THE ENTOMOLOGICAL SOCIETY OF INDIA

New Delhi, 110 012

ESI- BEST Ph.D. THESIS AWARD 2021

1. Name of the applicant: **SUMAN SARKAR**
2. Year of the award: **2021**
3. Date of birth: **25/07/1990**
4. Field of specialization: **ENTOMOLOGY**
5. Mode of award collection: In person / in absentia- **IN PERSON**
6. Postal address (with Phone/Fax/Email etc.): **PADMAPUKUR MORE (IN FRONT OF LODGE KRISHNA), PO- BALURGHAT, DIST.- DAKSHIN DINAJPUR, WEST BENGAL, PIN- 733101**
7. Educational qualifications beginning with the first-degree or equivalent (in a tabular form)

S.No.	Degree	Institution	Year
1	SECONDARY	Balurghat Lalit Mohan Adarsha Uchcha Vidyalaya	2006
2	HIGHER SECONDARY	Balurghat Lalit Mohan Adarsha Uchcha Vidyalaya	2008
3	B.Sc (Honours)	Raiganj Surendranath Mahavidyalaya	2012
4	M.Sc	University of Gour Banga	2014
5	Ph.D	University of Gour Banga in collaboration with Tea Research Association (NBRRDC)	2021

8. Date on which qualifying examination passed: **08/02/2021**
9. Transcript of the course work done, if any, as part of the Ph.D. degree programme. (enclose photocopy): **Course Work was done and the scanned copy enclosed herewith.**
10. Was the thesis submitted in partial fulfillment of the requirement of the Degree? Yes/No: **Yes**
11. Date on which successfully completed thesis viva voce examination: **08/02/2021**
12. Date of the Degree/provisional certificate: **09/02/2021**
13. Have you received best thesis award earlier? Yes/No: **NO**

14. Details of the thesis: **Separate Copy enclosed**
    (i) Title of the thesis
    (ii) Department/Division/Institution where research work was done
    (iii) Institution/University to which thesis was submitted as a part of the Ph.D. degree programme
    (iv) Name and designation of the thesis supervisor
    (v) Research problem: Hypothesis, brief description, scientific, technological, socio-economic relevance and priority (limit to 1 page)

(vi) What standard methods and modern procedures were used in the experimental work? (limit to one page)

(vii) Briefly describe the significant results obtained? (Not more than 3 pages)

(viii) In what way these results have made an original contribution to science and have impact

(ix) Publications (in journals/along with NAAS rating as on 1.1.2021, Seminar proceedings, University/Institute Newsletter, Lecture delivered, Book chapter etc. (publications only from the thesis to be included, only those publications in published/accepted/proof stage will be considered, no marks will be given for other publications not related with thesis works)

(x) Soft copy in PDF format needs to be submitted for the above including whole thesis

15. Whether any patents have been taken/applied for, if yes, attach evidence: **No**

16. Professional recognition, awards, fellowships received (In a separate sheet give full particulars such as the agency/ organization which gave the award, purpose, the nature of the award, etc.).: **Yes (Separate sheet attached)**

17. A concise statement (about 150 words) highlighting the most significant aspects of the research work done that you would like to see in your citation of award, if chosen.

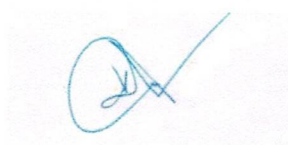
The present study highlites that, the tea pest *Hyposidra talaca* was found to successfully complete its life cycle on artificial diet. This indicates that, we can easily mass rear them under laboratory conditions for experimental purposes throughout the year. Among all the tested cultivars, B157 was found to be moderately susceptible to *H. talaca*, which specifies that, the attack of *H. talaca* on this cultivar would be less compared to other highly susceptible cultivars. The study result of seasonal abundance, predatory efficiency and lifetable of *Sycanus collaris* and *Eocanthecona furcellata* concerns about successful management of *H. talaca* in tea filed. The impact of the parasitoid *Cotesia ruficrus* and augmentative release of *S.collaris* proved the possibility of implementation of natural enemies for managing the *H. talaca* population in tea field as biological control agent.

18. Certificate by the student that all the details given are true

Suman Sarkar

Signature

19. Certificate by the supervisor/guide that the information submitted has been verified and true



Signature

20. Forwarding note by the Head of the Department/professor

This is to certify that, Dr. Suman Sarkar has been working Junior Research Fellow and done his research work leading to PhD as a student of Department of Zoology of University of Gour Banga, Malda, West Bengal and has fulfilled the requirements prescribed for the Ph. D degree of this institute. The Ph.D thesis entitled, "ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM" was carried out under my joint supervision. To the best of my knowledge, no part of the thesis was submitted for the award of any degree or diploma prior to that date.

Name and Designation

Seal

Dr. A. Babu, Ph.D
Chief Scientist & Deputy Director (R)
Tea Research Association
North Bengal Regional R & D Centre
Nagrakata -735225, Dist. - Jalpaiguri
West Bengal, INDIA.

14. Details of the thesis:

(i) Title of the thesis: **ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM**

(ii) Department/Division/Institution where research work was done: **Department of Entomology, Tea Research Association, North Bengal Regional Research and Development Centre, Nagrakata, Jalpaiguri, WB.**

(iii) Institution/University to which thesis was submitted as a part of the Ph.D. degree programme: **University of Gour Banga, Malda, WB**

(iv) Name and designation of the thesis supervisor: **Supervisor-Dr. Kaushik Chakraborty, Associate Professor, Zoology Department, University of Gour Banga (Presently Professor of Raiganj University), Joint Supervisor- Dr. Azariah Babu, Chief Scientist & Deputy Director of Tea Research Association, North Bengal Regional Research and Development Centre, Nagrakata, Jalpaiguri, WB.**

(v) Research problem: Hypothesis, brief description, scientific, technological, socio-economic relevance and priority (limit to 1 page)

The research work was designed on both the field and laboratory basis. Natural enemies included in the research plan, were not being reared as laboratory stock culture. So it was a big challenge of the research work to collect the natural enemies. After that, a continuous field survey, consultation with tea garden Filed Assistant and Labour, discussion with the Joint-Supervisor and reviewed the published literature the natural enemies were collected and further experiments were completed as per the research objectives. The specimen of *Sycanus collaris* was sent to Dr. K. Sahayaraj, Associate professor of Zoology, St, Xavier's College (Autonomus), Palayamkottai- 627002, Tiruneveli, Tamil Nadu for identification.

In the beginning Flavonoid estimation of green tea leaf was planned by using Catechin as a standard. But due to the unavailability and being costly standard reagent in the preliminary phase some problem was there for standardizing the method. After that, Quercetin was used as a standard for estimating the Flavonoid.

At the starting point of the study of Varietal preference of *Hyposidra talaca* on the selected tea cultivars, the leaf was going to dry under the laboratory experimental conditions (27± 2^0 C, 70-80% RH and 16:10 LD photoperiod) and taking the weight of leaf, larva and fecal matter of larva were not proper. The discussion with the Joint-Supervisor the methodology was modified and the experiment was completed.

In case of mass rearing of the predator S. collaris and *Eocanthecona furcellata*, at the beginning different types of shade tree larvae were collected and provided as food, but the food was not sufficient for the predator. Then after discussion with faculty of Uttarbanga Krishi Viswavidyalaya, Coochbehar, WB the adult, egg and larvae of rice meal moth were collected. The rice meal moth then reared in laboratory and the predators were reared.

(vi) What standard methods and modern procedures were used in the experimental work? (limit to one page)

The artificial diet for rearing the larvae of *H. talaca* was prepared following the procedure adopted by Babu *et al*., (2015).

The Flavonoid estimation was done by following the method of Akbay *et al*., (2003).

(vii) Briefly describe the significant results obtained? (Not more than 3 pages)

In the current study, carried out for two years at Banarhat TE and TRA experimental plot from February 2017 to January 2019. The survey was conducted on the population dynamics of the major tea looper *H. talaca* and its interaction with the ecological trophic levels of in tea ecosystem. In the similar way survey work was also conducted on the potential predators (*S. collaris* and *E. furcellata*) and parasitoid (*C. ruficrus*). These studies provide sequential information on the seasonal abundance, bio-ecology of pest and natural enemies and the impact of the abiotic factors like temperature (Maximum/Minimum), Rainfall and Relative Humidity were also worked out. A thorough information about the predatory efficiency, predatory behaviour of *S. collaris* and *E. furcellata* on the pest *H. talaca*. The current investigation also provides the evidence of the parasitic impact of *C. ruficrus* on *H. talaca*.

- Studies on the seasonal abundance and bio-ecology of *H. talaca* and its natural enemies (*S. collaris*, *E. furcellata* and *C. ruficrus*) revealed that the population dynamics of both the pest and natural enemies coincides with the recurrent oscillations. The abiotic factors like maximum and minimum temperature, rainfall and relative humidity were found to influence on the population dynamics. Both the pest and natural enemies were found foraging on alternate hosts available adjacent to tea ecosystem.
- Study on the biology and life table of *H. talaca* on tea leaf, artificial diet and shade tree leaf revealed that, a better survival fitness of *H. talaca* on artificial diet followed by tea leaf and shade tree leaf. The highest fecundity was observed when feeding on artificial diet.
- Results on the study of susceptibility of *H. talaca* on the selected tea cultivars (TV1, TV20, TV16, TV22, TV26, HP12, ST520, K1/1, SNT 8 and B157) revealed that, the highest food consumption and growth of *H. talaca* were observed when feeding on TV20 (Highly susceptible) and lowest food consumption and growth was recorded on B157 (Moderately Susceptible).
- The primary metabolites (Protein, carbohydrate, lipid and chlorophyll) of the leaves of selected tea cultivars (TV1, TV20, TV16, TV22, TV26, HP12, ST520, K1/1, SNT 8 and B157) were estimated and was found comparatively high in the cultivars of TV20, TV1, K1/1 followed by other cultivars. Whereas the secondary metabolites (Phenol, flavonoid,

alkaloid and carotenoid) were found in high quantity in B157 and HP12 compared to other tested cultivars.

- The study on biology and survival rate of the predators (*S. collaris* and *E. furcellata*) on *H. talaca* and *C. cephalonica* indicated no significant difference on the biological parameters of *S. collaris* and *E. furcellata*. However, the fecundity rate was more when reared on *H. talaca*. The high mortality rate was found for first instar nymphs. Whereas, *E. furcellata* showed high fecundity when feeding on larvae of *C. cephalonica*.
- The results of the life table study of *S. collaris* and *E. furcellata* revealed that, the intrinsic rate of natural increase "rm" as 0.062 day^{-1} and 0.149 day^{-1} while "Ro" was 252.78 and 218.14 female offspring per adult female respectively. The gross reproductive rate ($\sum mx$) was recorded as 278.98 and 244.69 while the finite rate of increase was 1.06 day^{-1} for both the predators.
- Predatory potential of both the predators (*S. collaris* and *E. furcellata*) in a free- choice and no- choice conditions showed that all the stages of the predators were voraciously feeding on the larvae of *H. talaca*. The feeding potential gradually increased with the advancement of life stages of predators. Adult female consumed more number of larvae per day compared to male. The feeding potential was found to be higher in no-choice conditions compared to free-choice condition.
- *S. collaris* and *E. furcellata* showed the predatory behaviour when offered a visual stimulus by providing different larval stages of *H. talaca*. Theses stimulus lead to arouse, erect posture and extension of antennae and rostrum of *S. collaris* and *E. furcellata* towards the prey.
- Field release experiment of *S. collaris* revealed that, the predators get established in the ecosystem which was evidenced from the reduction of pest population in the released plots compared to the control plot.
- *C. ruficrus* successfully completed its life cycle on the larvae of *H. talaca*. This parasitic wasp showed a selective preference towards 4^{th} instar larva as a suitable host for the parasitism compared to 2^{nd} and 3^{rd} instar larvae.
- Life table study showed that, the intrinsic rate of natural increase (rm) of *C. ruficrus* as 0.203 day^{-1} and the net reproductive rate (Ro) was 41.11 female offspring per adult female.

The gross reproductive rate (∑mx) was 50.09 and the finite rate of increase (λ) was 1.23 day^{-1}.

- The parasitic impact of *C. ruficrus* has hampered the food consumption and growth of *H. talaca*. The haemocyte number and morphology of *H talaca* were also affected by the parasitic effect of *C. ruficrus*.
- Study on the evaluation of the impact of pesticides on the predators and parasitoid (*S. collaris, E. furcellata* and *C. ruficrus*) revealed that, the commonly used pesticides like Thiomethoxam and Quinalphos were highly toxic followed by Emamectin benzoate, >Deltamethrin > Bifenthrin > Flubendiamade> Fenpyroxymate> *Beauveria bassiana* > Azadirachtin.

(viii) In what way these results have made an original contribution to science and have impact

Insect pest control in the tea ecosystem was mainly achieved by the use of synthetic pesticides until today. But it is known to all that use of Synthetic pesticides has negative impact on environment and pesticide residue in made tea which leads harmful effect on human health as well. The present study result revealed that among all the tested cultivars, B157 was found to be moderately susceptible to *H. talaca*, which specifies that, the attack of *H. talaca* on this cultivar would be less compared to other highly susceptible cultivars, and the management tools may use accordingly. The establishment of biological control strategy in management of *H. talaca* in tea field is a big challenge. The present study proved that, the predators and parasitoid can be conserve and augmentative field release is possible. As a part of the current study predator of *S. collaris* was mass reared in laboratory on rice meal moth and released in Kurti Tea Estate and Hope Tea Estate and about 39% reduction of *H. talaca*. The effectiveness of conventionally used pesticides were tested on the predators and parasitoids, which emphasis the conservation strategy of Natural enemies. The seasonal abundance of the predators (*S. collaris* and *E. furcellata*) and parasitoids (*Cotesia ruficrus*) concerned that the adaptation of this sustainable and environment friendly biological control agents are coincided with the pest population throughout the year. So that control of *H. talaca* can be easily managed by using this biological control agents described in the current study.

(ix) Publications (in journals/along with NAAS rating as on 1.1.2021, Seminar proceedings, University/Institute Newsletter, Lecture delivered, Book chapter etc. (publications only from the thesis to be included, only those publications in published/accepted/proof stage will be considered, no marks will be given for other publications not related with thesis works)

Sl No.	Title	Journal	ISSN No.	NAAS rating as on 1.1.2021
1	**Sarkar, S**., Babu, A., Chakraborty, K. and Deka, B. 2019. Study on the Biology, Feeding Behaviour and predatory Potential of *Sycanus collaris* (Fabricius) (Heteroptera: Reduviidae), a new Predator of *Hyposidra talaca* (Walk.) (Lepidoptera: Geometridae), a major Tea pest andmass Rearing on *Corcyra Cephalonica* (Stainton) in Laboratory. **International Journal of Current Advanced Research**, 08(06):19258-19262.	International Journal of Current Advanced Research	Online: 2319-6475, Printed: 2319-6505	3.07
2	**Sarkar, S**., Babu, A., Chakraborty, K., Deka B, and Roy, S. 2020. Predatory behaviour of *Eocanthecona furcellata* (Hemiptera: Pentatomidae) feeding on larvae of *Hyposidra talaca* (Lepidoptera: Geometridae), a major tea pest of North East India. **International Journal of Scientific Research,** 9(3): 68-70.	International Journal of Scientific Research	2277 - 8179	UGC care listed
3	**Sarkar, S**., Babu, A., Chakraborty, K. and Deka, B. 2020. Biology and life history of *Cotesia ruficrus* (Hymenoptera: Braconidae) a potential parasitoid of *Hyposidra talaca* (Lepidoptera: Geometridae) larvae, a major tea pest of West Bengal and Assam in India. **Journal of Biopesticides**, 13(1):79-84.	Journal of biopesticides	Online: 2230-8385, Printed: 0974391X	Scopus indexed
4	Deka, B., Babu, A., Baruah, C., **Sarkar, S.,** and Sharma, D. K. 2020. Conservation of the tea (*Camellia sinensis* (L.) O. Kuntze) ecosystem through enhancement of natural enemies of pests. **Asian Journal of Conservation Biology**, 9 (2):183-187.	Asian Journal of Conservation Biology	2278-7666	Scopus and WoS indexed
5	**Sarkar, S.**, Babu, A., Chakraborty, K., Deka B, and Roy, S. 2021. *Eocanthecona furcellata* (Wolff) (*Hemiptera*: *Pentatomidae*), a potential biocontrol agent of the black inch worm, *Hyposidra talaca Walker* (*Lepidoptera*: *Geometridae*) infesting tea.	Phytoparasitica	Electronic ISSN 1876-7184 Print ISSN 0334-2123	Impact factor:1.5

	Phytoparasitica, https:// doi. org/ 10. 1007/ s12600- 021- 00888-x			
6	**Sarkar, S**., Babu, A., Chakraborty, K., Deka, B., Kashyap, B., and Adhikary, B. 2021. Study on varietal preference and nutritional indices of tea looper *Hyposidra talaca* (*Lepidoptera*: *Geometridae*) on ten selected tea varieties. **International Journal of Tropical Insect Science**, https://doi.org/10.1007/s42690-021-00502-x	International Journal of Tropical Insect Science	Electronic ISSN: 1742-7592	Impact factor:1.0
7	**Sarkar, S.**, Babu, A., Chakraborty, K., Deka B, and Roy, S. 2021. Seasonal abundance of *Cotesia ruficrus* (Hymenoptera: Braconidae) and its host tea looper, *Hyposidratalaca* (Lepidoptera: Geometridae) in tea ecosystem, **International Journal of Pest Management**, DOI: 10.1080/09670874.2021.1918359.	International Journal of Pest Management	Print ISSN: 0967-0874 Online ISSN: 1366-5863	Impact factor:1.9

Seminar proceedings:

Sl No.	Status of the Seminar	Venue	Year of the Seminar conducted
1	6th Biopesticide International Conference	Amity University, Raipur	2019
2	35th Tocklai Conference (International)	TTRI, Jorhat, Assam	2019
3	National Seminar on Recent Advance in Bio-Science And Annual General Meeting of Zoological Society of Assam	Pragjyotish College, Guwahati, Assam	2018
4	National Seminar on Advancement of Biology in 21st Century	Viswabharati University, Shantiniketan, West Bengal	2020
5	National conference on Recent Advance in Crop Protection including IPM and Environmental Science from GLP Perspective.	Hotel Le Palace, Chennai	2021

16. Professional recognition, awards, fellowships received (In a separate sheet give full particulars such as the agency/ organization which gave the award, purpose, the nature of the award, etc.).:

- Name of the organization which gave the award: **Dr. B. Vasantharaj David Foundation, Chennai**
- Event of the Award**: National conference on Recent Advance in Crop Protection including IPM and Environmental Science from GLP Perspective on 17th October, 2021**
- Purpose: **Contribution to Biological Control of Insect Pest in Tea Ecosystem**
- The nature of the award: **Yong Agricultural Scientist**

International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: 6.614
Available Online at www.journalijcar.org
Volume 8; Issue 06 (D); June 2019; Page No.19258-19262
DOI: http://dx.doi.org/10.24327/ijcar.2019.19262.3705

Research Article

STUDY ON THE BIOLOGY, FEEDING BEHAVIOUR AND PREDATORY POTENTIAL OF *Sycanus* collaris (FABRICIUS) (HETEROPTERA: REDUVIIDAE), A NEW PREDATOR OF *Hyposidra talaca* (WALK.) (LEPIDOPTERA: GEOMETRIDAE), A MAJOR TEA PEST AND MASS REARING ON *Corcyra cephalonica* (STAINTON) IN LABORATORY

Suman Sarkar[1], Azariah Babu[1], Kaushik Chakraborty[2] and Bhabesh Deka[1]

[1]Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India
[2]Entomology Laboratory, Department of Zoology, University of Gour Banga, Mokdumpur, Malda, West Bengal, 732103, India

ARTICLE INFO

Article History:
Received 10th March, 2019
Received in revised form 2nd April, 2019
Accepted 26th April, 2019
Published online 28th June, 2019

Key words:

Sycanus collaris, predatory potential, tea looper, *Hyposidra talaca,* biological control agent.

ABSTRACT

The sustainable utilization of biological control agents in agro-ecosystems depend on the data on biology, bio-ecology and feeding behaviour of that biological control agents on their main or alternative host. In the present study, the biology, feeding behavior and predatory potential of a newly recorded reduviid predator *Sycanus collaris*, from tea ecosystem found predating on one of the major tea pests *Hyposidra talaca,* have been observed under laboratory conditions. The incubation period, duration of the nyphal stages and longevity of adult stages were observed both on *Corcyra cephalonica* (rice meal moth) and on *H. talaca.* The incubation period was recorded as 13.6±1.1 and 11.8±2.3, duration of nymphal stages as 58.4 ±3.9 and 64.8±4.1, adult longevity 99.8±3.5 and 108.6±2.8 days respectively on rice meal moth and tea looper respectively. The fecundity (total number of eggs laid /female) was found to be 282.0± 23.9 and 320.4± 44.2 eggs/female when feed on larvae of *C. cephalonica* and *H. talaca* respectively. Predatory potential of the reduviid bug *S. collaris,* has been studied by providing larvae of tea looper, *H. talaca* in laboratory. The predator *S. collaris* attacked more prey to satiate itself at a given point of time. In the case of free choice feeding condition, wherein the adult males consumed a 4.6±1.8 fifth instar larvae of *H. talaca* while the adult female consumed 5.0±1.6per day. However, the nymphal consumption varied between 3.2±1.3 on third instar and 2.2±0.8 fifth instar of looper. The feeding behaviour of the predator such as the time taken for approach and attacking, paralyzing, sucking on the prey were also recorded. The adult female could paralyze a grown-up looper within 5-8 seconds and sucked the body sap within 119-121 seconds. First instar nymph of the reduviid bug preferred only second instar larvae of looper and group feeding was observed whereas, with the advancement of the nymphal instar they prefer to predate on later stages of looper (fourth and fifth instars) when compared to the early instars.

INTRODUCTION

Reduviidae a large family belongs to the order Hemiptera, found to be efficient predators of different insect pest, preferably lepidopteran larvae (Ambrose *et al*., 2009). *Sycanus collaris*, known as assassin bug, all of its life stage efficiently feed on the target insect. Depending on the feeding on different insect the developmental period and fecundity rate is also different when fed on different hosts (George, 2000).The perennial monoculture crop tea (*Camellia sinensis* L.), provides a stable shelter, food and microenvironment for breeding for divers species of arthropod throughout the year (Babu *et al.,* 2014). Among them, some arthropods are considered as pest and some are considered as biological control agents. In the tea ecosystem of Dooars and Darjeeling regions of West Bengal among different *Sycanus* species of Reduviidae family of order Hemiptera only *Sycanus croceovittatus* (Dohrn) have been reported (Das *et al.,* 2010 and Mitra *et al*., 2018). The sequential predatory behaviour of the Genus *Sycanus* on its prey is very active (Ambrose, 1999). Sahayaraj, (2012) developed a rearing technique of reduviids using meat-based artificial diets which couldbe useful for mass rearing and pest management programme. There is no information available on *Sycanus collaris* as a predator of *H. talaca* in tea ecosystem of West Bengal and North East India

******Corresponding author:* **Suman Sarkar**
Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India

Suman Sarkar
21.10.2021

ORIGINAL RESEARCH PAPER

Volume-9 | Issue-3 | March-2020 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

PREDATORY BEHAVIOUR OF EOCANTHECONA FURCELLATA ((HEMIPTERA: PENTATOMIDAE) FEEDING ON LARVAE OF HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE), A MAJOR TEA PEST OF NORTH EAST INDIA

Zoology

Suman Sarkar Department Of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India.

Azariah Babu* Department Of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India. *Corresponding Author

Kaushik Chakraborty Department Of Zoology, Raiganj University, Uttar Dinajpur, West Bengal, 733134, India.

Bhabesh Deka Department Of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India.

ABSTRACT

Eocanthecona furcellata (Wolff.) is an important predator of several pets associated with agricultural crops, especially lepidopteran pest. The predatory behaviours of this insect such as approach and attacking, paralyzing, sucking were recorded. The adult female could paralyze a larvae in 4.7±0.6 seconds and suck the body sap within 95.3±5.0 seconds. First instar nymph preferred only second instar larvae of looper and group feeding was observed. The incubation period was recorded as 7.6±1.1days and total duration of nymphal stages was 18.4±1.5days. The longevity of adult male and female were recorded as 30.0±1.9 days and 32.8±0.8 days respectively. The hatchibility rate of egg was 94.5% with 96.2% adult survival rate was recorded, when reared on *Coeryra cephalonica*. Moreover this study revealed that, in the absence of main host, *C. cephalonica* could be used as alternative host to mass rear *E. furcellata,* successfully for field release.

KEYWORDS

Predatory Behaviour, *Eocanthecona furcellata*, Tea Looper.

INTRODUCTION:

Perennial monoculture crop tea (*Camellia sinensis* L.), provides shelters, food, microenvironment for breeding for divers species of arthropod throughout the year (Babu *et al.,* 2014). Tea plant foliage is infested by about 167 arthropod species in the tea belt of Northeastern regions of India (Mukhopadhyay and Roy, 2009). The looper stage of the lepidopteran pest *Hyposidra talaca* have migrated and adapted in tea growing area of Darjeeling Terai and the Dooars and Assam causing substantial damage to the crop (Basumajumdar and Ghosh, 2004). Among them some arthropods are considered as pest and some are considered as biological control agents. In the tea ecosystem of Dooars and Darjeeling regions of West Bengal there are 29 species belonging to 28 genera of hemipteran bugs, among them the highest species is of family Pentatomidae have been recorded (Mitra *et al.,* 2018). In order to concise the application of synthetic chemical pesticides, in the tea gardens for the management of lepidopteran tea pests especially *H. talaca*, biological control measures are being adopted worldwide (Mobed *et al*., 1992 and Gillespie *et al*., 2000). *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae) is one of the important predator that has recently included in the field of biological control due to its potential to prey different orders of insect pests such as, lepidoptera, coleoptera and heteroptera (De Clercq, 2000). This predacious stink bug *E. furcellata* (Wolff) is efficient lepidopteran caterpillar predators in the field of, soyabean, beans, vegetable and forest ecosystems found to feeding on fall army worm, *S. frugiperda* in maize (Navarajanpaul, 2002). In the present study, predatory behaviour and stage specific predation of this stink bug while feeding on larvae of *H. talaca* and biology and survival rate on alternative host were studied.

MATERIALS AND METHODS:

REARING OF HOSTS AND PREDATOR:

Field collected healthy moths of *H. talaca* were, put them into mating and egg laying chamber (glass chimney) with 10% honey solution as food source. After hatching of the eggs, larval stages were reared on tea leaves preferably using TV1 (Tocklai Vegetative 1) under the laboratory conditions (27± 2°C, 70-80% RH and 16:10 LD photoperiod) by following the methodology developed by Babu *et al.,* (2014). Eggs of rice meal moth of *Corcyra cephalonica* were collected from Uttar Banga Krishi Viswavidlaya, Coochbihar, India and reared on plastic container containing maize powder under the same laboratory conditions as an alternative host of *E. furcellata*. Adult stink bug were collected from the TRA (Tea Research Association) experimental plot and kept into glass chimney for mating and laying eggs containing few tea shoots along with larvae of *H. talaca*. Shade tree barks were kept inside the mating chamber for egg laying and the egg masses were transferred into separate chamber. Newly hatched first instar and then second instar nymphs of the predator were reared in group. Third, fourth, fifth and adult stages were put into separate Tarson sample container (Diameter 4.3, height 5.4cm) to avoid cannibalism following the method of Lenin and Rajan, (2016) with slight modifications.

PREDATORY BEHAVIOUR OF *E. FURCELLATA*:

In order to record the predatory behaviour of all the life stages of *E. furcellata* on the different larval instars of *H. talaca*, an experiment was conducted using large petridish (14.5cm in diameter). Each life stage of *E. furcellata* were maintained for 1.5h starved condition and then placed into that petridish with different larval instars of *H. talaca* separately. The time taken by the stink bug for approach attacking, paralyzing and sucking the prey by different life stages of were recorded (Rajan *et al.,* 2017). Mean were calculated by Tukey-Kramer HSD Post-Hoc Test.

STAGE SPECIFIC PREDATION:

Selection of specific stage of larvae of *H. talaca* and predation by different life stage *E. furcellata* were also studied under the same laboratory conditions. Different larval instars like, II, III, IV and V of *H. talaca* were provided to the individual stages of *E. furcellata*. The maximum number of prey consumption and type of feeding were observed at 24h interval.

STATISTICAL ANALYSIS:

Mean of the experiment of predatory behaviour was analyzed by Tukey's multiple comparison test at $p<0.05$.

REARING OF *E. FURCELLATA* ON ALTERNATIVE HOST:

From the laboratory rearing conditions 100 eggs were separately put into glass chimney and observed carefully till hatched. Newly hatched first instar nymphal instars were transferred into individual container and head crushed larvae of *C. cephalonica* were provided as food source from the laboratory stock culture. Every nymphal instars were carefully maintained till moulted into adult. Ten pairs of saults were separately put into glass chimney along with sufficient larvae of rice meal moth. After laying eggs onto the previously provided shade tree bark, it was collected and put into separate chimney. The incubation period, each nymphal duration for development, mortality and survival rate of each life stages were recorded at 24h intervals.

Suman Sarkar
21.10.2021

Biology and life history of *Cotesia ruficrus* (Hymenoptera: Braconidae) a potential parasitoid of *Hyposidra talaca* (Lepidoptera: Geometridae) larvae, a major tea pest

Suman Sarkar*[1], Azariah Babu[1], Kaushik Chakraborty[2] and Bhabesh Deka[1]

ABSTRACT

The black inch looper, *Hyposidra talaca* is considered as a major pest in tea in northern part of West Bengal and North East India. Among the natural enemy reported, *Cotesia ruficrus* is considered as one of the most gregarious endo-parasitoid wasps. In order to assess the potential of this natural enemy, a study on the biological parameters of *C. ruficrus* was evaluated on the different developmental stages (second, third and fourth instars) of the host larvae, *H. talaca*. The results indicated that, the mean duration of larval development was 12.0 ± 0.32, 11.0 ± 0.45 and 9.2±0.37 days in second, third and fourth instar host larvae respectively. The pupal period of *C. ruficrus* was found to be significantly different among the different larval stages of *H. talaca*. The successful parasitism of *C. ruficrus* and the number of cocoon formation of the parasitic wasp was reliant on the stage, body size and the physiological conditions of host larvae that it parasitizes. A maximum of 65.2±1.85 cocoons were formed when the fourth instar host larvae parasitized, followed by 27.2±3.04 in the third instar and 4.6±0.68 in the second instar host larvae. The number of females and males hatched out from each clutch was compared to the different host stages. .

Key words: Black inch looper, *Hyposidra talaca,* Parasitic wasp, *Cotesia ruficrus,* Tea, Parasitism.

MS History: 12.04.2020 (Received)-05.05.2020 (Revised)- 10.05.2020 (Accepted).

Citation: Suman Sarkar, Azariah Babu, Kaushik Chakraborty and Bhabesh Deka. 2020. Biology and life history of *Cotesia ruficrus* (Hymenoptera: Braconidae) a potential parasitoid of *Hyposidra talaca* (Lepidoptera: Geometridae) larvae, a major tea pest. *Journal of Biopesticides,* **13**(1):79-84.

INTRODUCTION

The black inch looper, *Hyposidra talaca* (Lepidoptera: Geometridae), considered as a major tea pest, which causes considerable damage to tea plantations leading to loss in yield and the quality of manufactured tea as well. In general, chemical insecticides are being used for the control of tea pests including this black inch looper (Hazarika *et al*., 2009) by the tea planters. Hence the use of chemical pesticides has many negative impacts such as development of resistance in insects, abolition of natural enemies, imbalance in natural ecosystems and increasing environmental contamination besides causing ill-health to human beings. Therefore, non-chemical control measures are extremely important for the management of this destructive pest (Deka *et al*., 2017; Nguyen *et al*., 2018). Biocontrol agents play a vital role for the management of pests, especially lepidopteran pests with a well-balanced ecological systems, by helping in the reduced use of pesticides in major agricultural crops, including tea.

The tea ecosystem, which is considered as a semi-forest ecosystem, harbor more than 1034 arthropod species associated within (Hazarika *et al*., 2009). Among the diversity of arthropod natural enemies in sub-Himalayan tea growing region of northern part of West Bengal, parasitoid groups belonging to the families such as Braconidae and Ichneumonidae are dominant ones. Among the parasitoids,

Suman Sarkar 21.10.2021

Asian Journal of Conservation Biology, July 2020. Vol. 9 No. 2, pp. 183-187 AJCB: EN0018
ISSN 2278-7666 ©TCRP Foundation 2020 https://doi.org/10.53562/ajcb.EN00018

EDITORIAL

Conservation of the tea (*Camellia sinensis* (L.) O. Kuntze) ecosystem through enhancement of natural enemies of pests

Bhabesh Deka[1]*, Azariah Babu[1], Chittaranjan Baruah[2], Suman Sarkar[1] and Dhirendra K Sharma[3]

[1]*Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal - 735225, India*
[2]*Postgraduate Department of Zoology, Darrang College (Gauhati University), Tezpur- 784001, Assam, India*
[3]*School of Biological Science, University of Science & Technology, Meghalaya - 793101, India*

Tea (*Camellia sinensis* (L.) O. Kuntze), being its perennial and monoculture nature, provides a stable microclimate for various insect pests, which cause substantial loss of crop (Li *et al*., 2019). With the escalating cost of insect pest management and increasing concern about the adverse effects of the pesticide residues in manufactured tea, there is an urgent need to explore other avenues of alternate pest management strategies (Babu, 2011). In general, the tea plantations provide a stable microclimate and food supply for several notorious pests, such as insects, mites, and nematodes, etc. They also support an array of natural enemies in the ecosystem. Although there are numerous non-conventional methods available, pest control in the tea ecosystem was mainly achieved by the use of synthetic pesticides until today. Biological pest control methods are adopted globally in major crops to avoid the negative impact of synthetic pesticides (Gillespie *et al*., 2000). Several tea pests may be controlled by using natural enemies as biological control agents in an integrated pest management approach (Babu *et al*., 2011).

The natural enemy guild is dominated by predators in several ecosystems. Muraleedharan and Roy (2016) reported a total of 200 predatory arthropod species were recorded in the tea ecosystem. The overall species composition reflects the richness of arthropod natural enemies, *i.e.,* predators and parasitoids of tea pests, where the natural enemy to pest ratio is 1.7:1. The tea plantations in Northeast India harbour several species of coccinellids, such as *Cryptogonus bimaculatus, Juravia quandrinotata, J. opaca, Menochilus sexmaculatus,* and *Stethorus gilvifrons*, which feed on eriophyid mites, spider mites, aphids, and scale insects (Somchoudhury *et al*. 1995). The parasitoids, *Apanteles coedicius*, *Trioxys indicus,* and *Aphidus colemani*, have several hosts, like *Toxoptera aurantii* feeding on tea, and *Aphis gossipii* and *Aphis craccivora* on weeds in tea fields. The tea mosquito bug *H. theivora are* being preyed upon by *Chrysoperla carnea*, *Oxyopes* sp., *Plexippus* sp., *Phidippus* sp., and *Scymnus* sp. and *mantids*. Eggs of *H. theivora* were found parasitized by *Erythmelus helopeltidis* Gahan in South India (Sudhakaran and Muraleedharan, 2006). The activities of predators and parasitoids have been found to be high in Northeast India. In the areas of North Bengal, Roy *et al*. (2005) found 35 species of spiders and 25 species of coccinellids as natural enemies in the tea ecosystem, while 94 species of predators and 33 species of parasitoids were reported from the sub-Himalayan tea plantations of North Bengal, among which the predators, spiders and ladybird beetles, and among the parasitoid groups, Braconidae and Ichneumonidae, were dominant (Das *et al*. 2010).

***Sycanus collaris* (Fabricius):**

Reduviidae a large family that belongs to the order Hemiptera, are found to be efficient predators of different insect pests, preferably lepidopteran larvae (Ambrose *et al*., 2009). *Sycanus collaris, (*Fabricius), known as the assassin bug, all of its life stages efficiently feed on the target insect. The sequential predatory behaviour of the genus *Sycanus* on its prey is very active (Ambrose *et al*., 2009). *S. collaris is* found to feed on different hosts, like the tea red slug caterpillar, *Eterusia magnifica* (Butler) as well as the pupal stage of the tea looper, *Hyposidra talaca Walker*. During the winter period (December to February), when the tea plants are subjected to pruning, *S. collaris* forages for food and shelter in the un-pruned plots and shade trees. They preferred to shelter in small jungle trees associated with tea fields. The voracious predatory behaviour of *S. collaris* effectively prevented the increasing population density of *H. talaca* under field conditions. Sarkar *et al*., (2019). Sarkar *et al*., (2019) reported the predatory efficiency of *S. collaris* on the larvae of *H. talaca* and reconfirmed that the larger size of life stage *S. collaris* preferred by the later stages (IV and V instar larvae) to fulfill the nutritional requirements. Predatory behaviour of feeding preference highlights the vital role of this predator as an efficient biological control agent in the tea ecosystem. Conservation of this predator in the plantation belt would be useful in developing a bio-control-based looper pest management strategy in the tea ecosystem.

***Eocanthecona furcellata* (Wolff)**:

The stink bug, *Eocanthecona furcellata* (Wolff) is one of the important predator that has recently included in the field of biological control due to its potential to prey different orders of insect pests such as, lepidoptera,

**Corresponding Author's E-mail: bhabesh.deka@gmail.com*

Suman Sarkar 21.10.2021

Phytoparasitica
https://doi.org/10.1007/s12600-021-00888-x

ORIGINAL ARTICLE

Eocanthecona furcellata (Wolff) (Hemiptera: Pentatomidae), a potential biocontrol agent of the black inch worm, *Hyposidra talaca* Walker (Lepidoptera: Geometridae) infesting tea

Suman Sarkar · Azariah Babu · Kaushik Chakraborty · Bhabesh Deka · Somnath Roy

Received: 24 April 2020 / Accepted: 14 January 2021

Abstract Field observations were made to find out seasonal abundance of *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae) a predatory bug of an invasive pest, the black inch worm, *Hyposidra talaca* Walker (Lepidoptera: Geometridae) in tea ecosystem. The trend of population study revealed that *E. furcellata* was abundant throughout the cropping period, with peaks during June to September. Investigations were also carried out on the biology and predatory efficiency of *E. furcellata* on the larvae of *H. talaca*. The fecundity of the predatory bug was recorded as 276.6 ± 15.8 eggs/female. The incubation period was 7.0 ± 1.0 days, total nymphal development period 21.8 ± 0.7 days and adult longevity was 30.8 ± 1.9 days. Construction of life table of *E. furcellata* by rearing the tea looper *H. talaca* indicated that, the life table parameters like, intrinsic rate of natural increase (rm) was 0.149, net reproductive rate (Ro) was 218.14 eggs/female, gross reproduction rate (∑mx) was 244.69, generation time (T) 35.49 d, doubling time (DT) 4.63 d and finite rate of increase (λ) was 1.161. The adult female consumed 10.2 ± 0.8 s instar looper in 'no-choice' condition, whereas in 'free-choice' condition the consumption was 9.8 ± 1.1 second instar and 5.4 ± 1.1 fifth instar larvae of *H. talaca* per day. The impact of commonly used pesticides on the predator indicated varying degree of mortality on nymphs and adults after 24 h of exposure. Hence, *E. furcellata* could effectively be utilized in the IPM programme envisaged for tea for effective management of *H. talaca*.

Keywords Seasonal abundance · Life table · Stink bug · Black inch looper · Predator · Tea

S. Sarkar · A. Babu (✉) · B. Deka
Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Jalpaiguri District, Nagrakata, West Bengal 735 225, India
e-mail: azariah.babu@gmail.com

K. Chakraborty
Department of Zoology, Raiganj University, Uttar Dinajpur, West Bengal 733134, India

S. Roy
Department of Entomology, Tocklai Tea Research Institute, Jorhat, Assam 785008, India

Introduction

Tea, *Camelia sinensis* Kuntze, ecosystem offers food, shelter and serving as a breeding ground to numerous arthropods, resulting increasing the number to about 167 pests (Das 1965) and diverse natural enemies (Das et al. 2010; Roy et al. 2014). Among all the tea pests, the polyphagous lepidopteran pests migrated to tea ecosystem from the nearby forests and make their habitat in tea plantation as well as on shade trees *Albizzia* spp. (*A. odoratissima*, *A. chinensis*) (Das and Mukhopadhyay 2014). The *Hyposidra talaca* (Walker) (Lepidoptera: Geometridae), commonly known as the black inch looper, is the dominant lepidopteran arthropod pest which causes substantial damages (11–55%) to the crop in Dooars, Terai (plains in the foothills of the eastern Himalayas in

Published online: 23 January 2021

Suman Sarkar 21.10.2021

International Journal of Tropical Insect Science
https://doi.org/10.1007/s42690-021-00502-x

ORIGINAL RESEARCH ARTICLE

Study on varietal preference and nutritional indices of tea looper *Hyposidra talaca* (*Lepidoptera*: *Geometridae*) on ten selected tea varieties

Suman Sarkar[1] · Azariah Babu[1] · Kaushik Chakraborty[3] · Bhabesh Deka[1] · Bishwapran Kashyap[2] · Biplab Adhikary[2]

Received: 30 September 2020 / Accepted: 11 March 2021

Abstract
To find out the varietal preference of *H. talaca* larvae, leaves of ten selected tea cultivars were provided separately to II, III, IV, and V instars. The food consumption by different larval instars was the maximum on TV20 followed by TV1 > K1/1 > TV22 > TV26 > TV16 > SNT8 > TS520 > HP12 > B157. The nutritional indices showed the highest ECD and ECI values on TV20 followed by other cultivars. However, AD values were inversely proportional to the ECI and ECD. Biochemical analysis of the host leaves indicated higher carbohydrate and lipid concentrations in TV20 which was positively correlated (r = 0.6351) with the mean food consumption, whereas, the lowest carbohydrate and lipid concentration was observed in TS520. The levels of secondary metabolites such as alkaloids (r = -0.6137) and flavonoids (r = -0.7403) showed a negative correlation with larval food consumption. Results of HPLC analysis showed the presence of different types of catechins like, EGC, Catechin, EC, EGCG, ECG, and caffeine in variable quantity in all cultivars that were positively correlated with larval feeding except the Gallic acid which showed a negative correlation (r = -0.5610). Based on the larval food consumption, the susceptible index of cultivars were categorized as 'highly susceptible' (TV20, TV1, K1/1, TV22, TV26, TV16, and SNT8), 'susceptible' (TS520 and HP12), and 'moderately susceptible' (B157). Based on cluster analysis A1 grouped (TS520 and HP12), A2 indicated B157 whereas sub-branches B1 grouped (TV22, TV16, TV26, and SNT8) and B2 grouped (TV1, TV20, and K1/1).

