was submitted in GenBank, NCBI (GenBank Accession No: MN831480). The insects were reared in the rearing cabinets positioned in the outdoor facility during September 2019. Relative humidity, rain fall and temperature were monitored. The insects were provided with honey and water as food and liquid sources. The flies arrived near the cabinet were trapped with fly net and female of the species was kept in the cabinet. The bovine meat kept in rearing cabinet served as reflex stimuli for the adult female fly to lay eggs. Vermiculite was kept as the bottom layer in the cabinet to assist migration of third instars for pupation.

The second instar larvae were collected and washed many times in distilled water. To kill the larvae and to prevent deformation changes, the larvae were kept in boiling water (96-99°C) for two minutes and finally preserved in 70% alcohol (Adams and Hall, 2003). Sample preparation for SEM included dehydration using 99.5% alcohol followed by ultra sonification and air drying. After being dried at room temperature, larval specimens were gently placed on to stubs fixed with double tape. The specimen was coated with gold using gold sputtering for 10 seconds with 10mA current in the sputter unit (JFC 1600, Japan). Images were taken under JEOL Model JSM-6390 LV, Scanning electron microscope (SEM), JEOL Ltd. Japan, in Sophisticated Analytical Instrumentation Facility (SAIF), Cochin University of Science and Technology, Kochi, Kerala. Larval terminology follows Courtney *et al.* (2000) with a few additional terminology prepared by Szpila and Villet (2011).

The second instar larvae of *H. ligurriens* were 5.27±0.43 mm in length, muscoid, vermiform, pointed anteriorly and blunt posteriorly. Average relative humidity, rain fall and temperature during September 2019 were 88.16 ± 4.38 %, 20.33 ± 10.65 mm and 27.01 ± 1.15°C respectively.

Cephalic region: The antero-dorsal side of both pair of pseudocephalon are occupied by an antenna in the shape of a dome which has a superior cleft and is placed on a ring like base (Fig.1a) and a circular disc shaped maxillary palpus (Fig.1b).The

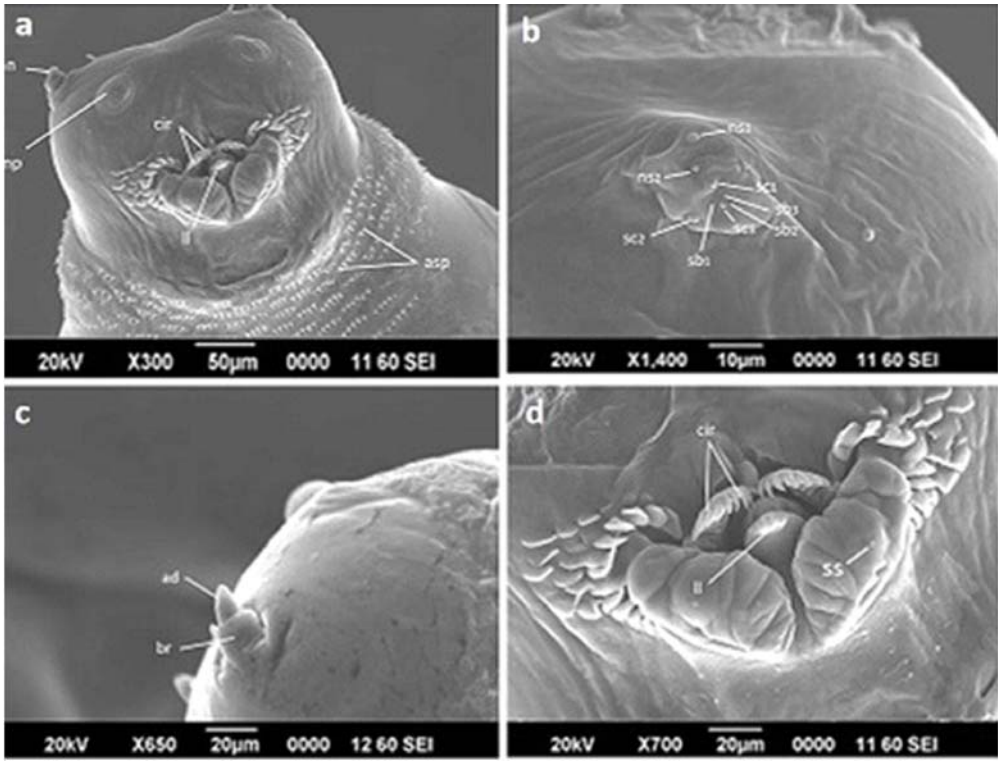

Fig. 1 Micrographs of second instar of *H.ligurriens.* a) pseudocephalon showing antennal complex (an), maxillary palpus (mp), cirri (cr), labial lobe (ll) and anterior spinous process of the first thoracic segment (asp), b) Maxillary palpus showing eight sensillae (sc1-3; sb1-3; ns1-2), c) Antennal complex showing antennal dome, d) functional mouth opening showing cirri (cr) and labial lobe (ll), spines (sp), sensory structures (SS)

height of dome is shorter than that of the height of basal ring (Fig.1c) in contrast to some European *Lucilia* species (*sericata, ampullacea, caesar, cuprina, richardsi, silvarum*) where it is greater (Szpila and Villet, 2011). The diameter of the maxillary palpus is more than the antennal length (Fig.1c). Groups of many sensilla were present in the maxillary palpus (Fig.1b). Sensilla coeloconica (sc1- 3) are three in number and are arranged in a single row with some space in between them. Sensillae basiconicum (sb1-3) are also three in number, highly reduced and not visible prominently and positioned adjacent to the sensilla coeloconicum. Two more sensillae known as 'first and second additional sensillum coeloconicum' are seen dorsal to sensilla coeloconicum and basiconicum cluster. These arrangements are similar to the observations made by earlier workers (Sukontason *et al.,* 2008; Klongklaew *et al.,* 2012; Szpila *et al.,* 2013).

Facial mask is very prominent on the ventral aspect of the pseudocephalon (Fig.1a). Numerous well-structured cirri are dominating in the facial mask and are ten in number. They are characteristically arranged bilaterally on each side of the mouth opening and are gently curved medially. This kind of arrangement of spinulous cirri was not reported in the earlier studies (Sukontason *et al.,* 2008). Three rows of spine clusters were present dorso-medial to the functional mouth opening. The first and second anterolateral rows of spines were with shapes of elongated pyramids of different sizes having broad bases and flat blunt ends .Third postero-medial row of spines were with broad bases and thin concavo-convex apex. Oral ridges were not prominent. Labial lobe was well developed with fleshy lateral lobes constituting a very distinctively demarcated ventral arch area and a medial small lobe which is different from the observations made

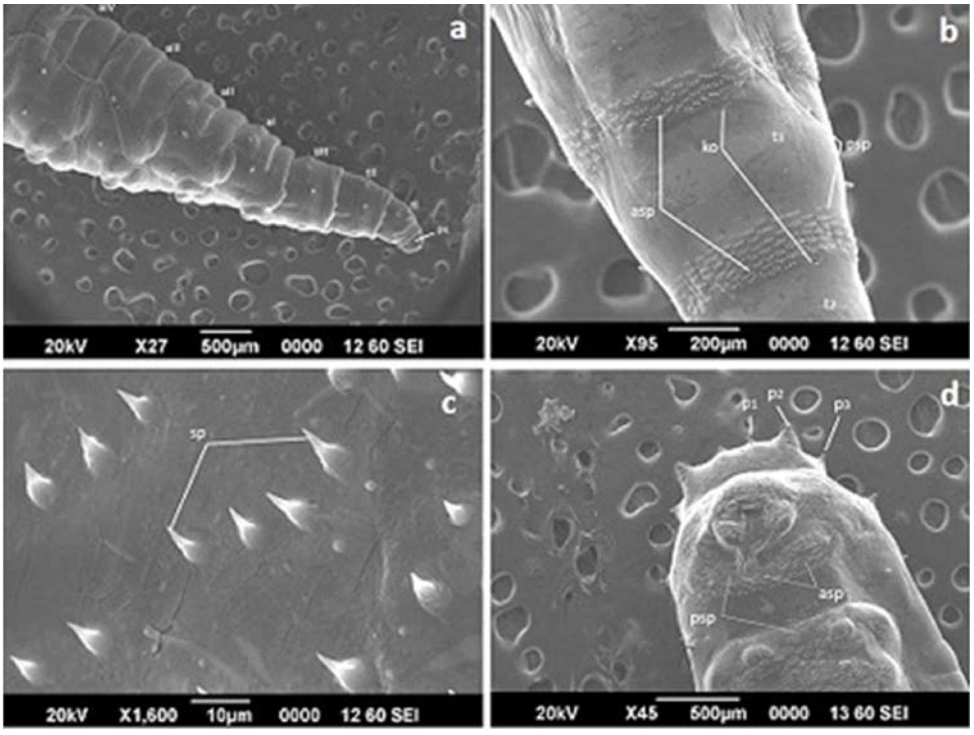

Fig. 2 Micrographs of second instar of H. *ligurriens.* a) second instar showing body segments till fourth abdominal segment, b) second and third thoracic segments showing anterior spinous processes (asp), posterior spinous process (psp), Keilin's organ (ko), c) SEM images of spines with bulbous base and sharp tips between first and second thoracic segments d anal segment displaying dorsal papillae (p1-p3), d) anal segment displaying dorsal papillae (p1-p3), anterior and pesterior spinous processed asp & psp)

by Sukontason *et al.* (2008). Rounded sensory structures were seen on lateral lobes (Fig. 1d) and it is similar to the earlier observation by Sukontason *et al.* (2008) on the same species. In *L. cuprina* and in *L. sericata*, the cirri were seven and eight in number (Szpila *et al.,* 2013). In *L. sinensis* oral cirri were seen with flattened bases and constricted tips (Sanit *et al.,* 2017).

Thorax: Characteristic acuminate spines were present on the anterior and posterior margins of the ventral and lateral surfaces of all the three thoracic segments (Fig. 2a). Spines have a bulbous base, slender sharp tips and are directed backwards (Fig. 2c). These characters were different from the observations made by Sukontason *et al.* (2008) on *H. ligurriens*, where spines were acuminate with flat broad bases. Special sense organs known as Keilin's organs which are sensitive to humidity are present on the ventral side of all thoracic segments (Fig. 2b). In Lucilinae, the thoracic spines show several variations in their shape and structure. Szpila *et al*. (2013) described the spinulations on the thoracic segments of *L. sericata, L. cuprina and L. ampullacea* which are flattened with triangular bases and curved hook like tips. In *L. sinensis,* the thoracic spines are flattened with pigmented sharp tips (Sanit *et al.,* 2017) in *L. porphyrina* and the spines are triangular with dark tips (Klongklaew *et al.,* 2012).

Abdomen: In all abdominal segments, spines were present on the ventral and lateral surfaces. The shape of spines in all abdominal segments were similar to thoracic segments except the last anal segment which have filiform spines in contrast to the verrucate and echinate spines observed by Sukontason *et al*. (2008). Anal papillae are prominent (Fig. 2d) with a broad conical base especially in outer dorsal and outer ventral papillae. These papillae were surrounded by microtrichia (Fig. 2d). Anterior spinous bands are 4-5 in number

and posterior spinous bands are narrow and 2-3 in number. The spinulation pattern was similar to that of the thoracic segments. In *L. sinensis*, the outer ventral papillae were extremely elongated (Sanit *et al.,* 2017) whereas in *L. porphyrina*, all six pairs of inner, middle, outer dorsal and ventral tubercles are prominent but not very large in size like that of *L. sinensis* (Klongklaew *et al.,* 2012). In *L. cuprina*, the dorsal and ventral tubercles were prominent but not so elongated like that of *L. sinensis* (Mendonca *et al.,* 2013)

In most of the studies conducted across the world (in Europe, Africa, Australia and in Asian countries like Thailand, Malaysia) the larval morphology of Luciliinae species were discussed with emphasis on the specific keys to identify the species in those specific geographical locations. This is to address the wide variety of variations in the larval morphology observed in this subfamily. An attempt was made in this study to identify *H. ligurriens* through the unique ultra structural details of second instar larvae. The diagnostic features which helped to differentiate *H. ligurriens* from other species were the spinulous oral cirri which consist of three rows of spine clusters present dorso-medial to the mouth opening .The postero-medial rows were with broad bases and thin concavo-convex apex. The well-developed labial lobes, characteristic thoracic and abdominal spines and prominent outer dorsal and ventral anal papillae were also diagnostic. The ultra structural details of *H. ligurriens* provided in this study would definitely help in the rapid and accurate identification of this species in forensic investigations to estimate time since death.

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New host records of Lepidoptera, defoliating Himalayan silver oak, *Quercus leucotrichophora* A.Camus and ring-cupped oak, *Q. glauca* Thunb. (Fagaceae) in Uttarakhand, Western Himalayas, India

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ABSTRACT: Survey on the lepidopteran insects attacking oak trees *Quercus leucotrichophora* and *Q. glauca* in forest areas revealed 65 species which are mostly polyphagus in habit. The study reports 13 species of lepidopteran belonging to Limacodidae, Erebidae, Geometridae, Pyralidae and Limacodidae as new host for *Q. leucotrichophora* and four species belonging to Arctiidae and Limacodidae on *Q. glauca* from both Garhwal and Kumaon regions of Uttarakhand state, India.

KEY WORDS: Oak, Ban, Phaliyant, Garhwal, Kumaon, larval host plants, feeding pattern, distribution

Oaks (*Quercus* spp.) are the dominant tree species of temperate forests of the Indian Himalayan region and about 35 species of them are extensively distributed in this region between 1000-3500m elevations. There are about ten oak species in Eastern Himalayas and five in Western Himalayas, out of which the Himalayan silver oak or ban oak, *Q. leucotrichophora* is the most important species in Western Himalayas (Troup, 1921). Five species of evergreen oaks namely *Q. glauca* (Ring-cupped oak or phaliyant or harinj), *Q. leucotrichophora* (ban), *Q. lanuginosa* (rianj oak), *Q. floribunda* (tilonj or moru oak) and *Q. semecarpifolia* (brown or kharsu oak) grow naturally in the western Himalaya (Bargali *et al*., 2013). Oaks have an important place in the Himalayan region because of their significant contribution in soil and water conservation, sustaining rural ecosystems, maintaining biodiversity and other ecosystem services (Bhatt *et al*., 2015). Ban oak is a multipurpose tree. The oak forests are source of fuel wood, fodder and can be correlated with natural springs and wildlife (Singh, 1981). The leaves are used as fodder during lean period and bedding for livestock (Kala, 2004). Many oaks are keystone species without which the complex web of the ecosystem would soon unravel (Shrestha, 2006). The galls that develop on the leaves are a natural source of gallic acid, a potential antitumoral/pro-oxidant agent. The gum from old trees is used in ethno-medicine for treating colds and as an analgesic (Ambu *et al*., 2020).

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As many as 51 species of Lepidoptera are known to defoliate Ban oak, *Q. leucotrichophora* trees in the Western Himalaya forests (Beeson, 1941; Mathur and Singh, 1959; Verma *et al*., 1979; Smetacek and Smetacek, 2011; Thakur *et al*., 2015; Singh *et al*., 2019). Field surveys were conducted on the lepidopteran insects attacking oak trees *Q. leucotrichophora* and *Q. glauca* in forest areas of the Western Himalayas during 2018-2020. The studies revealed 64 species and identified 13 species on *Q. leucotrichophora* and four species on *Q. glauca* as new host records from both Garhwal and Kumaon regions of Uttarakhand state, India. Information pertaining to 17 species belonging to five families reported on *Q. leucotrichophora* and *Q. glauca,* as new hosts for first time, are presented.

a. Defoliators of Himalayan silver oak, *Quercus leucotrichophora* A.Camus (syn. *Q. incana* Bartram, 1791).

1. Name: *Cheromettia apicata* (Moore, 1879), Family: Limacodidae

Distribution: The species is distributed in the Oriental tropics (India and Sri Lanka).

Host range: *Camellia sinensis* (L.) Kuntze, *Ceiba pentandra* (L.) Gaertn, *Cocos nucifera* L., *Gliricidia sepium* (Jacq.) Steud., *Schleichera oleosa* (Lour.) Oken, *Schleichera trijuga* Willd, *Vernicia fordii* (Hemsl.) Airy Shaw, *Aleurites fordii* (Hemsl.) Airy Shaw, *Butea monosperma* (Lam.) Taub., *Coffea arabica* L., *Derris elliptica* (Wall.) Benth, *Juglans regia* L., *Pyrus communis* L., *Theobroma cacao* L., *Toona ciliata* M. Roem. and *Malus pumila* Mil.

(https://en.wikipedia.org/w/index.php?title=Arctornis_submarginata&oldid=983434738; https://en.wikipedia.org/w/index.php?title=Perina_ nuda&oldid=932677322).

Habit: Larva defoliates by feeding on leaf tips and margins.

Life-history: Larva (18 mm and width 9 mm) is a slug like watery caterpillar (Fig. 1a) enclosed in smooth oval shaped shape and having a dotted pattern of minute yellow spots scattered at equal intervals all over the dorsal surface. According to Subhalaxmi (2018) caterpillar is nearly oval, dull bluish green with longitudinal rows of small yellow spots. Two sluggish-watery caterpillars were recorded defoliating *Q. leucotrichophora* trees in the New Forest Campus (30.3333N & 78.0166E; 670m) of the Forest Research Institute, Dehradun. Larvae pupated (length 25 mm) is enclosed in hard, white-spherical cocoon amongst 2-3 green leaves folded together on the tree itself. Moth (Wing span: 30mm) emerged on 09.ix.2020, from the cocoons by an opening of the lid like operculum at one end of the cocoon (personal observation). Male is chestnut brown; forewing is red-brown, (wing span: 30mm; Fig.1 b & c) basal area darker, boundary by wavy central line, dark mark beyond cell end, indistinct wavy line towards outer margin, black patches on wings with grey specks. Hindwing is black-brown with outer margin straight (Subhalaxmi, 2018).

Pest status: Minor pest in Uttarakhand.

Remarks: Uncommon in oak ban forests.

***2. Suana concolor* Walker,1855, Family:** Lasiocampidae

Distribution: The species is distributed in India, and Sri Lanka to S. China, Java, Borneo and the Philippines**.**

Host Range: Other host plants are *Careya, Ceiba, Canarium, Shorea, Castanea, Cinnamomum, Litsea,Persea, Albizia, Cassia, Gossypium, Hibiscus, Emblica, Eucalyptus, Psidium, Syzygium, Citrus, Sonneratia, Theobroma, Camellia, Schima* and *Tectona* (Holloway, 1987; Robinson *et al.*, 2010); *Acacia mangium* Willd. (Chey, 2004) and *Acacia farnesiana* (L.) Wight et Arn. (Ahmad and Ho, 1980).

Habit: Larva defoliates by consuming the entire foliage.

Life-history: A larva (85 mm; Fig. 2a) of this lappet moth was recorded feeding on the leaves of oak plantation in New Forest campus, Dehradun. There are seven larval instars and larval development usually lasts 60–80 days for the males and 85-100 days for the females (Pugaev and Skrobotov, 2011). Shiny, brown, elongated, bean shaped pupa (length 100mm) inside a cocoon was formed on 20.vi.2020. Female moth (Fig. 2c & d) emerged on 03.vii.2020 in the laboratory at FRI, Dehradun. According to Browne (1968), the adult female could produce about 2000 eggs, which she places in clusters on the twigs of the host tree.

Pest status: Minor pest.

Remarks: Locally widespread in lower reaches of Uttarakhand.

3. ***Pida decolorata* (Walker, 1869), Family:** Erebidae

Distribution: The species is known to be distributed in India from Himachal Pradesh, Uttar Pradesh, Uttarakhand, West Bengal and Khasi Hills and in China (Swinhoe, 1923; Shah *et al*., 2018; Kaleka and Kaur, 2019) and Taiwan (www.nic.funet.fi/).

Hosts: The larval food plants are not known however the food plant of an allied species, *Pida niphonis* which occurs in Japan is *Fagus crenata* Blume (Robinson *et al.*, 2010).

Habit: Larva defoliates by feeding on leaf margins and finally consuming the entire leaf.

Life-history: Three 2nd instar larvae (Fig. 3a) were recorded feeding the leaves of *Q. leucotrichophora* in an Oak forest in Chakrata hills (Chakrata Forest Division: 30·7246 N & 77.8610E; 2100m), Garhwal, Uttarakhand, India. Life history on *Q. leucotrichophora* was studied (Table 1). Another individual (male moth: wing span 50 mm) of the same species was also captured on from Ban oak tree in Chakrata Forest Division, Uttarakhand.

The insect is whitish, head and fore parts of the thorax are pale fawns in colour. Palpi erect, slender, fringed in front, rising higher than the vertex; third joint is elongate conical, less than one fourth of the length of second. Antennae are moderately pectinated. Abdomen is brown from above, whitish at base, pale ochraceous at the tips. Legs are slender; fore femora and fore tibia with pale ochraceous fringe. Fore wings are acute, partly suffused with very pale ochraceous, thinly and minutely black speckled; a large divide pale fawn coloured thickly black speckled apical patch. Hindwings are without markings. Length of body is 12 lines; of the wing 38 lines.

Pest Status: Minor pest

Remarks: Occasional in ban oak forests

4. **Clearwing Tussock Moth, *Perina nuda* Fabricius, 1787, Family:** Erebidae

Distribution: The species occurs in the Indian sub-region, Sri Lanka up to southern China, Hong Kong, Thailand and Sundaland (https://en.wikipedia.org/wiki/Perina_nuda).

Host Range: Other host plants are *Ficus benghalensis* L., *F. benjamina* L., *F. carica* L., *F. elastic* Roxb., *F. microcarpa* L., *F. pumila*L., *F. racemosa* L., *F. religiosa* L., *Mangifera indica* L., *Artocarpus integer* Merr., *A. integrifolia* Lam. (Robinson *et al*., 2010). Cheanban *et al*. (2017) described the life history on fig trees.

Habit: Larva feeds on leaves

Life-history: Eruciform larva with grey head and dark brownish dorsum was collected from *Q. leucotrichophora* plantation in New Forest campus, Dehradun. The total larval period was 28days before pupation.

Pupa (17mm; Fig. 4a) is yellowish green colour covered with orange hairy setae and two brown spots. Emergence of moth took place in the laboratory on 29.i.2019 (Wing Span:

Table 1. Life history stages of *Pida decolorata* (Walker, 1869) on Ban oak, *Quercus leucotrichophora*

Stages	Duration	Description	Feeding pattern
2nd instar	5 days	Length of larva is 10-11 mm, head black and body brown in colour and having orange coloured tuft of hairs on the middle abdominal region of the body.	Larva was found feeding on the margins of ban oak leaves.
3rd instar (Fig. 3a)	6 days	Length of larva is 20 mm, head enlarged in size and body colour changes from brown to dark brown and long white hairs all over the body	Feeding takes place on the leaf margins.
4th instar	8 days	Length of larva is 23 mm, head enlarged in size and whole body is covered with brown and black hairs and larva possess black band behind the head region.	Feeding takes place on the leaf tips
5th instar	21 days	Full grown larval length is 30 mm, body colour changes from dark brown to light brown with brown and white hairs all over the body.	Feeding takes place on the leaf tips and margins.
Pupa (Fig. 3c)	16 days	Length of pupa is 35 mm, brown in colour	Attaches itself to folded oak leaves inside the cocoon made of larval hairs.
Adult (Fig. 3b & c)	2 days	Male (Wingspan: 46 mm) active inside the breeding cage.	Emergence took place at dusk

40mm; Fig. 4b & c). Cheanban *et al.* (2017) observed that males have very small proboscis, bipectinate antenna, body length is 10-14 mm, transparent forewing, one large brown frenulum at the anterior of the hind wing whereas female have pale yellow head and labial palp, bipectinate antenna, body length ranges 11.0-12.50 mm, abdomen covered with white hairs and 2-3 smaller frenulum on the hind wing.

Pest Status: Minor pest

Remarks: Rare in Ban oak forests

5. ***Olene inclusa* Walker,1856, Family:** Erebidae

Distribution: *Olene inclusa* Walker,1856 occurs in the N.W. Himalayas, Poona (Maharashra, India), Java (Hampson, 1892), West Malaysia, Indonesia, Hong Kong, New Guinea, Java, South East Asia, Thailand and Andaman Islands (Robinson *et al*., 2010).

Host Range: Larval host plants recorded for this moth are *Annona, Averrhoa, Durio, Ricinus, Leea, Pelagonium, Acer, Arachis, Crotalaria, Derris, Erythrina, Mucuna, Ficus, Musa, Calyptranthes, Eugenia, Rosa, Citrus, Theobroma, Muntingia, Conggea* (Holloway, 1999); *Octomeles sumatrana* Miq. (Chung *et al*., 2008); *Solanum melongena* L., *Casuarina* sp. (Robinson *et al*., 2010).

Life-history: Larva of male are dark brown in colour, with lateral tufts of long hair; head red-brown; two white dorsal lines on 4th somite

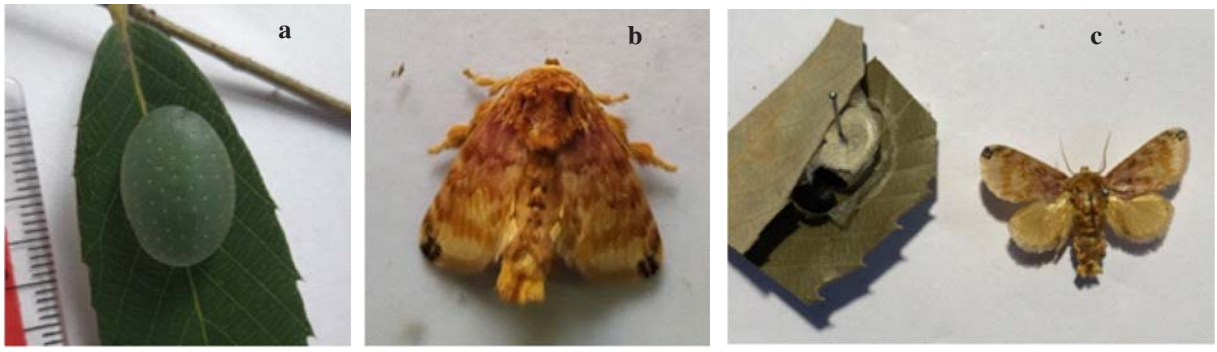

Fig.1. Life history stages of *Cheromettia apicata* (Moore,1879) on Ban oak-
a) Larva, b) Moth, c) Cocoon and pinned moth (upperside)

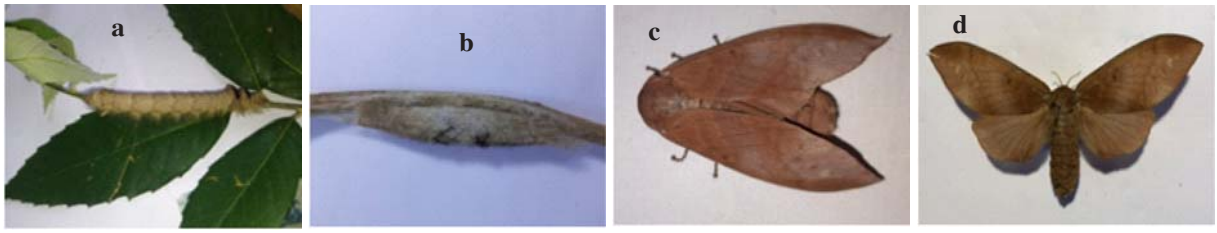

Fig. 2. Life history stages of *Suana concolor* Walker,1855 on Ban oak, *Quercus leucotrichophora*-
a) Larva, b) Cocoon, c) Moth, d) Pinned moth (upperside)