Keywords Tea variety · *Hyposidra talaca* · Food consumption · Secondary metabolites · Nutritional indices · Susceptible index

Introduction

The perennial plant tea *Camellia sinensis* (L.) Kuntze is cultivated on large and small scale in the Assam and Sub-Himalayan region of West Bengal in Northern India. Tea plantation along with shade trees provides shelter and food for diverse arthropod species. The black inch looper, *Hyposidra talaca* Walker, causes significant crop loss in tea growing regions of India especially West Bengal (Dooars and Terai) and Assam and has gained the status of major destructive pest of tea (Sinu et al. 2011; Roy et al. 2017). This widely distributed lepidopteran insect has been reported to attack several host plants viz., cinchona (*Cinchona officinalis*), coffee (*Coffea arabica*) litchi (*Litchi chinensis*), longan (*Dimocarpus longan*), mango (*Mangifera indica*), mangosteen (*Garcinia mangostana*) Hill glory bower (*Clerodendron infortunatum*), Indian mahogany (*Chukrasia tabularis*), Sea derris (*Derris robusta)* (Sinu et al. 2011; Basu Majumdar et al. 2010; Intachat et al. 2001). The developing stages of *H. talaca* consume tender and mature leaves with an average of 12,690.33 cm^2 leaf area leading to significant crop loss besides causing stress to the tea plant (Prasad and Mukhopadhyay 2013). Continuous application of synthetic pesticides for controlling this pest has its limitations leading to

✉ Suman Sarkar
sumanrb25@gmail.com

[1] Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, West Bengal, 735225 Nagrakata, Jalpaiguri, India

[2] Department of Biochemistry, Tea Research Association, North Bengal Regional R & D Centre, West Bengal, 735225 Nagrakata, Jalpaiguri, India

[3] Department of Zoology, Raiganj University, West Bengal, 733134 Raiganj, India

Suman Sarkar 21.10.2021

INTERNATIONAL JOURNAL OF PEST MANAGEMENT
https://doi.org/10.1080/09670874.2021.1918359

Seasonal abundance of *Cotesia ruficrus* (Hymenoptera: Braconidae) and its host tea looper, *Hyposidra talaca* (Lepidoptera: Geometridae) in tea ecosystem

Suman Sarkar[a], Azariah Babu[a], Kaushik Chakraborty[b], Bhabesh Deka[a] and Somnath Roy[c]

[a]Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Jalpaiguri, West Bengal 735225, India; [b]Department of Zoology, Raiganj University, Uttar Dinajpur, West Bengal 733134, India; [c]Department of Entomology, Tocklai Tea Research Institute, Jorhat, Assam 785008, India

ABSTRACT

Investigations were undertaken for a better understanding of seasonality, interaction with tea ecosystem, and parasitic impact of an endoparasitoid *Cotesia ruficrus* (Haliday) (Hymenoptera: Braconidae) on the destructive tea looper *Hyposidra talaca* (Walker) (Lepidoptera: Geometridae). The population abundance of *C. ruficrus* was noticed as high in the months of pre-winter and spring seasons which was coincided with the population increase of *H. talaca*. *C. ruficrus* found to foraging and collecting nectar from the flowers of *Lantana camera L.*, *Moringa oleifera* Lam., and *Clerodendron infortunatum* L. associated with the tea ecosystem. The life table parameters including intrinsic rate of natural increase (r_m) and net reproductive rate (*Ro*) of *C. ruficrus* were 0.203 per day and 41.11 female offspring/female, respectively, with the gross reproductive rate ($\sum mx$) 50.09 eggs/female. The parasitic impact of *C. ruficrus* has significantly affected the food consumption and development of *H. talaca*. Resultantly, a drastic reduction in body weight, changes in differential hemocyte count (DHC), and morphology of hemocytes were observed in parasitized host larvae. Toxic effect of quinalphos and thiamethoxam on *C. ruficrus* showed 100% mortality followed by bifenthrin > deltamethrin > emamectin benzoate > flubendiamide > fenpyroxymate after 72 h of the application.

ARTICLE HISTORY
Received 30 June 2020
Accepted 12 April 2021

KEYWORDS
Seasonal abundance; life table; tea; *Hyposidra talaca*; parasitism; *Cotesia ruficrus*

1. Introduction

In tea plantation of Terai, Dooars of West Bengal and Assam in India, the tea looper, *Biston suppressaria* (Guenée) (Lep.: Geometridae), the black looper, *Hyposidra talaca* (Walker) (Lep.: Geometridae), *H. infixaria*, *Ascotis*, and *Ectropis* sp. reported to be the problematic lepidopteran pests (Das et al. 2010; Chutia et al. 2012). Among these black inch looper, *H. talaca* acquire special attention as a serious pest for its harmful characteristics on tea plant (Antony et al. 2011). *H. talaca* has migrated from the forest ecosystem and get acclimatized to the tea ecosystem. The perennial crop tea gets attacked by this pest throughout the year in the tea-growing area. Synthetic pesticides are traditionally being used for the management of this pest, which develops resistance, contaminates the made tea, and affects the environment. To avoid the negative impact of the use of synthetic pesticide application and conservation of biological control agents is one of the tools of pest management worldwide (Basu et al. 2012). Biological control agents play a crucial role in the regulation of pest population keeping the pests under the economic threshold level (ETL) in most of the agricultural fields and forest ecosystems (Sanap et al. 2016). Braconid wasps as promising parasitoids are being considered as potential natural enemies in several agro-ecosystems (Rahman and Bhola 2011). Insect pest management strategy using biological control tools is one of the important challenges for all experts in the relevant field. The fitness of a parasitoid could be assessed by studying its life table and seasonal dynamics, especially the evaluation of bio-ecology of the parasitoid, its relation with lepidopteran pests, and the effect of commonly used pesticides are the basic tools for collecting data about the natural enemies (Hailemichael et al. 1997; Eliopoulos and Stathas 2008; Sarkar et al. 2020). This demographic information can be useful for evaluating and selecting the potential biological control agent, its mass multiplication under laboratory conditions, and augmentative release in the field.

Endoparasitoid belonging to the family Braconidae lay eggs and complete their larval period inside the suitable host insect (Jung et al. 2006).

CONTACT Azariah Babu azariah.babu@gmail.com Deputy Director (Research) & Senior Principal Scientist, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata - 735 225, Jalpaiguri District, West Bengal, India

Suman Sarkar
21.10.2021

UNIVERSITY OF GOUR BANGA

Established under West Bengal Act XXVI of 2007 & recognized by UGC U/S 2(f) & 12(B)
NAAC accredited University with "B" Grade (2016)
P.O. - Mokdumpur, Dist.: Malda, West Bengal, Pin -732103

Dr. Biswarup Sarkar
Controller of Examinations

URL: www.ugb.ac.in
Phone : (03512) 223668
Fax : (03512) 223668
E-mail: controller@ugb.ac.in

Ref. No. 0152/UGB/CE-2021

Date: 09/02/2021

PROVISIONAL RESULT SHEET

The Hon'ble Vice Chancellor has been pleased to order that the below mentioned candidate(s) be declared to have qualified for the degree of Doctor of Philosophy on presentation of the thesis as noted against the name(s).

Sl. No.	Name and Sex of the Candidate	Regn. No.	Name of the Supervisor(s)	Department	Title of the thesis	Date of Award
1.	Swapan Kumar Chowdhury (Male)	1620607	Prof. Vivekananda Mandal	Botany	"Characterization of Bacillus sp. LBF-01 as potent biocontrol agent against some fungal diseases of crop plants."	February 05, 2021
2.	Snigdha Das (Female)	1613604	Prof. Chandan Bhattacharyya	Sanskrit	"ŚRĪMADBHĀGAVATE SĀṂKHYA-DARŚANA-SAMĪKṢĀ"	February 06, 2021
3.	Suman Sarkar (Male)	1621607	Dr. Kaushik Chakraborty Dr. Azariah Babu	Zoology	"Assessment on the host preference, bio-ecology of looper Hyposidra Talaca (Lepidoptera: Geometridae) and its natural enemies in tea ecosystem."	February 08, 2021

09/02/2021
(Dr. Biswarup Sarkar)
Controller of Examinations

Copy forwarded for information to:

Controller of Examinations
University of Gour Banga
Malda - 732103

1. Hon'ble Vice Chancellor, University of Gour Banga
2. Registrar, University of Gour Banga
3. Librarian, University of Gour Banga
4. The secretary, University Grants Commission, Bahadur Shah Zafar Marg, New Delhi 110002
5. The Librarian, Association of Indian Universities, AIU House, 16, Comrade Indrajit Gupta Marg, New Delhi 110002
6. The Secretary, Council of Scientific and Industrial Research, Anusandhan Bhawan, 2 Rafi Marg, New Delhi 110001
7. Supervisor, University of Gour Banga
8. Head of the Department of Concerned Subject, University of Gour Banga
9. External Expert of the Concerned Subject in India.

Suman Sarkar
21.10.2021

West Bengal Board Of Secondary Education

Index No. Q1-014

ADMIT

ROLL Q2361 NO. 0496

Registration No. Q1014051-006

SUMAN SARKAR

S / ~~XXXXX~~ of SUKUMAR SARKAR

to the Madhyamik Pariksha (Secondary Examination) 2006.

His / ~~Her~~ date of birth is TWENTY FIFTH *day of* JULY

nineteen hundred and NINETY ******

SUBJECT COMBINATION

FL-> BENGALI SL-> ENGLISH

ADL-> WORK EDUCATION
GROUP

EXAMINATION CENTRE

BALURGHAT

Gopa Basu (Dutta)

Deputy Secretary (Exam.)

~~101991~~

NB : i) This Admit Card should be carefully preserved.
ii) Alteration made in the Admit Card without the approval of the Board will disqualify the Candidate from sitting at this or any subsequent Examination.
iii) The Languages in which answers in the Non-Language subjects can only be written are Bengali, English, Hindi, Nepali, Oriya and Urdu.

Suman Sarkar
21.10.2021

UNIVERSITY OF GOUR BANGA

Ph.D. Course Work Examination, 2017

This is to certify that Smt./Sri **SUMAN SARKAR** *bearing Roll:* **0017PHD406** *No.:* **0006** *has successfully completed the Ph.D. Course Work in* **ZOOLOGY** *of this University in accordance with the U.G.C. (Minimum Standard and Procedure for Awards of Ph.D. Degree) Regulation, 2009.*

Following is the statement of marks, she/he obtained in the Ph.D. Course Work Examination, 2017:

Paper Code	Course	Paper Name	Half	Full Marks	Pass Marks	Marks Obtained	Class/ Grade
I	Research Methodology	General Research Methodology	1st	50	20	28	Qualified
		Research Methodology in Zoology	2nd	50	20	30	
II	Computer Application	General Computer Applications	1st	50	20	33	
		Computer Applications in Zoology	2nd	50	20	28	
III	Foundation of Zoology and Advanced Zoology Specialization	Foundation of Zoology	1st	50	20	31	
		Advanced Zoology Specialization	2nd	50	20	27	
IV	Review of Published Research works and Development of Research Proposal	Review of Published Research Works	1st	50	20	30	
		Development of Research Proposal	2nd	50	20	28	
Grand Total				400	160	235	

Sanatan Das

(Dr. Sanatan Das)
Controller of Examinations (A/C)

Dated: 24.05.2017

Suman Sarkar
21.10.2021

Suman Sarkar

ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM

SUMAN SARKAR

Registration No. 1621607

Ph.D. THESIS

2020

UNIVERSITY OF GOUR BANGA

MALDA, WEST BENGAL

ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM

A THESIS PRESENTED BY

SUMAN SARKAR

TO

UNIVERSITY OF GOUR BANGA

MALDA, WEST BENGAL

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF
DOCTOR OF PHILOSOPHY

YEAR: 2020

Dedicated to

My Parents and Tea Industry

DECLARATION BY THE STUDENT

I, **Suman Sarkar** hereby declare that I had carried out the work under the supervision of Dr. Kaushik Chakraborty, Associate Professor of University of Gour Banga (Presently in lien), Malda and joint supervision of Dr. Azariah Babu, Chief Scientist & Deputy Director (Research) of Tea Research Association (NBRRDC), Nagrakata depicted in the thesis entitled **"ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM"** submitted to university of Gour Banga, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the faculty .

No part of the thesis has been submitted for the award of any other degree or diploma prior to this date.

Date:

(Suman Sarkar)
Ph.D Scholar
Dept. of Zoology, UGB

UNIVERSITY OF GOUR BANGA

Mokdumpur, Malda, West Bengal, 732103

DR. KAUSHIK CHAKRABORTY
MSc., Ph.D.
Associate Professor (presently in lien)
Department of Zoology

Certificate by Supervisor

Name of the guide. Dr. KAUSHIK CHAKRABORTY

Department: Zoology

This is to certify that **Mr. Suman Sarkar** is a student of Department of Zoology of this Institute and has fulfilled the requirements prescribed for the Ph. D degree of the University of Gour Banga, Malda, West Bengal.

The Ph. D thesis entitled, **"Assessment on the host preference, bio-ecology of looper *Hyposidra talaca* (Lepidoptera: Geometridae) and its natural enemies in tea ecosystem"** was carried out under my direct supervision. No part of the thesis was submitted for the award of any degree or diploma prior to this date so far my knowledge goes.

Signature

Date: **(DR. KAUSHIK CHAKRABORTY)**

TOCKLAI
TEA RESEARCH ASSOCIATION
NORTH BENGAL REGIONAL R&D CENTRE, NAGRAKATA
Nagrakata – 735 225, Dist. Jalpaiguri, West Bengal, India, Telephone (03565) – 272059
Fax : 91-3565-272059, E-mail : TRA.nagrakata@tocklai.net, Website : www.tocklai.net

CERTIFICATE

This is to certify that **Mr. Suman Sarkar,** is a student of Department of Zoology of University of Gour Banga, Malda, West Bengal and has fulfilled the requirements prescribed for the Ph. D degree of this institute.

The Ph. D thesis entitled, **"ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER *HYPOSIDRA TALACA* (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM"** was carried out under my joint supervision. To the best of my knowledge, no part of the thesis was submitted for the award of any degree or diploma prior to this date.

Date:

Dr. AZARIAH BABU
Chief Scientist &
Deputy Director (Research),
Tea Research Association,
NBRRDC, Nagrakata
and
Joint supervisor,
Ph.D Programme of Mr. Suman Sarkar

Regd. Office : 113 Park Street, Kolkata – 700 016
Director's Office : Tocklai Tea Research Institute, Jorhat – 785 008, Assam

Approval of thesis

The thesis entitled

ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM

Submitted by

SUMAN SARKAR

For the degree of

Doctor of Philosophy

UNIVERSITY OF GOUR BANGA
MALDA, WEST BENGAL

Is evaluated and approved by

……..

Name of the Guide

……..

Name of Thesis Examiner

Acknowledgements

I wish to extend my profound gratitude to the then Vice Chancellor (Dr.) Swagata Sen, and deepest respect to the present Honourable Vice Chancellor the Professor (Dr.) Chanchal Chaudhuri University of Gour Banga, Malda, West Bengal who provided me such kind of platform of my research work.

I feel extremely indebted to Dr. Kaushik Chakraborty Associate Professor (Presently in lien) of University of Gour Banga, Malda and presently working as Professor Department of Zoology, Raiganj University, Raiganj, Uttar Dinajpur for his esteemed guidance as supervisor, keen interest, constructive criticism and reviewing the manuscript of the research work.

I express my deepest gratitude to Dr. Azariah Babu, Chief Scientist and Deputy Director (Research) of Tea Research Association, North Bengal Regional Research and Development Centre, for his constant support and encouragement in all my endeavors as a Joint-Supervisor without which the entire work would have not been possible.

I am indeed grateful to Professor Shyamapada Mandal, Dept. of Zoology of University of Gour Banga for his valuable advice in drafting this research work, suggestions for improvement during the entire research work and for providing necessary laboratory facilities during the progress of this work.

I wish to express thanks to Dr. Shubhrajyoti Roy, Dr. Manaj Lama, Dr. Anjali Rawani and Dr. Mitali Das, Associate Professors of Zoology Department, University of Gour Banga for their helpful suggestions from time to time.

Many thanks are due to the Advisory Officers of NBRRDC, Mr. Sam Verghese, Dr. Trina Mandal and Dr. Soumen Baisya for their encouragement and support. Thanks, are also due to the Scientists Dr. Bhabesh Deka, Dr. Biplab Adhikary, Dr. Harisadhan Malakar and Dr. Buddhadeb Das for their help in conducting different experiments.

I am grateful to Mr. Tapan Talukdar and Dr. Biswapran Kashyap Technical officers of NBRRDC for instructing the laboratory experiments.

A special thanks to Dr. Dipanjana Mazumder, Assistant Professor, Department of Zoology of Siliguri College and Dr. Debashri Mondal, Assistant Professor, Raiganj University, Uttar Dinajpur for the technical support in the morphological studies.

My sincere thanks to the Dr. K. Sahayaraj, Professor of Zoology, St, Xavier's College (Autonomus), Palayamkottai, Tiruneveli, Tamil Nadu- 627002, India for the taxonomic identification of natural enemy, Sycanus collaris.

I specially thank all the respected Managers and Assistant Managers of Banarhat, Nagrakata, Hope and Kurti Tea Estates of Dooars region for providing me full access to their estates and for helping in survey work.

I would especially like to thank Mr. Sugata Barua, Mr. Bijay Lohar and Mr. Shyam Manger of office and laboratory attendant of NBRRDC for helping me in the laboratory as well as in the field experiments.

I express my thanks to all the research scholars of NBRRDC, working with me during the period of 2016-2019 for their assistance and support in my study. I am also grateful to my friends and Ph. D batch mates of University of Gour Banga for their continuous support in my study. Special thanks to my friend Bijayanta Sircar.

All the respected Officers and staffs of Office of the Registrar, Controller of examination and Finance of University of Gour Banga are greatly acknowledged for their help in the official formalities.

Special thanks to Mrs. S. Vasanthakumari Babu, for her constant encouragement and moral support in both academically and personally.

Finally, I offer my salutations to my beloved parents for their understanding and patience, without their support and prayers this study would have not been possible.

(Suman Sarkar)
Ph.D Scholar
Dept. of Zoology, UGB

Declaration for non-plagiarism

I, **Suman Sarkar***, declare that:*

1. *The research finding reported in this thesis, except where otherwise indicated is my original research.*

2. *This thesis has not been submitted for any degree or examination at any other institution.*

3. *This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.*

4. *This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted:*

4.1 *Their words have been re-written and the general information attributed to them has been referenced.*

4.2 *Where their exact words have been used, their writing has been placed in italics inside quotation marks and referenced*

5. *This thesis does not contain text, graphics or tables copied and pasted from the work of other persons, unless specifically acknowledged, and the source being detailed in the thesis and in the references section. However, to make the thesis more comprehensive some photographs were taken from the internet. The sources of the photographs were acknowledged as far as possible.*

6. *The plagiarism of the text of the thesis has been checked with URKUD software system, which showed around 6% similarity (Annexure VI).*

Date:

Suman Sarkar
Ph.D Scholar
Dept. of Zoology, UGB

Table of Content

Contents		Page No.
Declaration by the student		**IV**
Certificate of guides		**V-VI**
Approval of thesis		**VII**
Acknowledgement		**VIII**
Declaration for Non-Plagiarism		**X**
Table of content		**XI**
List of figures		**XVIII**
List of tables		**XXIX**
Abbreviation		**XXXIII**
Synopsis		**XXXV**
Chapter-I- Introduction		
1.1	Invention of tea in India	1
1.2	Biochemical components of tea	2
1.3	Tea cultivation and production in India	2
1.4	Tea cultivars developed by Tocklai Tea research Institute (TTRI)	2
1.5	Important insect pests of tea ecosystem	3
1.6	Tea black inch looper (*Hyposidra talaca*)	5
1.7	Management of *H. talaca* using chemical pesticides	6
1.8	Biological control measures	8
1.9	Biological control agents	9
1.10	Scope of the study	9
1.11	Objectives of the study	10
Chapter-II- Literature Review		
2.1	Lepidopteran pest in tea ecosystem	11
2.2	Biology of *H. talaca* on different hosts	12
2.3	Seasonal occurrence	13
2.4	Host preference of *H. talaca*	13
2.5	Feeding on different tea cultivars and extension of damage	13
2.6	Tea clones developed by Tea Research Association (TRA)	15
2.7	Biochemistry of tea leaf and defense against insect	16
2.8	Effect of leaf characteristics on insect feeding	19
2.9	Biological control agents in tea ecosystem	19
2.10	Seasonal abundance of *Sycanus collaris* and interaction with ecology	21
2.11	Biology and life table of *S. collaris*	22
2.12	Predatory efficiency of *S. collaris*	23
2.13	Predatory behaviour of reduviid bug	23
2.14	Seasonal abundance and interaction with ecology of *Eocanthecona furcellata*	24
2.15	Biology and life table of *E. furcellata*	24
2.16	Predatory efficiency of *E. furcellata*	25

Contents **Page No.**

2.17 Predatory behaviour of E. *furcellata* 26
2.18 Biology of *Cotesia ruficrus* 26
2.19 Seasonal abundance and interaction of *C. ruficrus* with ecology 27
2.20 Parasitic impact of *C. ruficrus* on pest 28
2.21 Effect of pesticides on natural enemies 29

Chapter-III- Materials and methods

3.1 Location of the study 32
3.2 Bioecology and seasonal abundance of *H. talaca*, *S. collaris*, *E. furcellata* and *C. ruficrus* 32
3.3 Rearing of *H. talaca* on natural diet (tea leaves) and shade tree leaf (*Acacia lenticularis*) 34
3.4 Rearing of *H. talaca* on artificial diet 35
3.4.1 Procedure of artificial diet 36
3.5 Rearing of *Corcyra cephalonica* 36
3.6 Rearing of *S. collaris* and *E. furcellata* on larvae of *H. talaca* and *C. cephalonica* 37
3.7 Rearing of *C. ruficrus* on *H. talaca* 38
3.8 Life table of *H. talaca*, *S. collaris*, *E. furcellata* and *C. ruficrus* 39
3.9 Selection of tea cultivars for the present study 40
3.10 Study on the food consumption and development of larvae of *H. talaca* on different tea cultivars 41
3.11 Quantitative assay of biochemical profiles of selected tea cultivars 42
3.11.1 Preparation of leaf for biochemical analysis 42
3.11.2 Estimation of total carbohydrate 43
3.11.3 Estimation of total protein 43
3.11.4 Estimation of lipid 44
3.11.5 Estimation of polyphenol 44
3.11.6 Estimation of total alkaloids 45
3.11.7 Estimation of total flavonoid 45
3.11.8 Estimation of total chlorophyll and carotenoids 46
3.11.9 Individual Catechins and Caffeine by using HPLC method 46
3.12 Tea Leaf biophysical characters 47
3.12.1Trichome density 47
3.12.2 Leaf thickness 47
3.13 Predatory efficiency of the predators *S. collaris* and *E. furcellata* on *H. talaca* 48
3.13.1 No-choice feeding 48
3.13.2 Free-choice feeding 48
3.14 Predatory behaviour of *S. collaris* and *E. furcellata* 48
3.15 Stage specific predation of *S. collaris* and *E. furcellata* 48
3.16 Mass rearing of *S. collaris* on larvae of *C. cephalonica* 49
3.17 Field release of *S. collaris* 49

Contents **Page No.**

3.18 Parasitization on different host instar and affects food consumption and growth 49
3.19 Differential haemocyte count (DHC) and morphology of haemocytes 49
3.20 Effect of pesticides on natural enemies (*S. collaris. E. furcellata* and *C. ruficrus*) of *H. talaca* 50
Chapter-IV- Results
4.1 Observation on climatic parameters 51
4.2. Study on the bio-ecology and seasonal incidence of *Hyposidra talaca* in relation to the climatic parameters of *Dooars* region of West Bengal 53
4.2.1 Observation on bio-ecology of *H. talaca* 53
4.2.1.1 Observations on host plant as alternative food source 53
4.2.1.2 Observations on host plant for egg-laying 53
4.2.2. Seasonal abundance of H. talaca during the period of observation 54
4.2.2.1 Periodicity of *H. talaca* 54
4.2.2.2 Observation of 'trends line' of *H. talaca* during the period of observation 56
4.2.2.3: Impact of abiotic parameters 56
4.2.2.3.1 Observation and correlation value 56
4.2.2.3.2 Regression analysis 59
4.2.3. Study on biology and survivality of *H. talaca* under laboratory conditions 60
4.2.3.1. Biology of *H. talaca* on three different diets 60
4.2.3.2. Survival percentage of *H. talaca* reared on three different diets 62
4.2.3.3. Life table study of *H. talaca* reared on three different diets 63
4.3. Study on bio-ecology and seasonal abundance of *S. collaris* during the period of observation 66
4.3.1 Observation on bio-ecology of *S. collaris* 66
4.3.2 Periodicity of *S. collaris* 66
4.3.3. Observation of 'trends line' of *H. talaca* during the period of observation 67
4.3.4. Observation and correlation value 67
4.3.5. Regression analysis 70
4.4. Study on bio-ecology and seasonal incidence of *Eocanthecona furcellata* during the period of observation 72
4.4.1 Observation on bio-ecology of *E. furcellata* 72
4.4.2 Periodicity of *E. furcellata* 72
4.4.3. Observation of 'trends line' of *E. furcellata* during the period of observation 74
4.4.4. Observation and correlation value 74

Contents **Page No.**

4.4.5 Regression analysis 76
4.5. Study on bio-ecology and seasonal incidence of *Cotesia rufirus* during the period of observation 78
4.5.1 Observation on bio-ecology of *C. ruficrus* 78
4.5.2. Periodicity of *C. ruficrus* 78
4.5.3 Observation of 'trends line' of *H. talaca* during the period of observation 79
4.5.4 Observation and correlation value 79
4.5.5 Regression analysis 82
4.6. Observation on the biotic interaction between the *H. talaca* and natural enemies 84
4.6.1 At Banarhat TE (L1) 84
4.6.2 At TRA experimental plot (L2) 90
4.7. Study on the biochemistry of tea leaves and susceptibility index of selected tea clones against *H. talaca* 98
4.7.1 Observations on the tea leaf biochemistry 98
4.7.1.1. Analysis of primary metabolites 98
4.7.1.1.1 Carbohydrate 98
4.7.1.1.2 Protein 98
4.7.1.1.3 Lipid 99
4.7.1.1.4 Chlorophyll 99
4.7.1.1.5 Correlation regression 99
4.7.1.2. Analysis of secondary metabolites 99
4.7.1.2.1 Total polyphenol 99
4.7.1.2.2 Total alkaloid 100
4.7.1.2.3 Total Flavonoid 100
4.7.1.2.4 Carotenoids 101
4.7.1.2.5 Individual Catechins and Caffeine 102
4.7.1.2.6 The correlation coefficient 102
4.7.1.3 Tea leaf biophysical characters 108
4.7.1.4 Study on food consumption and weight gain by *H. talaca* on selected cultivars 109
4.7.1.5 Susceptible index (Status of host preference on different tea cultivars by *H. talaca*) 111
4.7.1.6 Cluster analysis 112
4.8. Study on biology and life table of *S. collaris* 114
4.8.1 Study on the biology of *S. collaris* on *H. talaca* and *C. cephalonica* 114
4.8.2 Study on life table of *S. collaris* reared on *H. talaca* 114
4.8.3 Study on predatory efficiency of *S. collaris* on larvae of *H. talaca* 116
4.8.3.1 No-choice condition of feeding 116

Contents **Page No.**

4.8.3.2 Free-choice condition of feeding 117
4.8.4 Predatory behaviour of *S. collaris* consumption on larvae of *H. talaca* 119
4.8.5 Mass rearing of *S. collaris* on *C. cephalonica* 120
4.8.6 Study on effect of pesticide on *S. collaris* 121
4.8.7 Field release of *S. collaris* 122
4.9. Study on biology and life table of *E. furcellata* 124
4.9.1 Study on biology of *E. furcellata* on *H. talaca* and *C. chephalonica* 124
4.9.2 Study on life table of *E. furcellata* reared on *H. talaca* 125
4.9.3 Study on predatory efficiency of *E. furcellata* on different stages of *H. talaca* 126
4.9.3.1 No-choice condition of feeding 127
4.9.3.2. Free-choice condition of feeding 127
4.9.4 Study on predatory behaviour of *E. furcellata* on different stages of *H. talaca* 128
4.9.5 Study of the toxic effect of pesticides on immature and mature stages of *E. furcellata* 128
4.10 Study on biology and life table of *C. ruficrus* on *H. talaca* 130
4.10.1 Study on biological parameters of *C. ruficrus* reared on *H. talaca* larvae under laboratory conditions 130
4.10.2. Study on life table of *C. ruficrus* reared on larvae of *H. talaca* 132
4.10.3 Effect of parasitism on food consumption and growth of *H. talaca* 133
4.10.4 Differential haemocyte count (DHC) and morphology of different haemocytes 135
4.10.5 Effect of pesticide on *C. ruficrus* 137

Chapter-V- Discussion

5. 1 Study on the bio-ecology and seasonal incidence of *Hyposidra talaca* in relation to the climatic parameters of *Dooars* region of West Bengal 139
5. 1.1 Observation on bio-ecology of *H. talaca* 139
5. 1.2 Seasonal abundance of *H. talaca* during the period of observation 139
5.1.3 Biology of *H. talaca* on three alternative diets 140
5.1.4 Survival of *H. talaca* reared on three different diets 141
5.1.5 Life table of *H. talaca* reared on three different diets: 141
5.2 Seasonal abundance of *S. collaris* during the period of observation 142
5.3 Seasonal abundance of *E. furcellata* during the period of observation 143
5.4 Seasonal abundance of *C. ruficrus* during the period of observation 144
5.5 Interaction between *S. collaris*, *E. furcellata*, *C. ruficrus* and *H. talaca* 145

Contents **Page No.**

5.6. Study on the biochemistry of tea leaves and susceptibility index of selected tea clones against *H. talaca* 145
5.6.1 Tea leaf biochemistry 145
5.6.1.1 Analysis of primary metabolites 145
5.6.1.2 Analysis of secondary metabolites 147
5.6.1.3 Analysis of secondary metabolites using HPLC method 148
5.6.2 Food consumption and susceptibility index of *H. talaca* on tea leaves 149
5.7.1 Biology of *S. collaris* on H. talaca and *C. cephalonica* 151
5.7.2 Predatory efficiency of *S. collaris* on larvae of *H. talaca* 152
5.7.3 Predatory behaviour of *S. collaris* fed on larvae of *H. talaca* 153
5.7.4 Survival and life table of *S. collaris* reared on larvae of *H. talaca* 154
5.7.5 Mass rearing of *S. collaris* on *C. cephalonica* 155
5.7.6 Effect of pesticide on *S. collaris* 155
5.7.7 Field release of *S. collaris* 156
5.8.1 Biology of *E. furcellata* on H. talaca and *C. cephalonica* 156
5.8.2 Predatory efficiency of *E. furcellata* on larvae of *H. talaca* 157
5.8.3 Predatory behaviour of *E. furcellata* on different stages of *H. talaca* 158
5.8.4 Survival and life table of *E. fuecellata* reared on larvae of *H. talaca* 159
5.9.1 Effect of parasitism on food consumption and growth of *H. talaca* 160
5.9.2 Differential haemocyte count (DHC) and morphology of different haemocytes 160
5.9.3 Effect of pesticide on *C. ruficrus* 161
5.9.4 Biological parameters of *C. ruficrus* reared on *H. talaca* larvae under laboratory conditions 162
5.9.5 Life table of *C. ruficrus* reared on larvae of *H. talaca* 163
Chapter-VI- Summary and conclusion **164**
Bibliography **168**
Annexure-I publications from thesis ***A-I***
Annexure- II Seminar attended certificates Identification report ***A-IV***
Annexure -III CV ***A-VI***
Annexure –IV Identification certificate of S. collaris ***A-VII***
Annexure –V Certificates from TE authority ***A-VIII***
Annexure -VI Plagiarism report ***A-X***

List of Figures

No. of figure	Title of figure	Page No.
Fig. 1.1	Major tea producing area: (a) throughout the world, (b) in India and (c) in West Bengal	**3**
Fig. 1.2	Tea plant infested by looper (*H. talaca*): (a) and (b) healthy tea bush (red circle indicates the point of interest), (c) attacked by looper, (d) initial stage of damage, (e and f) severe damage.	**6**
Fig. 1.3	Trends of application of insecticides in tea gardens	**7**
Fig. 3.1	Location map of the study area	**32**
Fig.3.2	Two study sides, (a) first location (Banarhat TE) and (b) second location (TRA experimental plot)	**33**
Fig.3.2.1	Pest and natural enemies in tea ecosystem: (a-b) larvae of *H. talaca*, (c) cocoons of *C. ruficrus*, (d) adult *S. collaris*, (e) nymph of *S. collaris* and (f) adult of *E. furcellata*	**33**
Fig. 3.3	Rearing of *H. talaca*: (a) tea leaves are provided for looper, (b) rearing condition of looper on tea leaves, (c) shade tree leaves are provided for looper and (d) rearing condition of looper on shade tree leaf covered	**34**
Fig. 3.4	Rearing of looper on artificial diet: (a) early instar of looper and (b) advanced instar larvae	**35**
Fig. 3.4.1	Ingredients of artificial diet: (a) fraction A, (b) fraction B, (c) fraction C, (d) fraction D, (e) mixture of all ingredients poured in a petridish and (f) prepared artificial diet	**36**
Fig. 3.5	Rearing of *C. cephalonica* on maize powder, (a) rearing condition of *C. cephalonica* in laboratory, (b) moths in the culture container, (c) the collected eggs, (d) larvae of different instars, (e) pupae and (f) male and female moths	**37**
Fig. 3.6	Rearing of *S. collaris* on (a) looper and (b) larvae of *C. cephalonica*; rearing of *E. furcellata* on (c) looper and (d) larvae of *C. cephalonica*	**38**
Fig. 3.7	Ten selected tea cultivars for the present study	**41**
Fig. 3.8	Food consumption of looper: (a) prepared leaf disc, (b) earlier instar of larva fed on leaf disc and (c) advanced instar larva consumed total leaf disc.	**42**
Fig. 3.9	Biochemical analysis of tea leaf: (a) tea leaf powder, (b) estimation of chlorophyll, (c-d) estimation of alkaloid, (e) estimation of quercetin, (f) estimation of protein, (g) estimation of polyphenol, (h) estimation of carbohydrate	**46**
Fig. 3.10	Measuring of trichome density and leaf thickness	**47**
Fig. 2.1.1	Host plant as alternative food source, larvae of *H. talaca* were found to feed on (a) *Phyllanthus* sp. (b) *Ageratum conyzoides* (c) *Polyalthia longifolia*	**53**
Fig. 2.1.2	Egg-laying of *H. talaca* on alternative hosts, (a) During egg laying on mango tree, (b) Egg clutches on mango tree, (c) Mating of male and female on Bakain tree, (d) Egg clutches on Bakain tree bark.	**54**

No. of figure	Title of figure	Page No.
Fig. 2.2.1.1	Seasonal abundance of *H. talaca* and the trends line (in dotted line) suggesting the prediction of the incidence of *H. talaca* during 2017-2018 for both the study locations	**55**
Fig. 2.2.1.2	Seasonal abundance of *H. talaca* and the trends line (in dotted line) suggesting the prediction of the incidence of *H. talaca* during 2018-2019 for both the study locations	**56**
Fig. 2.2.3.1	Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2017-2018 at Banarhat TE	**57**
Fig. 2.2.3.2	Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2017-2018 at TRA experimental plot.	**58**
Fig. 2.2.3.3	Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2018-2019 at Banarhat	**58**
Fig. 2.2.3.4	Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2018-2019 at TRA experimental plot.	**59**
Fig. 2.3.1	Stages of life cycle of *H. talaca*: (a) clutches of eggs, (b) newly hatched1st instar larvae, (c) 2nd instar larvae, (d) 3rd instar larva, (e) 4th instar larva, (f) 5th instar larva, (g) male and female pupae and (h) mating of male and female moths.	**61**
Fig. 2.3.3	Life table of *H. talaca* when reared on tea leaf	**64**
Fig. 2.3.4	Life table of *H. talaca* when reared on artificial diet	**64**
Fig. 2.3.5	Life table of *H. talaca* when reared on shade tree leaf	**65**
Fig. 3.2.1	Seasonal abundance of and the trends line (in dotted line) suggesting the prediction of the incidence of *S. collaris* during 2017-2018 for both the study locations	**66**
Fig. 3.2.2	Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *S. collaris* during 2018-2019 for both the study locations	**67**
Fig. 3.4.1	Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2017-2018 at Banarhat TE	**68**
Fig. 3.4.2	Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2017-2018 at TRA experimental plot	**68**
Fig. 3.4.3	Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2018-2019 at Banarhat TE	**69**
Fig. 3.4.4	Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2018-2019 at TRA experimental plot	**69**
Fig.4.1	Female of *E. furcellata* laying eggs on shade tree.	**72**

No. of figure	Title of figure	Page No.
Fig. 4.2.1	Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *E. furcellata* during 2017-2018 for both the study locations	**73**
Fig. 4.2.2	Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *E. furcellata* during 2018-2019 for both the study locations	**73**
Fig. 4.2.4.1	Regression line representing relationship between abiotic factors and population abundance of *E. furcellata* in the season of 2017-2018 at Banarhat TE	**74**
Fig. 4.2.4.2	Regression line representing relationship between abiotic factors and population abundance of *E. furcellata* in the season of 2017-2018 at TRA experimental plot	**75**
Fig. 4.2.4.3	Regression line representing relationship between abiotic factors and population abundance of *C ruficrus* in the season of 2018-2019 at Banarhat TE	**75**
Fig. 4.2.4.4	Regression line representing relationship between abiotic factors and population abundance of *E. furcellata* in the season of 2018-2019 at TRA experimental plot	**76**
Fig. 5.2.1	Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *C. ruficrus* during 2017-2018 for both the study locations	**78**
Fig. 5.2.2	Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *C. ruficrus* during 2018-2019 for both the study locations	**79**
Fig. 5.4.1	Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2017-2018 at Banarhat TE	**80**
Fig. 5.4.2	Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2017-2018 at TRA experimental plot	**80**
Fig. 5.4.3	Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2018-2019 at Banarhat TE	**81**
Fig. 5.4.4	Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2018-2019 at TRA experimental plot	**81**
Fig. 6.1.1	Population dynamics of *S. collaris* in respect to densities of *H. talaca* at Banarhat TE (2017-2018)	**84**
Fig. 6.1.2	Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at Banarhat TE (2017-2018)	**85**
Fig. 6.1.3	Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at Banarhat TE (2017-2018)	**85**
Fig. 6.1.4	Regression line representing relationship between population abundance of *H. talaca* and *E. furcellata* at Banarhat TE (2017-2018)	**86**

No. of figure	Title of figure	Page No.
Fig. 6.1.5	Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at Banarhat TE (2017-2018)	**86**
Fig. 6.1.6	Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at Banarhat TE (2017-2018)	**87**
Fig. 6.1.2.1	Population dynamics of *S. collaris* in respect to densities of *H. talaca* at Banarhat TE (2018-2019)	**87**
Fig. 6.1.2.2	Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at Banarhat TE (2018-2019)	**88**
Fig. 6.1.2.3	Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at Banarhat TE (2018-2019)	**88**
Fig. 6.1.2.4	Regression line representing relationship between population abundance of *H. talaca* and *E. furcellata* at Banarhat TE (2018-2019)	**89**
Fig. 6.1.2.5	Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at Banarhat TE (2018-2019)	**89**
Fig. 6.1.2.6	Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at Banarhat TE (2018-2019)	**90**
Fig. 6.2.1	Population dynamics of *S. collaris* in respect to densities of *H. talaca* at TRA Experimental plot (2017-2018)	**91**
Fig. 6.2.2	Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at TRA experimental plot (2017-2018)	**91**
Fig. 6.2.3	Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at TRA experimental plot (2017-2018)	**92**
Fig. 6.2.4	Regression line representing relationship between population abundance of H. talaca and *E. furcellata* at TRA experimental plot (2017-2018)	**92**
Fig. 6.2.5	Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at TRA experimental plot (2017-2018)	**93**
Fig. 6.2.6	Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at TRA experimental plot (2017-2018)	**93**
Fig. 6.2.2.1	Population dynamics of *S. collaris* in respect to densities of *H. talaca* at TRA Experimental plot (2018-2019)	**94**
Fig. 6.2.2.2	Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at TRA experimental plot (2018-2019)	**94**
Fig. 6.2.2.3	Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at TRA experimental plot (2018-2019)	**95**
Fig. 6.2.2.4	Regression line representing relationship between population abundance of *H. talaca* and *E. furcellata* at TRA experimental plot (2018-2019)	**95**
Fig. 6.2.2.5	Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at TRA experimental plot (2018-2019)	**95**

No. of figure	Title of figure	Page No.
Fig. 6.2.2.6	Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at TRA experimental plot (2018-2019)	**95**
Fig. 7.1.1.1.	Standard curve of carbohydrate.	**98**
Fig. 7.1.1.2.	Standard curve of protein.	**99**
Fig. 7.1.2.1	Standard curve of polyphenol.	**100**
Fig. 7.1.2.3	Standard curve of Quercetin.	**100**
Fig. 7.1.1	Regression line showing correlation between food consumption of *H. talaca* and tea leaf primary metabolites	**101**
Fig. 7.1.2	Regression line showing correlation between food consumption of *H. talaca* and tea leaf secondary metabolites	**102**
Fig. 7.1.2.6	Regression equation and correlation between food consumption and percentage of weight of EGC, Catechin, EC, EGCG, ECG, Caffeine and Gallic acid	**104**
Fig 7.1.2.7	Chromatograms of green leaf of different tea cultivars and catechins mixed standard	**105-108**
Fig.7.1.3	Regression line representing relationship between tea leaf biophysical characters and food consumption of *H. talaca*	**109**
Fig.7.1.4	Leaf discs fed by 2nd instar larvae of *H. talaca*	**111**
Fig.7.1.5	Leaf discs fed by 3rd instar larvae of *H. talaca*	**111**
Fig. 7.1.6	Leaf discs fed by 4th instar larvae of *H. talaca*	**112**
Fig. 7.1.7	Dendrogram based on the mean of all larval food consumption, body weight gain and nutritional indices of *H. tacala* fed on different tea cultivars	**113**
Fig. 8.1	Different life stages of *S. collaris* reared on larvae of *H. talaca* and *C. cephalonica*: (a) egg raft, (b) newly hatched nymph from egg, (c) first instar nymph, (d) second instar nymph, (e) third instar nymph, (f) fourth instar nymph, (g) fifth instar nymph and (h) adult are mating	**114**
Fig. 8.2	Survival percentage of *S. collaris* reared on *H. talaca*	**115**
Fig. 8.3	Age specific survival rate (lx), fecundity (mx) and maternity (Xlxmx) of *S. collaris* on *H. talaca*	**116**
Fig. 8.4	Mean of predatory efficiency on all the larval instars by individual life stage of *S.collaris* in both no-choice and free-choice conditions	**117**
Fig. 8.5	Feeding of *S. collaris*: (a) group feeding of 3rd instar nymph on looper and (b) on larvae of *C. cephalonica*; (c) adult female feeding on looper and (d) on larvae of *C. cephalonica*; (e) feeding of fourth instar nymph and (f) fifth instar nymph	**118**
Fig. 8.6	Condition of looper after feeding by *S. collaris*: (a) healthy looper and (b) dead looper	**119**
Fig. 8.7	Mass rearing of *S. collaris*	**121**
Fig. 8.8	Population reduction percentage of *H. talaca*, in the *S. collaris* released plot	**123**
Fig. 8.9	Field release of *S. collaris*: (a) at Kurti TE and (b) Hope TE	**123**