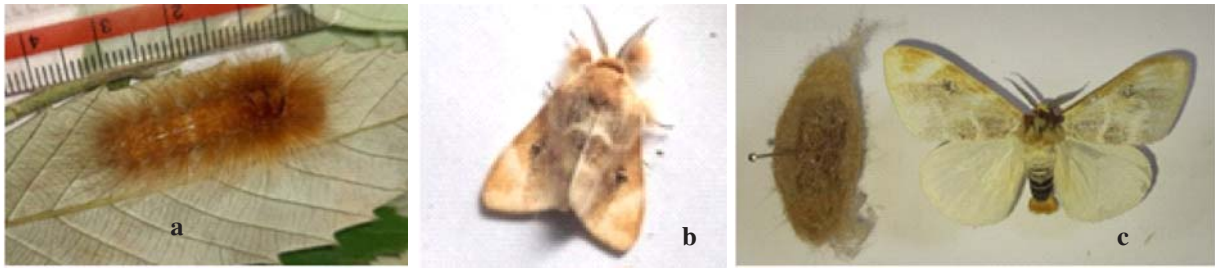

Fig. 3. Life history stages of *Pida decolorata* (Walker,1869) on Ban oak, *Quercus leucotrichophora*-
a) Larva, b) Moth (male), c) Cocoon and pinned moth (upperside)

and dorsal tufts of silky reddish hair from 4th to 7th somite. While the larva of female has dorsal tufts dark brown; a sundorsal white stripe and crimson dorsal spots on 9th and 10th somites (Fig. 5a). *O. inclusa* was recorded on young plantation in New Forest campus, Dehradun, Uttarakhand, India during 2018-2020. Its incidence was observed from June to November. A full grown fifth instar larva measured 30 mm in length (Fig. 5a). The larval period varied from 14 to 17 days. Pupa (24mm) was formed inside a tightly woven cocoon (30mm; Fig. 5c) in the laboratory. Pupal period varied from 5 to 6 days in July. Both male (wingspan: 36-38 mm; Fig. 5b) and female (wingspan: 50mm; Fig. 5c) moths emerged in the laboratory during July. Male moth had a wingspan of 40 mm and was dark brown with indistinct lines and waved brown band beyond the post-medial line and hind wing brownish fuscous while the female is larger with 52mm wingspan and has a indistinct pale brown sub-basal mark on the upper forewing (Hampson, 1892).

Pest Status: Minor pest.

Fig. 4. Life history stages of *Perina nuda*Fabricius, 1787 on Ban oak, *Quercus leucotrichophora*- a) Pupa, b) Pupal case and emergent moth, c) moth pinned (upperside)

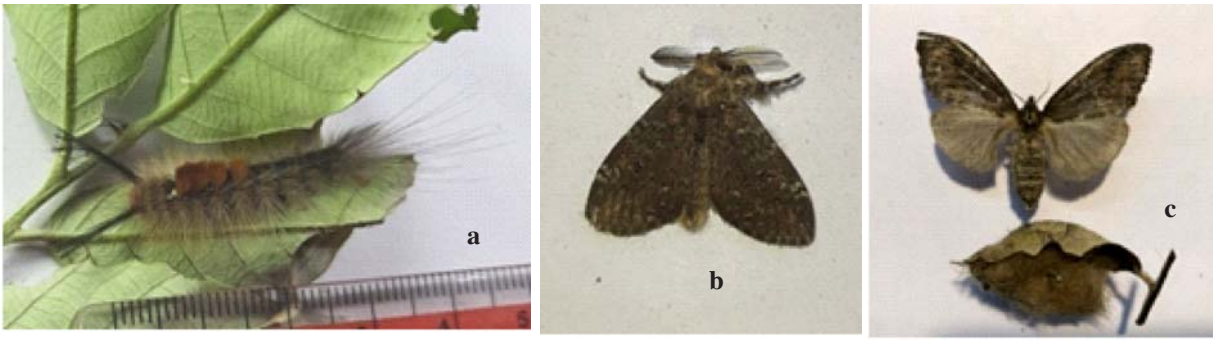

Fig. 5. Life history stages of *Olene inclusa* Walker,1856 on Ban oak, *Quercus leucotrichophora*- a) Larva, b) Moth (male), c) Cocoon and moth pinned (female upperside)

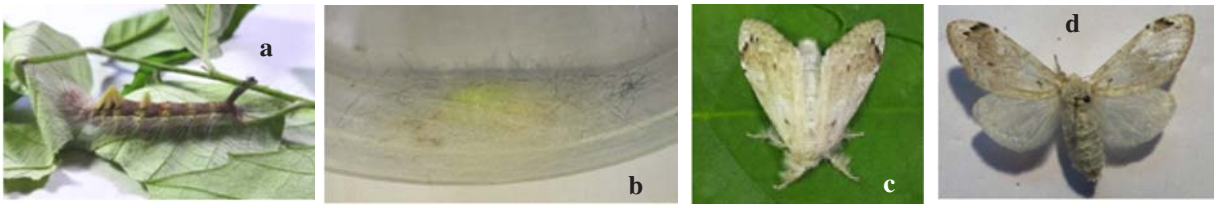

Fig. 6. Life history stages of *Olene dudgeoni*Swinhoe, 1907 on Ban oak, *Quercus leucotrichophora*- a) Larva, b) Cocoon with pupa, c) Emergent moth (female) and d)pinned moth (female) upperside

Remarks: Common in Ban oak forests at lower elevation.

6. ***Olene dudgeoni* Swinhoe, 1907, Family:** Erebidae**.**

Distribution: This moth is distributed from N.E. Himalaya to Taiwan and Sundaland (Holloway, 1999); China (Lui *et al*., 2012). It has also been recorded from Godavari village near Kathmandu in Nepal (Central Himalaya).

Host range: Other host plants are *Camellia oleifera* C. Abel (Lui *et al*., 2012); *Camellia sinensis*(L.) Kuntze (Theaceae).

Habit: Larva feeds on the leaf margin and then entire leaf leaving only behind the midrib.

Life cycle: Larva (Fig. 6a) of this moth were recorded defoliating *Q. leucortrichophora* tree in Chaubati village (29.81294N & 80.21558E; 1838 m) in Pithoragarh district, Uttarakhand. Length of full grown larva was 43 mm. Body is ashy black from the dorsal region with yellow patches on the lateral side and white coloured from ventral surface from which white hair like setae are rising laterally and head in pinkish in colour; four yellow tuft of hairs lies on the dorsal surface of the body

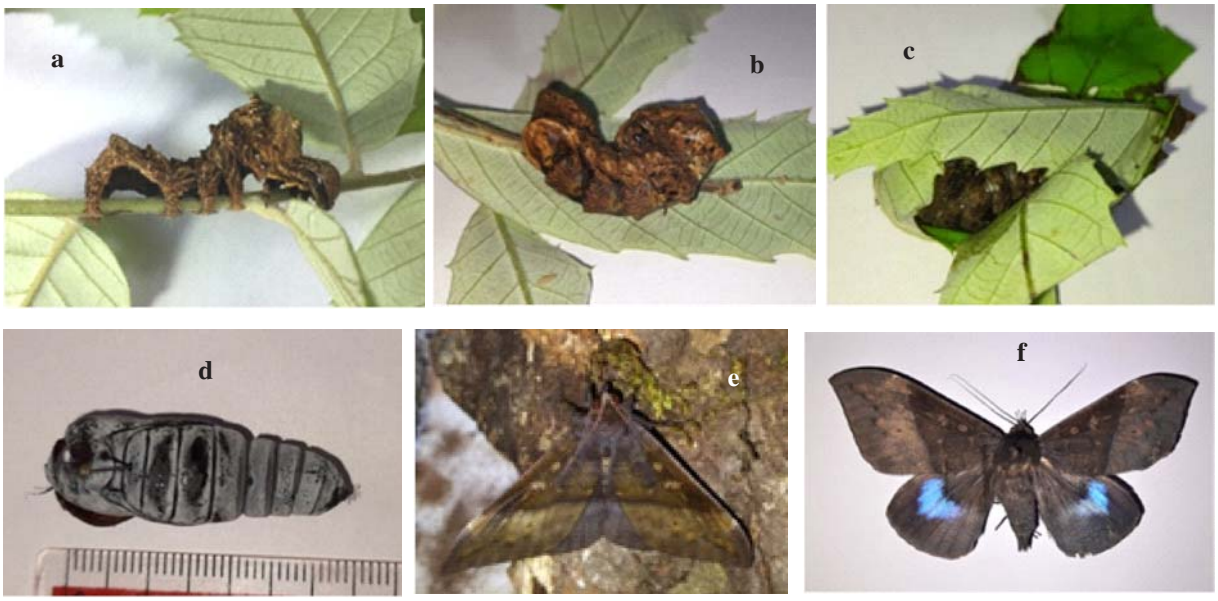

Fig. 7. Life history stages of *Ischyja manila* (Cramer, [1776]) on Ban oak, *Quercus leucotrichophora*- a) Vth instar larva, b) larva in folding position on being threatened, c) Cocoon in folded leaves, d) pupa, e) emergent moth, f) pinned moth (female)

Fig. 8. Life history stages of *Arctornis submarginata* (Walker,1855) on Ban oak, *Quercus leucotrichophora* - a) Vth instar larva with feeding pattern, b) Pupa, c) Emergent moth (upperside) with pupal shell, d) pinned moth (female)

and one black tuft of hairs lies at the last segments of the body and white hair like setae are present near the head region and black setae lies at the last abdominal segment of the body longitudinally. Pupa was formed after 16 days of larval feeding. Pupa (30 mm; Fig. 6b) is yellowish-green in colour and enclosed in cocoon whose length is 40 mm attached to the surface. Pupal period was 11 days. Moth female wingspan was 46 mm (Fig. 6c & d). According to Holloway (1999), this species resembles *O. mendosa* Hubner, to some extent but the forewings are a darker, more leaden grey, with the transverse, black anti medial in a more basal position, without a pale blotch basal to it.

Pest Status: Minor pest.

Remarks: Sporadic infestation in Ban oak forests in mid elevations.

7. ***Ischyja manila* (Cramer, 1776), Family:** Erebidae

Distribution: The species has distribution in Philippines, Ceylon and Burma; Andamans; Java (Hampson, 1894), Palau (Fukushima, 1947), Australia (Nielsen *et al.,* 1996), Burma (Myanmar), Thailand, China, Okinawa (Japan), Sundaland (Thailand), Sulawesi (Indonesia); S. Moluccas (ssp. *amboinensis*) (Holloway, 2005) and in the Indian sub-region, Arunachal

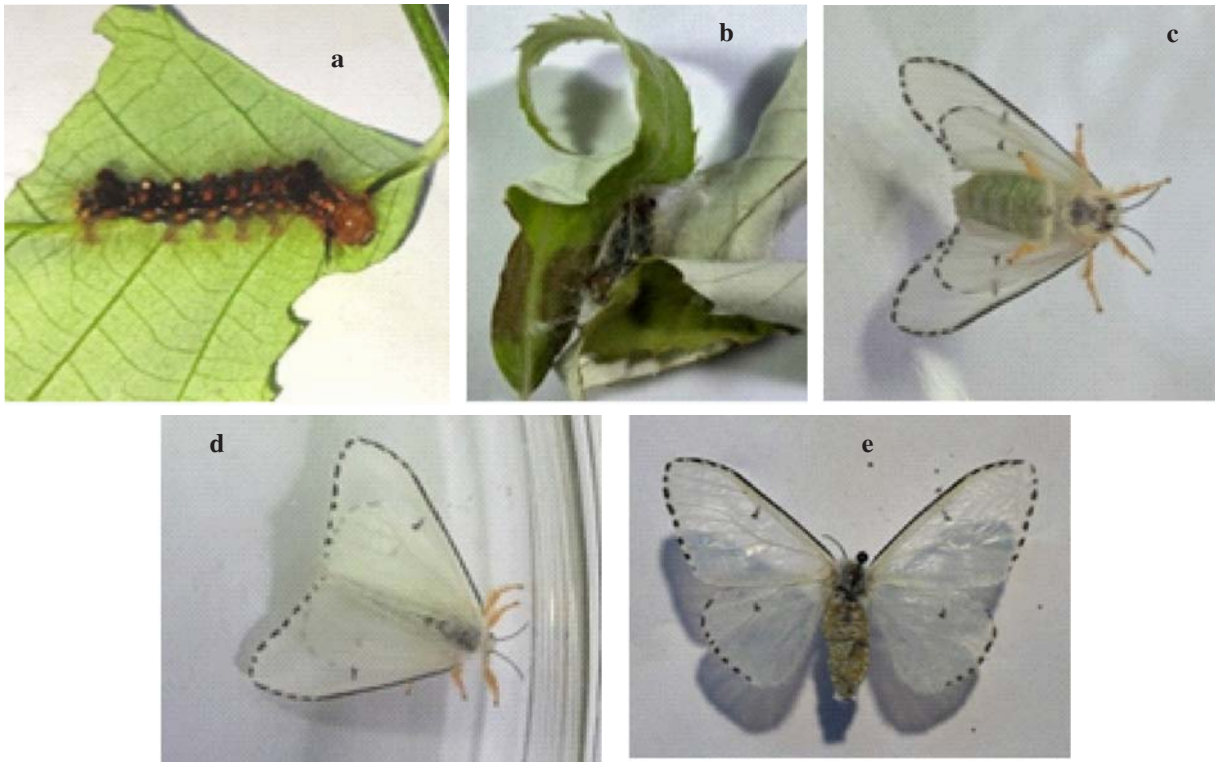

Fig. 9. Life history stages of *Swannia marmarea*Prout1926 on Ban oak, *Quercus leucotrichophora*- a) v instar larva, b) Cocoon in folded leaves, c) Emergent moth (underside), d) Emergent moth (upperside), e) pinned moth (female).