No. of figure	Title of figure	Page No.
Fig. 9.1	Life stages of *E. furcellata*: (a) egg; nymphal stages of (b) first instar, (c) second instar, (d) third instar, (e) fourth instar, (f) fifth instar; (g) adult male and (h) adult female	**125**
Fig. 9.2	Survival percentage of different life stages of *E. furcellata* when reared on larvae of *H. talaca*	**125**
Fig. 9.3	Age-specific survival rate (lx), age-sepcific fecundity (mx) and maternity (Xlxmx) of female *E. furcellata* feeding on larvae of *H. talaca*.	**126**
Fig. 9.3.1	Feeding *E. furcellata* on larvae of *H. talaca*: (a) group feeding of first instar nymph, (b) feeding of first instar nymph and (c) feeding of adult stink bug	**127**
Fig. 9.3.2	Mean of predatory efficiency on all the larval instars by individual life stage of *E. furcellata* in both no-choice and free- choice conditions	**128**
Fig. 10.1	Number of cocoon formation of *C. ruficrus*, adult (female and male) wasp emergence from a single host larva from different stages. Values are significant at P <0.05 (One-way ANOVA).	**131**
Fig. 10.2	Life stages of *C. ruficrus*: (a) adult *C. ruficrus*, (b) larvae of *C. ruficrus* emerging from host larva, (c) larvae of *C. ruficrus* forming cocoons and (d) cocoons of *C. ruficrus*	**132**
Fig. 10.3	Age-specific survival rate (lx), age-sepcific fecundity (mx) and maternity (Xlxmx) of female *C. ruficrus* parasitized on larvae of *H. talaca*	**133**
Fig.10.4	Food consumption (mg) of parasitized (white) and unparasitized (black) larvae of *H.talaca*. Values are significantly different at p<0.05 according to Tukey's HSD test	**134**
Fig. 10.5	Body weight (mg) of parasitized (white) and unparasitized (Black bar) larvae of *H. talaca.* Values are significantly different at p<0.05 according to Tukey's HSD test	**135**
Fig. 10.6	Parasitism by *C. ruficrus* on host larva, *H. talaca*: (a-c) larva of *C. ruficrus* into the body of *H. talaca*, (d) parasitic wasp made whole on the host body, (e) larvae of *C. ruficrus* emerging from the host body and (d) cocoon formation by the parasitic larvae	**135**
Fig. 10.7	Morphology of different haemocytes of parasitized and un-parasitized larvae of *H. talaca viz.*(A) un-parasitized OE, (B) parasitized OE, (C) un-parasitized AD, (D) parasitized AD, (E) un-parasitized PR, (F) parasitized PR and GR, (G) parasitized GR, (H) un-parasitized PL and (I) parasitized PL.	**137**

List of Tables

No. of tables	Title of tables	Page No.
Table 1.1	Important lepidopteran pests from tea ecosystem in India	**12**
Table 1.2	Alternative host plant of *H. talaca* in tea ecosystem (Adopted from Roy *et al.,* 2017 after modification)	**14**
Table 1.3	Tea varieties (Clones) released by Tocklai Tea Research Institute under TV series (Year of releases is in the parenthesis) (Adopted from Barman, 2011)	**16**
Table 1.4	Tea varieties (Clones) released by Tocklai Tea Research Institute under garden series (Adopted from Barman, 2011)	**16**
Table 1.5	Species of *C. ruficrus* parasitized on pests associated with agriculture	**28**
Table 2.4	Ingredients of artificial diet	**35**
Table 2.9	Selected tea cultivars for the experiment	**40**
Table 4.1.1	Climatic factors observed during first season (2017-2018) at both the study locations	**51**
Table 4.1.2	Climatic factors observed during second season (2018-2019) at both the study locations	**51**
Table 4.2.3.1	Correlation between *H. talaca* populations and agro-climatic conditions of L1 and L2	**59**
Table 4.2.3.2	Regression equation between *H. talaca* populations and climatic factors of both the locations	**60**
Table 4.2.3.3	Biology of *H. talaca* reared on three different diets	**62**
Table 4.2.3.4	Survivality (%) of *H. talaca* on three alternative dietary sources	**63**
Table 4.2.3.5	Life table parameters of *H. talaca* feeding on three different diets	**65**
Table 4.3.4	Correlation between *S. collaris* population with climatic factors of both locations	**70**
Table 4.3.5	Regression equation between *S. collaris* populations and climatic factors of both the locations	**71**
Table 4.2.4	Correlation between *E. furcellata* populations with climatic factors of both locations	**76**
Table 4.2.5	Regression equation between *E. furcellata* populations and climatic factors of both the locations	**77**
Table 5.4	Correlation between *C. ruficrus* populations with climatic factors of both locations	**82**
Table 5.6	Regression equation between *C. ruficrus* populations and climatic factors of both the locations	**83**
Table 6.3	Correlation between the population dynamics of *H. talaca* and its natural enemies	**97**
Table 6.4	Regression equations between the population dynamics of *H. talaca* and its natural enemies	**97**
Table 7.1	Quantitative estimation of tea leaf primary and secondary metabolites	**101**
Table 7.1.2.6	Correlation between food consumption of *H. talaca* and biochemical compositions tea leaves	**103**

No. of tables	Title of tables	Page No.
Table 7.1.2.7	percentage of weight of EGC, Catechin, EC, EGCG, ECG, Caffeine and Gallic acid	**103**
Table 7.1.2.8	Regression equation and correlation between food consumption and percentage of weight of EGC, Catechin, EC, EGCG, ECG, Caffeine and Gallic acid	**104**
Title 7.1.3	biophysical characters of tea leaf	**109**
Table 7.1.4:	Regression equation and correlation between food consumption of *H. talaca* and leaf biophysical characters	**109**
Table 7.1.5:	Food consumption of *H. talaca* on tea leaves	**110**
Table 7.1.6	Susceptible index (Status of host preference on different tea cultivars by *H. talaca*)	**112**
Table 8.1	Biology of *S. collaris* on *H. talaca* and *Corcyra cephalonica*	**114**
Table 8.2:	Life table parameters of *S. collaris* reared on larvae of *H. talaca*.	**116**
Table 8.3	Predatory efficiency of *S. collaris* on different larval stages of *H. talaca* in No-choice feeding condition	**117**
Table 8.4	Predatory efficiency of *S. collaris* on different larval stages of *H. talaca* in Free-choice feeding condition	**118**
Table 8.5	Predatory behaviour of *S. collaris*, feeding on larvae of *H. talaca*	**120**
Table 8.6	Percentage of surviving of *S. collaris* reared on alternative host *C. cephalonica*	**120**
Table 8.7	Toxicity of certain common used pesticides on both mature and immature stages of *S. collaris*	**122**
Table 8.8	Assessment of population of *H. talaca* in both released and control plots before and after release of *S. collaris*	**123**
Table 9.1	Biology of *E. furcellata* on *H. talaca* and *C. chephalonica*	**124**
Table 9.2	Life table parameter of *E. furcellata* reared on *H. talaca*	**126**
Table 9.3.1	predatory efficiency of *E. furcellata* on different stages of *H. talaca* in No-choice condition	**128**
Table 9.3.2	Predatory efficiency of *E. furcellata* on different stages of *H.talaca* in Free-choice condition	**128**
Table 9.3.3	Predatory behaviour of *E. furcellata* feeding of different larval instars of *H. talaca*	**129**
Table 9.4	Effect of certain common used pesticides on nymph and larvae of *E. furcellata*	**130**
Table 10.1	Biology of *C. ruficrus* parasitized on larvae of *H. talaca*	**131**
Table 10.2	Survival percentage of *C. ruficrus* reared on *H. talaca*	**132**
Table 10.3	Life table of *C. ruficrus* reared on *H. talaca*	**133**
Table 10.4	Parasitic impact of *C. ruficrus* on food consumption of host larvae (*H. talaca*)	**134**
Table 10.5	Parasitic impact of *C. ruficrus* on weight gain of host larvae (*H. talaca*)	**134**
Table 10.6	Percentage of different haemocytes of normal and parasitized *H. talaca*	**136**
Table 10.7	Morphological analysis of different haemocytes of normal and parasitized *H. talaca*	**136**
Table 10.8	Effect of commonly used pesticides on *C. ruficrus*	**138**

Abbreviations

ABBREVIATIONS	ELABORATIONS
%	Percent
^{0}C	Degree centigrade
AD	Approximate digestibility
AD	Adipohemocytes
BSA	Bovine serum albumin
CIB	Central Insecticide Board
Cm	Centimeter
$CuSO_4$	Copper sulphate
DHC	Differential haemocyte count
DPX	Dibutylphthalate Polystyrene Xylene
Dt	Doubling time
EC	epicatechin
EC	Emulsifiable concentrate
ECD	Efficiency of conversion of digested food
ECG	epicatechin-3-gallate
ECI	Efficiency of conversion of ingested food
EDTA	Ethylenediaminetetraacetic acid
EGC	Epigallocatechin
EGCG	Epigallocatechin-3-gallate
ETL	Economic threshold level
GR	Granulocytes
H_2SO_4	Sulphuric acid
Ha	Hectare
Hcl	Hydrochloric acid
IPM	Integrated pest management
IPM	Integrated pest management
ISO	International Organization for Standardization
M	Meter
M kg	Million Kg

ABBREVIATIONS	ELABORATIONS
Mg	Miligram
MRL	Maximum residue level
N	Normal
NPV	Nuclear polyhedrosis viruses
OD	Optical density
OE	Oenocytoids
P	Parasitized
pH	Potential of hydrogen
PL	Plasmatocytes
PR	Prohemocytes
R_0	Net reproductive rate
r_c	Innate capacity for increase
RCR	Relative consumption rate
RF	Rain fall
RGR	Relative growth rate
RH	Average relative humidity
rm	Intrinsic rate of increase
SC	Suspension concentrate
SD	Standard deviation
SG	Soluble granule
T	Corrected generation time
T. Max	Maximum temperature
T. Min	Minimum temperature
T_c	Mean generation time
TE	Tea Estate
TV	Tocklai Vegetative
UP	Unparasitized
WG	Wettable granule
Wm	Weekly multiplication of population
µg	Microgram
µl	Microlitre

Synopsys of the thesis

ASSESSMENT ON THE HOST PREFERENCE, BIO-ECOLOGY OF LOOPER HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE) AND ITS NATURAL ENEMIES IN TEA ECOSYSTEM

Introduction: Tea of genus *Camellia* is the most important economic crop species with wide genetic variability and high outbreeding potentiality (Mondal *et al.,* 2001). The tea plantation is composed of heterogeneous population of various tea clones. The chemistry of tea leaves as well as the flavor and fragrance of the 'end product' vary in different tea clones and thus have alterable market value (Sabhapondit *et al.,* 2012).

Colonization of insect pests on tea host plant is preferably guided by both leaf primary and secondary metabolites (Fraenkel, 1959). Secondary metabolites modulate insect behaviour and offer resistance to tea plant from insect herbivory (Harborne, 1993). Polyphenol in plant play a crucial role in defense against insects (Agrawal *et al.,* 2012). Green tea contains comparatively high level of polyphenol (Gramza *et al*., 2005). The clones have variable amount of polyphenols with alterable range of resistance to insect pest attack (Hazarika *et al.,* 2011). Tocklai Experimental Station had released more than thirty tea clones under Tocklai Vegetative (TV) series, some of that are considered as 'yield potential clones' like TV20 and some of that are 'quality clones' with 'good' biochemical properties like TV1 (Baruah *et al.,* 2011). Extent of damage by tea herbivorous pests' vary differentially in respect of tea clones (Ahmed, 2012). The larval growth, development and survival of lepidopteran insects *Hyposidra talaca and H. infixaria* be influenced by the quality of tea clones they consume (Basumajumder *et al.,* 2010). Selection and cultivation of proper tea clone is found economically judicious to check insect pest menace with least toxic insecticide input (Zhang *et al.,* 1992).

Further, injudicious application of synthetic chemical pesticides imbalances the integrity of tea-ecosystem. Insecticidal application upsets both the incidence and abundance of field natural enemy population which ultimately is detrimental to the sustainability to tea-ecosystem. Accumulation of toxic insecticides in the produce due to 'bio-magnification' restricts the marketability (Mochizuki, 1994).

Augmentation of natural enemies to check *H. talaca* incidence is appreciated under modern IPM practices (Steinkraus *et al.,* 1994). Adoption of such practice and proper choice of tea clone as a part of modern Tea-IPM can minimize the overreliance on chemical insecticide (Kogan, 1998).

Review of literature:

Lepidopteran pests in tea: In tea ecosystem most of the insect pests are seasonal while some are perennial. Hazarika *et al.,* (2009) had reported that more than 1000 insect species ravages tea field. Sayanal *et al.,* (2012) from West Bengal had noted 580 moth species from Dooars but with superficial documentation. Grossly Lepidopteran species like *Buzurasuppressaria* (Guen.), *Hyposidra talaca*, *H. infixaria, Ascotis* sp. and *Ectropis*sp. cause about 11-55% tea plant damage (Gurusubramanian, *et al*., 2008). In India *B. suppressaria*, affects both the quality and quantity of tea production (Hazarika *et al.,* 2009). *H. talaca* (Walk.) and *H. infixaria* (Walk.) renders havoc damage (Nair *et al.,* 2008). Among these, *H. talaca* (Walker) has been considered as major defoliator pest of tea in Northern tea growing parts of West Bengal (Basumajumder *et al*., 2004).

Incidence of *H. talaca* in tea agro-climatic condition: In 2006, about 60,000 ha. of tea plantations was infested by *H. talaca* (Walk.) in the *Terai* and *Dooars* region of Northern part of West Bengal with extended severity in 2008 (Sinu *et al.,* 2011). *H. talaca*, had covered about eight broods in a year. 4th and 5th instar of *H. talaca* consumes on young pluckable leaves and makes it crucial to protect the tea cultivations (Antony *et al.,* 2012). Alterable temperature, fluctuating rain-fall and aggravated drought influence the extent of abundance of *H. talaca* (Intachat *et al.,* 2001). Das *et al*., (2010) had reported that *H. talaca* were found to defoliate tea leaves notably in monsoon season and even during the winter months in absence of obligatory winter diapause.

The tea leaf biochemistry and clonal preference of tea caterpillar: Bordoloi *et al*., (2011) had evaluated the Tocklai tea clones by comparing the crop yield, pruning litters and catechin profile. Tea contains huge amount of catechin component, a group of very active flavonoid. The total catechin contents in green leaf of different clones varies considerably in quantity (Bhuyan *et al*., 2009). Different green tea leaves contains approximately 80–360 mg g−1of polyphenols which influence the tea quality (Gupta *et al*., 2002).Black tea contains very high variation in catechin composition (Marles *et al.,* 2003). Basumajumder *et al.,* (2010) has studied bio-ecology of *H. infixria* on four tea

clone namely TV1, TV9, TV25 and Teen ali 17. Out of these, *H. infixria* consumed significantly higher on TV25.

Plants employ secondary metabolites to protect from herbivorous insects by altering feeding and ovipositon behaviour of insects (Karban *et al*., 1997 and Howe *et al*., 2008). Secondary metabolites like phenolics, terpenes, steroids and alkaloids provide adaptive fitness to plant against herbivours insects (Bourgaud *et al.*, 2001). Secondary metabolites of tea plants also repels the insect pests (Howe *et al.* 2008).

The natural enemies in tea ecosystem and its augmentation: Faunal diversity in tea-ecosystem shows a mosaic structure with mutualistic and/or parasitic relationship (Han, 2000). The intensity of pest infestation is in consonance with natural enemies. About 33 species of Hymenopteran parasitoids were recorded in the hilly tracks of Darjeeling (Das *et al*., 2010). In Dooars and Darjeeling hilly region, parasitoid population encompassing family Braconidae, Ichneumonidae, Eulophidae was noted and it shared 20.63-22.8% of natural enemy population (Mukhopadhyay *et al.,* 2007). Augmentation of different species of Hymenopteran parasitoid in tea ecosystem suppresses the looper population under improved IPM programme (Stiling *et al*., 2005).

Insecticide stress on insect natural enemy population of *H. talaca*: Instantaneous control of *H. talaca* is only relied upon impounding application of newer brands of chemical insecticides. But it aggravates the incidence of field insect natural enemies also (Sannigrahi *et al.,* 2003). Contrary to this, application of bio-pesticide has no advertent report on the prey consumption by natural enemies as evicted from the experiment related to the feeding potentiality of *Mallada desjardinsi* on tea red spider mite (Vasanthakumar *et al.,* 2011). Study on the bio-ecology of *H. talaca* in relation field natural enemy population is thus prioritized under modern tea-IPM system. Biochemical evaluation to identify resistant tea clones is found prudent to check *H. talaca* menace with least input of toxic of synthetic insecticides. Stress of insecticides to the insect pest and natural enemies have to be worked out. In this contemplation following objectives are forwarded:

Objectives of the study:

To study the bio-ecology and seasonal incidence of *Hyposidra talaca,* in relation to agro-climatic conditions at Dooars region of West Bengal.

To study on the biochemistry and susceptibility index of selected tea clones against *H. talaca.*

To assess on the bio-ecology and seasonal incidence of selected insect natural enemy in relation to the incidence of *H. talaca* and agro-climatic conditions of *Dooars.*

To evaluate stage specific effectiveness of natural enemy on *H. talaca.*

To assess the insecticide stress on natural enemy population of *H. talaca*.

Materials and Methods:

Location of the study area: Two conventionally operated Tea Estate (TE) is primarily selected as study area in the district of Jalpaiguri of West Bengal. Both the areas aerially separated by about 25 Km.

i. Banarhat T. E (26.78814°N 89.0408°E)

ii. TRA experimental plot (26°54′0″N 88°58′0″E).

To study on the bio-ecology and seasonal incidence of *H. talaca*: Population of *H. talaca* will be assessed at 15 days interval (Puja *et al.,* 2016). Meteorological data during the period of study will accordingly be recorded periodically.

To study on Life table of *H. talaca*: Life table construction of *H. talaca* using (a) suitable tea clone (b) alternate host and (c) artificial diet under laboratory conditions will be done considering the following parameters: (i) intrinsic rate of natural increase,(ii) age specific survival rate, (iii) age specific fecundity,(iv) gross reproductive rate,(v) mean generation rate,(vi) mean generation time, (vii) finite rate of increase and (viii) doubling time will be worked out following the methods as delineated by Deevey (1947), Brich (1948) and Southwood (1983), Mackauer (1983) with suitable modification.

To evaluate the biochemistry and susceptibility index of tea clones based on the feeding preference of *H. talaca:*

Assessment on tea-plant biochemistry: Biochemical profiling includes the assessment of (i) total carbohydrate (Hedge *et al*. 1962), (ii) total protein (Lowry, 1951 and Ferreira *et al*., 2002), (iii) total lipid (Bligh *et al*. 1959 and Kinght *et al*. 1972), (iv) total phenol

(Mallick *et al.* 1980), (v) total alkaloid (Harborne, 1973) and (vi) total flavonoid (Park *et al*., 2008). As and when required necessary modification of the methods will be done.

Assessment on susceptibility index: 10 tea clones preferably (TV1, TV20, TV16, TV22, TV26, HP12, ST520, K1/1, SNT 8 and B157) will be selected from Tea Research Association, Nagrakata. Fresh leaves of about same age from each clone will be given to larvae for feeding. The food consumption at 24h interval will be calculated for different selected clones and susceptibility index will be worked out accordingly (Henrich *et al.*, 1985 and Shah *et al.*, 2008).

To assess the bio-ecology and seasonal incidence of natural enemy in relation to agro-climatic conditions of Dooars: Population of natural enemy will be assessed at 15 days interval (Puja *et al.,* 2016). Meteorological data during the period of study will accordingly be recorded periodically.

To study on life table: Life table of natural enemy will be constructed based on the standard protocol as developed by Deevey (1947), Brich (1948), Southwood (1983) and Mackauer (1983).

To evaluate stage specific effectiveness of natural enemy on *H. talaca*: Larvae will be laboratory reared and all of the larval growth stages except 1st instar will be put separately into a glass chimney (10cmX 25cm) and a pair of natural enemies will be released to each chimney to determine the stage specific effectiveness and mode of attack.

To assess the insecticide stress on natural enemy population Effect of certain commonly used pesticides of both synthetic and of biological origin on natural enemies will be experimented under laboratory condition.

Representation of data: Data will be analyzed with the help of Microsoft Excel Worksheet statistics, SPSS software. Analysis of variance (ANOVA) and Tukey test (Tukey, 2002) will be carried out.

Expected outcomes:

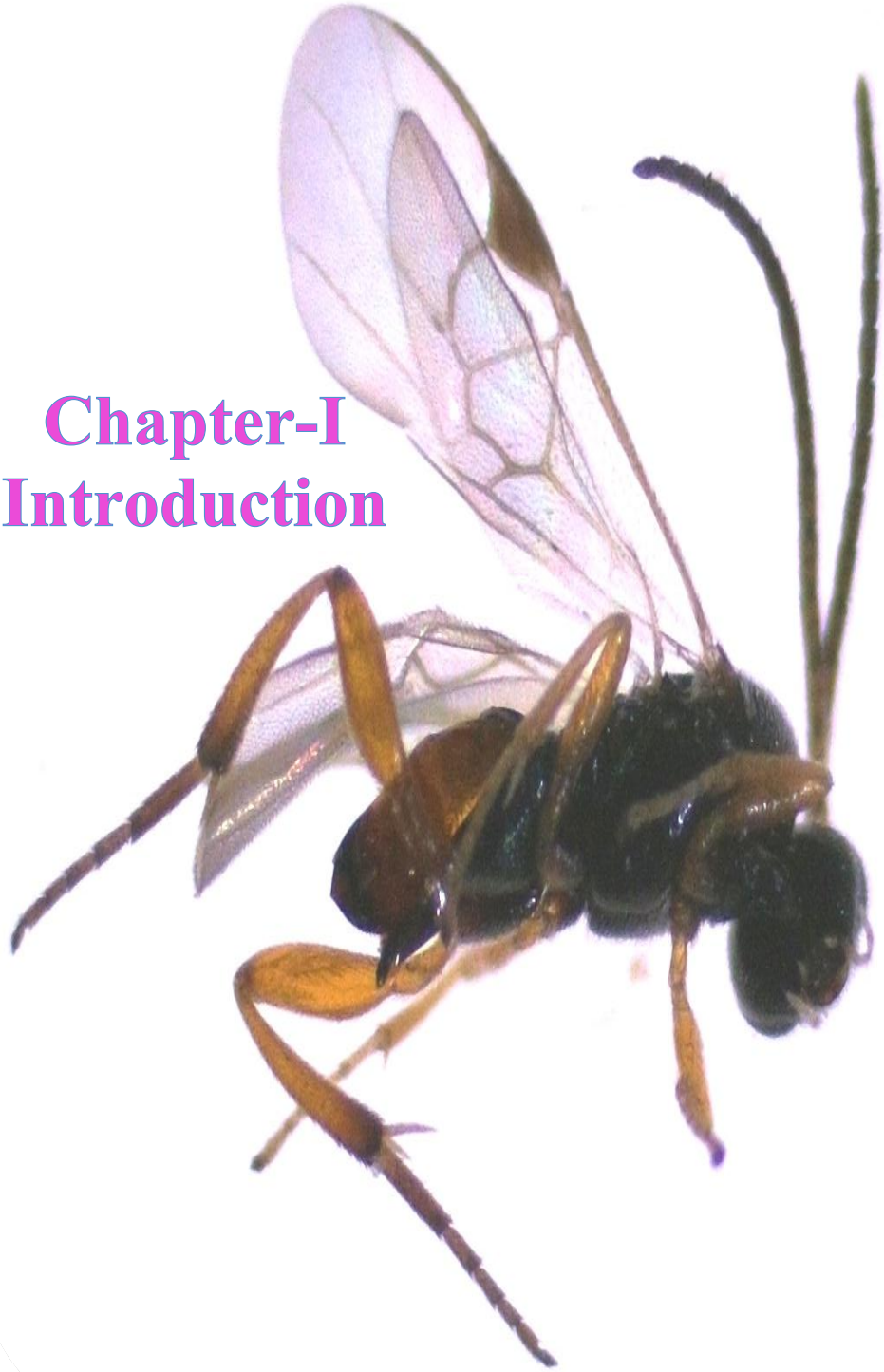
In consideration of the bio-ecology of *H. talaca:* Complete life cycle of *H. talaca*, will be worked out with descriptive observation on all of the stages of life cycle and accordingly life table will be prepared. Seasonal abundance in relation to tea-crop

phenology will be worked out. A correlation matrix will accordingly prepared on *H. talaca* incidence in relation to agro-climatic condition.

In consideration of the biochemistry and susceptibility index of tea clones: The susceptibility index of the selected tea clones will be worked out. Adoption of the proper tea-clone with least amount of toxic chemical insecticide can thus be forwarded as a part of tea-IPM for adoption.

In consideration of study on effective natural enemies of *H. talaca:* Species abundance, species richness, seasonal abundance of specific natural enemies and exploration of life stage specific effectiveness of natural enemy can be also utilized in IPM in tea.

Chapter-I
Introduction



INTRODUCTION

1.1 Invention of tea in India: Tea is commonly known as non-alcoholic instigating beverage throughout the world and ranked immediately after water in consideration of the consumption amount. Characteristic aroma and distinguished flavour together with the potential health benefits, tea is consumed by people from time immemorial. Historically, China first relished the taste of tea and it has come in India with hands of British. The word "Tea" is derived from '*t'e',* the dialect of Chinese Fukien language and in Cantonese language "Tea" is commonly known as *Ch'a* (Barua, 1989).

Probably in 2737 BC the Chinese Emperor and renowned herbalist, Shan-Nong was sitting under a tree and his servant was innocently boiling some water. At that time accidentally 'few leaves' were fell into that boiling water and an attractant fragrant was sweltering out. Shan-Nong drunk the infusion, felt refreshing and energizing. After that this infusion 'accidentally' discovered as a pleasant beverage was named as 'tea' (Majumder, 2010).

Robert Bruce (1823) discovered wild type of tea plant, *Camellia assamica* from upper Brahmaputra Valley of Assam on a trading mission. Subsequently, it was verified by Dr. Wallich, the contemporary superintendent of Botanical Garden of Calcutta. In 1834, Lord William Bentinck, Governor-General of India, appointed a committee for scientific commercialization of tea in India. G.J. Gordon as the secretary of the said committee introduced both seeds and plants and also acquired trained workmen from China to the hilly area of Assam for scientific tea cultivation (Barua, 1989 and Singh, 2006). Wight (1962) proposed the two races of tea plant viz. *Camellia sinensis* L. for China tea plant and *C. assamica* (Masters) for Assam tea plant. Kingdon-Ward (1950) advocated 'southern form' of tea as *Cambodiensis*. Subsequently, in 1837 tea cultivation was started in India from seed. In 1960 the first 'seed bari' was established in Cachar, Assam. China tea plant is about 1-3m tall, big shrub in shape and nature. Leaves are hard, thick and leathery with indistinct marginal vein, young leaves are garnet-brown through ox blood to purple in colour. Assam tea, on the other hand, is 10-15m tall like a small tree with a trunk and robust branch system. Leaves are thin, glossy with apex and distinct marginal veins, leaf blade usually broadly ellipted. Flowers single or in pairs, in which pedicels of three caucous bracteoles.

1.2 Biochemical components of tea: Based on the processing of green leaves, tea is of different types namely *viz.*'green tea', 'black tea' and 'oolong tea'. Green tea contains catechins viz. (−)-epigallocatechin-3-gallate (EGCG), (−)-epigallocatechin (EGC), (−)-epicatechin-3-gallate (ECG) and (−)-epicatechin (EC) and characteristic polyphenolic compounds. Biochemically black tea contains theaflavins, thearubigins, polyphenols, amino acids, total catechins and caffeine (Kottawa-Arachchi *et al.,* 2014). Besides, tea contain a rich source of flavonoids. Such chemical components perform peroxidative reactions, scavenge reactive oxygen species reduces their damage to lipid membranes, proteins and nucleic acids in cell (Balentine *et al.,* 1997). Tea polyphenol and flavonoids has significant role on cardiovascular health.

1.3 Tea cultivation and production in India: India being second highest tea producing country produced 1322M kg (Million Kg) in 2017-2018 from around 566000 ha tea planting area (Anonymus, 2018a). Warm-wet summer and a dry-cold winter is congenial for tea plant growth. Rainfall of more than 2000mm per year in rainy season is suitable for tea plant growth and development. 18^0C-32^0C optimum ambient temperature is helpful for tea cultivation. Well drained sandy loam soil with the pH of 4.5 to 5.5 is required (Barua, 1989 and Majumder, 2010). By sequential pruning cycle, the commercially cultivated tea plant is manipulated as a small. Different types of pruning, skiffing, plucking and tipping needed to the bushes in proper time for the cultivation of succulent vegetative shoots (Goswami, 2011 and Sharma, 2011).

The perennial crop tea is cultivated in monoculture practice under diverse agro-climatic conditions. Presently, tea is globally cultivated in more than 45 countries ranging from 41^0N to 16^0S latitude (Barua, 2016a and Barua, 1989). Among the major tea producing countries, India is fourth in position in exporting tea during 2016-2017 (Anonymous, 2018b). In India, more than ten states producing tea in small and large scale. Assam, West Bengal, Tamil Nadu and Kerala play important role tea production (Fig. 1.1).

1.4 Tea cultivars developed by Tocklai Tea research Institute (TTRI): TTRI released 14 biclonal seed stock, 153 TRA (Tea Research Association) series clones, 31 TV (Tocklai Vegetative) clones, over last 60 years. Out of these four stocks are suitable forDarjeeling and other hill areas of North east India. TV clones are categorized as standard, yield and quality based on its performances in yield and quality. Standard clones

of TV1 and TV31 was released by TRA in the year of 1949 and 2006 respectively (Barua, 1989).

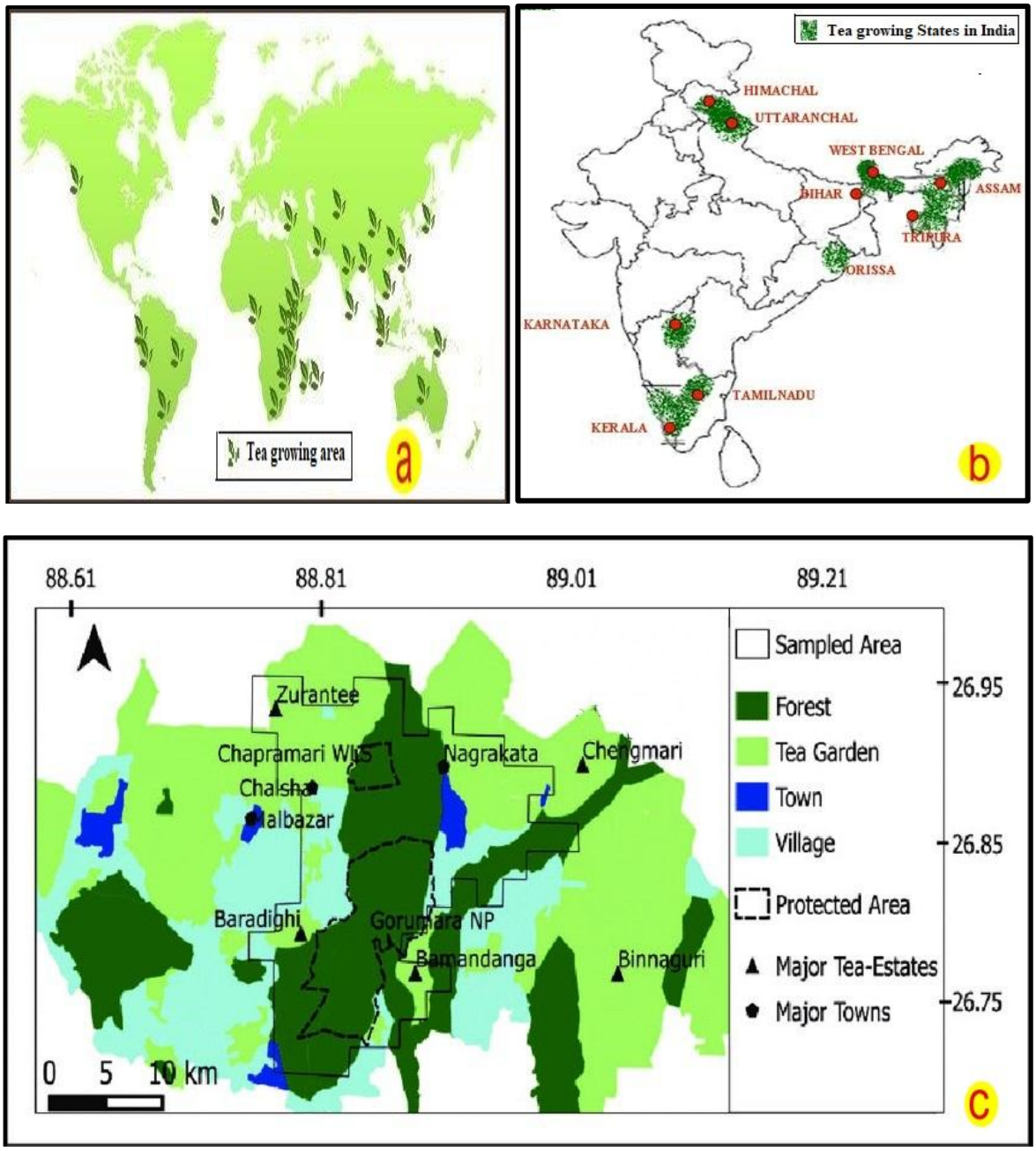


Fig. 1.1: Major tea producing area: (a) throughout the world, (b) in India (Source: http://www.google.com/url?sa=i&url=http....) and (c) in West Bengal (Source: Kshettry *et al.*, 2018)

1.5 Important insect pests of tea ecosystem: Tea, Camellia sinensis (L.) O. Kuntze, being a perennial monoculture crop provides relatively steady microclimate and food supply for arthropod communities. All of the parts of tea plant are affected by arthropod pest species, resulting in significant yieldloss. Globally 1031 arthropod species are found

in tea ecosystem, which are cannot be found all together in one country (Hazarika *et al*., 2009). Arthropod spectrum in a region depends on the climatic conditions, cultivation tactics and age of the plant of a region (Antony *at al*., 2012).From the major tea growing area of India about 300 species of phytophagous insects and mites has been recorded (Das, 1965). However, from North-East India and West Bengal, apparently 172 arthropod species are associated with tea ecosystem (Mitra *et al*., 2018).

An annual loss of about 15-30%is reported collectively due to the infestation of the insect pest from India (Anonymous, 2018b). Thus time fitted insect pest management strategy is found indispensable to check the insect pest induced loss. Leaf feeder and defoliator are prime insect pests of tea in India.

Infestation by the Acarine pest red spider mite, *Olygonychus coffeae* (Acarina: Tetranychidae) in tea leaves resulted in both discoloration and defoliation. Mites are generally smaller in size and occupies the lower surface of the mature leaves but some prefers the upper surface (Babu *et al*., 2015b).Tea thrips, *Scirtothrips dorsalis* (Hood), belongs to order Thysanoptera, attacks mainly on the buds and young leaves though occasionally petioles, tender stems and older leaves (Mukhopadhyay *et al.,* 1997). During feeding it makes slits on upper surface of the leaves, as a result brownish discoloration of the leaves (Seal *et al.,* 2010). Tea mosquito bug, *Helopeltis theivora* Waterhouse (Heteroptera: miridae) is one of the major sucking pest in most of the tea growing area. All of its life stages prefer to suck cell sap from buds tender stems and young leaves by making circular punctures of about 0.29 to2.51mmin size, resultantly changing the leaf colour into reddish brown (Roy *et al*., 2009). It causes about 10-50% of the tea leaf production loss in 80% tea growing area. Tea jassid *Empoasca flavescens* F. commonly known as "greenfly", both adult and nymphs suck tea leaves. Occurrence of the lepidopteran species including *Buzura suppressaria* (Guen.), *Hyposidra talaca*, *H. infixaria, Ascotis* and *Ectropis* species in North- East tea ecosystem cause 11-55% crop loss in general (Gurusubramanian, *et al.,* 2007 and Babu *et al.*, 2014). In India and China it has been observed from the beginning of the last century that, *Buzura suppressaria* (Guen.) as the major folivor of tea, affects the quality of tea production (Hazarika *et al.,* 2009).

1.6 Tea black inch looper (*Hyposidra talaca*): Among all the pests associated with tea ecosystem, *Hyposidra talaca* (Walker 1860), commonly known as "black inch" looper, is considered as one of the major tea leaf-eater, rendering serious economic loss to tea orchards (Fig. 1.2). This widely distributed pest is also recorded from Indonesia, Malaysia, Hong Kong, Taiwan, China, Thailand, Papua New Guinea and Australia (Browne, 1968). Like tea, *H. talaca* attacks cinchona (*Cinchona officinalis*), coffee (*Coffea arabica*) litchi (*Litchi chinensis*), longan (*Dimocarpus longan*), mango (*Mangifera indica*), mangosteen (*Garcinia mangostana*) Hill glory bower (*Clerodendron infortunatum*), Indian mahogany (*Chukrasia tabularis*), Sea derris (*Derris robusta)* (Sinu *et al.,* 2011b; Basu Majumdar *et al*., 2010 and Intachat *et al.*, 2001).

Considerable loss to tea garden is reported from Northern part of West Bengal due to *H. talaca* infestation (Basumajumdar and Ghosh, 2004). Maximum damage by *H. talaca* takes place during pre-monsoon season. Alterable temperature, fluctuating rain-fall and aggravated drought influence the extent of abundance of *H. talaca* (Intachat *et al.* 2001). The gravid female prefer the rough surface like, under the scales, cracks and crevices of barks of shade trees *viz., Albizzia odoratissima, Albizzia lebbek, Acacia lenticularis, Acacia auriculiformis, Derris robusta, Lagestremia speciosa, Schima wallichi, Dalbergia sisso* and *D. assamica*. The caterpillars of *H. talaca* migrate from shade trees to the tea bush and start feeding. The larva alone consumes young pluckable leaves. The early instars larvae prefer tender leaves, make pin holes on the leaves, and feed voraciously on resulting in the significant crop loss (Roy *et al*., 2017).The average duration of life cycle of *H. talaca* was 50-55 days during summer months and 30-39 days during the warmer months (April–June) (Das *et al*., 2010).

Foraging behaviour, feeding performance, reproductive behaviour and egg laying performance of *H. talaca* showed healthier adaptation to tea ecosystem. Fitness traits of *H. talaca* in selecting and feeding on nutritious food and exaggerate metabolism of different types of host plants (forest tree, shade tree and different tea cultivars) allelochemicals through enhance the production and activity of detoxification enzymes are the measurable indicator of acclimatization in tea gardens (Prasad and Mukhopadhyay, 2015). *H. talaca* prefers and utilizes tea leaves as main host in assessment with forest tree *Schima wallichii* which reflects through giving rise the healthy larvae, pupae and moths (Das and

Mukhopadhyay, 2014). In winter season due to cold weather practice when tea bushes are pruned, larvae of *H. talaca* depend feed on mature leaves of tea and shade tree as well.

Fig. 1.2: Tea plant infested by looper (*H. talaca*): (a and b) healthy tea bush, (c) attacked by looper (red circle indicates the point of interest), (d) initial stage of damage, (e and f) severe damage

1.7 Management of *H. talaca* using chemical pesticides: To increase the yield application of pesticides of mostly used formulation of different newer brands, in tea-gardens is found necessary (Anonymus, 2018a).A commonly used insecticide diffuses through the plant sap stream and spread over the entire landscape and affects both targeted pest and non-targeted residential tea-ecosystem biota. Such over reliance on insecticides guided by the supposition that synthetic agro-chemicals are generally 'environmentally' safe has fostered overuse and led to an increase in pest resistance to treatments (Andrew and Cuthbertson, 2020). Consequent application of different pesticides with high dose in tea-ecosystem without concern to the environment to combat pest frequently that reduce beneficial 'insects' formerly responsible to check many insect pests, while the pests themselves become resistant and necessitate higher amounts of 'sprays' for their control in the subsequent turn (Jallow *et al*., 2017).

A single tea bush, in average, has received more pesticide application than cotton during prophylactic treatment (Thapa, 2003). Other, similarly serious, long-term concerns

of the constructive agents within landscape may even upsurge host susceptibility to infestation and leads to pest outbreaks occasionally (Sivapalan, 1997). Overuse of insecticides result in ‘secondary pest outbreaks’ when ‘target pest’ species triggers subsequent outbreaks of other ‘non-target pest’ species.Injudicious application of different class of pesticides with higher dose fuels to the development of secondary pest, destructs natural enemies (Fig. 1.3) (Gurusubramanian *et al*., 2008), adversely affects human health (Cranham, 1996 and Rabindra, 2012).

Fig. 1.3: Trends of application of insecticides in tea gardens

Production of ‘residue-free’ tea is a big demand and that surges to sustainable organic tea cultivation. For the development of suitable IPM tools for‘eco-friendly’ management of tea insect pests, rather than curative practices, as specified by International Federation of Organic Agriculture Movement (IFOAM), intensivestudy on tea plant chemical ecology andlandscape managementtogether with the comprehensive knowledge on insect pest biology are immediately required (Hazarika *et al.*, 2009).For tea industry limited choice to a few for which MRL have been declared by the FSSAI, European Union, Codex etc., impose restrictions on the use of pesticides.Though FSSAI, European Union and Codexhad recommended Flubendiamide 20 % WG, Emamectin Benzoate 5 % SG, Deltamethrin 10 EC, Bifenthrin 8% SC and Quinalphos 25 ECto check tea insect pest menace, adoption of such insecticides at broader scale is very restricted (Anonymous, 2018b).

Further, adoption of other pest management tools and techniques in addition to the application of the insecticides is found crucial to manage the pest menace collectively. Application of plant extracts as bio-pesticides as non-chemical approach has presently gain momentum. Application of nuclear polyhedrosis viruses (NPV) against the lepidopteran insects resulted in restricted success (Babu *et al*., 2015b). *Bacillus thuringiensis* as entomopathogenic can suppress 50-60% *H. talaca* population (Khewa *et al.* 2014). Plant extract of *Azadirachta indica*, *Polygonum hydropiper*, *Annona squamosa*, *Clerodendrum viscosum*, *Argyreia speciosa* and *Leucas aspera* adversely affect the food consumption, normal growth and efficiency of conversion of ingested food compared to the normal larvae of *H. talaca* (Roy *et al*., 2017).Knowledge on defenders or natural enemies in agro-ecosystem and also information of chemical pesticides especially with broad-spectrum activity is indispensable. Identifying the pests, its behaviour, nature of damage and beneficial insects helps the farmers to aware and use appropriate toolsin pest management strategy.

1.8 Biological control measures: One of the problems of the ETL is that it is based on parameters that are changing all the time, and that are often not known. The damage or losses caused by a certain density of insects cannot be predicted at all. Many other aspects like crop ecology, growth status, association of natural enemies, weather conditions and their own economic and social situation have to consider before taking the crop protection approach. Under modern IPM emphasis is given to natural enemies, plant compensation ability and abiotic factors. Ecological engineering has recently emerged pest management tools that rely on the use of cultural techniques to enhance biological control which save natural ecology (Gurr *et al*. 2004).

As a consequence of effective ‘habitat manipulation’, biological control, as an important tool in IPM which manage the pest population. In order to conserve natural enemies and non-target organisms reduction of ‘pesticide load’ in tea gardens is required. The activity includes target specificity to insect pests, marginal negative impact on environment, less harmful effect on human health and as a whole, reduces the needless dependency on chemical synthetic pesticides. Natural enemies can reproduce rapidly, survive on alternative low host densities in IPM strategy (Landis *et al*., 2000).Adoption of non-chemical pest control practices like cultural practices, physical control, pheromonal control and botanical control contributes to the conserve natural enemies.

1.9 Biological control agents: Naturally occurring predator like *Tetraponera rufonigra*, *Oxyopes* sp., Robber fly, Reduviid bug, *Sycanus croceovittatus* and *Rhynocoris marginatus*, Pentatomid bug, *Eocanthecona furcellata*, *Orius* spp., praying mantis are still being explored to control the major tea pests in West Bengal (Das *et al*., 2010b). The Genus *Sycanus* is an effective predator (Ambrose, 1999). Further *S. collaris* exhibits a potential predatory role against larvae of *H. talaca* (Sarkar *et al*., 2019) and thus can be employed as an important IMP tool for management of *H. talaca*. However, in West Bengal only *S. croceovittatus* have been reported as effective predator (Das *et al*., 2010b). Rearing of 'potential predator' and their scientific augmentation is required under modern tea-IPM practice. Sahayaraj, (2012) developed a rearing technique of reduviids using meat-based artificial diets for pest management. However, information on *S. collaris* as predator of *H. talaca* is scanty. Mass rearing of *S. collaris* under laboratory conditions is necessary (Sarkar *et al*., 2019).

Further eleven families of Hymenopteran parasitoid species belonging to the family Braconidae are widely distributed in tea plantation area of Northern part of West Bengal. Out of the all parasitoid species, Ichneumonidae, Eulophidae, Scelionidae and Platygastridae shares 40% relative abundance in the northern parts of West Bengal. There is a significant decrease in food consumption by parasitized larvae in comparison to the un-parasitized ones. Growth of parasitoid *Cotesia* sp. (Hymenoptera: Braconidae), depressed larvae of *H. talaca*. On the other hand, *Argyrophylax* sp. (Diptera: Tachynidae) usually prefer healthy larva of lepidopteran pest leading to mortality. Development of parasitoid depends on the host's fitness, stage and physiological condition of host larvae (Kaiser *et al*., 2017).

1.10 Scope of the study: Information related to the perpetuation of parasitoid *C. ruficrus* on *H. talaca* is wanting. Further behaviour of *Eocanthecona furcellata (*Wolff) (Hemiptera: Pentatomidae) and *Sycanus collars* (Fabricius) (Heteroptera: Reduviidae) on *H. talaca* are to be explored.

In order to pamper the bio-rational and judicious application of synthetic pesticides and also to indulge the scientific argumentation of both predators and parasitoids an attempt has been taken to study on the management of *H. talaca* by its natural enemies.

However to employ predator for effective control of the pest, through and thoughtful observation on the pest life cycle is required.

1.11 Objectives of the study: In this contemplation following objective was taken in the present study are

- **To study the bio-ecology and seasonal incidence of *Hyposidra talaca,* in relation to agro-climatic conditions at *Dooars* region of West Bengal**
- **To study on the biochemistry and susceptibility index of selected tea clones against *H. talaca***
- **To assess on the bio-ecology and seasonal incidence of selected insect natural enemy in relation to the incidence of *H. talaca* and agro-climatic conditions of *Dooars.***
- **To evaluate stage specific effectiveness of natural enemy on *H. talaca.***
- **To assess the insecticide stress on natural enemy population of *H. talaca*.**

Chapter- II

Literature Review

LITERATURE REVIEW

Tea ecosystem generates micro-environment that is conducive for shelter, food, and also for reproduction for a variety of arthropod populations depending on the regional agro-climatic conditions. More than 1000 insect species are reported to adapt to the tea eco-system (Hazarika *et al.,* 2009). In India, considerable works on tea mite pest (Das, 1959) and insect pests were carried out (Watt & Mann 1903; Muraleedharan and Chen 1997 and Sundararaju and Sundara Babu 1999). Out of that, herbivorous lepidopteran pests are widely distributed globally. Apart from India, it covers Sundaland, Sulawesi, the Philippines, Sri Lanka, the Solomon Islands, Thailand, Taiwan, New Guinea, and a part of Australia and had attained economic importance (Holloway, 1993 and Singh *et al.,* 2019a). In India, the lepidopterans were mainly considered as a major tea defoliator mostly covering the tea growing area of Assam, Meghalaya, Himachal Pradesh, Uttarakhand, Goa, Madhya Pradesh, and Karnataka (Basu Majumdar & Ghosh, 2004 and Singh *et al.,*2019a) (Table 1.1). An ample number of species has also been en-counted from hilly track of Darjeeling including the Dooars region of West Bengal (Roy *et al.,* 2014).

2.1 Lepidopteran pest in tea ecosystem: Shah and Mitra (2015) had collectively enlisted 39 species of lepidopterans from the Northern parts of West Bengal which covers 15 tea pests. Mitra *et al*., (2018), on the other hand, from the Dooars and the hilly area of Darjeeling of West Bengal, had reported 20 species of insect pests. Sinu *et al*., (2013) had reported lepidopteran species namely *Ectropis obliqua, Ascotis* sp. and *Arctornis submarginata* (Lymantridae) from Doors region of West Bengal. Three lepidopterans species namely *Hyposidra talaca, H. infixaria* and *Buzura suppressaria* under the family Geometridae render 25-55% crop loss in sub-Himalayan plains of *Terai* and the *Dooars* region as reported by Das *et al*. (2010). Before 1900, *Buzura suppressaria* was supposed to be a migratory tea pest from forest to tea-ecosystem (Das, 1965). Basu Majumdar and Ghosh (2004) from Terai and Dooars regions of West Bengal had enlisted the host range of *H.talaca* and *H. infixaria*. The most damaging larval stages of *H. talaca* and *H. infixaria*, is commonly known as 'black inch looper'. Nair *et al.,* (2008), on the other hand, had reported that the larval stages of *H. talaca* consumed and defoliated the tea leaf. Apart from tea, Singh & Singh (2002) and Ahmad *et al*., (2003) had recorded that *H. talaca* can perpetuate of *Cinchona spp*. L. (Rubiaceae) and *Theobroma cacao*L. (Sterculiaceae). From India, Sen-Sharma and Thakur, (2008) reported that *H. talaca* was a serious pest of sal (*Shorea robusta* Roth) forests. Shah and Mitra (2015) and Mitra *et al*., (2018) advocated that, numerically, most of the pest species belong to the family Erebidae followed by the family Geometridae, Zygaenidae and Torticidae. The tea growing area of 100-150 years old has the largest number of insect pest species (Banerjee, 1983).

Table 1.1: Important lepidopteran pests from tea ecosystem in India

Common English name	Scientific name	Family	Reference
Sandwich caterpillar	*Agriophora rhombata* (Meyrick)	Tineidae	Devi *et al*., 2016
Bunch caterpillar	*Andracta punctate* (Walker)	Bombycidae	Danzinger, 2000.
Red coffee borer	*Zeuzera coffeae*(Nietner)	Cossidae	Devi *et al*., 2016.
Nettle grubs	*Thosea cervina* (Moore)	Limacodidae	Danzinger, 2000.
Jelly grub	*Cheromettia apicata* (More)	Limacodidae	Danzinger, 2000.
Lobster caterpillar	*Staurops alternus*(Walker	Notodontidae	Danzinger, 2000.
Tea leaf roller	*Caloptilia theivora* (Walsingham)	Gracillariidae	Danzinger, 2000.
Psychidcaterpillar	*Clania cramerii*	Psychidae	Hazarika *et al*., 2005
Flushworm	*Laspeyresia leucostoma* (Mayer)	Eucosmidae	Hazarika *et al*., 2005
Bark eatingcaterpillar	*lndarbela theivora*(Hamps)	Indarbellidae	Hazarika *et al*., 2005
Tea tortrix	*Homona coffearia* (Nietner)	Tortricidae	Danzinger, 2000.
Tea tortrix	*Tortrix dinota* (in Malawi)	Tortricidae	Danzinger, 2000.
Tea flushworm	*Cydia leucostoma* (Meyrick)	Tortricidae	Danzinger, 2000.
Blue striped vex grub	*Latoia lepida*	Limacodidae	Katoch and Malladi, 2017
Seat sponsored bother grub	*Thosea cervina*	*Limacodidae*	Katoch and Malladi, 2017
Vast Faggot worm	*Eumeta crameri*	Psychidae	Katoch and Malladi, 2017
-	*Creatonotos transiens* (Walker)	Erebidae	Shah and Mitra, 2015
Yellow tail tussock moth	*Somena scintillans* (Walker)		Mitra *et al*., 2018.
-	*Lymantria marginalis* (Walker)		Mitra *et al*., 2018.
-	*Miltochrista cuneonotata* (Walker)		Mitra *et al*., 2018.
Marbled white moth	*Nyctemera adversata* (Schaller)		Mitra *et al*., 2018.
-	*Argina argus* (Kollar)		Mitra *et al*., 2018.
-	*Arctornis submarginata (Lymantridae)*		Sinu *et al*., 2013.
-	*Orgyia sp.*		Mitra *et al*., 2018.
Tea looper	*Ascotis selenaria* (Denis & Schiffermiller)	Geometridae	Antony *et al*., 2012
Tea looper	*Biston suppressaria* (Guenee)		Antony *et al*., 2012 Majumder *et al.*, 2012
Tea looper	*Biston bengaliaria*(Guenee)		Antony *et al*., 2012
Black inch looper	*Hyposidra talaca* (Walker)		Antony*et al*., 2012 Majumder *et al.*, 2012
Tea looper	*Hyposidra infixaria* (Walker)		Antony*et al*., 2012 Majumder *et al.*, 2012
-	*Semiothisa eleonora* (Villers)		Mitra *et al*., 2018.
-	*Ectropis* sp.		Antony *et al*., 2012
-	*Cleora* sp.		Shah and Mitra, 2015
-	*Petelia* sp.		Shah and Mitra, 2015
Red Slug Caterpillars	*Eterusia aedea* (Linnaeus), *Eterusia magnifica* (Butler)	Zygaenidae	Roy *et al.*, 2018.
-	*Eterusia edcola* (Doubleday)		Shah and Mitra, 2015
-	*Trypanophora semihyalina* (Kollar)		Shah and Mitra, 2015

'_': Common English name not available

2.2 Biology of *H. talaca* on different hosts: The life cycle of *H. talaca* is very short with the absence of diapause in the winter season. Das *et al*., (2010) had noted that the incubation period for *H. talaca* was 6.0±0.0 days. They further had recorded that developmental period of I, II, III, IV and V instar larvae was respectively 4.64±0.13, 3.25±0.12, 11.58±0.35, 3.80±0.14, 4.41±0.15 days. The pupal duration was 18.94±0.300

days and the overall developmental period was 55.00±0.28 days. Chutia *et al*., (2012a) from Assam had reported that the incubation period was about 6.2 ± 0.45 days. While the duration of I, II, III, IV and V instars lasted for 2.4±0.54, 2.6±0.55, 3.6±0.55, 3.8±0.45 and 5.4±0.55 days respectively. Duration of pupal periods of male and female were 7.8±0.45 days and 9.4±0.55 days respectively. The longevity of male and female moths was 5.6±0.55 and 6.6±0.55 days respectively. Sharma *et al*., (2014), on the contrary, had observed that the total larval period varied from 20.25±1.46 to 21.25±1.42 days. Adult male longevity was 5.00±1.49 to 4.20±1.03days on teak plant in Jammu region of India.

2.3 Seasonal occurrence: Antony *et al*., (2012) had commented that temperature reduces the duration of the tea looper life cycle. Majumder, (2010) also observed that the incidence of looper population in the tea ecosystem of *Dooars* condition was highest during the summer season and lowest during the winter season. Das *et al*., (2010) had reported that *Hyposidra* spp. was best adapted during spring (March-May) followed by summer/rain (June-August) and autumn (September-November) in descending order.

2.4 Host preference of *H. talaca*: Being polyphagous, larva of *H. talaca* fed voraciously on forest trees, fruit plant, shrubs and on weeds apart from tea leaves (Browne, 1968) (Table 1.2). Chutia *et al*., (2012b) reported that the pest was abundant in the forest of Indo-Australian tropics extending from the northeast Himalayas to Queen's land and Solomons, mostly in India, Indonesia, Malaysia, Hong Kong, Taiwan, China, Thailand, Papua New Guinea and Australia. During 2007 in *Dooars* unprecedented outbreak of *H. talaca,* was noted (Anonymous, 2008). Sinu *et al*., (2011) had observed that prolonged drought and inconsistent rainfall inflicted *H. talaca* induced damage. Tripathy and Rout (2018) had recorded that *H. talaca* is a major pest of Teak in Coastal Odisha and the outbreak resulted in pin holes in the leaf. Sharma *et al*., (2014) also observed that *H. talaca* defoliated teak plantations in Jammu. Singh *et al.,* (2019a) had recorded that *H. talaca* fed on ban oak in Garhwal Himalaya. Besides, It prefers to consume the leaves of *Polygonum, Rubus, Coffea, Mussaenda, Anacardium, Gynura, Mikania, Cupressus, Schleichera, Theobroma, Camellia Aleurites, Aporusa,Bischofia, Breynia, Hevea, Manihot, Morus, Psidium* and *Citrus* plants (Park *et al.,* 2006 and Singh *et al.,* 2019a). A numer of plants had been identified as the alternative host of *H.talaca* (Table 1.2).

2.5 Feeding on different tea cultivars and extension of damage: Before 2008, *H. talaca* was known only as the pest of Sal tree but subsequently it was observed to defoliate tea plant (Sen-Sharma and Thakur, 2008) following the gradual changes of the agro-ecosystem.

Table 1.2: Alternative host plant of *H. talaca* in tea ecosystem (Adopted from Roy *et al.*, 2017 after modification)

Scientific name	Common English name	Family
Acacia mearnsii (De Wild)	Black wattle	Leguminosae
Albizia falcataria L. Fosberg.	Moluccan albizia	Mimosaceae
Annona reticulata L.	Wild sweetsop	Annonaceae
Annona muricata L.	Soursop	Annonaceae
Areca catechu L.	Betel palm	Arecaceae
Asparagus officinalis L.	Garden asparagus	Asparagaceae
Bombax malabaricum L.	Silk cotton tree	Malvaceae
Carissa spinarum L.	Conker berry	Apocynaceae
Manihot esculenta Crantz	Tapioca	Euphorbiaceae
Chromolaena odorata (=*Eupatorium odoratum*) (L.)	Siam weed	Asteraceae
Chukrasia tabularis A. Juss	Indian mahogany	Meliaceae
Cinchona officinalis L.	Cinchona	Rubiaceae
Clerodendron infortunatum L.	Hill glory bower	Lamiaceae
Derris robusta (Roxb. ex DC.) Benth	Sea derris	Leguminosae
Erechtites hieraciifolius L.	American burnweed	Asteraceae
Eucalyptus spp.	Eucalyptus	Myrtaceae
Ficus bengalensis L.	Banyan	Moraceae
Ficus parasiticus (Hampson, ibid.)	-	Moraceae
Gardenia sp.	Cape jasmine	Rubiaceae
Glochidion hongkongense Mull. Arg.	Hong Kong abacus plant.	Euphorbiaceae
Glycine hispida (L.) Merr.	Soybean	Leguminosae
Indigofera teysmanii Miq.	Indigofera	Leguminosae
Ipomoea batatas (L.) Lam.	Sweet potato	Dioscoreaceae
Ixora sp.	–	Rubiaceae
Largerstroemia speciosa (L.)	Pers. Giant crape-myrtle	Lythraceae
Leucaena leucocephala (Lam.) de Wit	White leadtree	Fabaceae
Mallotus philippensis (Lam.) Muell. Arg.	Kamala tree	Euphorbiaceae
Melia azaderech L.	Chinaberry tree	Meliaceae
Millingtonia hortensis L.f.	Indian cork tree	Bignoniaceae
Murraya koenigii (L.) Spreng.	Curry tree	Rutaceae
Paulownia spp.	Empress tree	Paulowniaceae
Paulownia fortunei L.	Princess tree	Paulowniaceae
Perilla frutescens L.	Beef steak plant	Lamiaceae
Persea americana Mill.	Avocado	Lauraceae
Piper umbellatum L.	Cow foot leaf	Piperaceae
Phaseolus vulgaris L.	French bean	Fabaceae
Pteridium sp.	–	Dennstaedtiaceae
Quercus incana W. Bartram.	Blue jack oak	Fagaceae
Schima wallichii Korth.	Chilaune	Theaceae
Sesbania speciosa Taub. ex Engler	Sesbania	Fabaceae
Shorea talura Roxb.	Taloora lac tree	Dipterocarpaceae
Solanum melongena L.	Eggplant	Solanaceae
Spathodea campanulata P. Beauv.	African tulip tree	Bignoniaceae
Terminalia arjuna (Roxb.)Wight & Arn.	Arjuna	Combretaceae
Vigna catjang (Burm.f.) Walp.	Cowpea	Fabaceae

Tea looper grossly affects the quality of tea production (Hazarika *et al*., 2009). The early instrars preferred younger leaf, whereas late instars consumed mature leaf. The fifth instar with long larval duration caused maximum damage to tea plant (Roy *et al.,* 2017).

Depending on the leaf morphology and biochemistry insect preferred the host plant (Rabindra, 2012). Hazarika *et al.,* (2009) had reported that the degree of attack on the tea clone, TV1 (Tocklai Vegetative) by insect pest was more. Majumder, (2010) had observed differential growth and development of *H. talaca* on four different tea clones *viz.*TV1, TV9, TV25 and Teen ali 17 under laboratory conditions. The results revealed that in the case of *H. talaca*, the duration of 2nd instar larvae was 2-3days. The shortest duration was found onTV9 (2.25 days) while the longest was noted on TV25 (2.75 days). The mean larval duration of 3rd and 4th instar larvae were shortest on the clone Teen ali 17. The total larval period ranged between 15-21days on TV1, TV9, TV25 and Teen ali 17 clones respectively. Among them the longest duration was recorded on TV25 (18.33 days) and TV1 (18.13 days), while, the shortest period was observed on Teen ali 17 (16.89 days) and TV9 (17.78 days). Maximum body weight (500mg) was noted when reared on Teen ali 17 clone and while the minimum body weight was observed on TV9 (440mg) followed by TV25 (483mg) and TV1 (497mg) in descending order.

Prasad and Mukhopadhyay, (2013), on the other hand, had recorded that 4^{th} and 5^{th} instar larvae of *H talaca* consumed tender pluckable tea leaves. The 4^{th} instar larva consumed about 3.55cm^2 leaf area (0.021g) and the average percentage of survivability was 25.1 days. Whereas, the 5^{th} instar larva consumed 16.19cm^2 leaf area with 19.7% survival percentage as noted by Antony *et al.,* (2011). They further had showed that, the occurrence, attack and mode of feeding on tea leaves lead to a significant economic damage. Hazarika *et al.,* (2009) had reported that, by the attack of major tea defoliator the quality of tea production was affected. Nair *et al.,* (2008) observed that during 2006-2008, *Hyposidra* spp. causes remarkable damage to tea agro-ecosystem and final production in India. To check such insect pest induced loss, development of tea clones with insect pest resistant property with high yield potentiality is required. Further the clone has to ensure good drink quality and also to withstand draught tolerance and water logging.

2.6 Tea clones developed by Tea Research Association (TRA): TRA has released 31 TV (Tocklai Vegetative) clones, 153 TRA/garden series clones and 14 biclonal seed stocks as planting materials in the tea growing area of NE India and North part of West Bengal for commercial production of tea (Table 1.3). Clones are categorized depending on yield, quality and yield attributes (Das, 2006 and Barman, 2011) (Table 1.4). To keep the

genetic variability and at the same time preserve the same, seed stocks are of equal importance for the tea industry. The stocks released by TRA for cultivation in plains are TS 397 (1976), TS 449 (1970), TS 450 (1970),TS 462 (1980), TS 463 (1984), TS 464 (1984), TS 491 (1989),TS506 (1994), TS 520 (1992), TS 589 (1996) and for Darjeeling hills the stocks are TS378 (1968), TS 379 (1989),TS 557 (1996) and TS 569 (1996) (Das, 2006). Most of the clones have insect pest resistant properties at different level.

Table 1.3: Tea varieties (clones) released by Tocklai Tea Research Institute under TV series (Year of releases is in the parenthesis) (Adopted from Barman, 2011)

Standard	Yield	Quality
TV1(1949), TV2(1949), TV3(1949), TV4(1959), TV5(1959), TV6(1959), TV7(1959), TV8(1959), TV9(1959), TV10(1963), TV11(1963), TV12(1963), TV13(1965), TV14(1967), TV15(1967), TV16(1968), TV17(1968), TV20(1974), TV24(1979), TV27(1985), TV28(1985), TV31(2006)	TV18(1970), TV19(1973), TV22(1976), TV23(1976), TV25(1982), TV26(1982), TV29(1990), TV30(1993)	TV21(1976)

Table 1.4: Tea varieties (clones) released by Tocklai Tea Research Institute under garden series, year of releases is in the parenthesis, (Adopted from Barman, 2011)

Region	Standard	Yield	High flavoured
West Bengal (Dooars)	Hantapara 12, Hantapara 30, Turturi 22	Leesh River 9/34, Huldibari 19	-
West Bengal (Terai)	Mohargung Gulma 25, Sanyasithan 8, Sanyasithan 9, Sanyasithan 10**,** Sanyasithan 27, Sukna 7, Sukna 23,Sukna 25,Kamalpur 6, Kamalpur 17	-	-
West Bengal (Darjeeling hills)	Tukdah 145,Lingia 12,Phoobsering 1404,Phoobsering 1258,Teesta Valley 1,Sikkim 1, Badamtam 15/263,Thurbo 3,Thurbo 9,Tukdah135,Rungli Rungliot 17/144, Balasun 7/1A/76, Balasun 9/3/76, Tukdah 253, Rungli Rungliot 4/5,Happy Valley 39, Sundaram (B/5/63), CP 1, Bannockburn 777	-	AV2 (Balai), Tukdah 246, Tukdah 78, Tukdah 383, Bunnockburn 668, Phoobsering 312, Bannockburn 157, Kopati 1/1

'-': There are no such varieties

2.7 Biochemistry of tea leaf and defense against insect pest: Secondary metabolites of plant are involved in the long term plant defense against insect herbivours and give characteristics colour in plants (Michael, 2010). When insect attacks on plant, is secrets oral saliva which acts as an elicitor that plant percept (Schmelz *et al.,* 2009). Upon insect attack, plant activates the complex signaling pathways that includes mitogen-activated

protein-kinase and calcium signaling resulting in nitric oxide and reactive oxygen species production for the modulation of phyto-hormonal levels, consequentially plant transcriptome, proteome and metabolome are recombined (Wu and Baldwin, 2010 and Hui *et al.,* 2003). Zhao *et al*., (2009) had commented that secondary metabolites of plant make the defensive strategy against herbivore insect pest.

Whereas indirect defense of plant is the emission of organic volatile compounds being attacked by insect pest that acts as a cues and attract the insect natural enemies for combating with the pest (Schuman *et al*., 2012 and Heil, 2015). In consequence, toxic secondary metabolites produced by plants directly hampered the growth, development, reproduction and other normal physiology of insect pests (Karban 2011; Taggar *et al.,* 2012 and Kaur *et al.,*2015). Magalhaes *et al.,* (2008) and Scott *et al*., (2010) showed that plant phenols have toxic and repellence activity properties against insect herbivory. The important function of phenol against predators was having a toxic nature and repellence activity to herbivore (Harborne, 1999 and Bourgaud *et al*., 2001). Phenols are found in young tea leaf in the form of polyphenolic compounds. Fraction of polyphenols are equal to 20-35% of dry weight of tea leaf (Salah *et al*., 1995). Sinija and Mishra, (2008) had reported that dried tea leaf contained total 37.0% polyphenol. Shah *et al.,* (2014), on the other hand, had estimated that TV1 tea clone contains on an average 0.007 unit/mg protein/min, while both TV23 and S3A3 tea clones contain about 0.006 unit/mg protein/min. For Tinali tea clone the quantity was 0.005unit/mg protein/min. Gogoi and Borua, (2017) reported that the seasonal average total polyphenol content in tea leaf was 23.46%.

The classes of natural secondary plant biochemical like flavonoids, terpenoids, phospholipids, glycosides, acids, esters, phenolics, and alkaloids act as feeding stimulants, show repellent and deterrent activity as well (Saunders *et al*., 1992). Usually, alkaloids and glycosides present in plants display optimistic function as insect repellent or deterrent (Ulubelen *et al*., 2001). Ge *et al*., (2015) found the alkaloid could decline the ecdysone of treated larvae and prepupae of *Spodoptera litura*. In tea, alkaloids are found as purine base (Manske, 1965). Chin *et al*., (2013) found three kinds of alkaloids in tea namely caffeine, theobromine and theophylline. The average total alkaloid in leaf bud, young leaf and old leaf ranged between 26.6-74.6 mg/g in direct extract method. While during soxhlet extract (SE) method the range was between 20.8-58.1 mg/g. In addition, presence of caffeine is

one of the important quality factor in green tea leaves Chin *et al*., (2013). Caffeine shares 0.3% dry weight of tea leaves (Balentine *et al*., 1997). Mithöfer and Boland, (2012) reported that caffeine paralyzes insect by inhibits phosphodiesterase activity. Lizarazo *et al*., (2008) had observed that alkaloids acted as repellant against *Spodoptera frugiperda*. Alkaloids of solasodines protect from files and ants (Grainge and Ahmeds, 1988). Chin *et al*., (2013) estimated that total caffeine content of tea leaf bud, young leaf and old leaf ranged from 54.9-58.8, 34.4-37.4 and 19.9-22.2 mg/g of dry weight of leaves respectively.

Polyphenols of tea are of mainly four groups such as catechines, flavonols, anthocyanidines and phenolic acids. Out of these four components, catechines, flavonols and anthocyanidines are related to wide-spread vegetable substances known as flavonoids (Harbowy and Ballentine, 1997). Flavonoids as the secondary metabolite in host plant modulate the strategy of food consumption and fecundity of insects. (Simmonds *et al*., (1990) had reported that, *S. exempta* was deterred by flavonoids present in plant. Engelhardt, (2013) stated that caffeine as polyphenol rendered the bitter and healthy effects of green tea. Song *et al.,* (2003) advocated that in green tea catechins shared 20-30% of the dry weight of green tea. Babu and Liu (2008) had showed that catechins is present in highest amount among the total flavonoids. Shah *et al.,* (2014) had noted that the flavonoid content of tea cultivars TV1, TV23, S3A3 and Tinali 17 varied considerably. TV1, TV23, S3A3 and Tinali 17 contained respectively 1.24, 1.12, 1.21 and 1.25mg/gm flavonoid respectively. Cabrera *et al*., (2006) and Jigisha *et al*., (2012) had reported that four kinds of catechines such as epicatechin (EC), epicatechin-3-gallate (ECG), epigallocatechin (EGC) and epigallocatechin-3-gallate (EGCG) are present in tea leaves. Reygaert (2017) had noted that EGCG shared around 59% catechines in tea leaves. This was followed by EGC (19%), ECG (14%) and EC (6%) in descending order .Seeram *et al*., (2006) had reported that around 40% EGCG was present in green tea. Galic acid (GA) is the major phenolic components present in tea. Chin *et al*., (2013) had documented that leaf bud contained 5.56mg/g GA of the dry weight of leaf, whereas in young leaf around 0.01mg/g and 0.99mg/g GA present in old leaf.

Plants fix carbon dioxide into carbohydrate as primary source of energy for the growth and development. Phytophagous insects sustain on plant carbohydrate and other nutrients. The carbohydrate pools in leaves might alter in the insect attacked plant. In tea, different cultivars contained different amounts of carbohydrates. Shah *et al.*, (2014),

estimated carbohydrate content in four tea cultivars, the result revealed that, amount of carbohydrate in TV1, TV23, S3A3 and Tinali 17 were as 0.175, 0.202, 0.165 and 0.170mg/gm leave respectively.

In tea most of primary metabolites are beneficial for plant growth and also for insect resistance. Protein content in tea changed depending on the age, growth and development of leaves (Rosenthal & Berenbaum, 1991 and Jager *et al*., 1996). Anonymous, (1996) and Sinija & Mishra, (2008) showed that protein constitute 15% dry weight of all chemicals in tea leaves. Shah *et al.*,(2014) estimated that protein of healthy tea leaf of four different tea cultivars. The results revealed that protein content in TV1, TV23, S3A3 and Tinali 17 were as 1.280, 1.249, 1.176 and 1.122 mg/gm leaves respectively. 2.0% lipid is present in dried tea leaf (Sinija and Mishra 2008). Lipids involve in the activity of many enzyme and act as energetic reserve (Anonymous, 1996).

2.8 Effect of leaf characteristics on insect feeding: Insects select a suitable host plant for food consumption and oviposition based on the morphological and physical characteristics of that plant. Depending on the degree of biophysical characteristics of a plant such as trichome density, leaf thickness plant becomes resistant to insects. The strength of overcome the structural barriers of insects in generally weaker than most vertebrate herbivores. Uthamasamy (1985) stated that trichome hair density was more in suitable variety than resistant one. The concentration and function of trichomes in plant are negatively correlated with the food consumption and oviposition of insects (Levin, 1973). The morphological character leaf thickness also manipulates the association, feeding and ovipositional behaviour of insects. Leaf thickness, leaf trichome density show negative impact on whiteflies population Leaf roller, *Eublemma olivacea* in brinjal crop (Bindu and Pramanik, 2017). Leaf thickness of brinjal influences the incidence of *Bemisia tabaci* (Ayyasamy and Baskaran, 2005). The attribution of tea leaf characters such as leaf thickness and leaf area of different cultivars show negative influence on fecundity and hatching percentage of tea red spider mite, *Oligonychus coffeae* (Dutta, 2015).

2.9 Biological control agents in tea ecosystem: Insect pest control by the biological agents play an important role to control tea pests below economic injury level (Babu *et al.*, 2011). The semi-forest, tea gardens and its surrounding natural ecosystems are suitable habitat for insect natural enemies. Roy *et al*., (2014) had reported that, out of 721 arthropod species in tea-ecosystem 380 were phytophagous insect pest and 341 were natural enemies. From 74 tea gardens of Darjeeling, Jalpaiguri, Alipurduar, Coochbihar

Districts of West Bengal, Mitra *et al*., (2018) had reported 167 insect species belonging to 139 genera as natural enemies. Natural enemies mostly belong to the insect order Diptera, Odonata, Coleoptera and Hemiptera. Hazarika and Chakraborti (1998) identified 23 predatory spider species from North-East India with wide range of feeding potentiality. Das *et al*., (2010) had documented 94 species of predators and 33 species of parasitoids from the sub-Himalayan tea growing area of Northern parts of West Bengal, India. Among all the natural enemies in consideration of numerical abundance spider (43%), Coleoptera (31%), Hemiptera (8%), Mantodea (7%), Neuroptera (5%) and Odonata (4%) ranked in descending order. And the relative abundance of parasitoids belongs to the family Braconidaecomprised 40%, Ichneumonidae 20%, Eulophidae 15%, Scelionidae 7%, Platygastridae 4% and the rest of the sixfamilies represented 14% in North Bengal tea plantations area. Roy *et al*., (2005) reported variable species richness and seasonal abundance of spider and lady bird fauna in tea growing area of northern part of West Bengal. In this study, they reported 35 species of spider, 25 species of coccinellid beetles, which were potential predators of tea pest, and among the parasitoids family Braconidae and Ichneumonidae were dominant. The coccinellid beetle, *M. discolor* significantly controls tea red spider mites, *Oligonychus coffeae* (Roy *et al*., 2010). Das *et al*., (2010b) reported that Braconid parasitic wasp *Catesia* sp. and the Tachinid endo-parasitoid *Argyrophylax* sp. causes 40-45%parasitization of the geometrid looper, *Buzura suppressaria*, *H. talaca*, *H. infixaria* and *Eterusia magnifica* in Darjeeling. Sudhakaran and Muraleedharan (2006) had recorded major parasitoids of tea lepidopteran caterpillars namely *Apanteles aristaeus*, *A. taprobanea*, *Sympiesis dolichogaster* and *Mestocharells javensis*. Basnet and Mukhopadhyay, (2014) had noted that *Oxypes* sp. had impart variable range of impact on tea mosquito bug *Helopeltis theivora*. Roy *et al*. (2005) had also recorded that, *Chrysoperla carnea*, *Plexippus* sp., *Phidippus* sp., *Scymnnus* sp. and mantids acted as generalist predators. The egg parasitoid *Erythmelus helopeltidis* (Gahan) acted as more efficient bio-control agents of *H. theivora* (Sudhakaran and Muraleedharan, 2006). Devi *et al*., (2016) had reported, *Elasmus homonae*, a Eulophid wasp is an active parasitoid of tea tortrix, *Homona coffearia*. Sarma (1979) had documented the role of natural enemies in controlling the tea pest population and the possibilities of integrated pest control in North-East India. The potential feeding and parasitic behaviour of natural enemies are the result of the minor status of several pests in tea. Population of scale insect *Fiorinia theae* and the aphid *Toxoptera aurantii* can be checked by natural enemies (Nagarkatti *et al.*, 1979 and Radhakrishnan *et al.*, 1988). Muraleedharan *et al.*, (1988) reported the predators and parasitoids, their bio-ecology and role in pest control measure

in tea ecosystem of South India. The natural parasitic wasp of leaf folding caterpillar, *Cydia leucostoma* can effectively check the population in the South-Indian tea growing areas (Rao *et al*., 1970). Roy *et al*., (2014) categorized 721 potential arthropod species in 13 Orders and 141 Families, related to tea ecosystem of India. Out of that 721 species, 341 species were enlisted as natural enemies of tea and shade tree pests. The Hymenoptran natural enemies exhibited the highest species richness. Most of the parasitoid species belongs to the Hymenopteran family Braconidae, Ichneumonidae and Eulophidae and play a crucial role in the biological pest control strategy (Robert *et al*., 1992; Sallam *et al*., 2002; Gillespie *et al*., 2005; Nguyen *et al*., 2012 and Tschopp *et al*., 2013). From the tea plantation area of West Bengal, 15 species were recorded as lepidopteran pests, whereas dragonfly *Orthetrum Sabina* and the species of true fly *Microstyllum Pseudoanantakrishnanii* were recorded as predators by Shah and Mitra, (2015). Muraleedharan *et al*., (2001) had reported 47 predatory insect and mites for biological control of tea red spider mite *Oligonychus coffeae*. Babu *at al*., (2011) had documented the variable range of predatory potential of green lacewings *Mallada boninensis* on *O. coffeae* and concluded as an efficient biocontrol agent. Sinu *et al*., (2011b) had reported the predatory behaviour of *T. rufonigra*a on *H. talaca*. Das *et al*., (2005) had observed the variable diversity of Hymenopteran parasitoids under different dose of chemical fertilizers and pesticides application at Darjeeling, West Bengal. Four parasitoid families *viz.* braconids, ichneumonids, eulophids and scelionids, showed greater diversity in organic tea plantation.

2.10 Seasonal abundance of *Sycanus collaris* and interaction with ecology: Kumaraswami and Ambose (1994) reported that the abundance of nymphal instars of five reduviid bugs during month of January to February. A decline of the nyumphal population was recorded from May to June. The peak population of bug was observed during September to December. Siddaiah *et al*., (2014) observed variable incidence of Reduviid predators, S. *collaris* in July and August at tea research station of Chattisgarh, Jharkhand and Orissa respectively.

From Southern parts of India, Vennison and Ambrose, (1990) had reported that *S. reclinatus* prefers mango trees for habitation adjacent to agro-ecosystems. Ambrose (1999) had reported 238 Indian Reduviid species from tea eco-system. Out of the total collection 34% resides under boulder, 13% resides on shurbs, 14% resides under bark and

3% resides in litter. Apart from this a number of species of Reduviid predators, were also found in adjacent agro-ecosystems.

From Southern parts of India, Vennison and Ambrose, (1990) had reported that *S. reclinatus* prefers mango trees for habitation adjacent to agro-ecosystems. Ambrose (1999) had reported 238 Indian Reduviid species from tea eco-system. Out of the total collection 34% resides under boulder, 13% resides on shurbs, 14% resides under bark and 3% resides in litter. Apart from this a number of species of Reduviid predators, were also found in adjacent agro-ecosystems.

2.11 Biology and life table of *S. collaris*: The predatory bug also known as assassin or kissing bug belongs to the family Reduviidae of the order Hemiptera (Vennison and Ambrose, 1990; Ambrose, 1999 and Nitin *et al*., 2017). Sahayaraj (2002) observed that reduviids play a crucial role in pest management in various agro-ecosystems. Das (1965) had reported that the reduviid bug *Sycanus* sp. is a potential predator in the tea ecosystem of North-East India. *S. croceovittatus* was documented as an effective predator of tea pest from the Darjeeling foot hills of West Bengal by Das *et al*. (2010b). Sarkar *et al*., (2019) had assessed the biology and predatory potentiality of *S. collaris* on larvae of *H. talaca* and *Corcyra cephalonica* in tea ecosystem of Dooars. They further had observed that the total nymphal period was 64.8±4.1 days. The adult male longevity was 42.4±2.1days. While adult female longevity was 59.4±3.4 days and fecundity was 320.4±44.2 days per female when reared on larvae of *H. talaca.* Total nymphal period, adult male longevity, adult female longevity and fecundity per female were comparatively less when reared on larvae of *C. cephalonica*. Srikumar *et al*., (2017) documented the development of *S. collaris* on tea mosquito bug (TMB), *Helopeltis theivora* (Waterhouse), a major tea insect pest. They had recorded that the incubation period was 22.0±01 days, duration of development from egg to adult was 71.7±0.8 days, egg clutches laid by the female was 8.5±0.4 and the total number of eggs was 720±44.5. Rajan *et al.,* (2017) assessed the biology of *S. collaris,* where the mean longevity of male and female adult were 73.58±2.12 and 80.64±3.40 days when fed on *C. cephalonica* and 75.82±2.82 and 85.48±3.20 days when reared on *Spodoptera litura.* The total nymphal duration of *S. collaris* was 49.3 ± 1.95 days, life span of females was 45.17 ± 1.83days and that for males was 31.83 ± 2.48 days (George *et al*., 1998b). Sahayaraj (2012) had recorded that the incubation period of *S. collaris* on artificial diet was 15 days, nymphal developmental

time was about 88 days and the sex ratio was 1: 0.67 (Female: male). Sundararaju (1984), on the other hand had reported that the incubation period of *S. collaris* was 11 days and the total nymphal developmental time was 77 days on the artificial diet.

Srikumar *et al*., (2017) had recoded the life table of *S. collaris* on *Helopeltis theivora*. The innate capacity of natural increase was 0.192females/female/day and the gross reproduction rate was 145.2. The total developmental time of *S. collaris* was 71.7 ±0.8 days and the total number of laid eggs was 720.0±44.5 by a female respectively. George *et al*. (1998b) had studied the biology and the life table parameters of *S. collaris* on *S. litura*. They have recorded that the net reproductive rate (R_o) was 30.46 eggs/ female, the true intrinsic rate of natural increase (r_m) was 0.066 and the time taken for the doubling was 10.56 days.

2.12 Predatory efficiency of *S. collaris*: Reduviidae a large family belongs to the insect order Hemiptera, found to be efficient predators of different insect pests, preferably predate on larval stages of lepidopteran insect (Ambrose *et al*., 2009). The genus *Sycanus* belonging to the subfamily of Harpactorinae have very active predatory efficiency on insect pest. *S. collaris*, known as assassin bug, efficiently searched, captured and attacked on the target insect. Depending on the food source the developmental period and fecundity rate of *S. collaris* differ considerably (George, 2000). Evangelin *et al*., (2014) described that the Reduviid bugs was highly prey specific and replete with evolving prey-capture strategies. Nitin *et al*., (2017) observed that the maximum predation of *S. galbanus* was 4 prey/predator in case of wax moth. The genus *Sycanus* is a predominant subfamily of Harpactorinae and all of its members have very active predatory efficiency on insect pest. Predatory behaviour and potential prey record of *S. collaris* encouraged the researcher to study the possibility of this biological control agent by augmenting and subsequently releasing it into the agro-ecosystem (George *et al*., 1998b; Singh, 1998; Ambrose, 1999 and Sahayaraj and Martin, 2003).