Fig. 10. Life history stages *Alcis variegata* Moore,1888 on Ban oak, *Quercus leucotrichophora*- a) Vth instar larva, b) feeding pattern, c) Emergent moth (upperside) with pupa, d) Emergent moth pinned (female upperside).

Pradesh, Uttarakhand, Assam and Karnataka (Sondhi *et al*., 2019).

Host Range: Larvae are known to feed on *Schima* (Theaceae) (Holloway, 2005); *Aglaialawii (Wight) Saldanha ex Ramamoorthy* (Meliaceae), *Cupaniopsisa nacardioides* (A. Rich.) Radlk (Sapindaceae), *Dalbergia monetaria* L.f. Moneybush, *Xylia xylocarpa* Roxb. Taub. (Fabaceae), *Terminalia paniculata* Roth (Combretaceae) (Robinson *et al.,* 2010).

Habit: Larvae feed on the frontal half of the leaf by cutting it into half (40 mm; Fig.7a & b).

Life-history: Hampson (1894) described pupa and Holloway (2005) described larva and adult. Pupa 35 mm in length, efflorescent, ashy black in colour and enclosed in cocoon whose length is 50 mm which is enclosed inside 3-4 ban oak leaves wrapped together around it from all the sides (Fig. 7c). Emerged female moth had a wingspan of 90mm (Fig. 7e & f).

Fig. 11. Life history stages of *Eupithecia maculosa* (Vojnits,1981)-
a) vth instar larva, b) pupa, c) Emergent Moth

Fig. 12. Life history stage of *Salma* sp. (Walker,1863) of Ban oak, *Quercus leucotrichophora*-
a) V instar larva, b) pupa, c) emergent moth (Upperside), d) Pinned moth (upperside)

Fig. 13. Larva of *Mahanta* sp. feeding on Ban oak, *Quercus leucotrichophora*

Pest Status: Minor pest.

Remarks: Sporadic infestation in ban oak forests in lower elevations.

***8. Arctornis submarginata* (Walker, 1855), Family:** Erebidae

Distribution: China

Host Range: Other host plants are *Camellia oleifera* C. Abel (Lui *et al.,* 2012); *Camellia sinensis* (L.) Kuntze (Theaceae).

Habit: Larva feed on leaf margins by eating part of it but never the entire leaf.

Life-history: Larvae (Fig. 8a) were collected from oak tree on 23.ix.2020 in Dhauli-Ghauli village (29.843N & 80.165E; 1027m), Pithoragarh district, Uttarakhand, India. Larvae preferred to rest on the midrib of the leaf on the under surface thus hiding by camouflaging. The length of full grown larva is 28 mm. Larval period was more than two weeks in September. Pupa (Fig. 8b) was plain green in colour and

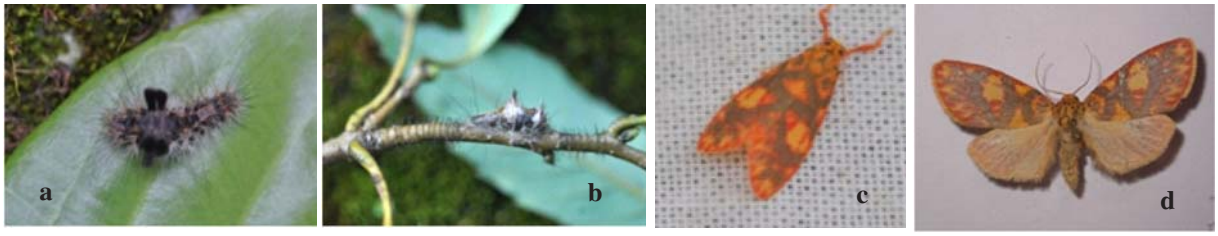

Fig. 14. Life history stages of *Floridasura tricolor* (Wileman,1910) on ring-cupped oak, *Quercus glauc*a-
a) v instar larva, b) Pupa on twig covered with rings of spine like hairs,
c) Emergent moth (underside), d) pinned moth (female).

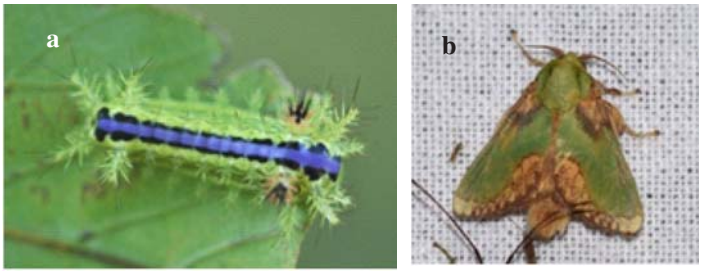

Fig. 15. Life history stages of *Parasa pastoralis* Butler, 1885 on ring-cupped oak, *Quercus glauca* -
a) v instar larva, b) cocoon, c) Emergent moth

Fig. 16. Life history stages of *Demonarosa rufotessellata* Moore, 1879 on ring-cupped oak, *Quercus glauca*-
a) Final instar larva (dorsal view), b) Final instar larva (lateral view),
c) Final instar larva before cocoon formation, d) cocoon inside folded leaf

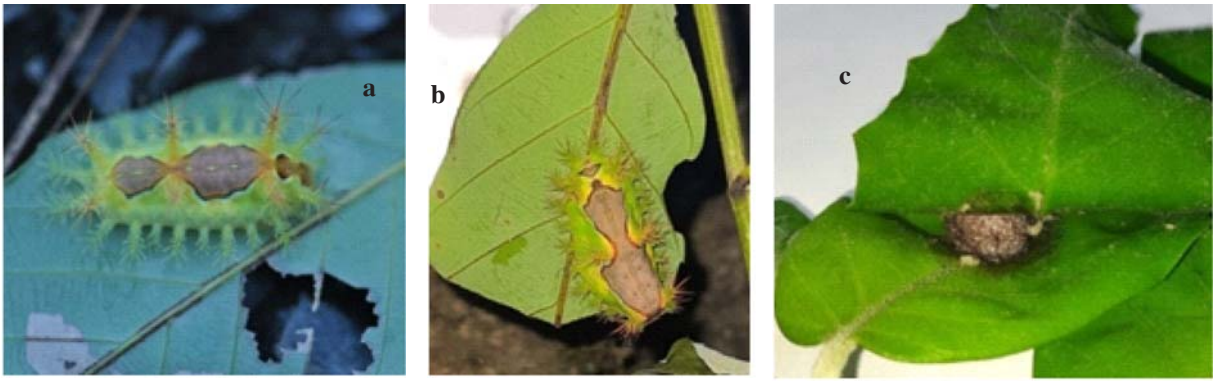

Fig. 17. Life history stages of *Adoneta* sp .on ring-cupped oak, *Quercus glauca*-
a) Final instar larva (Dorsal view), b) Final instar larva with half eaten leaf, c) Cocoon ball inside folded leaf

having small, yellow colour dots on the dorsal side was formed. Length of pupa was 17 mm. Pupal period was of seven days (27 September - 2 October 2020). Emergence of white male moth (Fig. 8 c & d; wing span: 40mm) with green abdomen and having a black spot near the middle of each forewing was noted on 2.x.2020. The mature 5th instar larva move to lower leaves and combine two complete leaves by spinning silk into a ridge shaped cocoon and then pupate inside it.

Pest Status: Minor pest.

Remarks: Common in Ban oak forests.

***9. Swannia marmarea* (Prout,1926), Family:** Geometridae

Distribution: This species was described by Prout (1926) from Myanmar also been recorded in Central Himalaya i.e. Nepal (Godavari village near Kathmandu) (Haruta, 1993). The present record of this species is from Chaubati village in Pithoragarh district in Uttarakhand and is 500 km west of Godavari village in Nepal, its known western most limit in the Himalayas.

Host Range: Data deficient.

Habit: Larvae feed on leaf margins.

Life-history: Larva (Fig. 9a) was collected from Ban oak on 25.ix.2020 in Chaubati village near Didihat (29.81294N & 80.21558E; 1838 m) in Pithoragarh district, Uttarakhand. Length of larvae ranged from 20 to 28 mm, body is black and head in brown in colour; a pair of dark brown tuft of hairs lies in the metathorax region and at the last few segments of dorsal surface of the body and pairs of raised brick-red spots on their dorsal and lateral side of the body and white hair like setae are present all over the body. Pupa was formed on 13.x.2020. The pupa is yellowish in colour (length is 10 mm; Fig. 9b), and enclosed in a cocoon (measures 22mm) attached in 2-3 ban oak leaves together. Pupal period was of 7 days. Emerged female moth (Fig. 9c - e) is white with sharp black wing margins that are chequered along the outer margin (termen), with a wingspan of 42 mm and legs yellow in colour.

Pest Status: Minor pest.

Remarks: Sporadic infestation in ban oak forests in mid elevations.

***10. Alcis variegata* Moore,1888, Family:** Geometridae

Distribution: This species is found in India, Sikkim, Nepal, Myanmar, Laos, southern China, northern Vietnam, Thailand, Peninsular Malaysia and Sumatra (https://en.wikipedia.org/wiki/ Alcis_variegata).

Host Range: In Japan another species of the same genus *i.e A. angulifera* Butler,1878 feeds on *Acer palmatum* Thunb., *Camellia japonica* L., *Castanea crenata* Siebold & Zucc., *Malus pumila* Mil., *Quercus acutissima* Carruth., *Q. mongolica* Fisch.ex. Ledeb., *Q. serrata* Murray, *Q. variabilis* Blume. While in Finland *A. repandata* Linnaeus,1758 feeds on *Alnus incana* (L.) Moench, *Betula pendula* Rotth, *Salix aurita* L., *Tilia cordata* Mill. (Robinson *et al.,* 2010).

Habit: Larva defoliates

Life-history: One larva (12 mm; Fig. 10a & b) was recorded on 03.iv.2019. Dark brown pupa (12m; Fig. 10c) was formed on 16.iv.2019 Emergence of moth (Wingspan: 26mm) took place on 26.iv.2019 in the laboratory (Fig.10c & d).

Pest Status: Minor pest.

Remarks: Uncommon in Ban oak forests in lower elevations.

***11. Eupithecia maculosa* (Vojnits,1981), Family:** Geometridae

Distribution: It is found in north eastern India and Pakistan (Mironov *et al*., 2008, 2010).

Host plants: Other species of the same genus i.e. *Eupithecia abbreviata* are known to feed on *Crataegus* spp., in Iran, *Quercus* spp., in British Isles. *E. abietaria* feeds on *Abies procera, A. concolor, Picea abies, Pinus cembra, P. sylvestris* in Nearctic and Holacrtic realm. One more species of same genus *Eupithecia interrubrescens* is known to feed on *Pinus* spp. in India (Robinson *et al.*, 2010).

Habit: Larvae feed on the leaf tips and margins of tender leaves

Life-history: A green coloured larva (24mm) feeding on foliage (Fig11a) was collected on 14.ix.2018 and it pupated on 23.ix.2018. Pupa (20 mm length, 4 mm width) is dark brown in colour (Fig. 11b). Adult moth emergence noted on 01.x.2018 (Fig. 11c).

Pest Status: Minor pest.

Remarks: Rarely seen in Ban oak forests at lower elevations

12. ***Salma*** **sp. (Walker, 1863), Family:** Pyralidae

Distribution: Oriental region

Host Range: The host plants for genus *Salma* in this region are mainly of the family Combretaceae - (*Terminalia* and *Anogeissus*) *i.e. Salma carbonifera* found in Oriental region feeds on *Terminalia tomentosa* Roxb*, T. bellirica* (Gaertn.) Roxb.*, T. paniculata* Roth*, Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr.*, Diospyrus melanoxylon* Roxb.*, Garuga pinnata* Roxb.*, Lagerstroemia parviflora* Roxb.*, Mangifera indica L.*, *S. plicatalis* found in India and Burma feeds on *Tectona grandis* L. and *Terminalia tomentosa* Roxb. (https:// www.nhm.ac.uk).

Habit: Larva defoliates

Life-history: One larva (10mm) was collected on 27.vi.2018 while feeding on oak leaves (Fig. 12a). Moulting into fifth instar larva took place on 05.vii.2018 (Fig. 12a & b). Full grown fifth instar larva measured 35mm in length. Shiny brown pupa (Fig. 12b; 15 mm) formed on 16.vii.2018. Emergence of moth (wing span 25mm; Fig. 12c & d) noted on 27.vii.2018 in the laboratory.

Pest Status: Minor pest.

Remarks: Rarely seen in Ban oak forests at lower elevations

13. ***Mahanta*** **sp., Family:** Limacodidae

Distribution: *Mahanta quadrilinea* Moore,1879 is distributed in India and Bhutan and Taiwan (http://www.wikiwand.com/en/ Mahanta_quadrilinea).

Host Range: Not known

Habit: Larva defoliates feeding on both young and mature leaves

Life-history: Larva (12mm) was recorded defoliating at Chakrata hills (Chakrata Forest Division: 30·7246 N & 77.8610E; 2100m), Garhwal, Uttarakhand, India on 28.viii.2019 (Fig. 13). Pupa is like brownish hardened ball.

Pest Status: Minor pest.

Remarks: Uncommon in Ban oak forests.

b. Defoliators of Ring-cupped oak or Phaliant, *Quercus glauca* Thunb., 1784

14. ***Floridasura tricolor*** **(Wileman,1910), Family:** Arctiidae

Distribution: The genus is widespread from Assam (Strand, 1922); north-eastern India through Myanmar, Thailand, Laos, Cambodia and southern Mainland China to Vietnam, Hainan and Taiwan Island (Hampson, 1914; Volynkin *et al*., 2019).