2.13 Predatory behaviour of reduviid bug: The assassinate bug of reduviid species exhibits some behavior prior to prey capture and also after punching its rostrum to the prey. All of the life stages of this reduvid bug show predatory behaviour (Nitin *et al*., 2017 and Sarkar *et al*., 2019). *Sycanus collaris* captures and kills prey by 'pin and jab' mode of predation (Ambrose, 1999). If the moving prey comes in the notice of *S. collaris*, this visual stimulus performs as primary sensory input for arousal in that reduviid bug. Kumar

et al.,(2011) reported that, the III, IV, V nymphal stages and adult *Coranus spiniscutis* took 0.36±0.12, 0.26±0.05, 0.18±0.04 and 0.17±0.03 minutes respectively for feeding on larvae of rice meal moth *C. cephalonica.* Whereas 0.33±0.07, 0.28±0.04, 0.22±0.03 and 0.15±0.03 min respectively were required for feeding on larvae of *S. litura*. Rajan *et al.*, (2017) observed that III, IV and V nymphal instars and adult revuviid bug *S. collaris* took 0.41±0.1, 0.36±0.06, 0.34 ± 0.05 and 0.30±0.2 min respectively for consumption on larvae of *C. cephalonica.* While for feeding on larvae of *S. litura* it took 0.45±0.07, 0.45±0.11, 0.43±0.05 and 0.4±0.15 min respectively. The reduviid bugs *S. reclinatus* and *S. collaris* take position to orients towards prey after getting arouse. The predators remain quite in juxta tibial position until the prey approaches to this predator and extend its antennae towards prey to capture the prey (Vennison and Ambrose 1992; Rajan *et al.,* 2017). The reduviid bug locates its prey with the antennal perception to kairomones and allomones (Hagan, 1987). Ambrose (1999) stated that, the 'approaching' and 'capturing' potentiality varied considerably in different harpactorine species. This predatory bug after capturing prey injects toxic venom with saliva for 'paralyzing' the prey. The predator then becomes more active and the shows an energetic character in prey capturing.

2.14 Seasonal abundance and interaction with ecology of *Eocanthecona furcellata*: Observations on the periodicity of predator population in relation to climatic parameters help to develop suitable management strategy to control pest population. Suyal *et al*., (2018) observed that *Eocanthecona furcellata* occurred during third week of August. The study revealed that temperature, relative humidity and evaporation act as limiting factor for population buildup of insect pests in soybean ecosystem. Claver and Jaiswal (2013) observed that the incidence of stink bugs namely *E. furcellata* and *A. spinidens* in the rice field increased from the crop heading stage up to grain-filling stage and then decline suddenly. However, the population of stinkbugs was not uniforms in the rice field; *E. furcellata* (15.03%) was less than *A. spinidens* (84.69%). Chakravarty *et al*., (2017) had observed that the incidence of heteropteran bugs namely *Eocanthecona furcellata* and *Rhynocoris fuscipes* from short duration pigeon pea cultivation field, starting from the 36 SMW to 47 SMW during 2012-2014 and had noted variable incidence.

2.15 Biology and life table of *E. furcellata*: *E. furcellata* is as a common stink bug of cotton, chickpea and vegetables in India, China, Taiwan and Japan Nyunt (2008).Tea plantations served as shelter, food and micro-habitat of diverse arthropods communities.

Mitra *et al*., (2018) documented *Eocanthecona furcellata* as an effective predator from Darjeeling district of West Bengal. Singh *et al*., (2019b) had reported that the predatory efficiency of *E. furcellata* from Muga ecosystem of Assam.

Lenin and Rajan, (2016) had studied the biology of *E. furcellata* on larvae of *Corcyra cephalonica.* The total number of 44±8eggs were laid and incubation period was 6±1.05 days. The total nymphal period was about 16±0.64 days. Longevity of male and female was 32±0.19 and 36+1.90 days respectively. Vanitha *et al*., (2018) reported that the incubation period of *E. furcellata* was 6-7 days while rearing on wax moth larvae. Five nymphal instars was completed in 15-19 days and no cannibalism was observed. Female bugs were bigger in size. The longevity of female bug was 28.12±2.91days compared to male bugs which was 23.8±03.30 days. Mean fecundity was 9.13±1.20 batches per female with 35.96±11.29 eggs/batch. Kumar *et al*., (2001) had studied on the biology of *E. furcellata* on *Spilarctia obliqua* (Walk.) in Mulberry plant and noted that the incubation period, total nymphal duration, longevity of adult male and female were 8.45±0.44, 19.90, 21.0±1.09 and 27.7±0.69 days respectively when reared on the small sized host larvae. But the duration was longer when rearing on large sized larvae. Tuan *et al*., (2016) conducted a comparative study of *E. furcellata* and *Plutella xylostella*. They found that Nymphs of *E. furcellata* developed more rapidly when rearing on diamondback moth larvae than on *S. litura*. Male adult longevity was longer compared with the female adults, fed on *S. litura* larvae; whereas almost similar longevity of male and female were observed when reared on *P. xylostella*. Kalaiyarasi *et al*. (2017) had reported that the nymphal duration of *E. furcellata* was 11 to 16 days when reared on *Henosepilachna vigintioctopunctata.* The developmental duration was 20-25 days.

Tuan *et al*., (2016) studied the life table of *E. furcellata* on *S. litura* and *P. xylostella* for understanding predator–prey relationship. They recorded the net reproductive rate, intrinsic rate of increase, finite rate, of *E. furcellata* reared on *P. xylostella* were 292.4 offspring, 0.1389/ day, 1.1490/day. Net predation rates were 644.1 third instars of *P. xylostella*, respectively. But these values were significantly higher in *S. litura*.

2.16 Predatory efficiency of *E. furcellata*: Predacious pentatomid bug *E. furcellata* being an efficient predator of lepidopteran caterpillar found in orchards, soyabean, beans, vegetable and forest ecosystems feeding on fall army worm, *S. frugiperda* in maize

(Navarajanpaul, 2002). De Clercq, (2000) reported that *E. furcellata*due can potentially be employed for lepidopteran and coleopteran insects pest. *E. furcellata* have been considered as an important predator on several important lepidopteran pests in India. *E. furcellata* has been documented as an important predator of *Earias* sp. (Pant, 1960), rice leaf folder, *Cnaphalocrocis medinalis* Guenee (Kumar and Singh, 2007), *Helicoverpa armigera* Hubner, *Spilarctia obliqua* (W.) Tiwari *et al*., (2017) had noted that 85.94% predation rate of *E. furcellata* on larvae of *M. vitrata* whereas 84.49% on larvae of *C. Cephalonica*. Rani and Vukkala (1993b) had reported that *E. furcellata* can actively feed on the larval instars of *S. litura*.

2.17 Predatory behaviour of *E. furcellata*: *E. furcellata* has gained the status of a significant potential predator in consideration of its predatory behaviour. This predatory bug may locate the prey by generating vibration instigated during feeding (Nyunt 2008). Yasuda (1998) reported that *E. furcellata* detected the prey of several lepidopteran larvae by the chemical cues. Searching, capturing and killing of prey are the sequential behaviour of *E. furcellata*. Initially, the visual stimuli activities the predatory bug. *E. furcellata* uses the antennal sensory structure and rostral jab to trigger as the stimuli response for capturing the prey (Kumar *et al*., 2001). Getting excited *E. furcellata* extends and penetrates the sword like rostrum in to the prey (Singh *et al*., 2019b). The predator efficiently penetrates the rostrum without holding the prey as the body of the prey is covered with thick hairs (Kumar *et al*., 2001). *E. fuecellata* injects venomous saliva into the prey by rostrum for paralyzing the prey. Usha Rani and Ha vukkala, (1993b) observed that *E. furcellata* can paralizes comparatively big size larva of *S. litura* within 3- 10 minutes.

2.18 Biology of *Cotesia ruficrus*: *Cotesia ruficrus* belongs to the family Hymenoptera of the order Braconidae. *C.ruficrus* is an endo-larval gregarious parasitoid which acts as efficient bio-control agent of lepidopterous larvae (Chen *et al*., 2016; Patil *et al*., 2016 and Kaiser *et al*., 2017). The development of the endo-parasitoids completes into the host body by host parasitoid interaction (Potting *et al*., 1997). Naganagoud and Kulkarni, (1998) had noted that *C. ruficrus* took 11.9 days from oviposition to larval emergence and 4.1 days to complete the pupal period when perpetuate on sorghum armyworm, *Mythimna separate*. They had recorded that the adult longevity was 8.1 to 12.26 days with the sex ratio 1.0: 1.4 (F: M). *C. ruficrus* were reported as an efficient parasitoid of *H. talaca* in the tea plantation area of the Northern parts of Bengal (Das *et al*. 2010b). Mc Cutcheon *et al*., (1983) studied the biology of *Apanteles ruficrus* (=*Cotesia ruficrus*) on *Pseudoplusia includens, Trichoplusiani* sp. and *Spodoptera frugiperda* and had noted that the duration

of development from egg to adult was 16 to 18 days. Hafez, (1947) reported that the duration of oviposition to adult emergence were as 14 to 24 days of *Apanteles ruficrus* when reared on *Agrotis ipsilon*. Chen *et al*. (2016) had reported the development of *C. ruficrus* larva on different stages of rice leaf folder *Cnaphalocrocis medinalis*. They mentioned that the developmental period for II and III instar larvae were 10.7±0.2 days and 10.4±0.3 days respectively. While that for IV instar larvae the developmental period was 7.7±0.2 days. Furthermore, the survival rate of IV instar host larva was comparatively higher by 77.4%. In addition to this, comparatively larger cocoon clutch size was recorded for 4th instar host larva. Omwega and Overholt (1997) did not find any singnificant difference in the progeny production between two parasitoids C. *flavipes* and *C. sesamiae* when reared on African stem borers, *Chilo orichalcociliellus, C. partellus* and *Sesamia calamistis.* But significant variation was observed when *C. flavipes* produced different number of progeny when reared on small to large-sized larvae of *C. partellus*. The development time was also shorter in large sized host larvae compared to small one. Khan *et al*., (2017) had studied the life cycle of *C. flavipes* on III, IV and V instar larvae of *C. partellus*. The mean developmental duration of III, IV and V instar host larvae was 16.26 ± 0.37, 16.86 ± 0.36 and 16.78 ± 0.27 days starting from parasitism to the emergence of the adult parasitoid. No significant difference was observed in the developmental period. The low pupal developmental period with 5.06 ± 0.21days and highest 44.6±0.32 pupal cocoon number was observed in IV instar host larvae. Parasitic wasps select large host size for oviposition for sufficient nutrition. Comparatively higher survival rate with morer emergent wasp's number and effective pupal-cocoon formation of parasitic wasp *C. ruficrus* was observed in large and healthy host larvae (Harvey and Strand, 2002).

2.19 Seasonal abundance and interaction of *C. ruficrus* with ecology: Satyagopal *et al.*, (2015) had reported that parasitoids collect pollen and nectar as food from tea ecosystem. Plantation of flowering plants or compatible cash crops along the border of tea plantation area and side by side arranging shorter plants towards the main crop conserve the parasitoids population. Wa¨ckers *et al*., (2007) had reported that the pollen nectar or honeydew enhances the longevity and fecundity of parasitoids. Zhu *et al*., (2015) studied that the longevity of parasitoid, *Apanteles ruficrus* in rice eco-system was more when fed on sesame nectar and pollen compared to either only water or nectar as food (Wa¨ckers *et al*., 2007). The impact of parasitism was well noted when flowering plans are available at the boundary of beneficial crops (Berndt *et al*. 2006; Simpson *et al*., 2011; Orre Gordon *et al.,* 2013 and Segoli and Rosenheim 2013).

Sharmaa *et al*., (2002) observed the population dynamics of armyworm, *Mythimna separate* along with five hymenopteran parasitoids *viz., Costesia ruficrus, Metopius rufus* Cameron, *Disophyrys* sp., *Compoletis chlorideae*, *Enicospilus* sp in Southern India. Out of that parasitism by *C. ruficrus* was found up to 47.15% in October and an abundant population of parasitoid was observed during September to March. Burgess *et al*., (1987) made a field survey on *Mythimna separata* and its gregarious endo-parasitoid, *C. ruficrus* over in two successive seasons during Maize crop at Pukekohe of South Auckland. The highest (86-98%) parasitization activity of *C. ruficrus* was observed in February. Both the parasitic activity and parasitoid population were then gradually reduced during March and April. The peak incidence of parasitism of *C. ruficrus* corroborated to the maximum occurrence of *M. separate* during late February to early March. Naganagoud and Kulkarni (2000) had noted that 20^0C temperature and 80-90% relative humidity was comparatively more suitable for the adult longevity, larval and pupal development of *Cotesia ruficrus*.

2.20 Parasitic impact of *C. ruficrus* on pest: In the sub-Himalayan tea growing region of northern part of West Bengal parasitoid groups belonging to the families Braconidae and Ichneumonidae are dominant ones **(**Table 1.5**)**. Among the parasitoids, *Cotesia ruficrus* was the effective parasitoid wasp against tea loopers (Das *et al*., 2010b). Works to understand the host- parasitic interaction between *C. ruficrus* and *Cnaphalocrocis medinalis* was carried out (Chen *et al*., 2016), *Agrotis ipsilon, Helicoverpa armigera, Mythimna separate*, *Spodoptera litura*, *S. exigua* and *Exelastis atomosa* (Hill, 1986 and Patil *et al*., 2016). The parasitoid, *Cotesia* spp. was an efficient parasitoid on *H. talaca* leading to the death of the host (Das *et al*., 2010a). Jung *et al*., (2006) had reported that the endo-parasitoids belonging to the family braconidae laid eggs and completed its larval period inside the suitable host insect. Just after emergience, the larvae of the parasitic wasp construct pulpal cocoons and after few days, the adults emerge out (Potting *et al*., 1997). They usually prefer healthy larva of lepidopteran pest. This kind of parasitism affects the fitness of the host larvae and ultimately leads to mortality. The braconid wasp alters the host's normal feeding and movement. The food consumption of parasitized host larvae were significantly decreased in comparison to the unparasitized ones (Powell, 1989 and Kuriachan *et al.,* 2011). The parasitic larvae survive haemolymph of the host larval that alters the cellular immunity of the host (Lavine and Strand, 2002).

Table 1.5: Species of *C. ruficrus* parasitized on pests associated with agriculture

Species of *Cotesia*	Target host	Crop	Location	Reference
C. marginiventri	diamondback moth, *Plutella xylostella*	Cabbage	Gainesville, Florida	Johanowicz and MitchellSource, 2000.
C. glomerata and *C. rubecula*	*Pieris rapae* and *P. brassicae*	Wild cabbage	Netherlands	Poelman *et al*., 2009.
C. congregata	Tobacco hornworm, *Manduca sexta*	Tobacco	Japan	Espagne *et al*., 2005.
C. ruficrus	Armyworm, *Mythimna separata* (Walker)	Sorghum	Dharward, India	Naganagoud and Kulkarni, 1998.
Apanteles sagax(Synonymous with *Cotesia ruficrus*)	*Sylepta derogata*	Cotton and Okro	Forest zone of Ghana	Duodu and Antoh, 1984
C. plutellae	*Plutella xylostella*	Oriental cabbage	Andong, Korea	Kim and Son, 2006
C. chilonis	*Chilo suppressalis*	Maize plants	Nigata, Japan	Hailemichael *et al*., 1997.
C. vestalis	*Plutella xylostella*	Cabbage	Hangzhou, China	Shi, *et al*., 2015.
C. sesamiae and *C. flavipes*	*Sesamia calamistis*, *Chilo orichalcociliellus* and *Ch. partellus*	Gramineous plants	Coastal Kenya	Omwega and Overholt, 1997
C. ruficrus	*M. separata*	Sorghum, Maize, Rice and Bermuda grass	South-Central India	Sharmaa *et al*., 2002.
A. kariyai	Pseudaletia separate	Italian rye grass	Kyushu, Japan	Tanaka, 1987.
C. glomerata	*P. brassicae*	Cabbage	Sargodha, Pakistan	Ullah *et al*., 2016.
A. obliquae	*Spilosoma obliqua*	Oilseeds, Pulses, Vegetables, Jute	Bangladesh	Sultana, 2003.

2.21 Effect of pesticides on natural enemies: Every crop is attacked by various arthropod pests rendering huge economic loss. Some of the pests may be managed by biological control agents like pathogens, predators, parasitoids and spiders (Cloyd *et al*., 2009). However injudicious application on insecticides cause serious damamge to crop eco-system. For this reason study on the side effect of insecticides on the natural enemies is highly required to assess the extent of detrimental effects on the natural enemy population (Kaushik *et al*., 2016). An integration of chemical and biological control strategy is suggested for insect pest management for the success of an IPM program (Smilanick *et al*., 1996; El-Wakeil *et al*., 2006 and Volkmar *et al*., 2008). Long term non-judicial use of non-selective pesticides subsumes natural enemy population and eventually increases the pest population in agricultural fields (Fernandes *et al*., 2010). Gallo *et al.* (2002) stated the insect resurgence and secondary pest outbreak due to unwise insecticide application.

Perera *et al.* (2000) reported that the pestistat use of Denatonium benzoate, Azadirachtin dettered the larvae of *Chrysodeixis eriosoma* and *P. xylostella* and also the the parasitoid, *Cotesia plutellae*. However out of the three antifeedants, Denatonium benzoate was comparatively safer to the parasitoids *C. plutellae*. Suh *et al*., (2000) investigated effect of Lambda Cyhalothrin, Cypermethrin, Thiodicarb, Profenophos, Spinosad, Methoxyfenozide, and Tebufenozide on the larval emergence, adult survival and adult fitness of *Trichogramma exiguum*. In the experiment, except Methoxyfenozide and Tebufenozide all the pesticides adversely affected *T. exiguum* emergence from *Helicoverpa zea* host eggs. Mahdavi *et al*., (2011) showed that, Abamectin did not affect significantly on the extent of parasitism of *Bracon hebetor*. Pratissoli *et al*., (2011), however, showed that there was no harmful effect of pesticide on *T. atopovirilia*. Bjorksten and Robinson (2005) reported that Abamectin did not affect the emergence rate of the parasitoid wasp *Hemiptarsenus varicornis*. Morais *et al*., (2016) reported that, b-Cyfluthrin, Bifenthrin, Imidacloprid and Chlorpyrifos had toxic effect on the braconid parasitoid *A. citricola*. Thanavendan *et al*., (2017), on the other hand, had noted that, Profenofos 50EC was most toxic while Chlorpyriphos 20EC was the least toxic effect on *B. brevicornis* and *C. blackburni*. NSKE 5% had at all, no effect on *B. brevicornis* and *C. blackburni.* They further had noted that chlorpyriphos 20 EC and 4% hexane crude extract of *Lantana camara* were harmless to *Cotesia plutellae*. Nagrare *et al*., (2016) reported that Quinalphos, Chlorpyriphos, Thiamethoxam and Profenophos had effected both cotton mealybug *Phenacoccus solenopsis* and also Encyrtid parasitoid *Aenasius bambawalei* following 24 h of exposure.

De Cock *et al*., (1996) and Torres *et al*., (2002) reported that Thiamethoxam and Imidacloprid affected the predatory behaviour and survivability of the pentatomid bug, *Podisus nigrispinus* in the field condition. Boyd and Boethel (1998) reported that, Permethrin, Emamectin benzoate and Methyl parathion were harmful to the nymphal instars of the oredatory bug, *Podisus maculiventris*. George and Ambrose (2004) had noted Methylparathion and Monocrotophos adversely affected the physiology of Reduvid predator *Rhynocoris kumarii*. Whereas Endosulfan showed least effect on the physiology of *R. kumarii*, followed by Dimethoate and Quinalphos. Thungrabeab and Tongma (2007) examined that *Beauveria bassiana* was non-pathogenic fungus to natural enemies and beneficial soil insects.

From the above review of literature, it has been clear that *H. talaca* is a major pest of tea that is responsible for a significant economic loss. A thorough study on *S. collaris*, *E. fuecellata* and *C. ruficrus* are important natural enemies of lepidopteran pests. Therefore it is needed to study these natural enemies to ensure the possibilities of their predacious and parasitic nature in biological control strategy for the management of *H. talaca* in the tea field.

Chapter-III
Materials & Methods

MATERIALS AND METHODS

Materials and methods are adopted to achieve the objectives designed in the scope of this study, during the period of investigation are presented as below

3.1 Location of the study: Two conventionally operated Tea Estate (TE) of Dooars region were selected as the study area in the district of Jalpaiguri of West Bengal in India. Both the areas aerially separated by about 25 Km (Fig.3.1).

i. Banarhat T. E (26.78814°N 89.0408°E)

ii. TRA experimental plot (26°54′0″N 88°58′0″E).

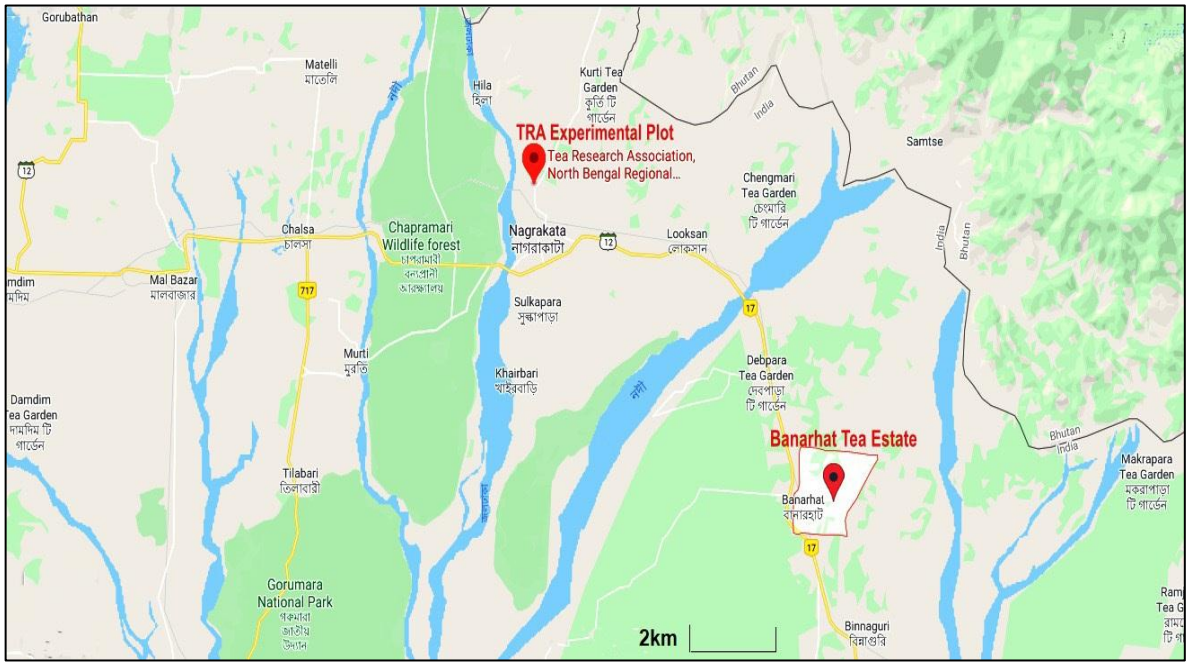


Fig.3.1: Location map of the study area (source: http://www.maplandia.com/india/west-bengal/jalpaiguri/nagrakata/)

3.2 Bioecology and seasonal abundance of *H. talaca, S. collaris, E. furcellata* and *C. ruficrus:* Out of the four insects three had already been identified except *S. collaris*, which has been identified from Crop Protction Research Centre, Palayamkotti, Tamil Nadu (*Appendix IV*). To study the bio-ecology and seasonal abundance of the major tea pest *H. talaca* and three natural enemies *S. collaris*, *E. furcellata* and *C. ruficrus*, a three hectare plot was selected in each location and from that plot randomly five subplots were marked and considered as five replications, each sub-plot consisted of 100 bushes. The interaction of these four insects with their ecology such as abiotic and biotic factors were observed and the data recorded for a period of two years (February 2017 to January 2019). The trends of the seasonal abundance of the pest, and the two predators were recorded by taking the count of number of individuals in randomly selected 30 bushes per replication

at fortnightly intervals. In the case of *C. ruficrus*, cocoons were randomly collected from each replication by randomly selected 30 bushes (Fig. 3.2.1). Method was adopted from Puja and Sabiha (2016); Suyal *et al*., (2018) and Hill and Atkins, (1983). Data on the weather parameters of the study period were collected from metrological division of Banarhat TE and TRA experimental plot (Fig. 3.2).

Fig. 3.2: Two study sides (a) first location (Banarhat TE) and (b) second location (TRA experimental plot)

Fig. 3.2.1: Pest and natural enemies in tea ecosystem: (a-b) larvae of *H. talaca*, (c) cocoons of *C. ruficrus* (red circle indicates point of intrest), (d) adult *S. collaris*, (e) nymph of *S. collaris* and (f) adult of *E. furcellata*

3.3 Rearing of *H. talaca* on natural diet (tea leaves) and shade tree leaf (*Acacia lenticularis*): Gravid male and female moths of *H. talaca* were collected from the selected fields by hand collection. Moths were put in mating and egg laying chamber (30.48x30.48x45.72cm^3, wooden cage) and provided 10% honey solution as food source under laboratory conditions (27± 2^{o}C, 70-80% RH and 16:10 LD photoperiod). Shade tree barks were provided for their oviposition and then the bark containing eggs were kept in separate chamber for further monitoring. After hatching of the eggs, one batch of larvae were reared on leaf of susceptible selected tea clone and another batch on the leaves of a common shade tree *Acacia lenticularis* were provided with a conical flask and covered with wooden box (Fig. 3.3). The culture was maintained by cleaning and changing of host leaves on a daily basis following the methodology developed by Babu *et al.*, (2014) with minor modifications until pupation. After adult emergence, the adults were sexed by separating females and males in a mating chamber at 1.12 ratio. The number of egg laid by the female, incubation period of egg, larval developmental duration for each instar, duration of pupal period, adult longevity were also observed and data recorded from both rearing conditions.

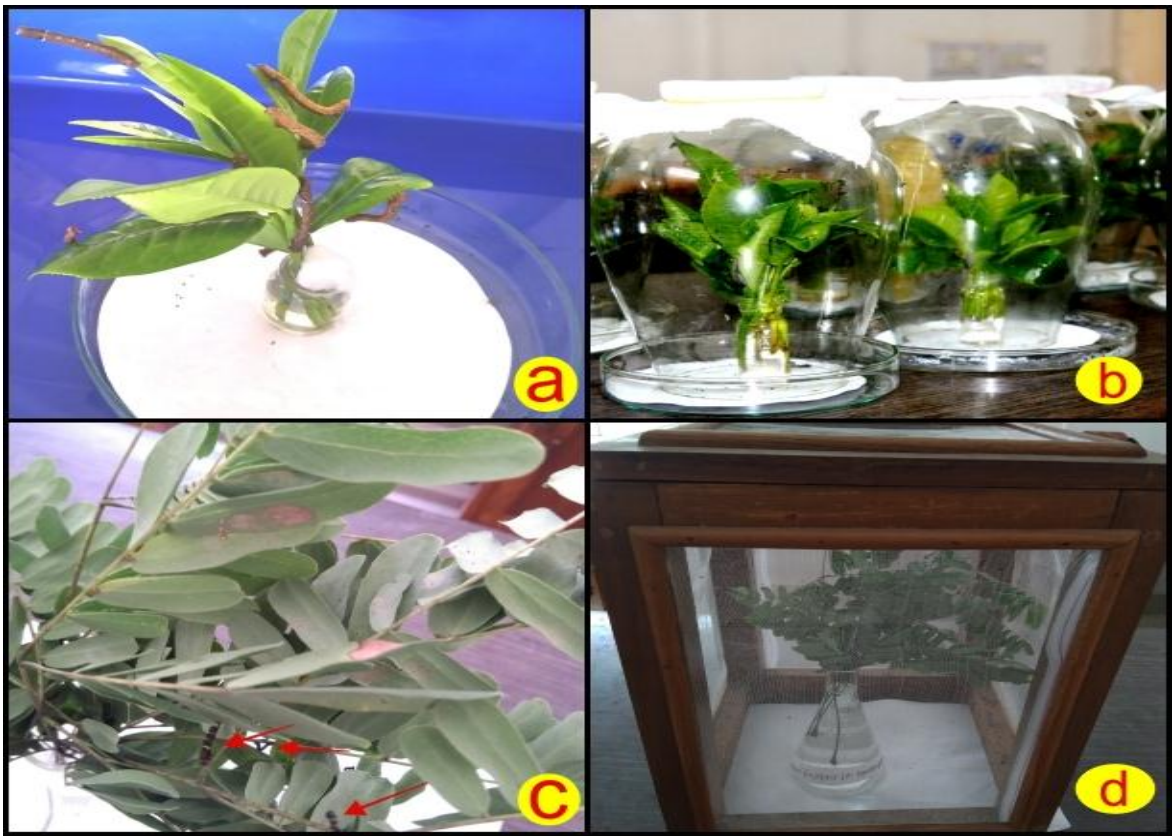


Fig. 3.3: Rearing of *H. talaca* (a) tea leaves are provided for looper, (b) rearing condition of looper on tea leaves, (c) shade tree leaves are provided for looper and (d) rearing condition of looper on shade tree leaf covered

3.4 Rearing of *H. talaca* on artificial diet: An artificial diet for rearing the larvae of *H. talaca* was prepared using the ingredients listed in Table 2.4 following the procedure adopted by Babu *et al*., (2015a). The artificial diet was kept under refrigerated conditions. The newly hatched larvae of *H. talaca* were provided a piece of artificial diet pricking with toothpick in Tarson sample collecting container (4.3x5.4cm^2). A piece of filter paper (4.3cm diameter) was also put inside the container to absorb the moisture and to avoid contamination (Fig. 3.4). Excreta of the larva was removed daily and diet was changed if needed. All the biological parameters were observed and recorded in a similar manner followed for the natural food.

Fig. 3.4: Rearing of looper on artificial diet: (a) early instar of looper and (b) advanced instar larvae

Table 2.4 Ingredients of artificial diet

Fraction	Ingredient	Quantity
A	Tea leaf	7gm
	Tea seed powder	7gm
	Proteinex powder	1gm
	Yeast powder	1.25gm
	Sorbic acid	0.5gm
B	Ascorbic acid	0.40gm
	Streptomycin	0.625gm
	Multivitamin	¼ tablet
	Vitamin-E	1 drop
C	1% formalin	1.25ml
D	Agar-Agar	1.56gm
	Distilled water	100ml

3.4.1 Procedure of artificial diet

1. Fraction A was mixed with 50ml water and blended for 2 minutes.
2. Fraction B was added to the above mixture and again blended for 1 minute.
3. Fraction C was then mixed to the above mixture in the blender and blended for another 1 minute.
4. Fraction D was boiled in 50ml water and added in the blender and blended again for another 1 minute with the above mixture.
5. The prepared diet is then poured in the petri plate and allowed to get solidified (Fig. 3.4.1).

Fig. 3.4.1: Ingredients of artificial diet: (a) fraction A, (b) fraction B, (c) fraction C, (d) fraction D, (e) mixture of all ingredients poured in a petridish and (f) prepared artificial diet

3.5 Rearing of *Corcyra cephalonica*: Eggs of Rice meal moth of (*Corcyra cephalonica*) were collected from Entomology department of Uttar Banga Krishi Viswavidyalaya, Coochbihar, India. Eggs were sprinkled in the maize powder kept in a plastic container (25x115x8cm^3) under the laboratory conditions (27± 2^{o}C, 70-80% RH and 16:10 LD photoperiod). After the successful development from egg to larva in the maize powder, emerged adult were collected and transferred into the mating chamber for egg laying (Fig. 3.5). Methodology followed by Rashmi (2009) with minor modifications was adopted in this experiment.

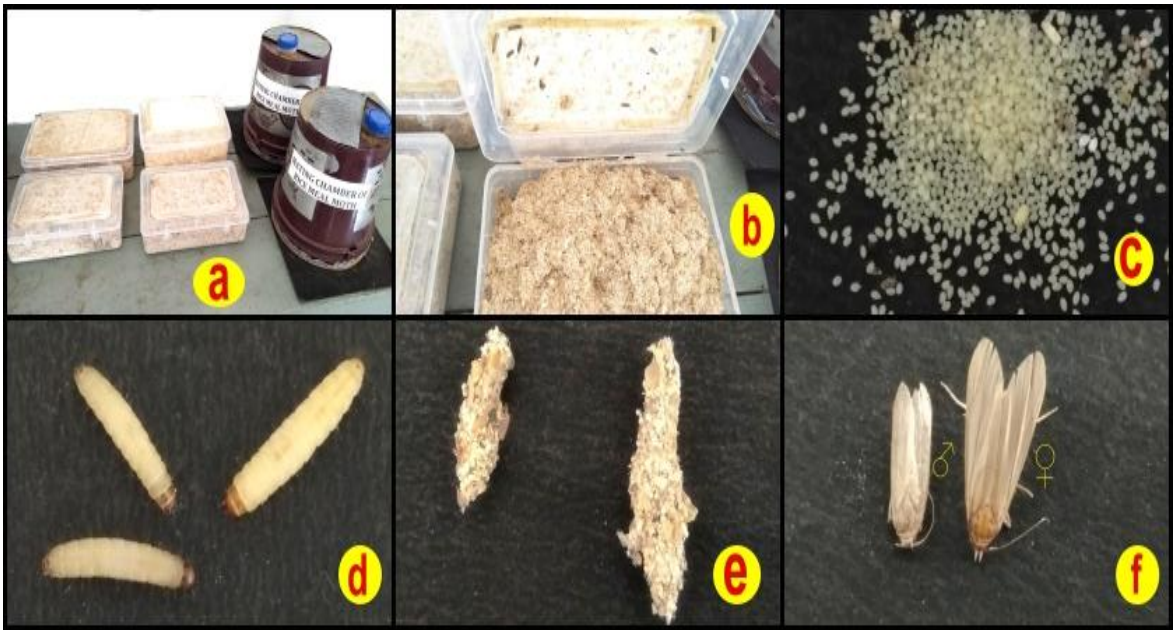


Fig. 3.5: Rearing of *C. cephalonica* on maize powder, (a) rearing condition of *C. cephalonica* in laboratory, (b) moths in the culture container, (c) the collected eggs, (d) larvae of different instars, (e) pupae and (f) male and female moths

3.6 Rearing of *S. collaris* and *E. furcellata* on larvae of *H. talaca* and *C. cephalonica*:

The field collected adult of these two predators were kept in glass chimney in different rearing set (opening of the chimney was covered with muslin cloth) under laboratory conditions (27± 2^{o}C, 70-80% RH and 16:10 LD photoperiod) for mating and laying eggs. Larvae of *H. talaca* and *C. cephalonica* were provided in two different culture conditions for feeding (Fig. 3.6). Shade tree barks were kept inside the chamber for egg laying and the egg masses were collected and kept in separate containers for maintaining the culture. A piece of wet cotton was put in the chamber for maintaining the moisture. The moist cotton pieces were changed every day to prevent the fungal infection. After hatching of eggs, the first and second nymphal instars of the predators were reared in group until molted into next stage. Third instar, fourth, fifth stages were put in separate Tarson sample collecting container (Diameter 4.3, height 5.4cm) in order to avoid cannibalism. Adults were kept in separate glass chimney for mating and egg laying of *S. collaris* (Sahayaraj 2012 and Rajan *et al.,* 2017) and *E. furcellata* (Lenin and Rajan, 2016 and Tiwari *et al*., 2017). Both the predators were reared in laboratory for two generations in order to record the incubation period, duration of nyphal stages, longevity of adult stages, number of eggs laid by female when feeding on the larvae of *H. talaca* and *C. cephalonica*.

Fig. 3.6: Rearing of *S. collaris* on (a) looper and (b) larvae of *C. cephalonica*; rearing of *E. furcellata* on (c) looper and (d) larvae of *C. cephalonica*

3.7 Rearing of *C. ruficrus* on *H. talaca*: The parasitoid cocoons were collected from field and put into a glass funnel chamber until adult emergence under laboratory conditions (26±1^{0}C and RH 73±5%). After adult emergence 10% honey solution was provided using a cotton swab for feeding and mating. The glass funnel was used for exposing the parasitoid wasps into the glass chimney containing healthy host larvae of different stages. After 4-6h the host larvae were transferred in another chamber and reared on tea leaves. After maturation inside the host body, parasitoid larvae were emerged out and formed cocoons. Rearing of *C. ruficrus* was done using larvae of *H. talaca* following the methodology of Chen *et al*., (2016). Duration of larval stages, longevity of adult stages, number of cocoon formation on the larvae of *H. talaca* were recorded.

3.8 Life table of *H. talaca, S. collaris, E. furcellata* and *C. ruficrus*: To know the successive age intervals, age specific survival, the developmental, fecundity rate and the expectation of further life of *H. talaca* reared on three different food regimes (tea leaf, shade tree leaf and artificial diet) and life tables were constructed for *S. collaris, E. furcellata* and *C. ruficrus* reared on larvae *H. talaca*, under laboratory conditions. Prior to the implementation of a natural enemies in the pest control programme, it is essential to know all the parameters of life tables of the respective natural enemies. For constructing the life table of these four insects, ten pairs of healthy male and female were kept into the glass chimney containing proper food for maintaining the culture. Shade tree bark were put into the chimney for laying eggs of *H. talaca*, *S. collaris* and *E. furcellata*. Hundred eggs were collected and kept separately into a glass chimney covered with muslin cloth. The eggs were kept under daily observation and after hatching out of eggs, the immature stages of the insects were put into separate chimney containing their food. The rearing of the four insects were continued till maturation. Duration and survival rate of each immature stages were observed till it moulted into adult. Sex ratio of adult male and female were recorded and kept separately in glass chimneys. Ten pairs of male and female were kept under observation along with prey larvae as food, duration of pre-oviposition, oviposition, number off egg laid by a female and the adult longevity were recorded.

From the above observations life table parameters like age specific fecundity, age specific survival rate, gross reproductive rate, intrinsic rate of natural increase (r_m), net reproductive rate, mean generation time and finite rate of increase at room temperature were designed according to Brich (1948), Deevy (1947) and Southwood (1978). Doubling time was determined according to Mackauer (1983).

The net reproductive rate (R_0), which is the rate of population multiplication in each generation, equal to the sum of the l_xm_x products as in the following equation: $R_0 = (\sum l_xm_x)$. Mean length of generation time (T_c) determined the mean-time, calculated from birth of parents to birth of offspring. The precise value of mean length of a generation was calculated in the equation, $T_c = \Sigma\, Xl_x\, m_x/\Sigma\, l_x\, m_x$. The innate capacity for increase (r_c) was calculated as, $r_c = (\log_e R_0)/\, T_c$. This is the arbitrary value of r_m. Two trial values of the intrinsic rate of increase (rm) up to 2 or 3 decimal place selected on either side of it and substituted in the equation $\Sigma e^{7-rmx}\, l_xm_x$ until the two values of the equation were found which lay immediately above or below 1097 (Atwal and Bains, 1974). The two values obtained from the above calculation were plotted against their respective arbitrarily 'rm' which give a straight line and intersected by a vertical line drawn from the described value

at 1097. The two point of intersection gave the accurate 'rm' value up to three decimal. The maximum population growth, innate capacity for increase (r_m) is the maximal rate of increase attained by a population of a particular organism at any particular combination of environment and expressed as the number of females per day, which was determined by using the formula $\sum e^{7-rm}\ l_x m_x = 1$, where, x is age of individual in days, l_x is number of individuals alive at age 'x' as a proportion of one; m_x = number of female offspring produced per female in the age interval 'x'. Corrected generation time (T) was obtained by using the formula, $T = (\log_e R_0)/r_m$. Finite rate of natural increase (λ), is the number of female offspring per female per day, calculated as, λ= antilog e^{rm}. Weekly multiplication of population (W_m) was calculated by using the following formula, $W_m = (e^{rm})^7$. Doubling time (Dt) is define as the number of days required by a population to double in number and was calculated by using the formula, $Dt = (\log 2)/ r_m$.

3.9 Selection of tea cultivars for the present study: For conducting the experiment on food consumption, 10 tea cultivars were selected from Tocklai Vegetative series, garden series and stock cultivars (Fig. 3.7) based on the quality or flavor, yield and standard (Table 2.9).

Table 2.9: Selected tea cultivars for the experiment

Category of cultivars	Quality/ flavor	Yield	Standard
Tocklai Vegetative (TV)	-	TV22 and TV26	TV1, TV16, TV20,
Garden Series	B157 (Bannockburn 157), K1/1 (Kopati 1/1)	-	SNT8 (Sanyasithan 8), (HP12) Hantapara 12
Tocklai Stock	TS-520		

'-': There are no such varieties

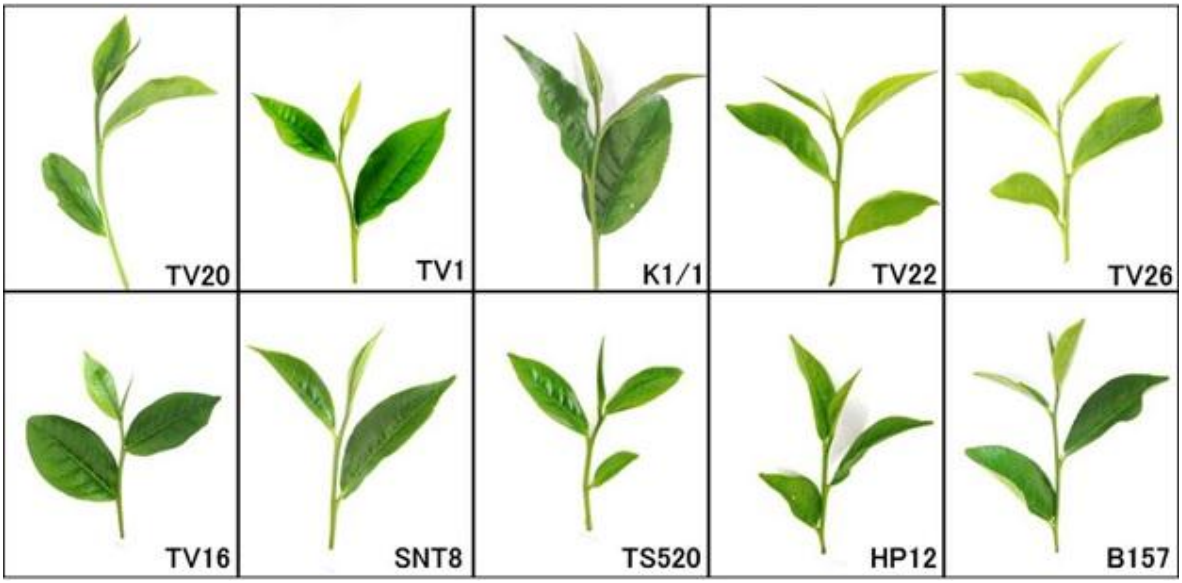


Fig. 3.7: Ten selected tea cultivars for the present study

3.10 Study on the food consumption and development of larvae of *H. talaca* on different tea cultivars: Second or third leaf of each cultivars were collected from TRA experimental plot. Leaf discs (3.2 cm in diameter) were cut and put in the Tarson sample collectingcontainer (Diameter 4.3, height 5.4cm) (Fig. 3.8). A small piece of wet cotton and toothpick were put in the same container for maintaining the moisture and larval movement. Freshly moulted II, III, IV and V instar larvae of *H. talaca* were taken from the stock culture and kept in starvation for 1.5h into a large Petridis. After 1.5h, larvae were released in separate container containing leaves of same cultivars. Food consumption and weight of fecal matter by each larval instar were recorded at 24 h intervals. All the cultivars were put in the similar manner and replicated 5 times for each larval instar. The food consumption and weight gain by larvae of *H. talaca* were determined by the approximate digestibility (AD), efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD), relative consumption rate (RCR) and relative growth rate (RGR) by following the basic methodologies of Waldbauer (1968), subsequently modified by Gurusubramanian *et al*., (1991). For constructing the susceptible index TV1 was used for relative susceptible check (RSC), method was adopted from the study of (Henrich *et al.*, 1985; Majumder *et al*., 2011 and Roy *et al*., 2009). Means of food consumption and body weight gain were statistically analyzed by Tukey's multiple comparison test

These parameters are calculated by using the following formulae:

Food consumption (C) = (Initial leaf weight - final leaf weight) – (Average transpiration loss by leaf).