Host Range: Not known

Habit: Larva defoliates by feeding on the lateral surface of the leaf

Life-history: Larvae were recorded defoliating *Q. glauca* trees in moist temperate forest at Ogla, between Didihat and Thal

(29.84339N & 80.16503E; 1560-1800m), Pitthoragarh district of Kumaon region of Uttarakhand (Western Himalaya) on 23.ix.2020. Full grown larva measured 20 mm in length (Fig. 14a), greyish in colour having long spiny hairs spread all over the body and two pairs of thick black hair tufts on the dorsal surface of the 4-5 segments of the body spread laterally. Up to 2-4 larvae were recorded defoliating a single twig. Larval period ranged from 3 to 4 weeks in September. Pupa (Fig. 14 b) is 15 mm (male) and 17 mm (female) in length, dark brown in colour and was formed attached to the twig longitudinally near the area of feeding with new foliage. Spines like setae are woven all around the twig in such a way that pupa lies in between and spine like barbs are present on anterior and posterior of pupa and all around in order to protect it from natural enemies. Pupa period is of 5-6 days in September. Moths (Fig.14 c & d) wing span 30mm (male) and 34mm (female)], emerged in during late September: three numbers on 30.ix.2020 and two on 05.x.2020. Fore wings are crimson colour with yellow patches on the centre and outer areas and four dark grey transverse bands; sub-basal and anti-medial bands are curved towards each other, touching about middle. Hind wings are pale ochreous, suffused with reddish (Wileman, 1910). According to Volynkin *et al.* (2019) antennae of both sexes are ciliate.

Pest Status: Minor pest.

Remarks: Moths are attracted to light in sub-tropical and moist temeprate forests in the state.

***15. Parasa pastoralis* Butler, 1885, Family:** Limacodidae

Distribution: This species is widespread in the Oriental tropics from N.E. Himalaya to Sundaland and in south-east Asia inluding India, Pakistan, Bhutan, Nepal, Myanmar, Southern China, Taiwan, Thailand, Vietnam, Borneo, Sumatra, Java and Bali (Holloway, 2005).

Host Range: Other host plants are *Musa* sp. (Musaceae), *Aleurites cordata* (Thunb.) Steud. (Euphorbiaceae), *Tectona grandis* L. (Verbenaceae), *Triadica sebifera* (L.) *Stillingia sebifera* (L.) Michx) (Euphorbiaceae) (Joannis, 1929); *Camellia sinensis* (L.) Kuntze (Theaceae) India) (Robinson *et al.,* 2010).

Life-history: Larva (17mm) was recorded on *Q. glauca* tree in moist temperate forest at Ogla, between Didihat and Thal (29.84339N & 80.16503E; 1560-1800m), Pitthoragarh district of Kumaon region of Uttarakhand (Western Himalaya) on 23.ix.2020 (Fig. 15a). Rounded brownish ball like pupa was formed on 06.x.2020. Emergence of greenish moth with brown markings took place on 18.x.2020 (Fig. 15b; female; wingspan: 38mm).

Habit: Larva defoliates by feeding on tender leaves.

Pest Status: Minor pest.

Remarks: Uncommon in *Q.glauca* forests.

***16. Demonarosa rufotessellata* Moore, 1879, Family:** Limacodidae

Distribution: This species is found in Borneo as well as in India, Nepal, Myanmar, Thailand, Laos, Vietnam, the Philippines, Taiwan and Japan. (https://en.wikipedia.org/wiki/Demonarosa_rufotessellata).

Host Range: Rock Oak, *Lithocarpus konishii*, *Litchi* spp. and *Liquidambar* spp. (James, 2017).

Habit: Larva defoliates

Life-history: A tent shaped greenish larva (Fig. 16a & b) was recorded defoliating *Q. glauca* tree in moist temperate forest at Ogla, between Didihat and Thal (29.84339N & 80.16503E; 1560-1800m), Pitthoragarh district of Kumaon region of Uttarakhand (Western Himalaya) on 23.ix.2020. Caterpillar 16mm in length moves slowly in a smooth, slug like fashion and does not travel far and, before moving on, will consume the same leaf until there is nothing left. It is green, with the dorsal

peaks outlined in brown and intricate, armour-plating markings across its top and sides (James, 2017). The larva only feed on the leaf margin and turned brownish just before pupation (Fig. 16c). Pupa, a hardened ball cocoon (Fig. 16d) is placed between two leaves tied together(10mm length), was formed on 25.ix.2020. The moth failed to emerge.

Pest Status: Minor pest.

Remarks: Locally common in *Q.glauca* forests

***17. Adoneta* sp., Family:** Limacodidae

Distribution: The genus is distributed in the Neacrtic and Palaeartic region.

Host Range: One species of the same genus i.e. *Adoneta spinuloides* feeds on the *Malus*, *Prunus* (Rosacae) and *Quercus* (Fagaceae) in the Neacrtic region (https://www.nhm.ac.uk) whereas *A. gemina* feeds on *Ebenopsis ebanob* (Berland.) Barneby & J.W.Grimes (Fabaceae) at Texas North America (https://bugguide.net/node/view/1034734).

Habit: Larva defoliates by feeding on the leaf margins before consuming the entire leaf.

Life-history: Larva (23mm) was recorded feeding leaves of *Q. glauca* trees in moist temperate forest at Ogla, between Didihat and Thal (29.84339N & 80.16503E; 1560-1800m), Pitthoragarh district of Kumaon region of Uttarakhand (Western Himalaya) on 23.ix.2020 (Fig.17a & b). A hard balled pupa (Fig. 17c) was formed on 08.x.2020 between a folded leaf and leaves.

Pest Status: Minor pest.

Remarks: Locally common at lower elevations.

With the current findings the total number of leaf eating caterpillars infesting *Q. leucotrichophora* and *Q. glauca* known till date is 68 species in the Western Himalayas and are mostly polyphagus in habit and distributed across the Himalayan region extending to south-east Asia. The study reports for the first time *Q. leucotrichophora* as new host for 13 species of lepidopteran belonging to Limacodidae, Erebidae, Geometridae, Pyralidae and Limacodidae and four species belonging to Arctiidae and Limacodidae on *Q. glauca* from both Garhwal and Kumaon regions of Uttarakhand state, India.

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Pongamia oil soap for the management of chilli mite, *Polyphagotarsonemus latus* Banks and its impact on spider population

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ABSTRACT: Field experiment was conducted to check the efficacy of the pongamia oil soap along with Spiromesifen and Neem oil soap at different concentrations in controlling chilli mite, *Polyphagotarsonemus latus* and its impact on spider population. Spiromesifen was found effective against chilli mite and showed persistent action in the field, whereas pongamia oil soap reported an immediate control over the pest but its effectiveness declined with time and concentration. Among the botanicals, 3% pongamia oil soap was found effective and was followed by the 2% pongamia oil soap. Pongamia oil soap proved effective against mite up to seven days after the treatment and the effect declined by 14 days after the spray. The botanicals as well as the chemical spiromesifen were found safe to spiders in the field.

KEY WORDS: Botanical pesticides, chilli mite management, spider safety

Polyphagotarsonemus latus Banks is a serious pest of chilli (*Capsicum annuum* L.) which infest the young plant parts leading to the symptoms like rat tailing, severe malformation and downward curling of leaves, stunted growth and complete crop failure at times. Chemical pesticides against pest have drawbacks like increased cost, pesticide-induced pest resurgence, residues in product, mortality of natural enemies etc. Botanical pesticides are safe and effective against various pests of crop. Pongamia seed oil has been evaluated against many pests and found effective as larvicide, antifeedant, oviposition deterrent, ovicide, juvenile hormone active agent and roachicide (Kumar and Singh, 2002). Flavanoids, chalcones, steroids and terpenoids are the secondary metabolites in pongamia oil which serve as natural pest repellents (Pavela, 2007).

Pongamia oil soap was prepared by following the method used for the preparation of ready to use neem oil garlic soap. Field evaluation was carried out at Instructional farm II of College of Agriculture, Padannakkad at Karuvacheri during November, 2019 – May, 2020. Vellayani athulya variety of chilli was grown in the field. The statistical design followed was RBD with eight treatments (Table 1) and three replications. The treatments were applied 2, 3 and 5 months after transplanting using sprayer. Spraying was carried out during early morning and precautions were taken to avoid drift. Six plants were selected randomly from a plot and tagged for taking pest and spider count. To count mite population, six leaves were collected at random from the top canopy of each selected plant and were brought to the lab in Zip lock bags. They were observed under stereo binocular microscope for

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counting mites. Population density was counted one day prior to treatment and 1st, 3rd, 5th, 7th and 14th day after the treatment application. Population of mite was not uniform during first spray and hence it was not recorded.

Square root transformations was followed for the data on population density The data were analysed using analysis of variance (ANOVA). For comparing the significance of each treatment WASP (Web Agri Stat Package) was used.

The pre-spray count population of mite came in the range of 17.78 – 19.00 mites/ 6 top leaves before the second spray. One day after the second spray, pongamia oil soap at 3% was found superior with a least mite count of 2.56 mites/ 6 top leaves and this was followed by pongamia oil soap 2% (3.61), 1% (4.39), standard check (5.33), pongamia oil soap 0.6% (6.00) and neem oil soap 0.6% (9.17). There was no much increase in the mite population in the 3% pongamia oil soap on the 3rd day and it recorded 2.94 mites / 6 top leaves, while count reduced in the standard check to 3.22 mites / 6 top leaves. Pongamia oil soap at 2% reported 4.50 mites / 6 top leaves followed by 1% (5.56), 0.6 % pongamia oil soap (7.06) and neem oil soap 0.6% (10.33). A sudden decrease in the population of mite was observed in the standard check with 0.89 mites / 6 top leaves on the 5th DAS. Among the botanicals pongamia oil soap at 3% remained superior over the others with 3.67 mites / 6 top leaves. Pongamia oil soap 2% and 1% were found on par with each other and recorded 5.72 and 6.39 mites / 6 top leaves respectively and this was followed by the 0.6% pongamia oil soap and neem oil soap (8.83 and 12.39 mites / 6 top leaves respectively). During all these days the soap solution and the control showed the highest mite population. The 7th day count revealed that the standard check was highly effective with a least population of 0.44 mites / 6 top leaves while a population of 5.44 mites/ 6 top leaves was counted from pongamia oil soap 3% and was on par with 2 % pongamia oil soap (6.94). Pongamia oil soap 1% recorded 8.78 mites/ 6 top leaves and was on par with 0.6% pongamia oil soap (10.72 mites/ 6 top leaves). This was followed by 0.6% neem oil soap (13.56) and soap solution (18.06) while the highest count was associated with control plot (25.00). A gradual increase in mite population was observed in all the treatment plots on the 14th day after the second spray, however the standard check reported as highly effective treatment with a population of 1.89 mites/ 6 top leaves. All the botanicals, soap solution and control recorded a high population (Table 1).

Mite population taken prior to the treatment application was at a range of 10.11 to 15.33 mites/ 6top leaves. Pongamia oil soap 3% was found superior with 2.22 mites/ 6 top leaves over soap solution (10.72) and control (16.28) on the first day after spray. Pongamia oil 2 and 1% were on par with each other with 3.28 and 3.72 mites/ 6 top leaves respectively and was followed by standard check (3.78 mites/ 6 top leaves) and pongamia oil soap 0.6% (5.00 mites/ 6 top leaves) which were also on par with each other. The neem oil soap at 0.6% has got a pest count of 7.61 mites/ 6 top leaves in the second spray. On the third day after the treatment, the standard check was found superior with 1.06 mites/ 6 top leaves and among the botanicals, pongamia oil soap at 3% was highly effective with 2.61 mites/ 6 top leaves while the control plot and soap solution recorded a pest count of 16.94 and 13.06 mites/ 6 top leaves respectively. 3.28 mites/ 6 top leaves were counted from the plot treated with 2% pongamia oil soap and was followed by 1% pongamia oil soap (4.06 mites/ 6 top leaves), 0.6% pongamia oil soap (4.94 mites/ 6 top leaves) and 0.6% neem oil soap (7.72 mites/ 6 top leaves). The population count taken on the fifth day after third spray showed that the standard check – spiromesifen as a highly effective miticide (0.11 mites/ 6 top leaves) over the control (17.22) and soap solution (13.28). The pongamia oil soap 3% reported 3.17 mites/ 6 top leaves followed by 2% pongamia oil soap (4.11 mites/ 6 top leaves) which was on par with the 1% pongamia oil soap (4.89 mites/ 6 top leaves). 0.6% pongamia oil soap got 5.89 mites/ 6 top leaves which were followed by neem oil soap 0.6% (10.06 mites/ 6 top leaves). A least count of 0.07 mites/ 6 top leaves was reported in the standard check followed by 3% pongamia oil soap with 3.11 mites/ 6 top leaves on the 7th day. Pongamia oil soap at 2% recorded 5.22

Table 1. Population density of chilli mite during field evaluation of pongamia oil soap on chilli

Treatment	Average population of mite (mites/ 6 top leaves/ plant)*											
	Second spray						Third spray					
	Pre spray	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS	Pre spray	1 DAS	3 DAS	5 DAS	7 DAS	14 DAS
T_1 - Spiromesifen 22.9 SC @ 96 g a.i./ha	19.00 (4.36)	5.33 $(2.31)^{d}$	3.22 $(1.79)^{g}$	0.89 $(0.94)^{g}$	0.44 $(0.64)^{g}$	1.89 $(1.35)^{c}$	12.22 (3.43)	3.78 $(1.94)^{d}$	1.06 $(1.02)^{h}$	0.11 $(0.78)^{g}$	0.07 $(0.75)^{c}$	0.83 $(0.88)^{c}$
T_2 - Pongamia oil soap 3%	18.67 (4.32)	2.56 $(1.60)^{g}$	2.94 $(1.72)^{g}$	3.67 $(1.91)^{f}$	5.44 $(2.33)^{f}$	17.94 $(4.23)^{b}$	12.50 (3.54)	2.22 $(1.49)^{e}$	2.61 $(1.62)^{g}$	3.17 $(1.92)^{f}$	3.11 $(1.87)^{bc}$	14.67 $(3.68)^{ab}$
T_3 - Pongamia oil soap 2%	18.94 (4.35)	3.61 $(1.90)^{f}$	4.50 $(2.12)^{f}$	5.72 $(2.39)^{e}$	6.94 $(2.63)^{ef}$	21.17 $(4.60)^{b}$	10.33 (3.20)	3.28 $(1.81)^{de}$	3.28 $(1.81)^{f}$	4.11 $(2.15)^{e}$	5.22 $(2.39)^{b}$	11.17 $(3.33)^{b}$
T_4 - Pongamia oil soap 1%	17.78 (4.22)	4.39 $(2.09)^{e}$	5.56 $(2.36)^{e}$	6.39 $(2.53)^{e}$	8.78 $(2.96)^{de}$	18.44 $(4.29)^{b}$	10.39 (3.19)	3.72 $(1.93)^{de}$	4.06 $(2.01)^{e}$	4.89 $(2.32)^{de}$	5.50 $(2.45)^{b}$	12.06 $(3.44)^{b}$
T_5 - Pongamia oil soap 0.6%	18.50 (4.30)	6.00 $(2.45)^{d}$	7.06 $(2.66)^{d}$	8.83 $(2.97)^{d}$	10.72 $(3.27)^{d}$	20.94 $(4.56)^{b}$	10.11 (3.00)	5.00 $(2.17)^{d}$	4.94 $(2.22)^{d}$	5.89 $(2.53)^{d}$	9.11 $(3.09)^{ab}$	12.72 $(3.50)^{b}$
T_6 - Neem oil soap 0.6%	18.00 (4.24)	9.17 $(3.03)^{c}$	10.33 $(3.21)^{c}$	12.39 $(3.52)^{c}$	13.56 $(3.67)^{c}$	16.94 $(4.08)^{b}$	17.17 (4.10)	7.61 $(2.76)^{c}$	7.72 $(2.78)^{c}$	10.06 $(3.24)^{c}$	14.83 $(3.88)^{a}$	21.50 $(4.58)^{ab}$
T_7 - Soap solution 0.5%	18.11 (4.26)	13.22 $(3.63)^{b}$	14.94 $(3.87)^{b}$	16.00 $(4.00)^{b}$	18.06 $(4.25)^{b}$	20.50 $(4.52)^{b}$	15.33 (3.82)	10.72 $(3.27)^{b}$	13.06 $(3.61)^{b}$	13.28 $(3.71)^{b}$	16.00 $(3.82)^{a}$	17.66 $(3.99)^{ab}$
T_8 - Control	18.78 (4.33)	19.06 $(4.36)^{a}$	20.50 $(4.52)^{a}$	21.39 $(4.62)^{a}$	25.00 $(5.00)^{a}$	28.17 $(5.30)^{a}$	12.89 (3.55)	16.28 $(4.03)^{a}$	16.94 $(4.12)^{a}$	17.22 $(4.21)^{a}$	17.72 $(4.23)^{a}$	26.06 $(5.09)^{a}$
CD (0.05)	NS	0.20	0.20	0.19	0.36	0.70	NS	0.44	0.19	0.23	1.29	1.58

*Mean observations from six plants. Figures in parentheses denote square root transformed values.Means superscripted by same letter are not significantly different at 5% level of DMRT. DAS- Days after spray; NS- Non significant

mites/ 6 top leaves and was on par with 1% and 0.6% pongamia oil soap (5.50 and 9.11 mites/ 6 top leaves) while the 0.6% neem oil soap, soap solution and control showed the highest population of 14.83, 16.00 and 17.72 mites/ 6 top leaves respectively. A gradual increase in the mite population was observed on the 14th day in all experimental plots except the standard check which has got a population of 0.83 mites/ 6 top leaves.

Comparing with the control and soap solution all the other treatments showed acaricidal activity during field study. Spiromesifen reported a significantly superior effect on yellow mite than other treatments. Due to the persistent action of spiromesifen, the population declined greatly one day after spray and gradually reached the lowest population. After 7th day (0.44 and 0.07 mites/ 6 top leaves) an increase in mite population was recorded on 14th day (1.89 and 0.83 and mites/ 6 top leaves) during the second and third spray. According to Varghese and Mathew (2013), spiromesifen 45 SC @ 100 g a. i. /ha had a superior effect in controlling chilli mite among the 8 chemicals tested and it also recorded a similar trend *ie*., a gradual decline in mite population up to 7 days after treatment and an increase thereafter on the 14th day.

Among the botanicals pongamia oil soap 3 % significantly reduced the mite population followed by pongamia oil soap 2%, 1%, 0.6% and neem oil soap 0.6%. In all botanically treated plots, pest population declined to a minimum immediately after the spray, gradually increased thereafter and the highest count was recorded on the 14th day. Prasad *et al*. (2017) proved the effectiveness of pongamia oil and neem oil against chilli mite. Neem oil (4ml/l) and pongamia oil (5ml/l) resulted a high percent mortality of 71.50 and 68.50 respectively after ten days of application in the field against the mite. The efficacy of pongamia oil soap in controlling the mite might be due to its repellent and insecticidal properties.

Spider population in the field was uniform before and after each spray application in the field (0.00 to 2.33) which confirm that the botanicals (pongamia oil soap and neem oil soap) and spiromesifen don't have any immediate and persistent impact on spiders. Hence all the treatments are safe to spiders in ecosystem. Sahana and Tayde (2017) recorded a mean spider population of 0.50 and 0.55 spiders/plant on 3% pongamia oil and neem oil sprayed plants which was at par with the untreated control (1.03 spiders/ plant). Baladhiya *et al*. (2018) confirmed that the spiromesifen 22.9 SC 96 g a.i. /ha didn't have any adverse impact on spider population.

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Genetic diversity of *Aedes aegypti* (Diptera: Culicidae) in rural and urban settings in Tamil Nadu, India

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ABSTRACT: *Aedes aegypti* populations collected from four different localities in Tamil Nadu, India were analysed using Random Amplified Polymorphic DNA (RAPD) markers to assess the level of genetic variations within and between populations. RAPDs were found to be polymorphic enough to detect genetic polymorphisms at both micro (within the city, <10 km) and macro spatial scales (between three districts, ~500 Km apart). Hetrozygosity within populations varied from 0.1150 ± 0.2140 to 0.3715± 0.1545, but pattern of genetic diversity was not found to be associated with the geographical distance between the populations and the prevalence of dengue infections.

KEY WORDS: Dengue vector, Nei's genetic distance, Shannon's index, polymorphic loci, dendrogram

Dengue is the most widespread and rapidly growing mosquito-borne disease in India, which frequently attains epidemic proportion in several parts of the country (Banik *et al*., 1994, Agarwal *et al*., 1999, Dar *et al*., 1999, Chaturvedi and Nagar, 2008). Dengue is primarily transmitted by *Aedes aegypti*, and it's anthropophilic, endophagic (indoor resting) nature, and the potential to breed in and around thickly populated urban areas enhances its epidemiological and social impact. Understanding biology, population dynamics and population genetics of *Ae. aegypti* are the major areas of research interests for developing effective and novel vector control strategies. The geographical distribution and prevalence of *Ae. aegypti* (Rao, 1967, Reuben, 1970, Das *et al*., 2014, Dev *et al*., 2014, Shriram *et al*., 2018), its potential to carry dengue virus (Kumar *et al*., 2015a, Mukherjee *et al*., 2017), and susceptibility to insecticides (Madhukar and Pillai, 1970, Biswas *et al*., 1988, Montada Dorta *et al*., 1993, Muthusamy and Shivakumar, 2015, Yadav *et al*., 2015) are well studied in India. However, the knowledge on genetic structure and the gene flow across *Ae. aegypti* populations are scanty. Previous genetic diversity studies on *Ae. aegypti* populations in India have revealed high level of genetic differentiation at both micro (Tyagi *et al*., 2017) as well as macro levels (Gokhale *et al*., 2015; Kumar *et al*., 2015b). A preliminary survey of *Ae. aegypti* populations from 31 districts of Tamil Nadu using

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Cytochrome oxidase I (Vadivalagan *et al*., 2016) (750 bp, potentially conserved genetic marker) reported different haplotypes circulating in each district, indicating high genetic diversity in the mosquito populations that needs to be investigated at the finer geographical scales. In this view, a pilot study was conducted to analyze the genetic diversity of *Ae. aegypti* at different spatial scales in Tamil Nadu, India.

A total of 39 *Ae. aegypti* adults were collected during 2008 from four different localities of Tamil Nadu, India; ten samples each from two municipal corporation zones of Chennai city namely; Chennai A (Kodambakkam) and Chennai B (Kolathur), eight from Madurai city and 11 from Thiruppuvanam village, Sivaganga. Since population genetic structure and the gene flow of mosquitoes are influenced by the geographical distance and the other ecological features (anthropogenic and environmental), the study sites were selected based on the prevalence of dengue and their spatial positioning (geographical distance). Chennai is a metropolitan city and hyper endemic for dengue, however, the land use pattern of the two sites within the city is different. While Chennai A is a typical urban area with automobile industries located in the middle of the city with high density of humans) and Chennai B is a peri-domestic area with humans having more open space with gardens around the house and less density in population. Madurai city (urban setting) has sporadic cases of dengue every year and Thiruppuvanam (rural area) is non-endemic for dengue. Spatial distance between the study sites vary from <10 km (Two Chennai city zones), ~50 km (Madurai and Thiruppuvanam) and ~500 km (Chennai and Madurai/ Thiruppuvanam). Sample collection was performed by collecting eggs of *Aedes* mosquitoes by Ovitrap method as described by Silver (2008). The Ovitraps were kept in the residential area for 24 hours and paddle of the ovitraps were air-dried, wrapped in separate polyethylene bags and safely transported to the laboratory. The paddles were checked for the presence of eggs with the dissection microscope. Collected eggs were allowed to emerge in to adult and identified as per the standard keys (Christophers, 1933; Pocock, 1933). Single female mosquito from each egg collection was used for this study for further analysis.

Whole adult mosquito was used for DNA isolation. Individual mosquitoes in the micro-centrifuge tubes were homogenized with lysis buffer (20 mM tris-HCl, pH 8.25, 25 mM EDTA, 25 mM NaCl, 1% SDS) in an indigenously designed homogenizer with the autoclaved glass rod. The suspension was incubated with 100 mg/ml of proteinase K (Boehringer Mannheim, Germany) for one hour at 56 ºC. The DNA was extracted with 100 µl of potassium acetate 3 M, ice incubation for one hour and centrifugation at 8000 xg for 10 min at 4 ºC. The DNA was precipitated by adding two volumes of absolute ethanol containing 0.3 M sodium acetate and placed at - 20 ºC for 30 minutes. The precipitated DNA was centrifuged at 10000 xg for 20 min. and the pellet washed in 70% ethanol. After air drying, the DNA was dissolved in 50 µL tris-EDTA buffer (TE) (1 mM tris-HCl pH 8.0, 1 mM EDTA pH 8.0). Any remaining RNA was eliminated with RNaseH (Boehringer Mannheim, Germany) and the suspension was incubated for one hour at 37 ºC. After extraction with equal volume of chloroform-isoamyl alcohol (24: 1), the aqueous phase was conserved at - 20 ºC. The DNA concentration was estimated spectrophotometrically by reading absorbance at 260 nm and the purity of the sample was examined by electrophoresis with a 0.8% agarose gel in TBE buffer (TBE 0.5x) (0.045 M tris-borate, 0,001 M EDTA) containing ethidium bromide (0.5 mg/ml) with visualization using a UV transilluminator (Vilber lourmet, France).

RAPD markers were used to reveal genetic diversity among *Ae. aegypti* populations. RAPD amplification was performed in a final volume of 25 µl using PCR master mix supplied by Bangalore Genei, India. Negative controls for each assay were run without DNA template to rule out contamination. The PCR amplification was carried out in a Thermal Cycler (MJ Research PTC 100, CA, USA). The following temperature profile was used: denaturation at 94^0 C for 4.00 minutes followed by 45 cycles of 94^0 C for 1.00 minute, 36^0 C for 1.00 minute for primer annealing and 72^0 C

for 2.00 minutes for strand extension. Final extension was allowed for 5.00 minutes at 72^0 C. The amplified products were visualized in 1.2% agarose gel in TBE buffer containing Ethidium Bromide (0.5 mg/ml). The RAPD profile was recorded with a gel documentation system. The presence or absence of each band was scored visually. One Kb DNA ladder (Fermentas Inc., www.fermentas.com) was used as a marker. The molecular weight of each band was estimated by comparing it with the co-migrating 1Kb DNA ladder. Unique fragments were identified and used as diagnostic profile.

Individual bands were scored for presence or absence using binary code (1 or 0, respectively) for each sample to count the level of genetic polymorphisms within and between mosquito populations. For genetic diversity analysis, it is assumed that *Ae. aegypti* populations are in Hardy-Weinberg equilibrium and therefore no selection processes favoring any particular genotype, RAPD markers used in this study segregate in a Mendelian fashion with constant evolution or substitution rate and recessive (band absent) and dominant (band that is present) alleles are identical in state among and between individuals. Genetic polymorphisms were analyzed based on the heterogeneities in the RAPD banding pattern. The extent of genetic similarity within each population was estimated using Nei's gene diversity (Nei, 1978) and Shanon's index. To understand the level of differentiation between populations, Nei's genetic distance was estimated. All the genetic analyses discussed above were performed using PopGene 1.31 software (Yeh and Boylet, 1997). To reveal genetic relationship between and within populations, dendrogram was constructed using Nei's genetic distance using unweighted pair group method with arithmetic averages (UPGMA) clustering strategy. Dendrograms were generated using RAPDPLOT computer programme.