Production (P) = Final body weight - initial body weight.

Assimilation (AS) = Food consumed (C) - Faecal matter (F).

$$AD = \frac{AS}{C} X100$$

$$ECI = \frac{P}{C} X100$$

$$ECD = \frac{P}{AS} X100$$

$$RCR = \frac{C}{\text{mean of the body wt. of a stage X feeding period (in days)}}$$

$$RGR = \frac{P}{\text{mean of the body wt. of a stage X feeding period (in days)}}$$

$$\text{Susceptible index (SI)} = \frac{\text{Food consumption on test cultivar}}{\text{food consumption on RSC}}$$

A dendrogram (Euclidean distance mapping) of selected tea cultivars was constructed based on the feeding and nutritional indices of larva of *H. talaca* by using GraphPad InStat software.

Fig. 3.8: Food consumption of looper: (a) prepared leaf disc, (b) earlier instar of larva fed on leaf disc and (c) advanced instar larva consumed total leaf disc

3.11 Quantitative assay of biochemical profiles of selected tea cultivars

3.11.1 Preparation of leaf for biochemical analysis: Tea leaves up to third leaf of selected cultivars were harvested from TRA experimental plot. Leaves were deactivated by steaming for 3 minutes and dried it at hot air oven at 65^0C for 10h. The dried leaves were blended in mixture grinder machine for preparing leaf powder. The further biochemical analysis were processed with these powder (Fig. 3.9).

3.11.2 Estimation of total carbohydrate

3.11.2.1 Reagents

i. Glucose stock standard solution: 100 mg of glucose was dissolved in 100 ml of distilled water in a volumetric flask.

ii. Working standard: 10 ml of the stock was diluted to 100 ml distilled water. In each 1.0 ml of this solution contains 100µg of glucose.

iii. Anthrone reagent preparation: 0.2% anthrone was dissolved in ice cold concentrated sulphuric acid.

iv. 2.5 N HCl.

3.11.2.2 Procedure: 100mg of the tea leaf sample was added in 5.0 ml of 2.5 N HCl into a boiling tube, hydrolysed by keeping it in a boiling water bath for three hours and allowed to cool at room temperature. Solid sodium carbonate was added slowly until the effervescence ceases and make up the volume to 100 ml and centrifuged. The supernatant was collected and 0.2 to 1.0 ml taken for analysis. Standards were prepared by taking 0.2-1.0 ml of the working standards. One test tube served as blank made up the volume with 1.0 ml distilled water. 4.0 ml of anthrone reagent was added, then heated for eight minutes in a boiling water bath, allowed to cool and read the green to dark green colour at 630 nm. The method was followed developed by Hedge and Hofreiter, (1962).

3.11.3 Estimation of total protein

3.11.3.1 Reagents

i. Folin –ciocalteau (**reagent D**).

ii. 20% Sodium carbonate was added in 0.1N sodium hydroxide (**Reagent A**).

ii. 0.5% Copper Sulphate (CuSO4.5H2O) was added in 1% potassium sodium tartrate **(Reagent B).**

iii. Alkaline copper solution was prepared by mixing 50ml of reagent A and 1ml of reagent B prior to use (**Reagent C)**

iv. Protein Solution (Stock Standard): 50mg of bovine serum albumin (fraction V) was dissolved in 50ml distilled water in a standard flask.

3.11.3.2 Extraction of preparation:

100 mg of leaf sample was mixed in 5ml of buffer used for the enzyme assay. The mixture was centrifuged and used the collected supernatant for protein estimation.

3.11.3.3 Procedure

i. Working standard of 0.2, 0.4, 0.6, 0.8 and 1.0ml were pipetting out into a series of test tubes.
ii. The sample extract of 0.1 ml and 0.2 ml were taken two other test tubes.
iii. The volume of all the test tubes was made up 1.0 ml with distilled water. A tube with only 1.0ml of distilled water was served as the blank.
iv. Reagent C of 5.0 ml was added to each test tube including the blank, allowed to 10min standing for reaction.
v. Reagent D of 0.5ml was added, mixed well and allowed to incubate at room temperature in the dark condition for 30min, blue colour was developed.

The readings were taken at 660nm Lowry *et al*., (1951).

3.11.4 Estimation of lipid: For the estimation of lipid 1g of prepared tea leaf sample was taken and mixed with 10 ml distilled water. Chloroform-methanol were mixed in the ratio of 2:1 and 30ml of this was mixed with the prepared sample solution and the mixture was left overnight at room temperature. An equal volume of chloroform and distilled water (20ml) were mixed with the mixture solution and the solution centrifuged at 1000 rpm for 10 min. After centrifugation three layer was formed in the centrifuge tube. Among these three layers, two upper layer were discarded and the lower layer which contained chloroform containing lipid collected in a Petridis. This layer was kept in an oven at 50^0C till the evaporation of chloroform. Weight of the remaining was taken and subtracted from the initial weight. Method was adopted from Bligh and Dyer (1959) and Dutta *et al*., (2013).

3.11.5 Estimation of polyphenol

3.11.5.1 Reagents

1. Methanol (70%)
2. Folin-Ciocalteau reagent (1N)
3. Sodium carbonate (20%)
4. Standard gallic acid solution (100µg/ml in water)

3.11.5.2 Total Polyphenol Content (TPC): The total polyphenol content was calculated using Folin-Ciocalteu reagent by following the method of ISO/CD 14502-1-2: (2001). 0.2gm of powdered sample was weighed and added with into 70% methanol/water mixture

for proper extraction. This mixture was diluted 100 times with distilled water. Then, 5 ml of Folin-ciocalteu reagent (1N) was added to 1 ml of the diluted extract followed by Sodium Carbonate solution (70%). The mixture was kept for 1 hour at room temperature. Absorbance was taken at 760 nm in ultraviolet–visible spectrophotometer and the result was express as weight percentage.

3.11.6 Estimation of total alkaloids: Tea leaf powder sample of 5 g was taken into a beaker and 200 ml of 10% acetic acid in ethanol was added. Allowed this condition for 4h for proper extraction. This mixture was filtered and the extract was concentrated on a water bath to one-quarter of the original volume. The concentrated extract was allowed to cool and then concentrated ammonium hydroxide added drop wise to the extract until the precipitation was completed. The solution was allowed to settle and the precipitated was collected and washed with dilute ammonium hydroxide and then filtered with Whatman filter paper number 1. The residue contained alkaloid, which was dried in hot air oven at 60^0C. Total alkaloids was measured by taken the initial and final weight of the Whatman filter paper by following the method of Harborne, (1973).

3.11.7 Estimation of total flavonoid: Quercetin of 10mg was weighed and dissolved in 100ml methanol. This methanolic solution was then diluted to 6.25, 12.5, 25, 50, 80, and 100µg/ml. Stock solution of tea leaf powder sample was prepared by weighing 100 mg and dissolved in 5ml methanol and transferred to 10ml volumetric flask. The volume was made up with methanol. 10% aluminium chloride and 1M potassium acetate were weighed and prepared the solution using distilled water.

The estimation was determined using 0.5ml of each extract stock solution and each dilution of standard quercetin taken separately in a series of test tubes. One test tube with only distilled water of same volume served as blank. In each test tube 1.5ml methanol, 0.1ml aluminium chloride solution, 0.1ml potassium acetate solution and 2.8ml distilled water were added. Each test tube was shaken in vortex machine for mixing well. All the prepared solutions were filtered through Whatmann filter paper and taken the absorbance at 415 nm against the suitable blank. Method was followed from Akbay *et al*., (2003) and Park *et al*., (2008).

3.11.8 Estimation of total chlorophyll and carotenoids: Fresh tea leaves were plucked from TRA experimental plot, then 1gm was taken for the assessment. Leaves was homogenized with mortar and pestle using 100ml 80% acetone. The homogenized sample was filtrate by filter paper and measured spectrophotometrically at 645nm and 663nm against acetone blank. Chlorophyll amount present in the extract is calculated according by using the formula:

Chlorophyll a: C*a* = 12.25 A663.2 – 2.79 A646.8

Chlorophyll b: C*b* = 21.50 A646.8 – 5.10 A663.2

Sum of Chlorophyll a and b was the total Chlorophyll.

Total carotenoids: Cx+c = (1000 A470 – 1.82 C*a* – 85.02 C*b*) / 198

The method was followed, developed by Lichtenthaler (1987).

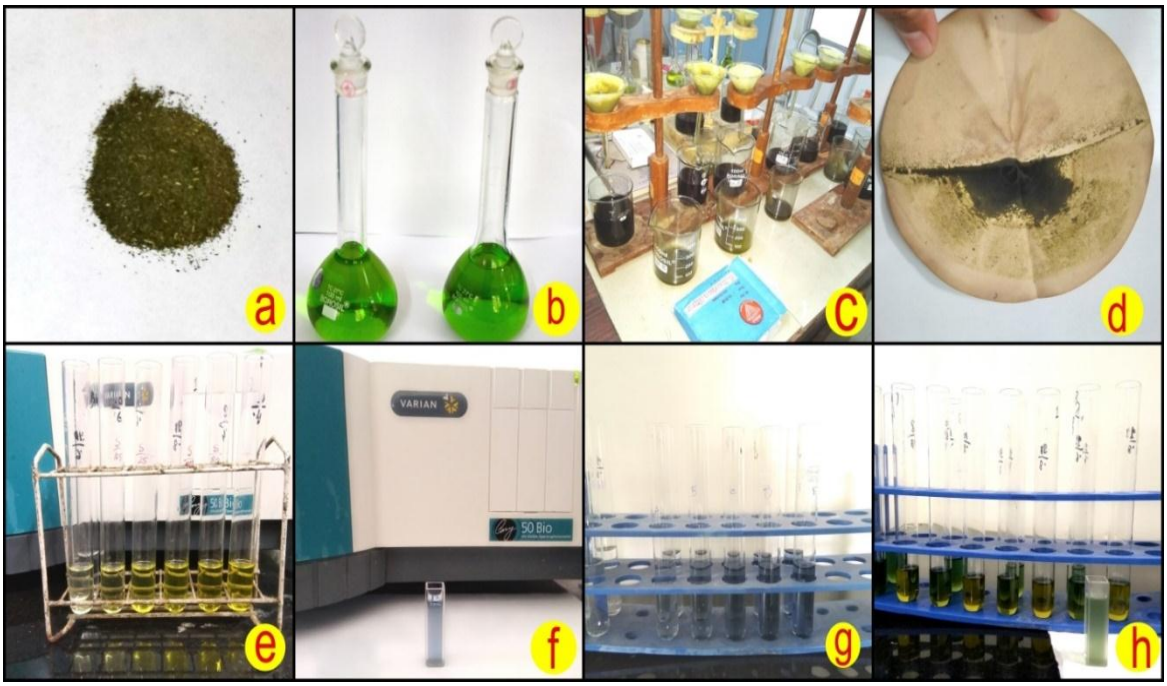


Fig. 3.9: Biochemical analysis of tea leaf: (a) tea leaf powder, (b) estimation of chlorophyll, (c-d) estimation of alkaloid, (e) estimation of quercetin, (f) estimation of protein, (g) estimation of polyphenol, (h) estimation of carbohydrate

3.11.9 Individual catechins and caffeine by using HPLC method: Individual catechin and caffeine was carried out and the quantity was analysed by using Agilent 1260 infinity series of HPLC fitted with ZORBAX Eclipsed plus Phenyl-Hexyl column (4.6 x 250 mm, 5µm) and Agilent ZORBAX Eclipsed Plus Phenyl-Hexyl guard column (4.6 x 12.5 mm, 5µm) following ISO 14502–2:2005(ed.) method. The composition of solvent water: acetonitrile: acetic acid (89:9:2 v/v) were used as mobile phase A and acetonitrile: water: acetic acid (40:9:1 v/v) as mobile phase B. 20 µg/ml EDTA was weighed and added to both the mobile phases to effectively sequester Fe^{3+} present in the solvent as even a small

amount of Fe^{3+} can cause significant on column degradation of the catechins. Flow rate of the column was fixed at 1 ml/min. The temperature was set at 20 ± 0.5 ˚C and UV detector was set at 278 nm. The binary gradient condition was carried out with 100 % mobile phase A for 10 min, after that over 15 min a linear gradient to 68% of mobile phase A, 32% of mobile phase B and hold at this composition for 10 min. prior to next injection, it was reset to 100% mobile phase A and allow to equilibrate for 10 min. The results were obtained by comparison of peak area covered by individual catechins with standard caffeine graph.

3.12 Tea Leaf biophysical characters: The tea leaf biophysical characters like trichome density and leaf thickness were measured by following the methodology Bindu and Pramanik (2017).

3.12.1 Trichome density: Ten leaves of almost similar age were plucked from each tea cultivar at peak infestation period of *H. talaca*. One square centimeter leaf area was measured by using graphpaper and was cut for measuring trichome density. Number of trichome per sq. cm on leaf lamina and midrib on both the surface (base, middle and tip portions) were counted under a stereomicroscope (Fig. 3.10).

3.12.2 Leaf thickness: The collected tea leaves of each variety were taken and cross section cut with a sharp blade at three different parts of the lamina. Then the thickness was measured using stage and ocular micrometer.

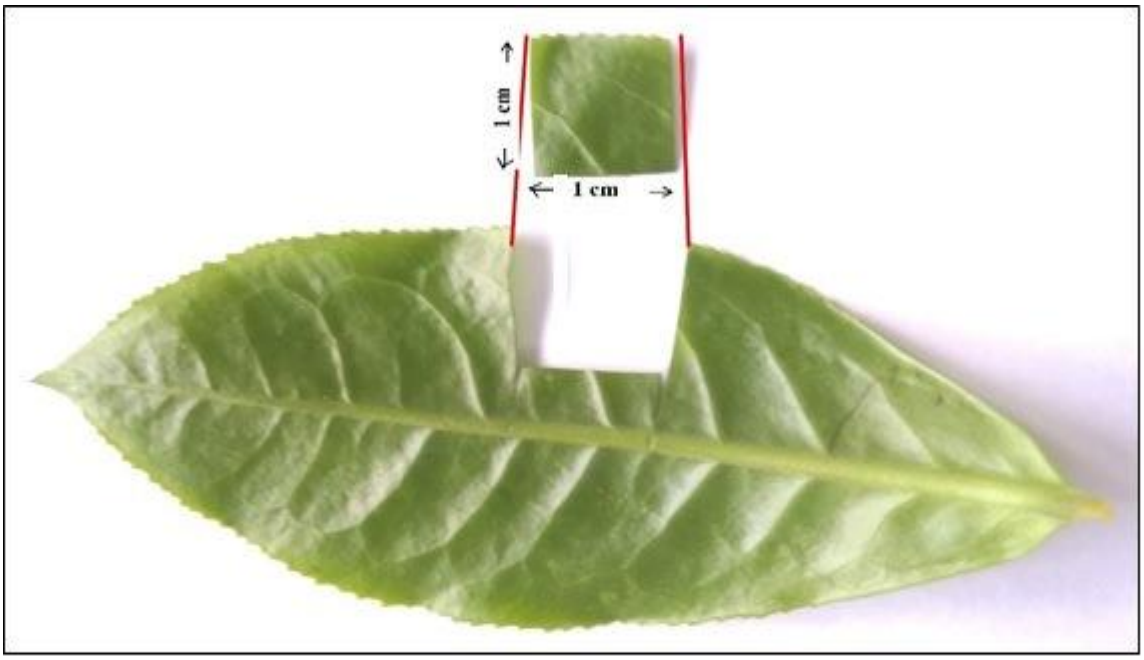


Fig. 3.10: Measuring of trichome density and leaf thickness

3.13 Predatory efficiency of the predators *S. collaris* and *E. furcellata* on *H. talaca*

3.13.1 No-choice feeding: In order to study the predatory efficiency of *S. collaris* and *E. furcellata* in no-choice condition, wherein different larval instars of *H. talaca* like second, third, fourth and fifth respectively were offered individually. Fifteen each larval instars of *H. talaca* were transferred into separate glass chimney from the laboratory culture. Tea shoots (three leaves and bud) in small glass vials were put in that glass chimney as food of larvae. Individual life stages of both the predators (nymphs and adults) were also introduced into the same chimney containing the larvae of *H. talaca*. The individual life stage wise prey consumption was recorded at 24h intervals by counting the prey number in each chimney. New tea were provided to the newly replenished prey stages and cleaning of chimney were done on a daily basis. Method was adopted from Barua *et al.,* (2016b).

3.13.2 Free-choice feeding: To study the predatory efficiency of *S. collaris* and *E. furcallta* the predators in free-choice condition of feeding, different larval stages of *H. talaca* were provided together to different life stages of both the predators. In each glass chimney with tea shoots released a total of 20 larvae (4 larvae of each instar) of *H. talaca*. Consumption and preference of different life stages of the predators were recorded and tabulated by counting each instar of prey larvae at 24h interval. Statistical analysis: The data recorded from both the experiments of predatory efficiency of *S. collaris* and *E. furcellata* subjected to analysis of variance (ANOVA) and means were separated by the Tukey's multiple comparison test.

3.14 Predatory behaviour of *S. collaris* and *E. furcellata*: To record the predatory behaviour of *S. collaris* and *E. furcellata* on the different instars of larvae of *H. talaca*, an experiment was conducted using a large petridish (14.5cm in diameter). Each life stage of *S. collaris* were maintained under starved condition for 1.5h and then placed into that petridish with different larval instars of *H. talaca* separately. The sequential pattern of predatory behaviours like the time taken in approach, attacking, paralyzing and sucking on the prey by different life stages of both the predators were assessed and recorded the time as well (Rajan *et al.,* 2017). Mean were calculated by Tukey-Kramer HSD Post-Hoc Test.

3.15 Stage specific predation of *S. collaris* and *E. furcellata*: Stage specific predation of different life stages of reduviid bug *S. collaris* and pentatomid bug *E. furcellata* were also studied under the same laboratory conditions. Different larval instars of *H. talaca* were provided to the individual stages of both the predatory bugs and the maximum number of prey consumption and type of feeding were recorded at 24h interval.

3.16 Mass rearing of *S. collaris* on larvae of *C. cephalonica*: Healthy adults *S. collaris* were collected from the study location and kept inside a glass chimney. Wet cotton piece was put inside for maintaining the moisture content. Larvae of *C. cephalonica* were provided from the laboratory stock culture as food of *S. collaris*. Eggs were collected and put into separate container. Newly hatched nymphs of *S. collaris* were reared by providing sufficient food as larvae of rice meal moth. The rearing condition was cleaned and larvae of rice meal moth replaced daily.

3.17 Field release of *S. collaris*: A small scale field trial was conducted at Kurti TE and Hope TE of Dooars region. Two plots were selected, one for control plot and another plot for release of *S. collaris*, each plot contains contained 300 bushes. The population of *H. talaca* was assessed by taking the count of larvae per bush before and after release of *S. collaris*. Reduction of population of *H. talaca* after release of *S. collaris* were assessed at 48h intervals up to 13^{th} day by taking the initial count and every 48h interval count of the population. Data were subjected to analysis of variance (ANOVA) according to Tukey's multiple comparison test.

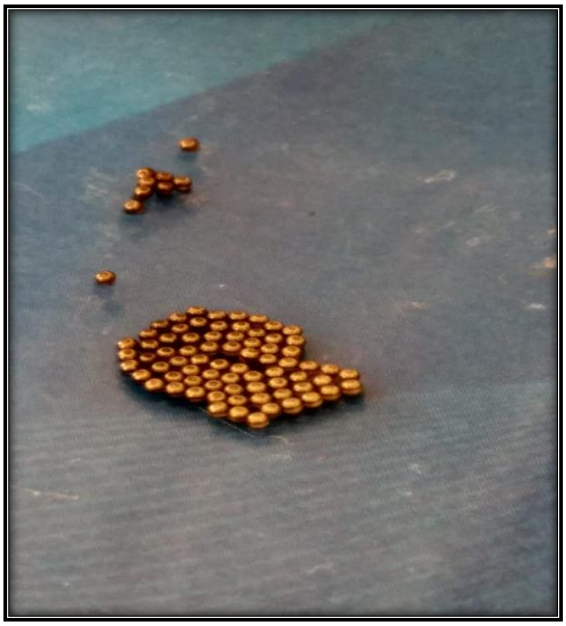
3.18 Parasitization on different host instar and affects food consumption and growth: The newly molted II, III and IV instar larvae of *H. talaca* were provided to adult parasitoid wasps of *C. ruficrus* for parasitization. After oviposition by the female parasitoid, the parasitized II, III and IV instar larvae were reared separately put in Tarson Container (Diameter 4.3, height 5.4cm). Leaf discs (3.2 cm in diameter) were provided as food. Similarly II, III and IV instar un-parasitized larvae were also reared in same experimental conditions, which served as control. Food consumption and host body weight of parasitized larvae were recorded at 24h interval by taking the initial and final weight of leaf disc and larvae until the egression of larvae of parasitoid wasp, similarly the control (un-parasitized) larval food consumption and body weight of the healthy larvae were also monitored at 24h interval until egression date of parasitoid from host Chen *et al*., (2016).

3.19 Differential haemocyte count (DHC) and morphology of haemocytes: For assessing the DHC a small drop of haemolymph was taken from parasitized and un-parasitized larvae separately on a grease free glass slide by clipping the pro legs. The air dried slide was stained with Giemsa (4%) for 2-3min and subsequently the slide was rinsed with distilled water, air dried and mounted with DPX (Mountant for histology). The morphological observation of haemocyte and DHC, were taken under phase contrast microscope at 40x magnification and images were captured by digital camera (Olympus BX51). For the estimation of DHC cell categories were counted in 200 cells from randomly chosen area of stained haemolymph

smear slide. The stained haemolymph smear slides were observed and the cell diameter were recorded under light microscope by using ocular and stage micrometer Sanap *et al*., (2016) for the determination of the size and shape and number of the haemocytes. Data generated on DHC were analyzed by one- way analysis of variance (ANOVA) with Tukey- HSD multiple comparison test using SPSS 17.0 package. Morphological analysis of different haemocytes of un-parasitized and parasitized larvae of *H. talaca* was also analyzed by t-test (SPSS 17.0).

3.20 Effect of pesticides on natural enemies (*S. collaris. E. furcellata* and *C. ruficrus*) of *H. talaca*: Study on the toxic effect of certain recommended synthetic chemical and bio-formulations (Acaricides and insecticides) on immature and mature stages of natural enemies of *H. talaca* was also conducted under laboratory conditions. From the stock culture different stages of natural enemies was taken and used for the experiment. Ten insects were taken into each glass chimney for a single replication and each treatment were replicated for five times. The pesticides of Quinalphos 25 EC (Organophosphates: Ekalux, Syngenta India Ltd. Acetylcholin esterase (AChE) inhibitors; Nerve action IRAC MoA No. 1B), Thiamethoxam 25WG (Neonicotinoids:Actara, Syngenta India Ltd, Nicotinic acetylcholine receptor (nAChR) competitive modulators; Nerve action IRAC MoA No.4A); Emamectin benzoate 5% SG (Avermectins: Missile, Crystal Crop Protection Pvt. Ltd., Glutamate-gated chloride channel (GluCl) allosteric modulators; Nerve and muscle action IRAC MoA No. 6), Deltamethrin 2.8 EC (Synthetic pyrethroids 3A: Decis, Bayer Crop Science Ltd., Sodium channel modulators Nerve action, IRAC MoA No. 3A), Bifenthrin 8% EC (Synthetic pyrethroids: Markar Super, Dhanuka Agritech Limited, Sodium channel modulators Nerve action, IRAC MoA No. 3A), Flubendiamide 20 WG (Diamides: Takumi, Rallis India Limited, Ryanodine receptor modulators, Nerve and muscle action IRAC MoA No. 28), Fenpyroximate 5EC (METI acaricides and insecticides: Mitigate Isagro Asia Agrochemicals Private Limited, Mitochondrial complex I electron transport inhibitors IRAC MoA No. 21A), *Beauveria bassiana* formulation and Azadirachtin 5% EC diluted in distilled water using the recommended dose and exposed. Control was treated with water. After 20minutes of the spray sufficient number of *H. talaca* larvae to the predators and cotton swab of 10% honey solution along with tea shoots were provided as food source. Spraying was performed with glass atomizer, maintaining the distance of 30-40cm. The toxic effect of each pesticides were observed at 24h intervals and the percentage of mortality were recorded by followed the methodology of Vasanthkumar et al., (2011). All the data were subjected to analysis of variance (ANOVA) according to Tukey's multiple comparison test.


Chapter-IV
Results




RESULTS

4.1 Observation on climatic parameters

4.1.1 During 2017-2018: During the first season of observation the maximum value of T. Max (38.2^0C) was noted in July while minimum value of T. Max (28.1^0C) was noted in January at the first location (L1, Banarhat TE) (Table 4.1.1). Whereas, at the second location (L2, TRA experimental plot), the maximum value of T. Max (32.0^0C) and minimum value of T. Max (23^0C) which were comparatively lower than L1. The higher value of T. Min was 24.2^0C in July and 21.9^0C in August at L1 and L2 respectively. Whereas, the value of T. Min was recorded in January at both the locations. On the other hand, the maximum value of RF was 708.6 mm. At L1 the highest RH was noticed in September (90.7%), when the maximum rainfall was observed in June (917.7mm). In case of L2 the highest RH percentage was observed in June (90.3%) while the highest RF occurred during August (997.4mm). Both the parameters were observed to be low in winter months.

4.1.2. During 2018-2019: The maximum T. Max was recorded as 39.1^0C in July and the minimum T. Max 25^0C in January (4.0^0C) at L1, while at TRA same parameters were recorded in June (32.9^0C) and in January (22.5^0C) at L2. The maximum T. Min was noticed in August (24.0^0C), whereas minimum T. Min was recorded in January (4.0^0C) at L1. Whereas at L2 the maximum T. Min was observed in July (21.8^0C) and minimum T. Max (7.2^0C) in January were also observed. The RH attained the peak in August (90.8%), while highest RF was 1021.0mm at L1. In case of L2, maximum RH percentage was recorded in June (90.0%) and highest rainfall was observed in September (1306.3mm) (Table 4.1.2).

Table 4.1.1: Climatic factors observed during first season (2017-2018) at both the study locations

Months	Locations of the study sites							
	Banarhat TE				TRA experimental plot			
	Temperature (^{0}C)		RH (%)	RF(mm)	Temperature (^{0}C)		RH (%)	RF(mm)
	T. Max	T. Min			T. Max	T. Min		
Feb	30.0	8.00	65.4	5.070	27.0	11.4	63.0	0.000
Mar	32.1	9.01	68.7	79.50	27.4	13.1	68.7	88.60
Apr	35.3	15.0	79.4	203.8	30.0	17.3	77.7	256.6
May	38.0	18.3	88.6	425.5	31.2	19.4	87.9	445.6
Jun	36.0	23.0	87.8	917.7	32.0	21.3	90.3	994.2
Jul	38.2	24.2	88.9	565.6	31.5	21.8	86.0	748.3
Aug	37.3	24.0	88.4	708.6	31.4	21.9	86.7	997.4
Sep	37.0	23.0	90.7	549.7	31.9	21.4	89.4	993.9
Oct	35.1	17.1	73.2	335.5	30.6	18.3	75.8	150.9
Nov	32.0	12.0	77.3	1.500	28.6	12.7	78.3	5.100
Dec	29.0	9.02	63.7	0.000	26.5	10.1	65.9	0.000
Jan	28.1	4.00	61.2	0.000	23.0	6.6	64.4	0.000

Table 4.1.2: Climatic factors observed during second season (2018-2019) at both the study locations

Months	Locations of the study							
	Banarhat TE				TRA experimental plot			
	Temperature (^{0}C)		RH (%)	RF(mm)	Temperature (^{0}C)		RH (%)	RF(mm)
	T. Max	T. Min			T. Max	T. Min		
Feb	26.3	12.3	63.8	0.0000	25.4	10.8	69.1	0.0000
Mar	32.0	13.1	69.8	82.300	28.7	14.0	72.6	136.70
Apr	34.0	15.0	77.4	142.10	30.3	16.7	70.9	150.40
May	35.1	18.1	80.5	507.00	32.4	18.5	87.2	906.80
Jun	38.0	18.2	89.6	854.50	32.9	20.9	90.0	1095.8
Jul	39.1	22.0	90.5	584.00	31.4	21.8	88.2	1091.9
Aug	38.0	24.0	90.8	249.00	32.3	21.6	84.2	1085.6
Sep	33.4	16.1	82.9	1021.0	31.3	20.5	82.9	1306.3
Oct	32.0	15.0	74.8	26.500	29.6	16.1	77.8	174.80
Nov	31.1	11.2	78.2	19.000	27.4	11.8	83.3	11.200
Dec	27.0	5.00	62.2	5.3000	25.2	8.4	66.1	8.9000
Jan	25.0	4.00	60.5	0.0000	22.5	7.2	64.4	0.0000

4.2. Study on the bio-ecology and seasonal incidence of *Hyposidra talaca* in relation to the climatic parameters of *Dooars* region of West Bengal

4.2.1. Observation on bio-ecology of *H. talaca*: Study on the bio-ecology of *H. talaca* is mostly concerned with the importance of the alternative host plants that assisted in the perpetuation of the pest. To assess the relative importance of alternative host plant as food source and also as a substrata for egg-laying of the pest during the off-season. Observation was carried out and around eight broods of *H. talaca* were noticed per year. The selected plots were pruned during 2017-2018 and subsequently the plots remained un-pruned during 2018-2019 at both the locations (L1 and L2) following the standard management practices. The study on the bio-ecology *H. talaca* was carried out in such conditions.

4.2.1.1. Observations on host plant as alternative food source: The newly hatched larvae of *H. talaca* were found to move to another plants and settled down. Soon it started feeding on them. Apart from tea plant, larvae of *H. talaca* were found to fed on some weeds, shade trees and other plants mostly belonging to a the plant families like Asteraceae, Phyllanthaceae and Annonaceae respectively (Fig. 2.1.1). Only the early instars were noticed to feed vigorously on the alternative host plants but the later instars of advanced growth staged tend to move to the tea plants.

Fig. 2.1.1 Host plant as alternative food source, larvae of *H. talaca* were found to feed on (a) *Phyllanthus* sp. (b) *Ageratum conyzoides* (c) *Polyalthia longifolia*

4.2.1.2. Observations on host plant for egg-laying: A number of host plants were noticed that are used as substrata for egg laying at both the locations. Apart from tea, eggs were laid on shade trees and other trees that are adjacent to the plantation area. Mango and wild Neem (Bakain) trees were found, in the present observation and the barks also act as the substrata for egg laying of *H. talaca* (Fig. 2.1.2.).

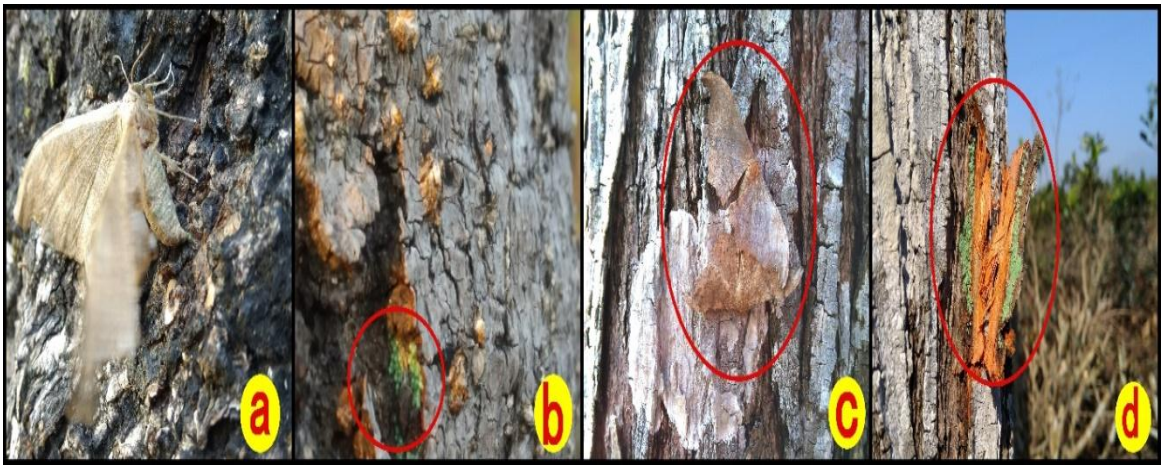


Fig. 2.1.2. Egg-laying of *H. talaca* on alternative hosts, (a) During egg laying on mango tree, (b) Egg clutches on mango tree, (c) Mating of male and female on Bakain tree, (d) Egg clutches on Bakain tree bark

4.2.2. Seasonal abundance of *H. talaca* during the period of observation

4.2.2.1. Periodicity of *H. talaca*: The periodicity was noted during the study periods for two consecutive years (2017-2018 and 2018-2019). For each of the years, incidence of the pest population was observed at fortnight interval and accordingly tabulated. Data was collected for each of the years separately and also for the two selected locations (L1 and L2). 'Trends line' was accordingly generated in order to predict the periodicity of the insect pest population. Relative difference, in consideration of the incidence of insect pest at two selected places (L1 and L2) are also noted in both the seasons.

4.2.2.1.1. During 2017-2018: Almost similar population trends were observed in both the locations (L1 and L2). The population increased gradually from February (6.4/bush).Noticeable fluctuation of population was observed during March extending upto the first week of April at first location (L1). The population of *H. talaca* attained the peak in June (13.1/bush) followed by a drastic reduction of population during July (4.2/bush). The population then increased in September (12.3/bush).

Pest dynamics at the second location (L2) had a conformity with the first place of observation. However the numerical abundance of the pest at the second location was comparatively higher along the observation period. In June, the population was 14.2/ bush, while in September it was 10.2/bush (Fig. 2.2.1.1).

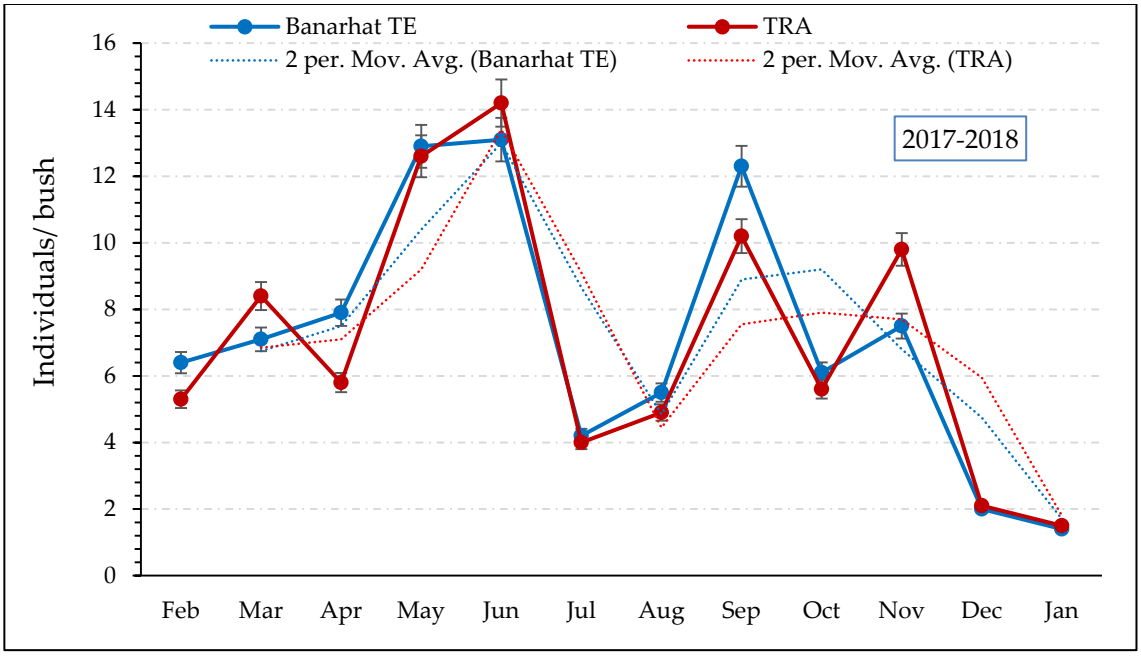


Fig. 2.2.1.1: Seasonal abundance of *H. talaca* and the trends line (in dotted line) suggesting the prediction of the incidence of *H. talaca* during 2017-2018 for both the study locations

4.2.2.1.2. During 2018-2019: The peak population at L1 was recorded in June (19.8/bush) while the least was recorded in July (8.20/bush) at L1. However at L2, the highest number of larvae/bush was recorded in June (19/bush) and comparatively less population was observed in July (8.20/bush). Besides the overall dynamics at L2 was similar to L1.

The population subsumed in the month of August and December respectively at both the places. A maximum of about eight 'broods' were observed in a year devoid of any distinct diapause stage even in winter months. The numerical abundance of pest population was comparatively higher during the study period of 2018-2019 compared to 2017-2018 (Fig. 2.2.1.2).

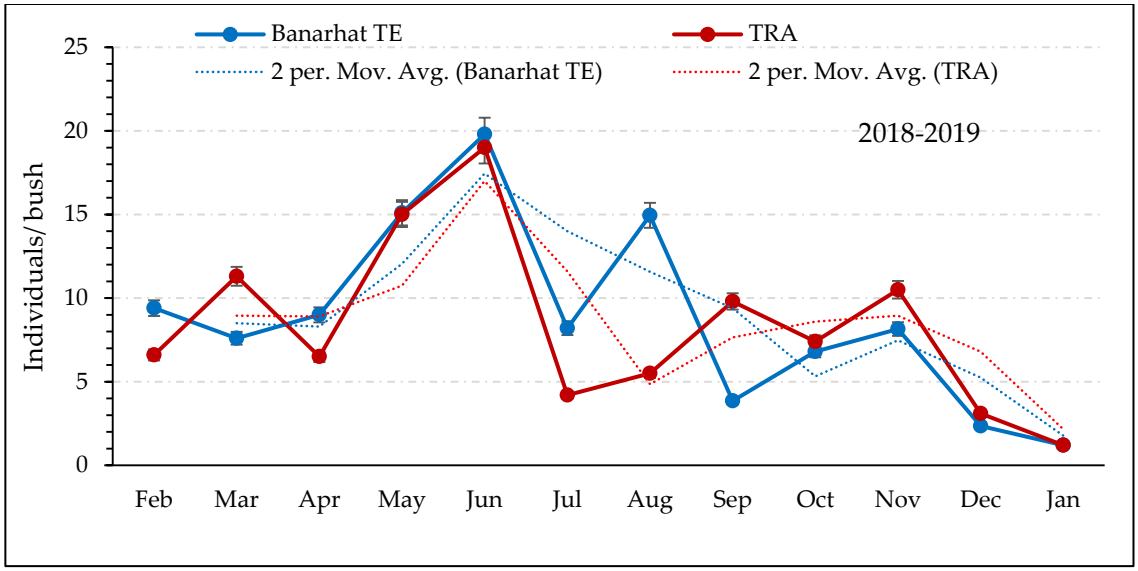


Fig. 2.2.1.2: Seasonal abundance of *H. talaca* and the trends line (in dotted line) suggesting the prediction of the incidence of *H. talaca* during 2018-2019 for both the stud locations

4.2.2.2. Observation of 'trends line' of *H. talaca* during the period of observation: A 'prediction line' for the immediately subsequent fortnight can be generated taking in consideration of the incidence of the pest population for the first two fortnights. Observation on trends line for both seasons at two places were noted at 2% moving average scale. Starting from February to June, the observed value on the incidence of *H. talaca* apparently synchronized with the predicted value of both study places. But after that, the observed population showed rapid oscillatory fluctuation from February to November for both the years. For these reasons the trends line can be considered only as a primary information to predict the population of *H. talaca* at late season. However, after February, the incidence of *H. talaca* population can be more precisely predicted from the trends line (Fig. 2.2.1.1 and 2.2.1.2).

4.2.2.3. Impact of abiotic parameters: Grossly the abiotic factors encompasses four prime climatic parameters that were considered in the present study. Value of individual climatic parameter and their impact were recorded fortnightly.

4.2.2.3.1. Observation and correlation value: Impact of individual abiotic parameters on the incidence of *H. talaca* at both places (L1 and L2) was assessed separately for the study period

4.2.2.3.1.1. During 2017-2018: T. Max imparted significant positive effect (r=0.6233 and r=0.5865) on the abundance of *H. talaca* at both the locations L1 and L2 respectively

(Table 4.2.3.1). Effect of T. Min, though positive (r=0.5283 and r=0.4928) but insignificant during the period of observation in both the locations. The extent of humidity during the study period was 61.2-90.7% at both the study locations. A significantly positive (r=0.6735 and r=0.6363) impact of humidity was also noted during the period of observation irrespective of the two selected study places. RF was positively correlated (r=0.5493 and r=0.4226) with the abundances of *H. talaca*, but showed insignificant relationship.

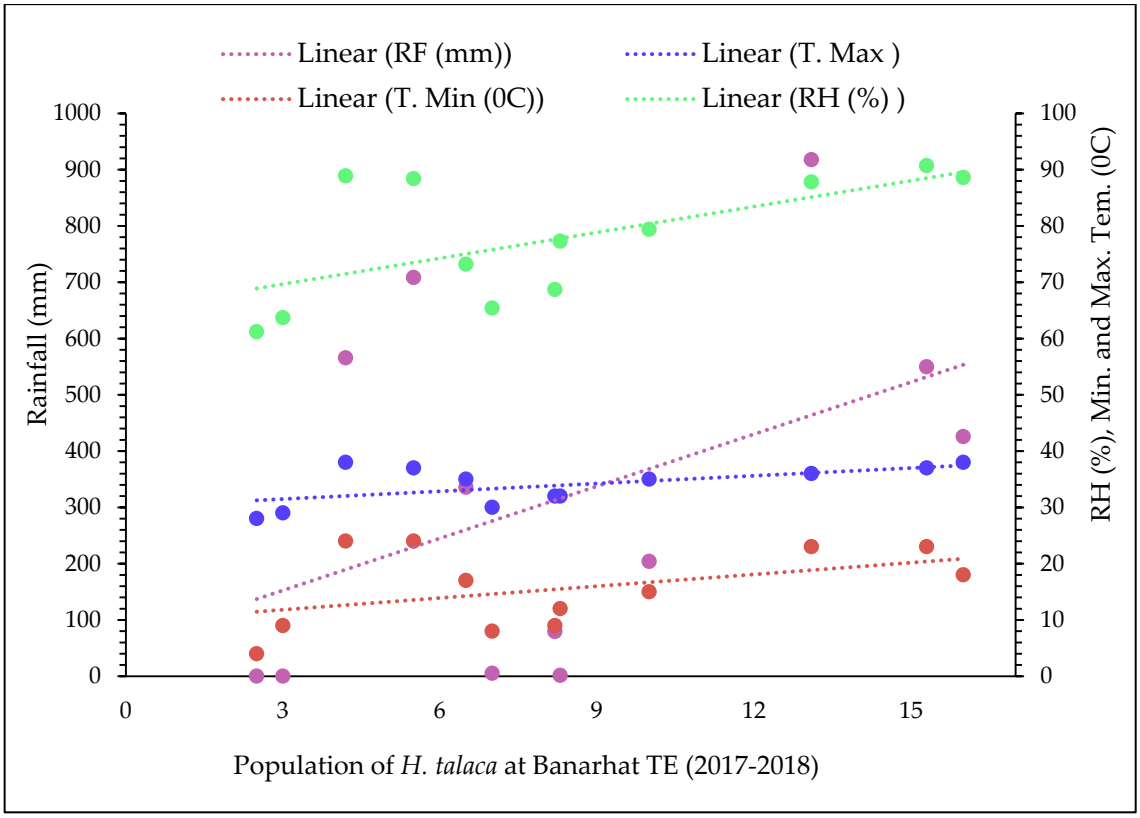


Fig. 2.2.3.1: Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2017-2018 at Banarhat TE

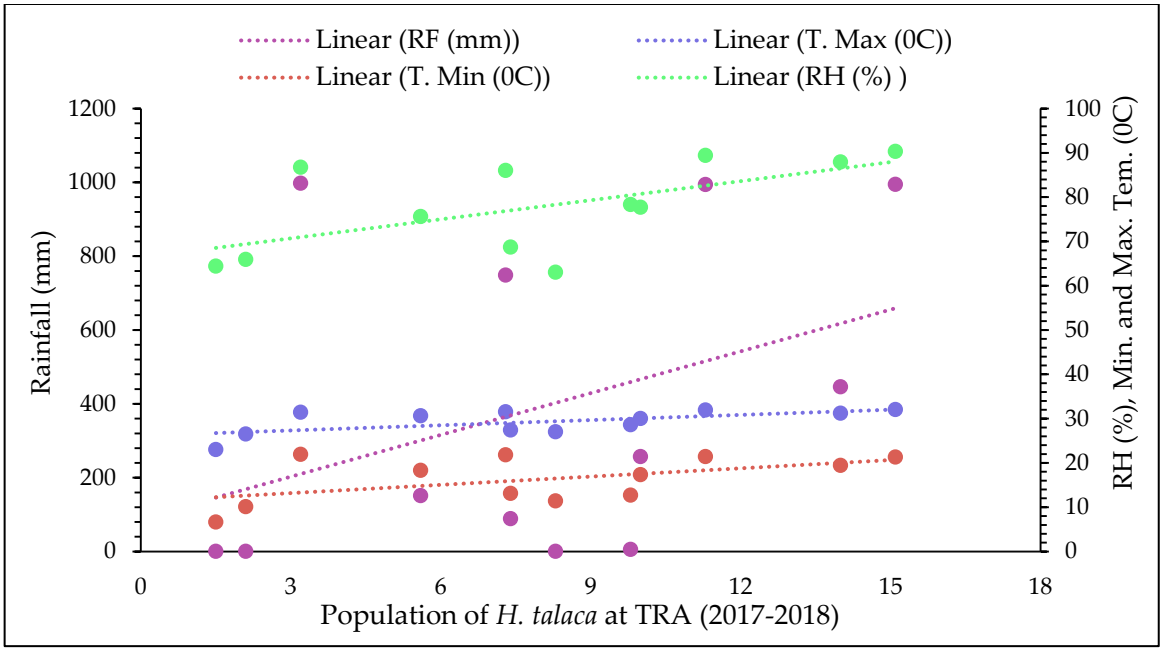


Fig. 2.2.3.2: Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2017-2018 at TRA experimental plot.

4.2.2.3.1.2. During 2018-2019: Significant positive effect (r=0.6902 and r=0.6073) of T. Max on the incidence of *H. talaca* was noted in both the location L1 and L2 (Table 4.2.3.1). Like the previous year, the effect of T. Min, though positive but insignificant. Humidity during the study periods was extended to 60.5-90.8%, which showed the positive correlation(r=0.6628 and r=0.6384) with the incidence of target pest. On the other hand, a positively insignificant impact of rainfall was observed with the population trends of *H. talaca*.

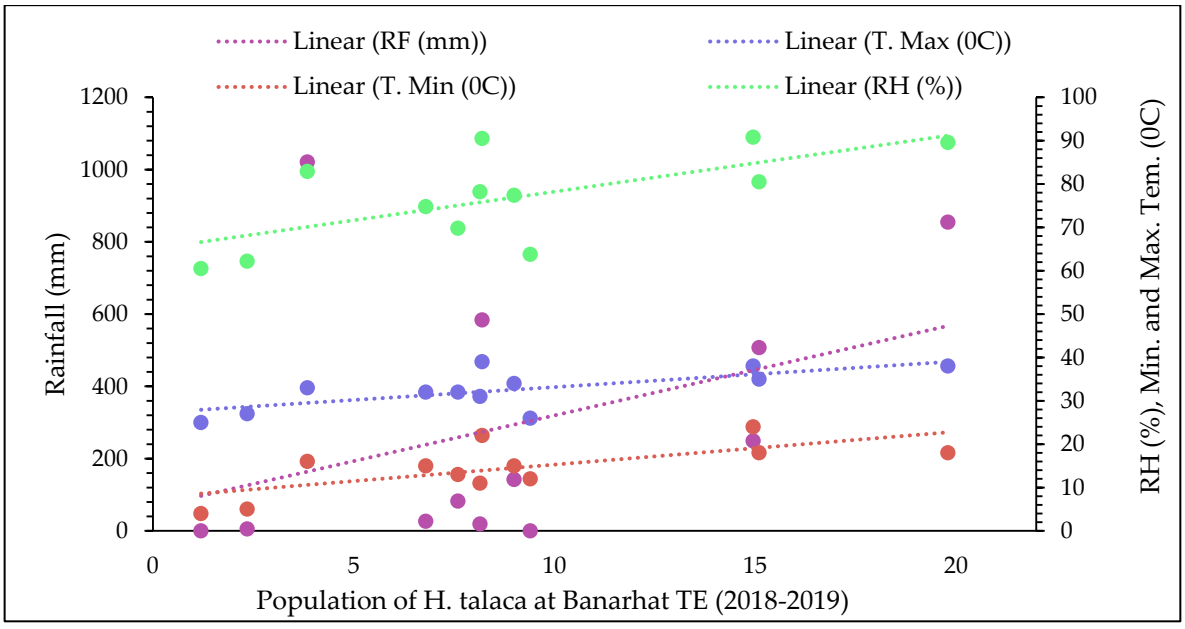


Fig. 2.2.3.3: Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2018-2019 at Banarhat TE

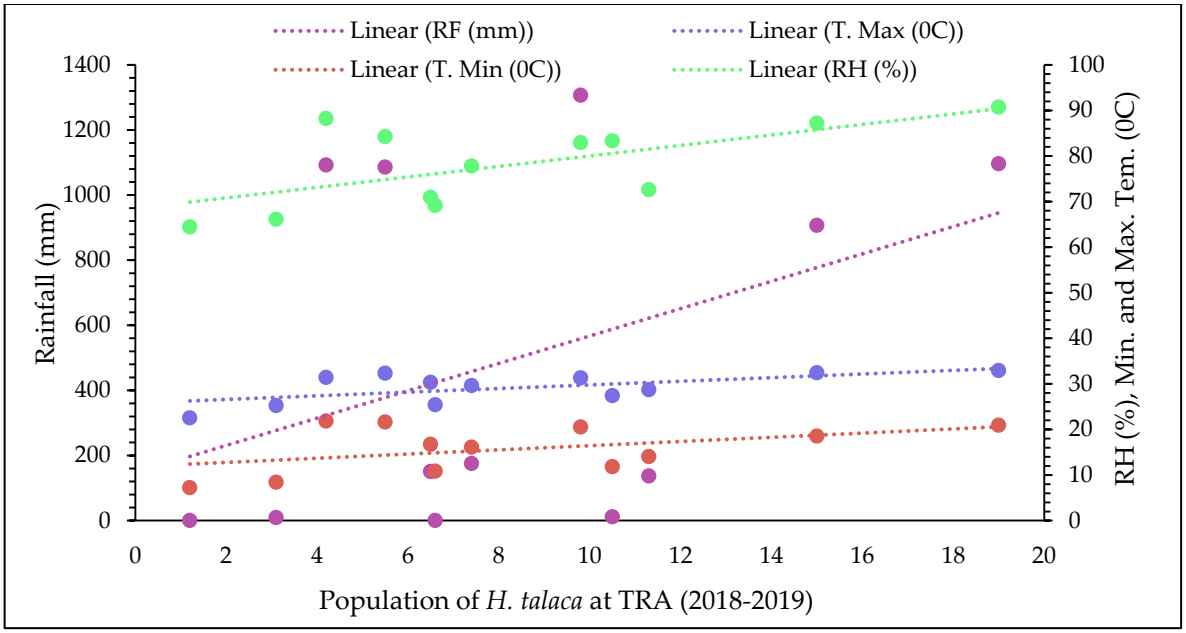


Fig. 2.2.3.4: Regression line representing relationship between abiotic factors and population abundance of *H. talaca* for the season 2018-2019 at TRA experimental plot

Table 4.2.3.1: Correlation between *H. talaca* populations and agro-climatic conditions of L1 and L2

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	0.6233*	0.5865*	0.6902*	0.6073*
T. Min	0.5283	0.4928	0.6932*	0.4489
RF	0.5493	0.4226	0.3814	0.3959
RH	0.6735*	0.6363*	0.6628*	0.6384*

*Values are significant at $p < .05$. (L1: Banarhat TE, L2: TRA Experimental plot)

4.2.2.3.2. Regression analysis

4.2.2.3.2.1. During 2017-2018: The regression analysis showed that, all of the abiotic factors were influenced the fluctuation of population of *H. talaca* (Fig. 2.2.3.1). The regression equations (y = 0.570x + 29.81 and y = 0.408x+26.38) showed positive relation between the looper population and T. Max at L1. But the intercepts (0.955 and 0.648) and R^2 values (0.279 and 0.242) of the equations for T. Min indicate insignificant relationship with the target pest at L1 and L2 (Fig. 2.2.3.1). The regression equations for rainfall showed the insignificant positive relation at both the study locations, while RH also showed positive equation (y = 1.91x + 64.02, R^2 = 0.454 and y = 44.91x+74.17, R^2 = 0.178) with the population trends of *H. talaca* from for L1 and L2 (Table 4.2.3.2).

4.2.2.3.2.2. During 2018-2019: The regression analysis for T. Max, showed the equations (y = 0.593x + 27.24 and y = 0.399x +25.78), positive R^2 values (0.476 and 0.368) indicated insignificant correlation with *H. talaca* populations at L1 and L2 respectively (Fig. 2.2.3.3). The regression equations (y = 0.759x + 7.68, R^2 = 0.480 and y = 0.46x + 11.85, R^2 = 0.201) of L1 and L2 showed positive but insignificant relation between T. Min and the pest (Table 4.2.3.2). The R^2 values (0.145 and 0.407) from the regression equation for both the locations showed insignificant but positive relation between rainfall and population trends of *H. talaca*. Whereas RH also showed positive regression equations for L1 and L1 with *H. talaca* population (Fig. 2.2.3.4).

Table 4.2.3.2: Regression equation between *H. talaca* populations and climatic factors of both the locations

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	y = 0.570x + 29.81 **R^2 = 0.388**	y = 0.408x+26.38 **R^2 = 0.344**	y = 0.593x + 27.24 **R^2 = 0.476**	y = 0.399x +25.78 **R^2 = 0.368**
T. Min	y = 0.955x + 8.617 **R^2 = 0.279**	y = 0.648x+11.71 **R^2 = 0.242**	y = 0.759x + 7.68 **R^2 = 0.480**	y = 0.46x + 11.85 **R^2 = 0.201**
RF	y = 44.58x -5.02 **R^2 = 0.301**	y = 1.633x+66.33 **R^2 = 0.404**	y = 25.28x + 66.68 **R^2 = 0.145**	y = 1.151x+ 68.51 **R^2 = 0.407**
RH	y = 1.91x + 64.02 **R^2 = 0.454**	y = 44.91x+74.17 **R^2 = 0.178**	y = 1.318x + 65.06 **R^2 = 0.439**	42.02x+ 46.82 **R^2 = 0.156**

4.2.3. Study on biology and survivality of *H. talaca* under laboratory conditions: During the off season, following pruning of the tea plant, observation on the life cycle is restricted until and unless, the detail biology of *H. talaca* is depend on alternative host plant. Study was conducted on three different diets including two alternative food sources, to assess the comparative survivality of the pest considered for the experimentation. Accordingly life table of the pest was constructed.

4.2.3.1. Biology of *H. talaca* on three different diets: Study on the biology of *H. talaca* was conducted on three different diets such as tea leaf (natural diet), artificial diet as prepared in the laboratory and a shade tree (*Acacia lenticularis*) leaf under laboratory conditions. Life stages of *H. talaca* consists of egg, larva (I-V instars), pupa and adult. The biological parameter was recoded as the average of all seasons, throughout a year (Table 4.2.3.3**)**.

4.2.3.1.1. *Eggs*: Eggs were laid into the cracks of shade tree bark, provided in the glass chimney. Clutches of eggs are greenish in colour appearing as bunch of grapes. The colour transformed from greenish to brownish yellow and finally into blackish prior to hatching. In a total 589.6±15.6 eggs were laid by a single female moth when reared on artificial diet. But when reared on tea leaf and shade tree leaf the values were 578.8±26.3 and 566±18.8 respectively. Variation of incubation period was also observed when reared on the three different diets. In case of artificial diet it was 6.4±0.9 days (Fig. 2.3.1). For natural diet and artificial diet the duration were 7.6±0.5 and 7.0±0.7 days respectively.

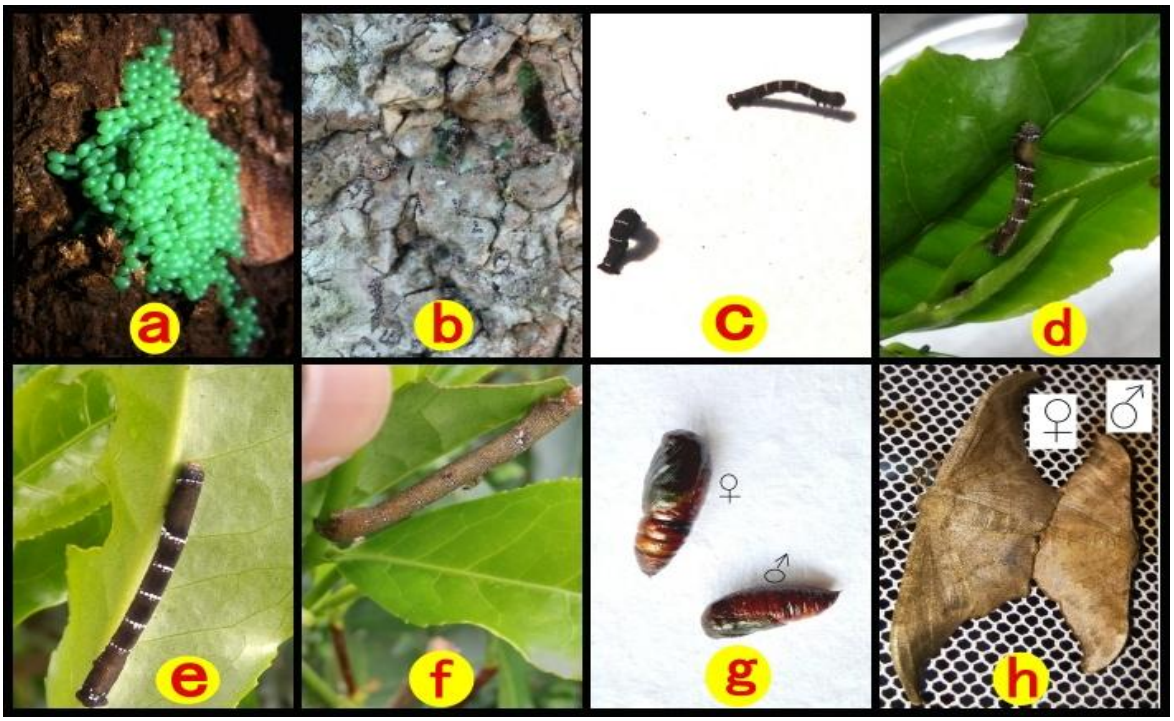


Fig. 2.3.1: Stages of life cycle of *H. talaca*: (a) clutches of eggs, (b) newly hatched I instar larvae, (c) II instar larvae, (d) III instar larva, (e) IV instar larva, (f) V instar larva, (g) male and female pupae and (h) mating of male and female moths

4.2.3.1.2. Larval instars: The black coloured (with white stripe) I instar larva is very small in size. It feeds on tea bud. Apart from tea bud, first or second leaf from the top of the tea plant was also affected by the early instars. Pinhole formation in the leaves were also common. As the mature tea leaves are comparatively less convenient to consume, the larvae generally scares to eat it. For this reasons, scratches in the lower portion of the mature leaf was noted due to invasion of the third instar larva. Duration of I instar larva was less on artificial diet (3.8±0.8 days) in comparison to tea leaf (4.2±0.8 days) and shade tree leaf (4.8±0.4 days) respectively. Both of the II and III instar larvae are dark black in colour with six white stripes. The black colour of the larvae changes in to dark brown and transformed into IV instar larva. The V instar larva was initially dark that turned into light brown as the growth stage advanced.

White stripes were noted dorsal to the body surface. All of the larval stages has three pairs of thoracic prolegs and one pair of abdominal prolegs. Duration of II instar larval stages varied significantly depending on dietary source. When reared on shade tree leaf, III instar larva took 5.0±1.0 days to attain adult stage. Duration of larval stage was comparatively less on natural diet and minimum on artificial diet. The duration of I and IV instar larvae were apparently same when reared on the same food. However, variation was noted when food sources differed. Irrespective of the food source the duration of fifth instar larva was same. Highest larval duration was noted for shade tree leaves (26.8±0.5 days). This was followed by tea leaf (25.2±2.4 days) and artificial diet (27.6±0.9 days) in descending order (Table 4.2.3.3). The larvae stopped feeding and got entry into the pupal stage.

4.2.3.1.3. Pupa: The pupa is dark brown in colour with distinct anal process. Pupation in field conditions occurred in soil while in laboratory conditions wooden dust acted as a pupation site. Duration of pupal period varied considerably depending on dietary sources. Maximum was noted for shaded tree (7.6±0.5 days) while the least was noted for artificial. Rearing on tea leaf had shown an intermediate pattern of pupal duration.

4.2.3.1.4. Adults: Adult female was characterized by the presence of both grayish and blackish brown wings. Forewings is wavy with dark semi-circular patches having distinct sub-marginal notch. In case of male moth, sub-marginal notch is absent. Pre-oviposition period is1.0 to 1.4 day. The ovipositional period was respectively 6.0±0.7, 6.4±0.5 and 5.8±0.8 days when reared on natural diet, artificial diet and shade tree leaves. Maximum longevity of the moth were recorded on artificial diet and while the least was noted for tea leaf.

Table 4.2.3.3: Biology of *H. talaca* reared on three different diets

Parameters	Reared on		
	Natural diet (Tea leaf)	Artificial diet	Shade tree leaf
Egg (Number)	578.8±26.3^{NS}	589.6±15.6^{NS}	566±18.8^{NS}
Incubation period (Days)	7.0±0.7^{ab}	6.4±0.9^{b}	7.6±0.5^{a}
I (Days)	4.2±0.8^{ab}	3.8±0.8^{b}	4.8±0.4^{a}
II (Days)	4.4±0.9^{b}	4.0±0.7^{ab}	4.8±0.4^{a}
III (Days)	4.6±0.5^{b}	4.2±0.8^{ab}	5.0±1.0^{a}
IV (Days)	4.0±1.0^{b}	3.6±1.1^{b}	4.8±0.8^{a}
V (Days)	9.0±0.7^{NS}	8.8±0.8^{NS}	9.2±0.8^{NS}
Total larval period (Days)	26.8±0.5^{b}	25.2±2.4^{b}	27.6±0.9^{a}
Pupal duration (Days)	7.2±0.8^{a}	6.4±0.5^{b}	7.6±0.5^{a}
Pre-ovipositional period (Days)	1.4±0.5^{NS}	1.2±0.5^{NS}	1.4±0.5^{NS}
Ovipositional period (Days)	6.0±0.7^{NS}	6.4±0.5^{NS}	4.6±0.5^{NS}
Male longevity (Days)	4.8±0.5^{ab}	5.0±0.7^{b}	5.2±0.5^{a}
Female longevity (Days)	6.0±0.8^{NS}	6.2±1.0^{NS}	6.0±1.0^{NS}

Values are the means (±SD) of ten replications. Values followed by the same alphabet in the same row are not significantly different at 5% level of significance according to Tukey's test. (NS, non-significance)

4.2.3.2. Survival percentage of *H. talaca* reared on three different diets: The survival rate of all the life stages was highest on artificial diet compared to tea leaf and shade tree

leaf. In case of artificial diet, the percentage of hatching of eggs was 98.2±0.9. The survivality of I, II, III, IV and V instar larvae were respectively 98.2±1.0, 87.6±1.1, 97.8±1.3, 98.4±0.2, 98.4±0.2 days. The rate of transformation from V instar larva was 98.0±0.4. While, in case of adult, the percentage of survivality was 98.6±0.5. On artificial diet, highest larval mortality was noted during the transition from I instar to II instar stage. Less mortality was observed during the formation of pupa for all of the diets (Table 4.2.3.4). Highest survivality (%) of moths were recorded on artificial diet followed by tea leaf and shade tree leaf respectively in descending order. But such differences are statistically insignificant.

Table 4.2.3.4: Survivality (%) of *H. talaca* on three alternative dietary sources

Survival % of	Dietary sources*		
	Tea leaf	Artificial diet	Shade tree leaf
Egg hatching	96.9 ± 1.4^{NS}	98.2 ± 0.9^{NS}	95.9 ± 0.7^{NS}
I	96.9 ± 1.4^{NS}	98.2 ± 1.0^{NS}	95.9 ± 0.7^{NS}
II	91.3 ± 1.3^{a}	87.6 ± 1.1^{b}	90.2 ± 1.4^{ab}
III	94.9 ± 0.2^{b}	97.8 ± 1.3^{a}	91.4 ± 0.7^{c}
IV	94.4 ± 0.6^{b}	98.4 ± 0.2^{a}	93.0 ± 0.5^{c}
V	93.9 ± 0.6^{b}	98.4 ± 0.2^{a}	92.5 ± 0.4^{b}
Pupa	97.8 ± 1.0^{b}	98.0 ± 0.4^{a}	92.6 ± 0.8^{c}
Adult	96.5 ± 0.5^{b}	98.5 ± 0.5^{a}	92.5 ± 0.1^{c}
Male	47.9 ± 0.6^{NS}	48.3 ± 0.8^{NS}	46.8 ± 0.2^{NS}
Feale	52.4 ± 0.8^{NS}	52.1 ± 0.8^{NS}	54.3 ± 0.2^{NS}

*Values are represented as mean±SD of five replications. Means followed by the same alphabet in a row do not differ significantly at p = 0.05 according to One-way ANOVA and Tukey's HSD.

4.2.3.3. Life table study of *H. talaca* reared on three different diets: Life table of *H. talaca* was constructed individually for all of the three dietary food sources (Table 4.2.3.5). The age specific fecundity rate (mx) was recorded as166.54 for artificial diet (Fig. 2.3.4), followed by164.64 and 156.36 were recorded for tea leaf (Fig. 2.3.3) and shade tree leaf (Fig. 2.3.5) respectively. Similarly, the age specific survival rate (lx) was 0.8 for artificial diet. While reared on tea leaf and shade tree leaf the value was 0.6. Net reproductive rate was recorded as 462.9±22.1 on artificial diet. This was followed by tea leaves (396.9±16.1) and shade tree leaves (377.6±20.0) respectively in discending order. Highest gross reproductive rate (∑mx) was 550.8±22.0 when *H. talaca* was reared on artifical diet. This was comparatively less for tea leaves (526.3±20.1) and shade tree leaves (505.4±25.0) respectively in discending order. The shortest mean generation time of *H. talaca* was 35.3±5.4 days when reared on artificial diet, whereas 36.1±6.5 and 37.1±7.2 days were respectively recoreded when the pest was reared on tea and shade tree leaf. Intrinsic rate of increase (rm) was 0.183±0.0 days for artificial diet. But the values

were respectively 0.174±0.0 and 0.164±0.0 days when reared on tea leaves and shade tree leaves. The finite rate of natural incrsease was 1.20±0.1 female offspring/ female/day on artificial diet. While 1.19±0.1 and 1.17±0.0 female offspring/ female/day were noticed when *H. talaca* was reared on tea leaves and shade tree leaves respectively. Doubling time was maximum (4.2±0.3 days) in case of shade tree leaf. While the shotest period was recorded for artificial diet (3.8±0.1days).

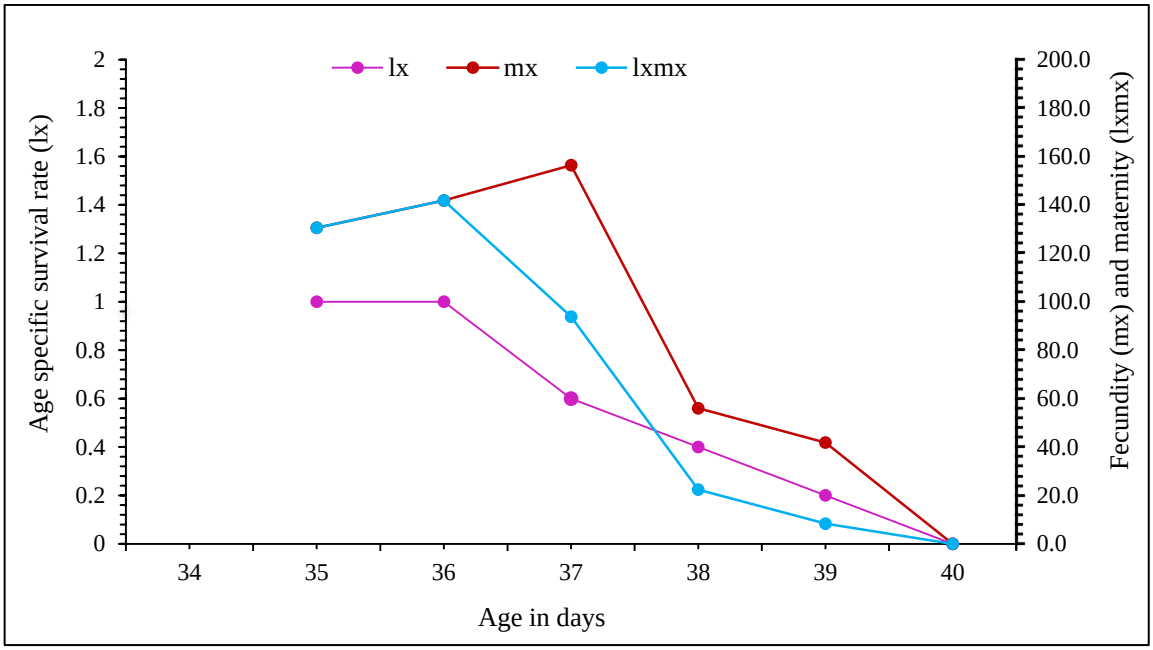


Fig. 2.3.3: Life table of *H. talaca* when reared on tea leaf

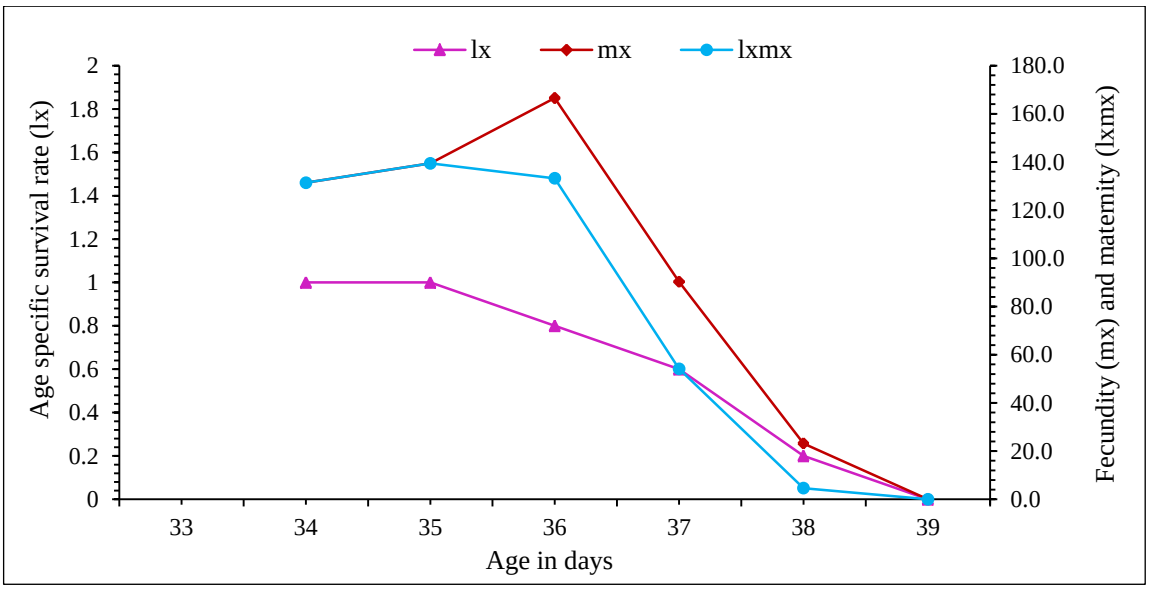


Fig. 2.3.4: Life table of *H. talaca* when reared on artificial diet

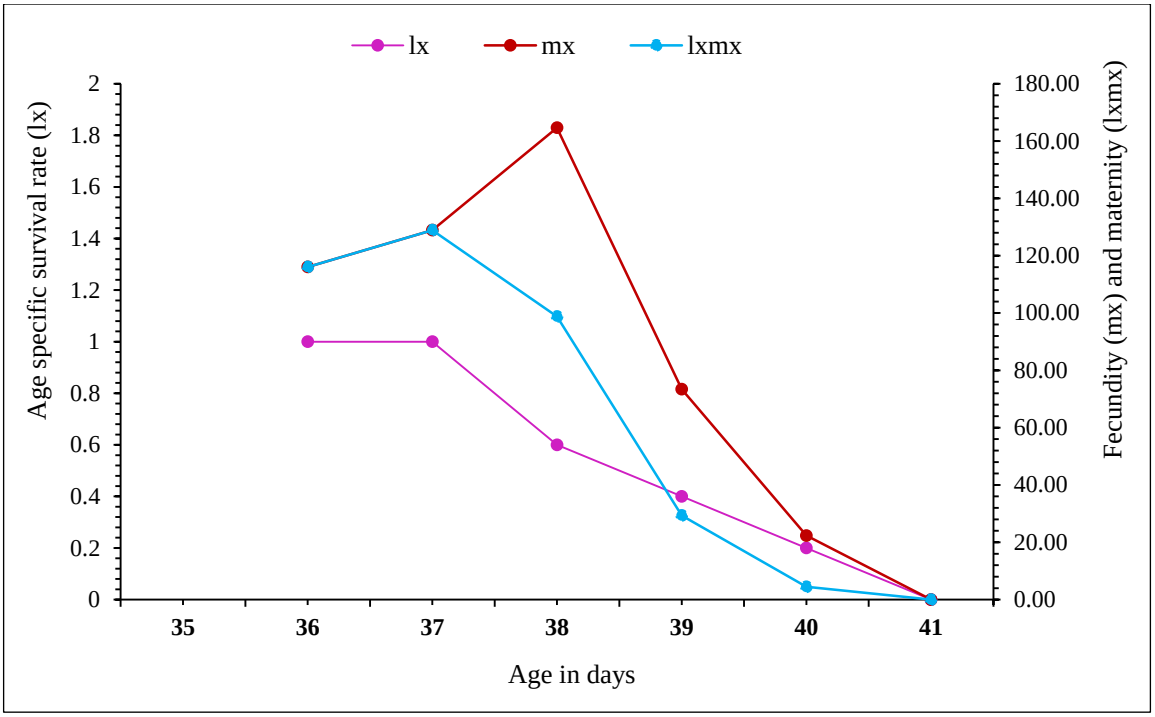


Fig. 2.3.5: Life table of *H. talaca* when reared on shade tree leaf.

Table 4.2.3.5: Life table parameters of *H. talaca* feeding on three different diets

Life table parameters	Dietary food source*		
	Tea leaf	Artificial diet	Shade tree
Precise value of intrinsic rate(r_m)	0.174±0.0*	0.183±0.0*	0.164±0.0*
Finite rate of increase(λ)	1.19±0.1	1.20±0.1	1.17±0.0
Net reproductive rate(Ro)	396.9±16.1*	462.9±22.1*	377.6±20.0*
Mean generation time(Tc)	36.1±6.5	35.3±5.4	37.1±7.2
Corrected generation timer(T)	34.4±6.4	33.5±5.4	36.1±3.9
Gross reproductive rate (GRR)	526.3±20.1	550.8±22.0	505.4±25.0
Weekly multiplication (Wm)	3.4±0.3	3.6±0.2	3.2±0.2
Doubling time (Dt)	4.0±0.7	3.8±0.1	4.2±0.3

Values are representing as mean±SD of five replications. *Data is significance at $p<0.05$, according to One-way ANOVA and Tukey's HSD

4.3. Study on bio-ecology and seasonal abundance of *S. collaris* during the period of observation

4.3.1 Observation on bio-ecology of *S. collaris*: During the study period *S. collaris* was observed to prefer dense tea bush for shelter. It was also noticed on shade tree for searching food and mating. Egg raft was observed and collected from shade tree bark, tip of tea leaf and tea bark. During the pupal period of *H. talaca S. collaris* was observed to feed on red slug caterpillar and other tea loopers. In the pruning season *S. collaris* was noticed to stay on shade tree and other plants adjacent to the tea garden.

4.3.2 Periodicity of *S. collaris*: During the two consecutive years, 2017-2018 and 2018-2019 respectively, the periodicity of *S. collaris* was noted. The incidence of *S. collaris* was observed at fortnight intervals. The 'trends line' was generated for entire study periods and for both the selected places (L1 and L2) separately in order to understand the periodicity of the predator.

4.3.2.1 During 2017-2018: The population of *S. collaris*, increased from March onwards (Fig. 3.2.1) at both the locations. The trends of increase of *S. collaris* was found to coincide with the population of *H. talaca*. At L1 the peak population of *S. collaris* was recorded in July (2.6/bush), whereas, at L2, the peak population was found in August (2.5/bush). The population tended to decline from October and attained the lowest in January.

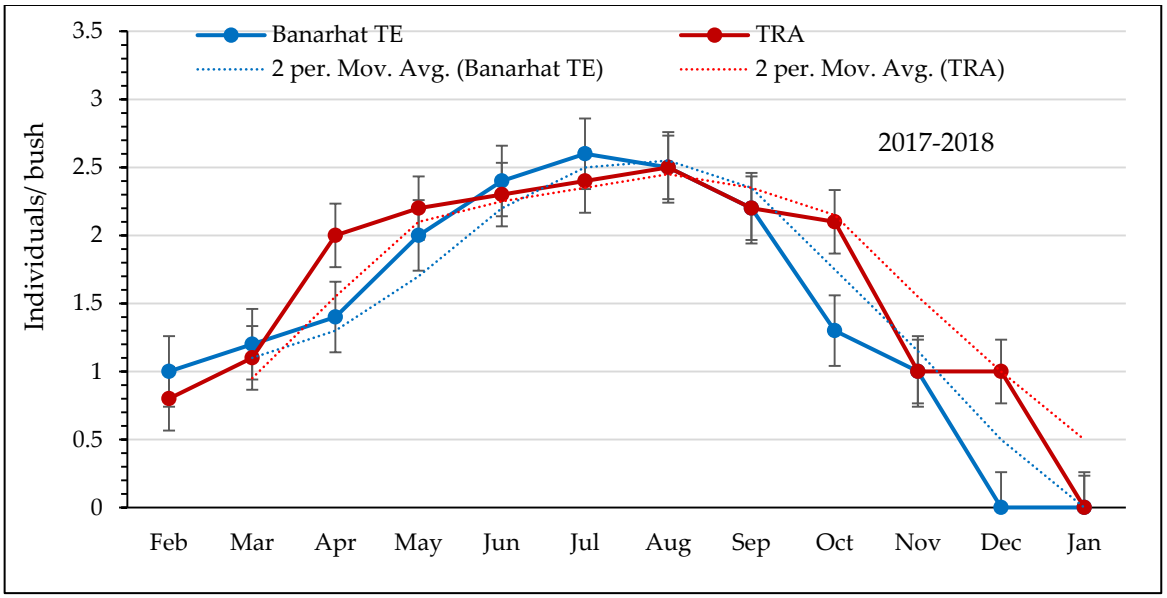


Fig. 3.2.1: Seasonal abundance of and the trends line (in dotted line) suggesting the prediction of the incidence of *S. collaris* during 2017-2018 for both the study locations

4.3.2.2 During 2018-2019: Persistent high level of *S. collaris* population trends were found from May to September at L1. But at L2, in addition to that the population till persisted upto October (Fig. 3.2.2). The population attained the peak in June with 2.8 individuals/bush at both the locations. After that, the population declined at both the study area having a parity with the population dynamics with the target pest.

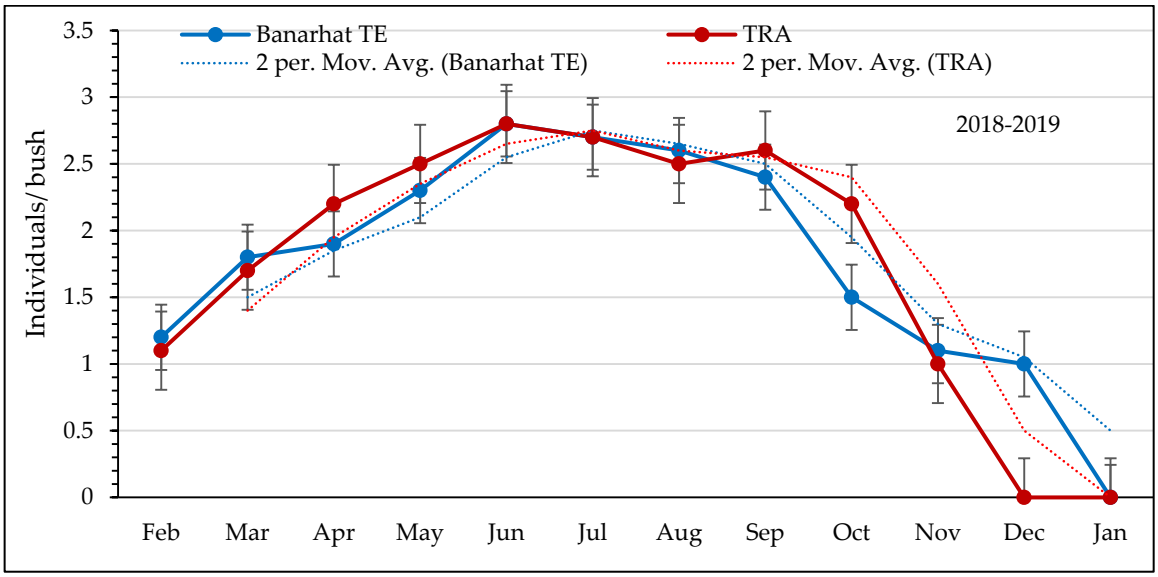


Fig. 3.2.2.: Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *S. collaris* during 2018-2019 for both the study locations

4.3.3. Observation of 'trends line' of *H. talaca* during the period of observation: A prediction line for the proximately later fortnight can be drawn taking in contemplation of the incidence of the *S. collaris* population for the first two fortnight observations. At 2% moving average scale, population dynamics of *S. collaris* in both seasons was calculated. The incidence of *S. collaris* from May to September population was seemingly harmonized with the predicted value. But after that, for both the seasons the observed population evicted rapid oscillatory fluctuation from August to January. For these reasons the trends line cannot be consider a prediction for the population of *S. collaris*. After February, the incidence of *S. collaris* population could be traced from the trends line (Fig. 3.2.1 and 3.2.2).

4.3.4. Observation and correlation value: The influence of each abiotic parameters on the population dynamics of *S. collaris* at both the study locations was assessed separately throughout the study period:

4.3.4.1. During 2017-2018: The results showed that, T. Max imparted significantly positive effect (r=0.9344 and r=0.9690) on numerical abundance of *H. talaca* at both the locations (Table 4.3.4). A significant positive correlation was observed between T. Min and the number of *S. collaris* (r=0.9331 and r=0.9807) for both the study areas. RF showed significant positive correlation (r=0.8809 and r= 0.7970) with *S. collaris*. Humidity of the study period imparted significantly positive (r=0.9320 and r=0.8694) effect on the population of reduviid bug irrespective of the two selected study places.