Genetic diversity of four *Ae. aegypti* populations was estimated using RAPD markers. Total three RAPD markers A-3 (AGTCAGCCAC), A-6 (GGTCCCTGAC) and A-12 (TCGGCGATAG) were tested for this study, however only one marker (A-12) was found to be informative with scorable bands amplified in all the mosquito samples. The results of A-12 marker were also found to be reproducible on multiple testing. Therefore, only A-12 was used for further analysis in this study. Total 17 bands were scored from A-12 marker among 39 mosquito samples. The molecular size of the amplified bands varied from 250bp to 6 Kb. A band of ~400 base pair was found common among all the mosquito samples genotyped in the study (Fig. 1). The visual comparison of RAPD profiles of each population revealed variation in the level of genetic diversity among the four *Ae. aegypti* populations. The individuals from Chennai B population showed maximum diversity in banding pattern, whereas majority of the individuals from Chennai A seemed to share the common banding patterns. Chennai B banding pattern looked different from all the other three populations on visual examination of RAPD profiles. Maximum banding patterns were observed in Chennai B (n=8), followed by Madurai A (n=6), Chennai A (n=5) and minimum patterns were observed in Thiruppuvanam (n=3). This observation was also supported by the number of polymorphic bands observed in each population. The maximum number of polymorphic bands (85%) was observed in Chennai B and the lowest was found in Thiruppuvanam (25%).

The genetic diversity of each population was estimated based on the heterogeneity in RAPD banding patterns. The expected heterogeneity estimated as Nei's gene diversity, varied from 0.1150 ± 0.2140 in Thiruppuvanam population to 0.3715 ±0.1545 in Chennai B population. Similar pattern was observed for the Shannon's diversity index, which varied from 0.1630 ± 0.3026 in Thiruppuvanam population to 0.5383 ± 0.2210 in Chennai B. The values of both Nei's Genetic distance and Shannon's index were almost similar for Madurai and Chennai A populations. The total diversity of all the populations was 0.3428 ± 0.1623 with Shannon's index 0.5051 ± 0.2244 (Table 1).

The genetic differentiation between populations was estimated using Nei's genetic distance. Noticeably, maximum genetic distance was observed between Chennai B and Thirupuvanam, while the minimum distance was observed between

Table 1. Genetic analysis of four populations of *Aedes aegypti* from four geographical areas

Areas	No. of samples	Nei's gene diversity	Shannon's index	Polymorphic loci (%)
Chennai- A	10	0.2396 -± 0.2569	0.3360± 0.3598	50.00
Chennai- B	10	0.3715 ± 0.1545	0.5383 ± 0.2210	87.50
Madurai	8	0.2286 ± 0.2443	0.3248 ± 0.3472	50.00
Thiruppuvanam	11	0.1150 ± 0.2140	0.1630 ± 0.3026	25.00
Overall	39	0.3428 ± 0.1623	0.5051 ± 0.2244	87.50

Thiruppuvanam and Chennai A. Chennai B was found to be highly distant from all the populations with Nei's Genetic distance varying from 0.2656 to 0.4146. Other three populations were found genetically closer with genetic distance varying from 0.05444 (Chennai A and Thiruppuvanam) to 0.1024 (Chennai A and Madurai) (Table 2). Since the spatial positioning of each population is different based on geographic distance between them, we estimated the correlation between genetic distance and the geographical distance between populations. There was a negative correlation between population genetic diversity and geographical distance between populations (r = -0.0838, P = 0.8745), however the relation between two parameters was found to be non-significant. The similar pattern of genetic relatedness between populations was also observed based on the dendrogram constructed using Nei's genetic distances (Fig. 2). The dendrogram revealed two clearly distinguishable clusters: (1) Chennai A, Madurai and Thiruppuvanam and (2) Chennai B, showing no effect of geographic origin or dengue endemicity on clustering pattern.

Even a single RAPD marker detected higher level of genetic differentiation within and between populations. The genetic distance between four populations varied from 0.05 to 0.4616. Notably, Chennai B (one of the sampling site within Chennai city) was found highly diverse showing maximum genetic distance from other three populations. The pattern of genetic diversity was found almost similar in Chennai A and Madurai. This might be due to the small sample size and the single genetic marker used for genotyping. The reason for the increased genetic differentiation in the metropolitan city, (Chennai, a hyper-endemic area for dengue) might be due to the selective pressure exerted by the periodic application of insecticides (Larvicide and adulticides) and the availability of a variety of breeding habitats created by the water storing practices of the community. Moreover, the man made changes in the metropolitan area has also been expected to provide breeding habitats for the profuse breeding of *Ae. aegypti*. Similarly, *Ae. aegypti* population collected from Madurai, showed high genetic diversity. Hemme *et al.* (2010) reported the influence of urban landscape in the population dynamics of *Ae. aegypti* in Trinidad. Similar observations were reported in many countries (Mousson *et al*., 2002; Ocampo and Wesson, 2004). Thiruppuvanam on the other hand showed minimum genetic diversity with only three banding patterns that too identical to the ones

Table. 2. Nei's genetic distance (below diagonal) between four *Aedes aegypti* populations

Populations	Chennai- A	Chennai- B	Madurai	Thiruppuvanam
Chennai- A	-	-	-	-
Chennai- B	0.3493	-	-	-
Madurai	0.1024	0.2656	-	-
Thiruppuvanam	0.0544	0.4146	0.1010	-

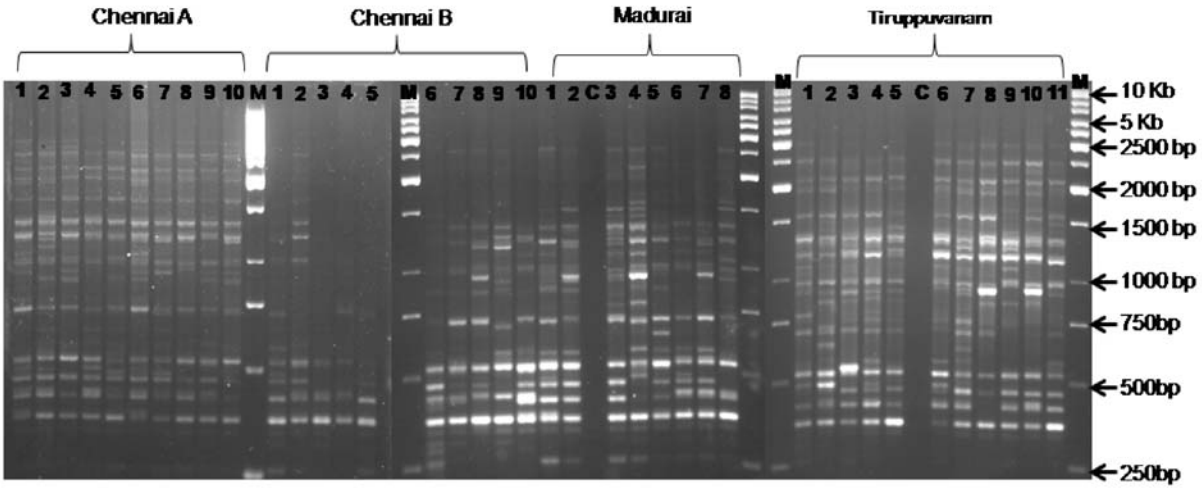

Fig. 1 RAPD banding pattern obtained from four *Aedes aegypti* mosquito populations using A-12 RAPD primer. Lane M: Molecular weight 1 Kb marker (size of the bands are shown with arrow marks), Lane C: negative control without DNA, Lanes covered by bracket above are showing the RAPD banding pattern obtained from individual mosquitoes collected from each population.

observed in Madurai and Chennai A. The low level of genetic diversity in Thiruppuvanam (rural area) might be the consequence of lower prevalence of *Ae. aegypti* in rural areas. Moreover, passive dispersal of the mosquitoes between populations can-not be under-estimated; however, confirmation needs a more detailed sampling to prove the hypothesis.

The dramatic pattern of genetic diversity was observed between two sites of Chennai city. Although the geographical distance between two sites is only ~7Km, the man made changes and land use pattern might have an influence on the mosquito populations. Chennai B has peri-domestic area with humans having more open space with gardens around the house and less density in population. Such landscapes can provide breeding spaces for the mosquitoes in the form of small flower pots, tree bases, tree holes etc and thus could lead to more genetic diversity.

Though the study included limited area for analysis, the results have demonstrated a spatial variation in genetic structure and a high level of genetic differentiation among the *Ae. aegypti* populations. It is worthwhile to correlate these findings with the transmission dynamics of dengue and the differential endemicity of the regions as the higher

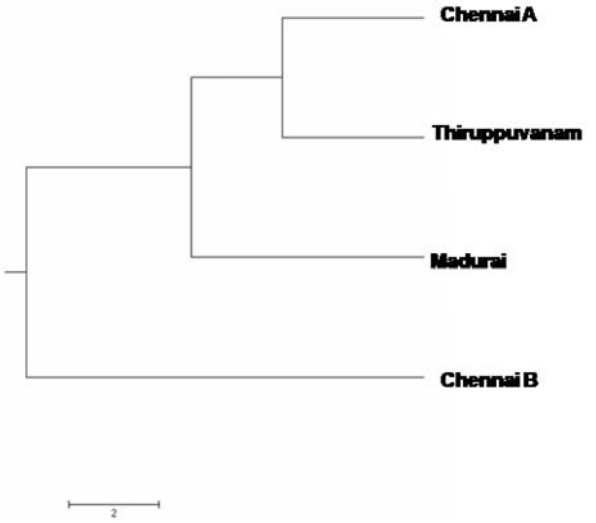

Fig. 2 Dendrogram constructed using Nei's genetic distance between populations using unweighted pair group method with arithmetic averages (UPGMA) clustering strategy.

genetic differentiation might favour the virus transmission as it has been experienced in city of Tartagal, North Argentina (Rotela *et al*., 2007). Further in-depth studies are highly warranted by improving the sample size, covering more areas would help in better understanding the genetic structure of the vector in southern India where dengue is a serious public health problem.

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Studies on the biology of *Tribolium castaneum* (Herbst, 1797) (Coleoptera: Tenebrionidae) with stereomicroscopic images of its life stages

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ABSTRACT: The life cycle and season's studies of *Tribolium castaneum* indicated that the most favourable season as monsoon (27±5<" C & 80±05 % RH) where they have completed their life cycle within 22 days. The most unfavourable season was the winter (15±3<" C & 35±05 % RH) where it extended till 45 days. Results showed the presence of seven larval instars in the life cycle of the beetle. Stereomicroscope was used to study the microscopic stages like eggs, sexual dimorphism of pupae and adults, morphometric of the beetle. This is the first compiled stereomicroscopic photographs of the life cycle of *T. castaneum*. © 2021 Association for Advancement of Entomology

KEYWORDS: Morphometric, stereomicroscopy, life stages, seasons

Tribolium castaneum (Coleoptera: Tenebrionidae) is one of the highly resistant pests and known to damage a wide range of stored grains (White and Lambkin, 1988; Hagstrum, 2017). Abiotic and biotic factors, which greatly influence the life cycle of the pest, are vital to the mass-rearing (Santos et al., 2018). However, standardisation claims for a major share of time. Hence, the collective knowledge of basic biology is of great importance to validate the efficacy of the new formulations (Arthur and Hoernemann, 2004). Interestingly, it has emerged as a better model for developmental studies than *Drosophila* (Richards *et al.*, 2008). Additionally, they work as an efficient early warning system in transgenerational epigenetic side effects caused by different pharmaceuticals (Bingsohn *et al*., 2016). A few studies on the biology of the pest have been recorded from different parts of India (Devi and Devi, 2015; Sreeramoju *et al*., 2016). However, distinctive photography explaining microscopic characteristics are lacking in the literature. As the number of larval instars varies with temperature, humidity (Karuppaiah and Sujayanad, 2012), detailed biology of *Tribolium castaneum* with unique characteristics of each stage, photographs and morphometric data were undertaken.

T. castaneum culture was collected from the Department of Zoology, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India and reared in the defined culture media of wheat flour, wheat grains, and Baker's yeast in the ratio of 6:3:1. The jars were covered with the muslin cloth for the ease of aeration. Cultures were divided into two sets where one was maintained in the laboratory to understand the growth curve in the warehouses. And other set was maintained in the humidity

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chamber at 27±2°C, 70±5 RH to be used for bioassay studies. Here, the biology study was conducted with the culture set maintained in the laboratory. This experiment continued throughout the year (April 2018- March 2019) to analyse the most favourable and unfavourable season for the growth of the beetle. The cultures were observed regularly for oviposition. A 250 µm sieve of 60 mesh size was used to separate the microscopic eggs from the media. Eggs were then isolated and kept in separate glass petriplate to study their incubation period. Newly emerged larvae were immediately transferred in the plastic container containing the media. The pupae were separated with the help of a paintbrush and transferred to a glass petriplate for the ease of study. On adult emergence, they were again transferred to the vials containing media. The time required to complete their life cycle was recorded. Morphological characteristics, morphometric analyses and photography were done using stereomicroscope (Computer assisted 13.1 mega pixel catcam stereomicroscope; Model no: LEICA MZ 16 A) at 200x magnification.

Biology:

Flour beetles reared in the natural conditions indicated that the most suitable season was monsoon i.e. July- August (27±5 °C & 80±05 % RH) where they have completed their life cycle within 22 days. The most unfavourable season was the winter (December - January) where it extended till 45 days. The temperature and humidity range were 15±3 °C and 35±05 per cent respectively. Each stage viz. eggs, larvae, pupae and adults is identified by unique characteristics and is explained below (Fig. 1) (Table 1).

Egg: Eggs are microscopic, oval in shape and pale white in colour. Flour particles often stick to their surface as they are sticky when laid. This makes it more difficult to identify even under the microscope. However, when observed carefully, they appear pale compared to flour particles. They are measured by about 0.088±0.004 mm in length and 0.056±0.005 mm in breadth.

Larva: A total of seven instars were recorded. They are campodeiform, slender in shape. Their dorsal surface is covered with fine bristles and the last abdominal segment is demarcated by the presence of anal cerci. Each larval stage is smaller in size from its succeeding stage. The 1st instar larva, emerged post incubation, is very tiny and hence very difficult to see it with the naked eye. They are ivory white in colour and measures about 0.87±0.04 mm in length and 0.096±0.005 mm in breadth. 2nd instar is mobile, linen white in colour, and measured about 1.78±0.04 mm in length and 0.28±0.02 mm in breadth. The 3rd instar is thread like, light yellowish in colour. They measure about 2.06±0.05 mm in length and 0.376±0.03 mm in breadth. The 4th instar is light brownish in colour & measured about 2.852±0.06 mm in length and 0.45±0.05 mm in breadth. The next one is tortilla colored, 5th instar, immature, and measured about 3.84±0.2 mm in length and 0.67±0.03 mm in breadth. The 6th instar is large and bulgy in appearance. They are light brown and measured about 4.97±0.04 mm in length and 0.79±0.02 mm in breadth. The 7th instar is highly mobile, heavy, and tawny in color and measured by about 5.95±0.05 mm in length and 0.972±0.03 mm in breadth.

Pupa: The pupal phase can be differentiated into three stages i.e. Pre pupal, pupal & post pupal stage based on their progressive development. The pre pupal stage is light yellowish, smaller in size. The dorsal side possesses fine bristles. Their head region is broad and curved whereas the tail region always bears shedding exuvia. The pupal stage is recognised by the dark coloration and shorter size. Hind limbs developed on the ventral side and small eyespots are seen. The post pupal stages are demarcated by the presence of fully developed eyes, hind limbs, and dark brownish coloration. The pupal stage shows sexual dimorphism where females and males have forked and stubby genital papillae respectively. Moreover, papillae in the case of females are longer and reach the length of the urogomphi whereas in males it is small and restricted to the last abdominal segment. Pupa measured about 3.88±0.04 mm in length and 0.96±0.05 mm in breadth.

Adult: Adults are dark brownish in colour. They have capitate type of antennae which is very prominent. They measure about 3.96±0.05 mm in

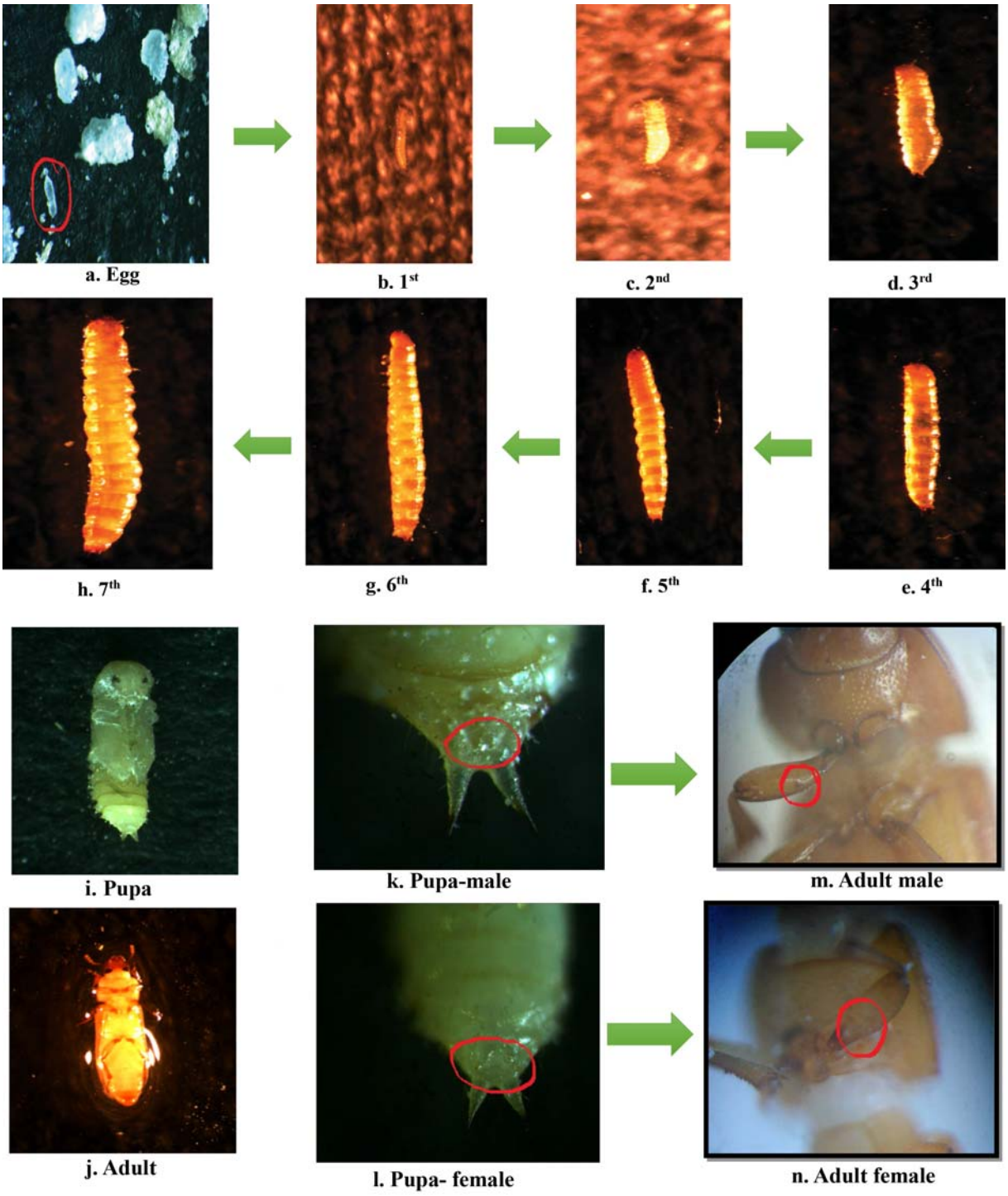

Fig.1 Different stages of *Tribolium casteneum* captured using the computer assisted 13.1 mega pixel catcam stereomicroscope with fine details.

a: egg, b: 1st instar, c: 2nd instar, d: 3rd instar, e: 4th instar, f: 5th instar, g: 6th instar, h: 7th instar, i: ventral view of pupal stage, j: ventral view of adult insect, k: male pupa where genital papilla is stubby, l: female pupa where genital papilla is forked reaching the urogomphi, m: male adult marked by the presence of setiferous patch on the forefemur, n: absence of setiferous patch in female adult

Table 1. Morphometric data of different stages of *Tribolium castaneum* of F1 generation (Mean of 10 individuals)

F1 Gen.	Size	Morphometric data(mm)			
		Mean	Range	±SD	SE
Egg	L	0.088	0.08- 0.09	0.004	0.001
	W	0.056	0.05-0.06	0.005	0.001
1st instar	L	0.87	0.8-0.9	0.04	0.01
	W	0.096	0.09-0.1	0.005	0.001
2nd instar	L	1.78	1.7-1.8	0.04	0.01
	W	0.28	0.25-.3	0.02	0.008
3rd instar	L	2.06	2-2.1	0.05	0.01
	W	0.376	.32-.4	0.03	0.01
4th instar	L	2.852	2.78-2.9	0.06	0.01
	W	0.45	0.4-0.5	0.05	0.01
5th instar	L	3.84	3.6-4	0.2	0.06
	W	0.67	0.64-.7	0.03	0.01
6th instar	L	4.97	4.9-5	0.04	0.01
	W	0.79	0.75-.0.8	0.02	0.006
7th instar	L	5.95	5.9-6	0.05	0.01
	W	0.972	0.93-1	0.03	0.01
Pupa	L	3.88	3.8-3.9	0.04	0.01
	W	0.96	0.9-1	0.05	0.01
Adults (Both male & female)	L	3.96	3.9-4	0.05	0.01
	W	1.08	1-1.1	0.04	0.01

L= Length; W = Width; SD= sample standard deviation SE= Standard error of the mean

length and 1.08±0.04 mm in breadth. They show sexual dimorphism where males possess a setiferous patch in the forefemur which is absent in the females. However, the character is microscopic and cannot be seen with the naked eyes.

Different temperature and humidity in different geographical locations has a profound effect on the life cycle of insect (Good, 1933; Karuppaiah and Sujayanad, 2012). The larval stage has a varying number of instars depending on the abiotic factors like temperature, humidity, and food availability (Good, 1933; Mukerji and Sinha, 1953). The present study has recorded seven larval instars. However, very minute differences were seen between the instars. So morphometric and associated morphological characteristics were taken into account to establish a complete comparative exposition. Microscopic egg stage and distinguishing characteristics of pupae and adults are fine enough to be observed by the naked eyes hence stereomicroscope was used in the study. In a similar study, biology of the beetle was documented from the Imphal, Manipur in the laboratory conditions from January to July (Devi and Devi, 2015). Result shows that the beetle took 164-194 days to complete its life cycle. Singh and Prakash (2015) documented the effect of temperature and humidity on the life cycle of *T. castaneum* collected from two different areas, Dayalbagh and Cantonment area of the Agra

city. Leelaja *et al*. (2007) have confirmed the presence of microscopic eggs of flour beetles using staining techniques. In a study, abnormal larva and adult of *T. castaneum* was photographed along with their normal counterpart using stereomicroscope (Santos *et al.*, 2011). A compiled micro photographic report on the life cycle of red flour beetle is the first study.

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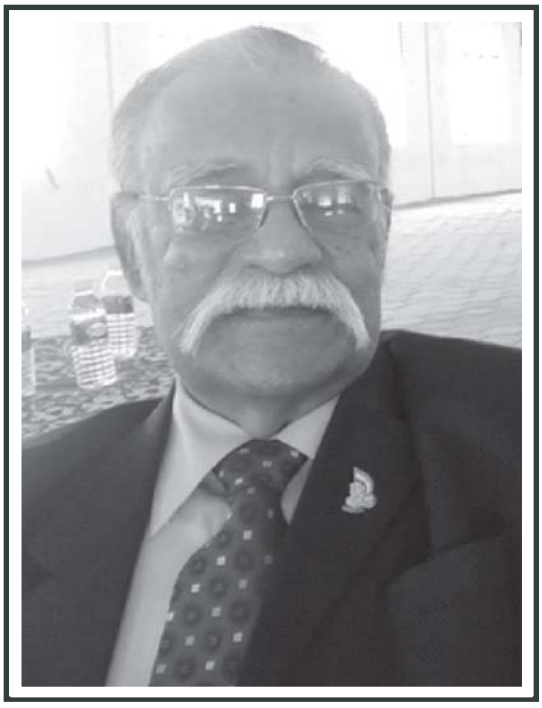

Professor Dr. P.C. Sundara Babu
(1939-2021)

Dr P. C. Sundara Babu former Professor and Head, Department of Entomology and Director, Centre for Plant Protection Studies and Registrar, Tamil Nadu Agricultural University, Coimbatore, born on 25th December 1939 at Salem, Tamil Nadu passed away on 07-03-2021 at the age of 82. His last breath came without any symptoms of illness at 09.45 am at his residence in Coimbatore. He is survived by his wife Professor Dr. Rajeswari Sundara Babu and two sons and daughter-in-laws and grandchildren.

He had his Undergraduate, Postgraduate and Doctoral Programs at the Agricultural College and Research Institute, Coimbatore. Mass culture techniques for green muscardine fungus *Metarhizium anisopliae* (Metchnikoff) Sorokin, as a biocontrol pathogen to control coconut rhinoceros beetle *Oryctes rhinoceros* (L) was a major contribution during his Doctoral Research Program.

Dr Sundara Babu was with the Agricultural College and Research Institute and Tamil Nadu Agricultural University, Coimbatore from 06.07.1961 to 31.12.1999. He was the Professor and Head, Department of Entomology for six years at Agricultural College and Research Institute, at Madurai as well as at Coimbatore. As the Director, Centre for Plant Protection Studies comprising of Departments of Entomology, Plant Pathology, and Agricultural

Nematology, he promoted biological control of crop pests during his tenure. Under his leadership infra-structure facilities for mass production of biocontrol agents viz., Nuclear Polyhedrosis Virus (NPV), *Trichogramma* parasitoid, *Chrysopa* predator and fungal pathogen, *Trichoderma viridi* were developed. Biocontrol programmes large scale demonstrations in farmers' holdings under Department of Biotechnology Projects, Government of India got accolades. His contributions in the studies on biology, host range and management of mango stem borer, *Batocera rufomaculata* De Geer are praiseworthy. Under his able guidance many research scholars did their Post graduate and Doctoral Research programs in ICAR funded projects.

He was the Registrar of Tamil Nadu Agricultural University, Coimbatore during 1998-99 and rendered effective Administrative Service for the development of the University. In between he was also Acting Vice Chancellor of the Tamil Nadu Agricultural University for a brief spell.

Professor Sundara Babu was awarded Nathaniel Gold Medal for his best doctoral research on coconut rhinoceros beetle. Recently he was awarded "Lifetime Achievement Award" in 2020 by Dr B. Vasantharaj David Foundation, Chennai. He was the Fellow of various societies including Entomological Society of India and National Biodiversity Society, India. He coordinated 67 Research Projects and 17 Research Schemes of various funding agencies. He has authored 10 books and contributed 15 book chapters. He has published 246 Research Papers in various National and International Journals. He has guided 16 Post graduate Students and 6 Doctoral Scholars in their Research Program. He was one of the Best Teachers in Agricultural Entomology. He was known for his beautiful hand writing which every one used to admire.

The Tamil Nadu Agricultural University has instituted a Gold Medal in his name as Dr. P.C. Sundara Babu Award for the Best Ph.D. thesis in Plant Protection.

He was a man of high human values and had friendly relationship with his students, staff, and colleagues and helped many who were in distress. After his retirement in 1999, Dr Sundara Babu was actively associated with Social Activities as Rotarian in Rotary Club of Coimbatore District by occupying various posts such as President, Asst. Governor, District Officer, and District General Secretary. The book entitled "All about Rotary" written by him is very informative.

The sudden demise of Professor Sundara Babu has caused profound grief to a large number of Students, Entomologists, Scholars and Academics in India and abroad.

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AUTHOR INDEX

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Key words should be 4 – 6, indicators of the work, not repeating the words already in the title, helpful in indexing the article.

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Acknowledgement of financial grants, technical assistance, and identification of specimens and supply of essential literature may be included.

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