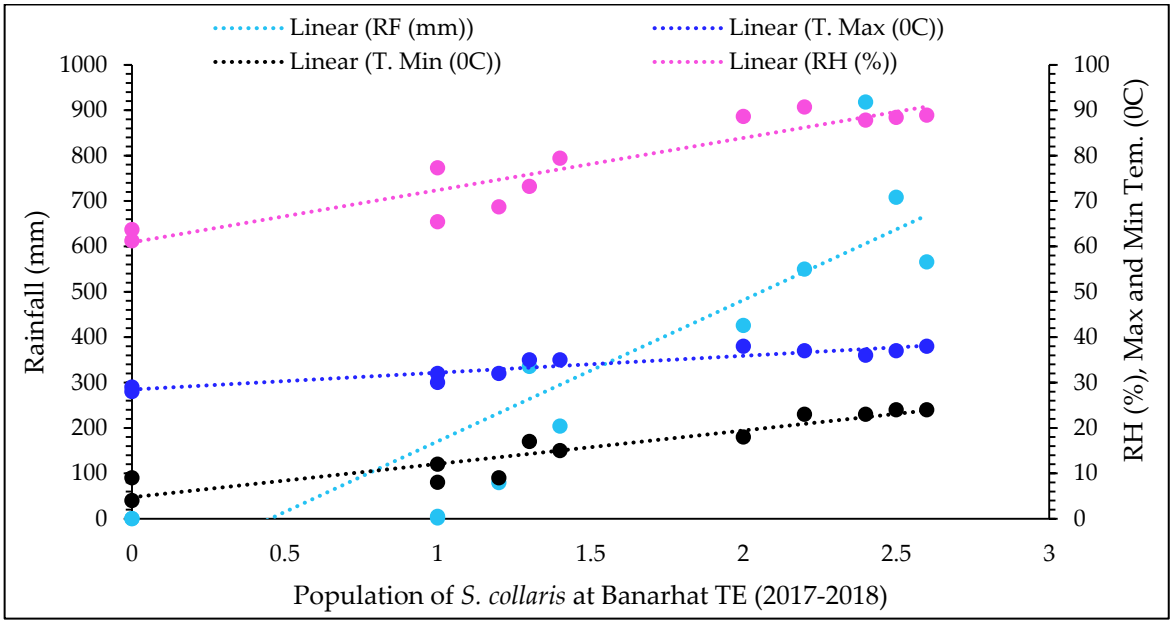


Fig. 3.4.1: Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2017-2018 at Banarhat TE

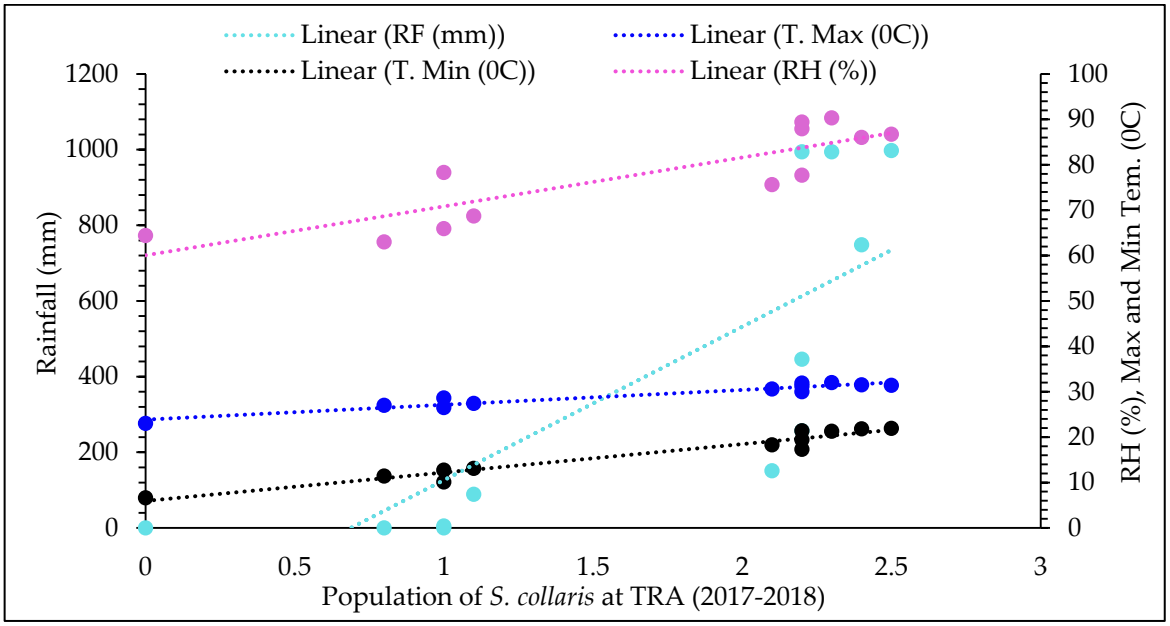


Fig. 3.4.2.: Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2017-2018 at TRA experimental plot

3.4.2. During 2018-2019: In the second season of the study, a significant positive correlation (r= 0.9242 and r=0.9568) was noticed between T. Max and numerical abundance of *S. collaris* at both the locations (Table 4.3.4) The T. Min was also positively correlated with the number of *S. collaris*, which was statistically significant. A positively significant (r=0.7469 and r=0.7887) impact of rainfall was also observed on the population dynamics of *S. collaris*. The value of correlation was significantly positive (r=0.8917 and r=0.8007) between *S. collaris* and RH at both L1 and L2.

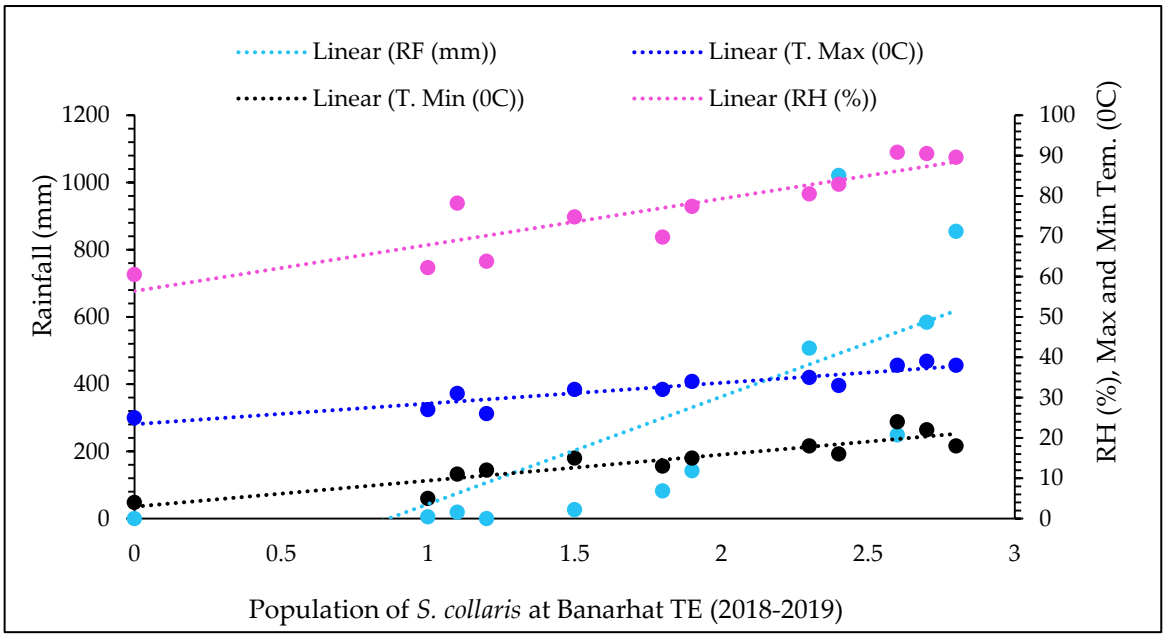


Fig. 3.4.3.: Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2018-2019 at Banarhat TE

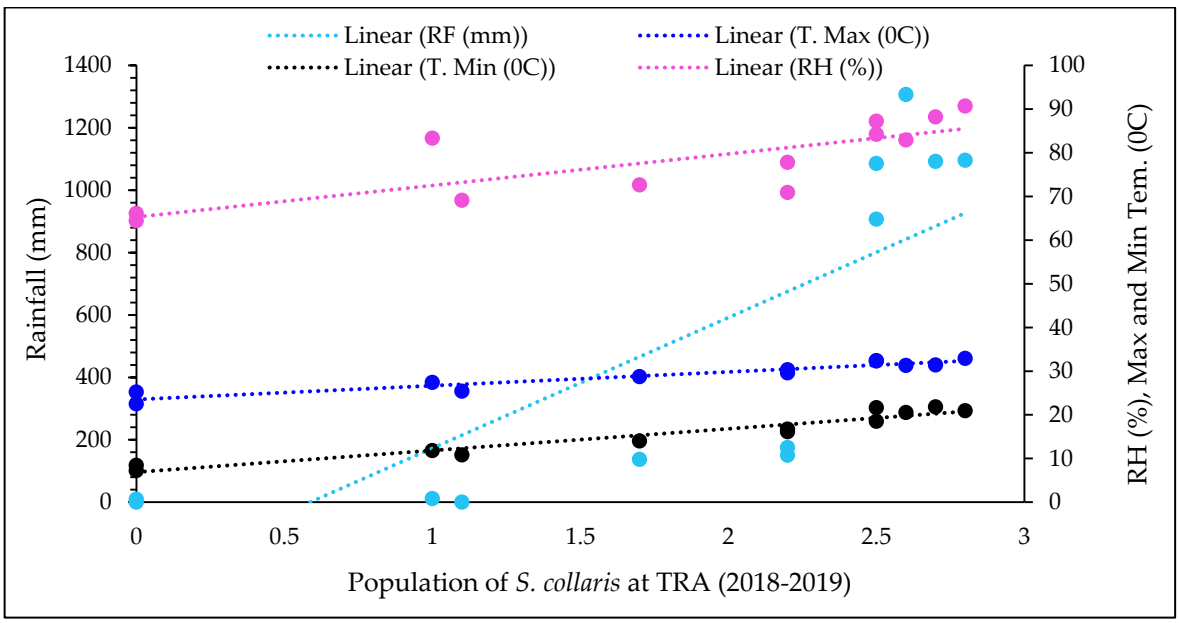


Fig. 3.4.4.: Regression line representing relationship between abiotic factors and population abundance of *S. collaris* for the season 2018-2019 at TRA experimental plot

Table 4.3.4: Correlation between *S. collaris* population with climatic factors of both locations

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	0.9344	0.9690	0.9242	0.9568
T. Min	0.9331	0.9807	0.9109	0.9669
RF	0.8809	0.7970	0.7469	0.7887
RH	0.9320	0.8694	0.8917	0.8007

Values are significant at $p < .05$.

4.3.5. Regression analysis

4.3.5.1 During 2017-2018: The regression equation at both L1 (Y=3.720x+28.459, R^2=0.873) and at L2 (Y=3.342x+23.799, R^2=0.9391) are significant (Fig. 3.3.1), T. Max showed strong positive impact on the population trends of *S. collaris* (Fig. 3.3.2). Whereas the R^2 values (0.870 and 0.961) of the regression equations of both the locations indicated a positive relationship between the T. Min and the target predators. From the regression equation, worked out for rainfall, a positive relation was found with the predator population at both the study locations. Whereas, the regression equations at L1(Y=11.503x+60.904, R^2=0.868) and at L2 (Y=11.051x+59.775, R^2=0.756) showed the positive relation between RH and population abundance of *S. collaris* (Table 4.3.5).

4.3.5.2 During 2018-2019: According to the regression equations between T. Max and predator population dynamics (Y=3.720x+28.459, R^2=0.873 and Y=3.342x+23.799, R^2=0.9391), an increasing trends of predator were observed from summer to autumn months at both the study locations (Table 4.3.5). T. Min at both the locations showed also the similar impact like T. Max on the same months. The regression equations (Y=391.87x-76.88, R^2=0.558 and Y=418.82x-46.4, R^2=0.622) of L1 and L2 showed significantly positive relation between RF and the predator populations (Fig. 3.4.3). Whereas, RH also showed positive impact on population abundance of *S. collaris* at both the study locations according to the regression equations (Y=11.459x+56.41, R^2=0.795 and Y=7.227x+23.531, R^2=0.641) (Fig. 3.4.4).

Table 4.3.5: Regression equation between *S. collaris* populations and climatic factors of both the locations

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	Y=3.720x+28.45, **R^2=0.873**	Y=3.342x+23.79, **R^2=0.9391**	Y=5.131x+23.39, **R^2=0.854**	Y=3.146x+23.53, **R^2=0.915**
T. Min	Y=7.348x+4.72, **R^2=0.870**	Y=6.391x+5.83, **R^2=0.961**	Y=6.447x+2.971, **R^2=0.829**	Y=4.958x+6.89, **R^2=0.935**
RF	Y=311.22x-140.44, **R^2=0.776**	Y=419.37x-294.9, **R^2=0.635**	Y=391.87x-76.88, **R^2=0.558**	Y=418.82x-46.4, **R^2=0.622**
RH	Y=11.503x+60.90, **R^2=0.868**	Y=11.051x+59.77, **R^2=0.756**	Y=11.459x+56.41, **R^2=0.795**	Y=7.227x+23.53, **R^2=0.641**

4.4. Study on bio-ecology and seasonal incidence of *Eocanthecona furcellata* during the period of observation

4.4.1 Observation on bio-ecology of *E. furcellata*: The adult pentatomid bug *E. furcellata* was observed to fly on shade tree for searching alternate food and shelter. Nymph and adult of this bug were noticed to feed on lepidopteran pest of shade tree and other tree adjacent to the tea garden. Egg mass was observed on shade tree (Fig.4.1) and lower surface of the tea leaf.

Fig.4.1: Female of *E. furcellata* laying eggs on shade tree

4.4.2 Periodicity of *E. furcellata*: The periodicity of *E. furcellata* for the two consecutive seasons of 2017-2018 and 2018-2019 was recorded at both the study locations at fortnightly intervals. The survey was conducted on the population incidence of this predator and the collected data was tabulated accordingly. In order to predict the periodicity of the predator, 'trends line' was drawn based on the collected data for the two selected places (L1 and L2) separately.

4.4.2.1 During 2017-2018: The population increasing trends of *E. furcellata* were observed from March onwards up to October at both the study locations (Fig. 4.2.1). The peak period of incidence of the stink bug per bush was in September (2.4). That was followed by July (2.0) and August (1.9) at both the study locations. The population decreasing trends were recoded from November on wards till February.

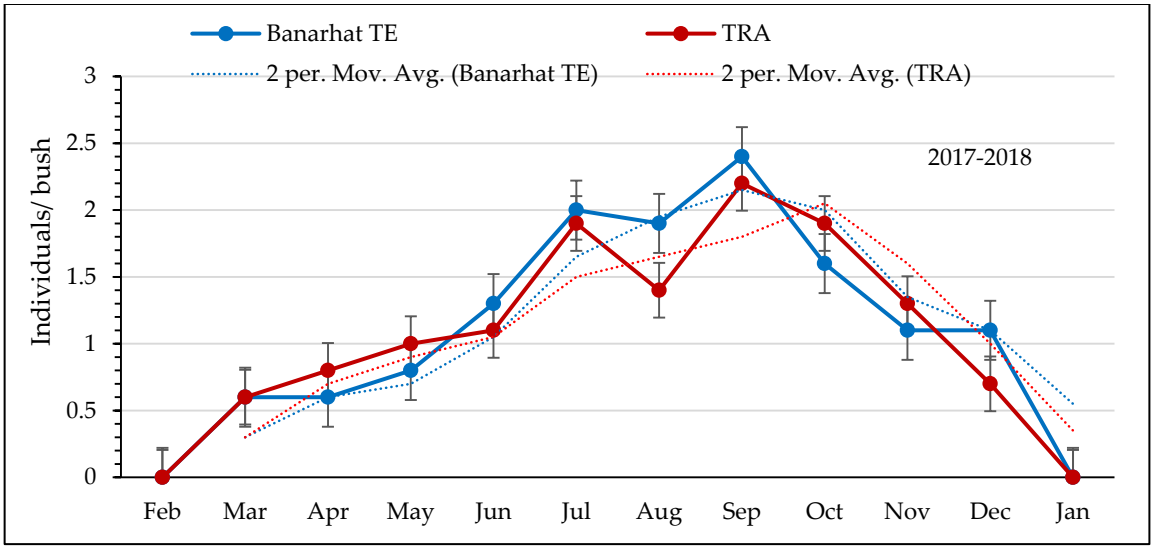


Fig. 4.2.1: Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *E. furcellata* during 2017-2018 for both the study locations

4.4.2.2. During 2018-2019: In the second season the highest population abundance of *E. furcellata* were found from June to September (1.3-2.5 bugs/ bush) at L1. This trends were noticed in June (2.1 bugs/ bush), July (2.2 bugs/ bush), August (1.8 bugs/ bush) and October (2.7 bugs/ bush) at L2 (Fig. 4.2.2). After that the population declined at both the study locations from November onwards. The average population dynamics of this stink bug in both the seasons at the two locations were coincided with the incidence of *H. talaca*.

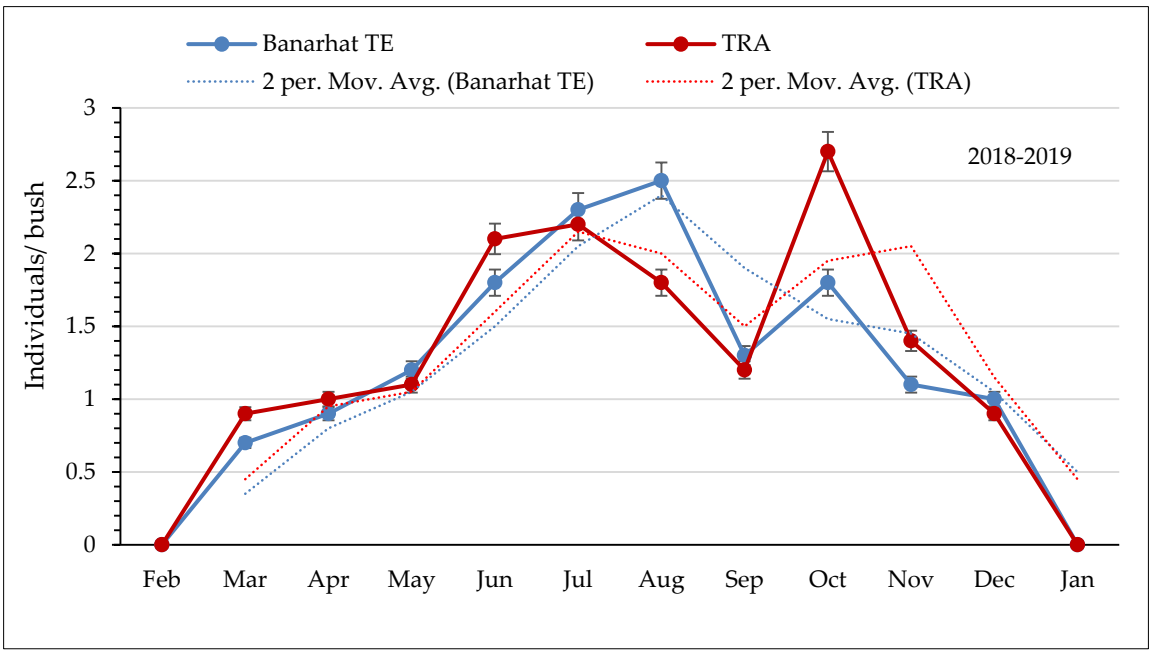


Fig. 4.2.2: Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *E. furcellata* during 2018-2019 for both the study locations

4.4.3. Observation of 'trends line' of *E. furcellata* during the period of observation: A trends line was generated in consideration of the incidence of the *E. furcellata* population for the first two fortnight observations. The trends line for both seasons at two places was noted at 2% moving average scale. Observations from April to July, the value on the incidence of the stink bug apparently synchronized with the predicted value at both places. The population for both the seasons showed rapid oscillatory fluctuation from August to December for both the years. For these reasons the trends line can be considered only as a primary information to predict the population of stink bug at late season. However, after February, the incidence of Stink bug population can be more precisely predicted from the trends line (Fig. 4.2.1 and 4.2.2).

4.4.4. Observation and correlation value: The interaction between the abiotic parameters and the population dynamics of *E. furcellata* at both the study locations was observed and evaluated separately in the study periods of:

4.4.4.1. During 2017-2018: Simple correlation between *E. furcellata* population and T. Max, showed significant positive correlation (r= 0.7011and r=0.7909) at L1 and L2 respectively (Table 4.2.4). T. Min showed positive impact on the stink bug population dynamics at L1 and L2. RF imparted positive effect on the incidence of *E. furcellata* at L1 and L2, which was statistically significant (r= 0.6749 and r= 0.7420). Relative humidity during the study periods was observed a significantly positive (r=0.9320 and r=0.8694) impact on the population trends of the stink bug.

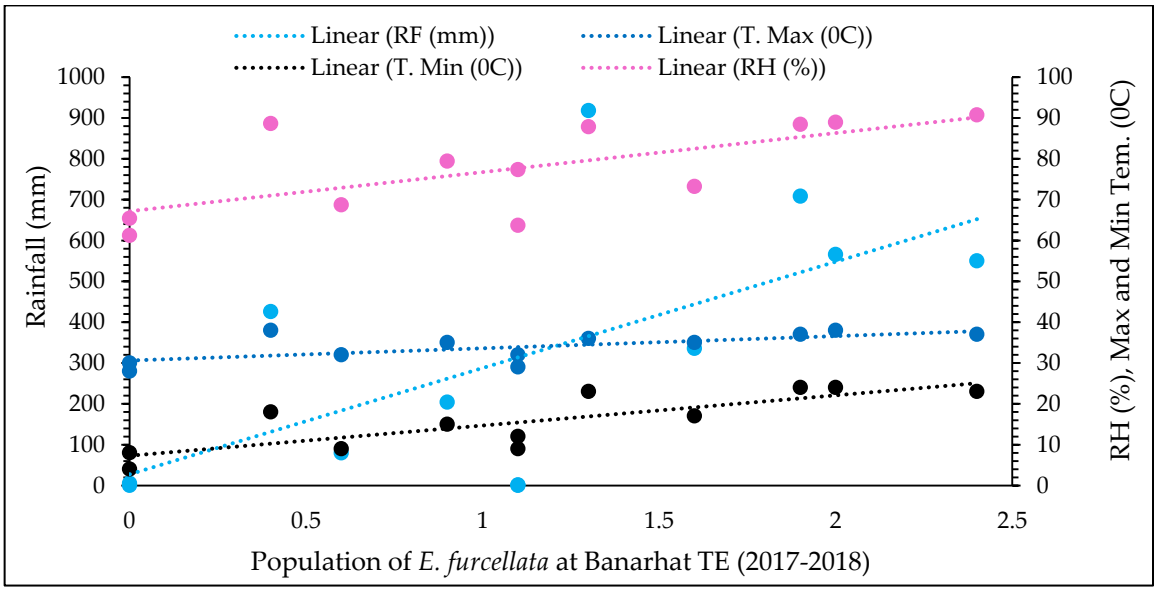


Fig. 4.2.4.1: Regression line representing relationship between abiotic factors and population abundance of *E. furcellata* in the season of 2017-2018 at Banarhat TE

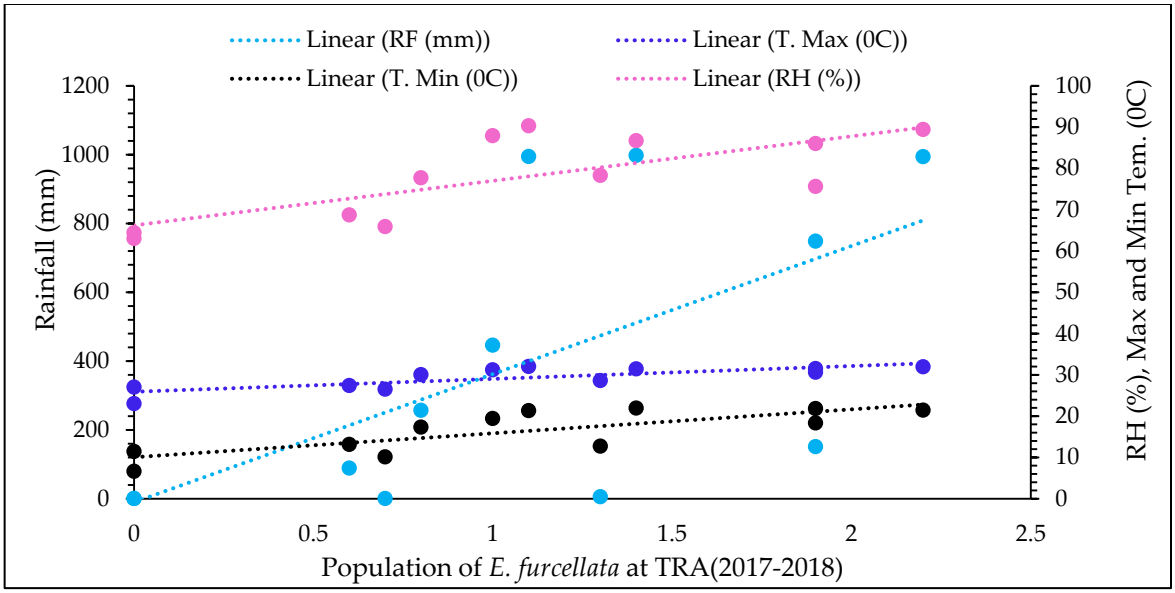


Fig. 4.2.4.2: Regression line representing relationship between abiotic factors and population abundance of *E. furcellata* in the season of 2017-2018 at TRA experimental plot

4.4.4.2 During 2018-2019: T. Max showed a significantly positive correlation (r=0.8598 and r=0.6953) with the population abundance of *E. furcellata* at both the locations (Table 4.2.4). The effect of T. Min, also positively correlated (r=0.7974 and r=0.6853) with the population dynamics of *E. furcellata*, which was statistically significant. RF was positively correlated, (r=0.4598 and r=0.4858) with the Population abundance of *E. furcellata*for both the locations. Whereas the significant and positive correlations were noticed (r=0.8615and r=0.7042) between the population dynamics of the stink bug an RH of L1 and L2.

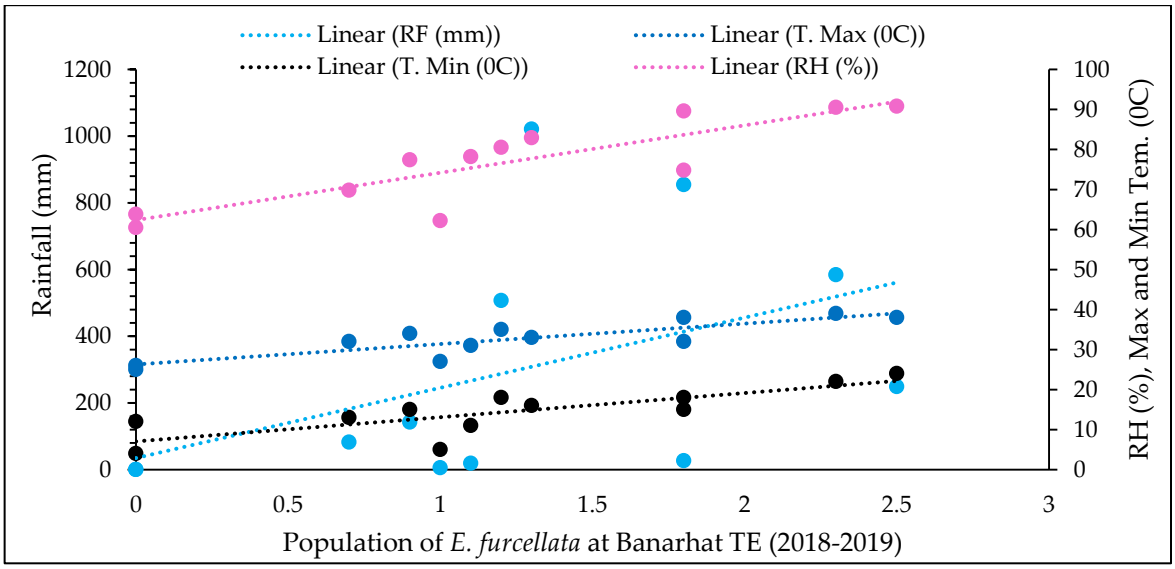


Fig. 4.2.4.3: Regression line representing relationship between abiotic factors and population abundance of *C ruficrus* in the season of 2018-2019 at Banarhat TE

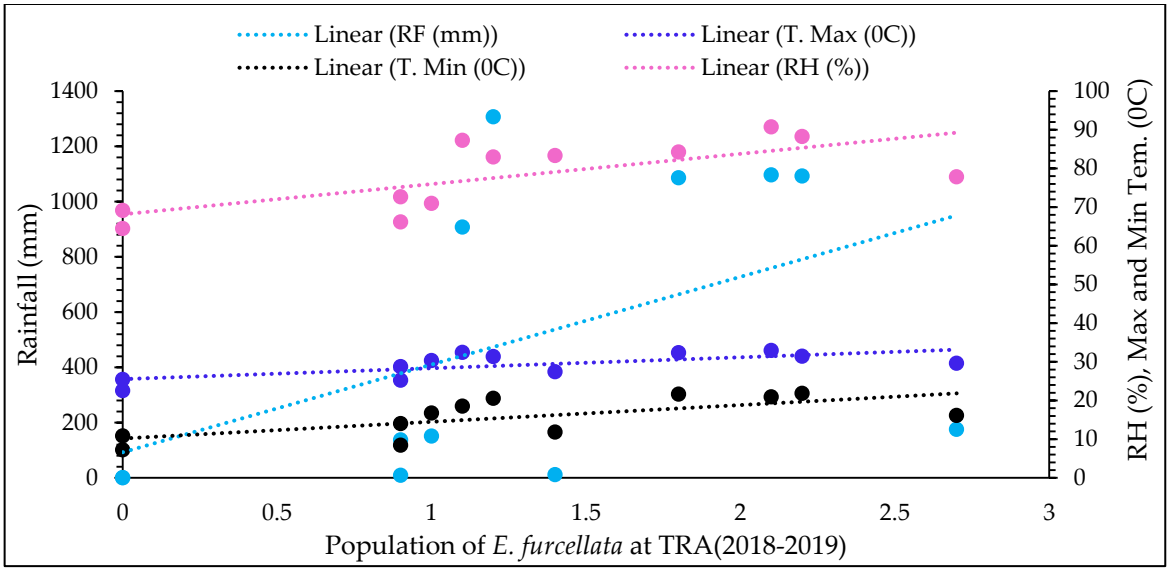


Fig. 4.2.4.4: Regression line representing relationship between abiotic factors and population abundance of *E. furcellata* in the season of 2018-2019 at TRA experimental plot

Table 4.2.4: Correlation between *E. furcellata* populations with climatic factors of both locations

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	0.7011	0.7909	0.8598	0.6953
T. Min	0.8412	0.7780	0.7974	0.6853
RF	0.6749	0.7420	0.4598	0.4858
RH	0.7216	0.8730	0.8615	0.7042

Values are significant at $p < .05$.

4.4.5 Regression analysis

4.4.4.5.1 During 2017-2018: The regression equations revealed that the climatic parameters under consideration influenced the population dynamics of *E. furcellata* at both the locations. The regression equation expressed the effect of temperature indicating that the population of the stink bug increased with the increase of T. Max ($Y=3.280x+30.253$, $R^2=0.491$ and $Y=3.115x+25.909$, $R^2=0.625$**)** (Fig. 4.2.4.1) and T. Min ($Y=7.783x+6.808$, $R^2=0.707$ and $Y=5.790x+10.05$, $R^2=0.605$) (Fig. 4.2.4.2). According to the regression equations of RF ($Y=280.17x+3.152$, $R^2=0.455$ and $Y=372.41x-10.287$, $R^2=0.384$**)** at L1 and L2, a positive relationship with stink bug population was noted. Whereas, the regression equations revealed the positive relationship between RH

(Y=910.464x+69.09, R^2=0.520 and Y=10.769x+66.248, R^2=0.5506) and population abundance of stink bug (Table 4.2.5).

4.4.4.5.2 During 2018-2019: The regression equation showed the impact of T. Max (Y=5.103x+26.29, R^2=0.739 and Y=2.814x+25.528, R^2=0.483**)** and T. Min (Y=6.034x+7.074, R^2=0.635 and Y=4.324x+10.177, R^2=0.469) at L1 and L2 (Fig. 4.2.4.3). Similar trends of population structure of *E. furcellata* like the previous seasons was noted at both the study locations. The regression equations for RF (Y=210.52x+34.76, R^2=0.2115 and Y=317.47x+92.587, R^2=0.236), depicted a positive effect at L1 and L2 (Fig. 4.2.4.4). Population of stink bug at L1 and L2 increased in parity of RF. Whereas, RH showed positive impact on stink bug (Y=11.836x+62.349, R^2=0.7423 and Y=7.823x+68.142, R^2=0.496) at both the locations (Table 4.2.5).

Table 4.2.5: Regression equation between *E. furcellata* populations and climatic factors of both the locations

Parameter	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	Y=3.280x+30.253, **R^2=0.491**	Y=3.115x+25.909, **R^2=0.625**	Y=5.103x+26.29, **R^2=0.739**	Y=2.814x+25.528, **R^2=0.483**
T. Min	Y=7.783x+6.808, **R^2=0.707**	Y=5.790x+10.05, **R^2=0.605**	Y=6.034x+7.074, **R^2=0.635**	Y=4.324x+10.177, **R^2=0.469**
RF	Y=280.17x+3.152, **R^2=0.455**	Y=372.41x-10.287, **R^2=0.384**	Y=210.52x+34.76, **R^2=0.2115**	Y=317.47x+92.587, **R^2=0.236**
RH	Y=910.464x+69.09, **R^2=0.520**	Y=10.769x+66.248, **R^2=0.5506**	Y=11.836x+62.349, **R^2=0.7423**	Y=7.823x+68.142, **R^2=0.496**

4.5. Study on bio-ecology and seasonal incidence of *Cotesia rufirus* during the period of observation

4.5.1 Observation on bio-ecology of *C. ruficrus*: The parasitic wasp *C. ruficrus* was found to feed on nectar and honey flower of tea, hill glory bower, wild sunflower, etc. adjacent to the tea garden. This parasitoid parasitized other lepidopteran pest of tea.

4.5.2. Periodicity of *C. ruficrus*: The periodicity of *C. ruficrus* for the two consecutive seasons was recorded and tabulated for both the study locations at fortnight intervals. The 'trends line' was accordingly drawn in order to predict the periodicity of the predator for the two selected places (L1 and L2) separately.

4.5.2.1. *During 2017-2018*: The population was found to be high in the months of pre-winter and spring seasons. The parasitoid wasp attained the highest population in September, October, November, December, February and March in both the locations (Fig. 5.2.1). In March and November the parasitoid wasp attained the peak population (2.8cocoons / bush) at the first location. Whereas the peak population at the second location was recorded in November (2.9 cocoons/bush). The decline of population of this parasitoid wasp was found from June to August in both the locations.

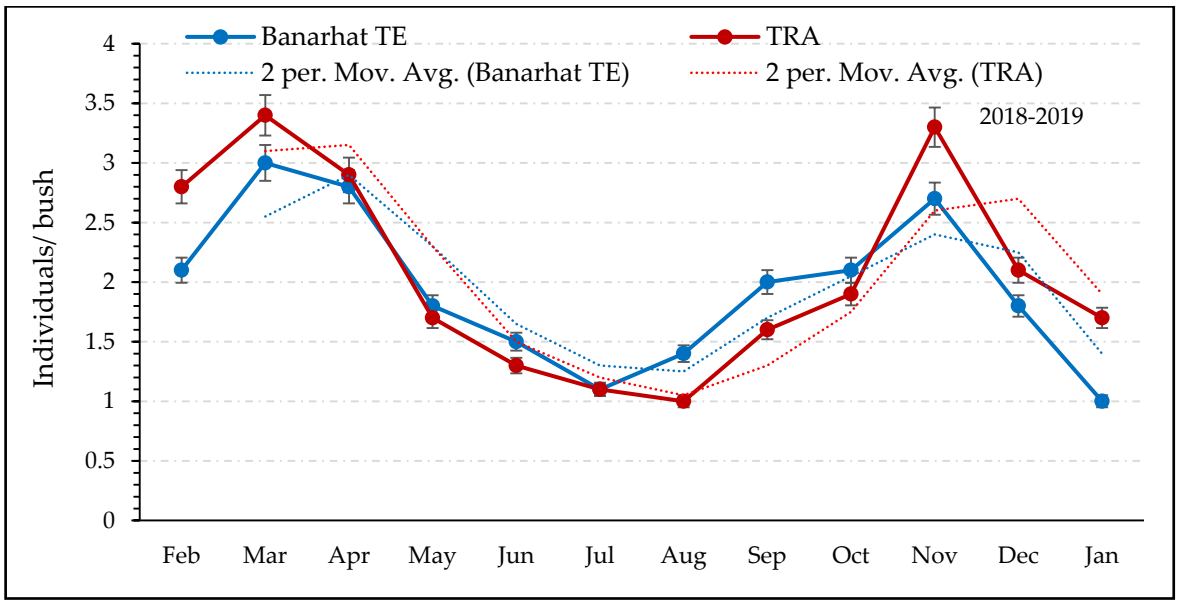


Fig. 5.2.1: Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *C. ruficrus* during 2017-2018 for both the study locations

4.5.2.2 During 2018-2019: In the second season the highest population trends were found from February to April and from September to December at both the locations (Fig. 5.2.2). The highest number of cocoons per bush was 3 and 3.4 cocoons/ bush in the March at L1 and L2 respectively. The least number of cocoons per bush was observed in the months of rainy seasons at both the locations.

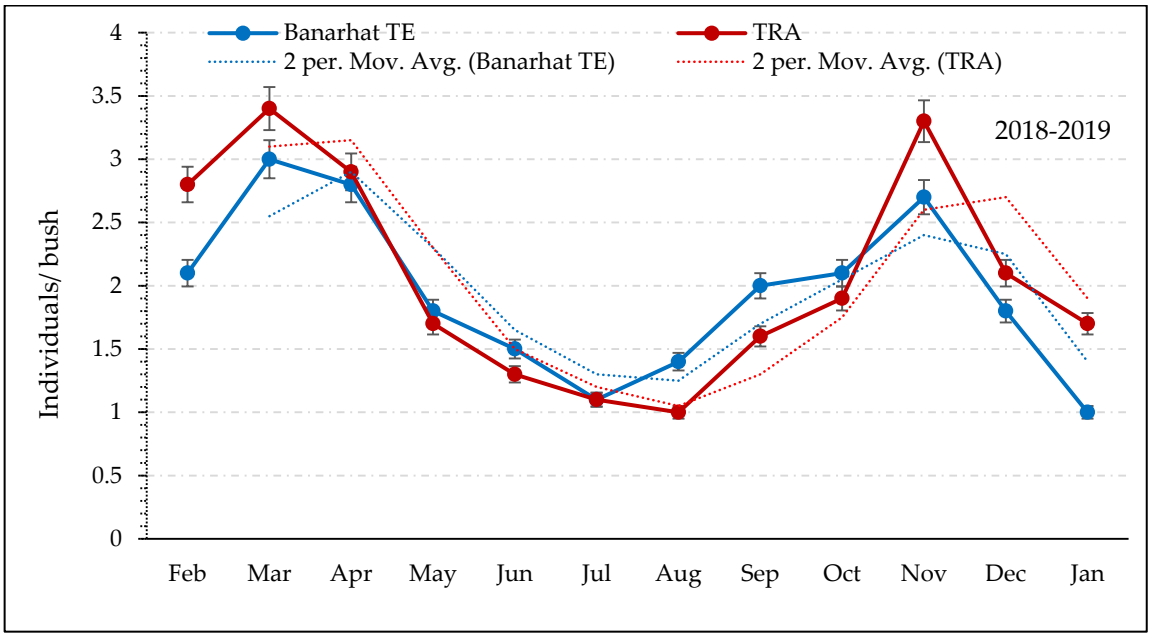


Fig. 5.2.2: Seasonal abundance and the trends line (in dotted line) suggesting the prediction of the incidence of *C. ruficrus* during 2018-2019 for both the study locations

4.5.3 Observation of 'trends line' of *H. talaca* during the period of observation: A prediction line was generated taking in consideration of the incidence of the *C. ruficrus* population for the first two fortnight observations (Fig. 5.2.1). Population dynamics in both seasons was worked out at 2% moving average scale. The incidence of *C. ruficrus* from April to June population was apparently synchronized with the predicted value. But after that the observed population for both the seasons showed rapid oscillatory fluctuation from August to March. For these reasons the trends line cannot be consider a prediction for the population of *C. ruficrus*. After February, the incidence of *C. ruficrus* population could be predicted from the trends line (Fig. 5.2.2).

4.5.4 Observation and correlation value: The influences of the climatic parameters on the population dynamics of *C. ruficrus* at both the study locations was observed and evaluated separately during the study periods of:

4.5.4.1 During 2017-2018: Simple correlations (r= -0.2114 and r=-0.3930) indicated that, T. Max imparted negative effect on the population increasing trends of the parasitoid wasp at both the study area. Similarly, the correlation (r=-0.3537 and r=-0.5482) also indicated the negative effect of T. Min on the population dynamics of *C. ruficrus* (Table 5.3). RF imparted negative correlation on the incidence of *C. ruficrus* at L1 and L2. RH of both the location showed also negative correlations (r= -0.2465 and r= -0.4744) on the population trends of the *C. ruficrus*.

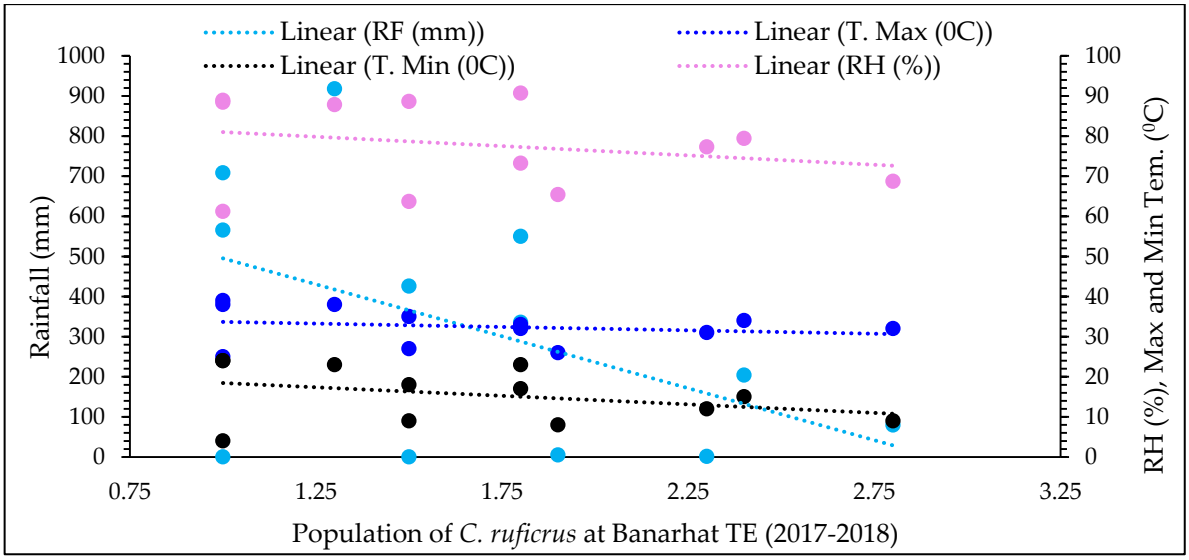


Fig. 5.4.1: Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2017-2018 at Banarhat TE

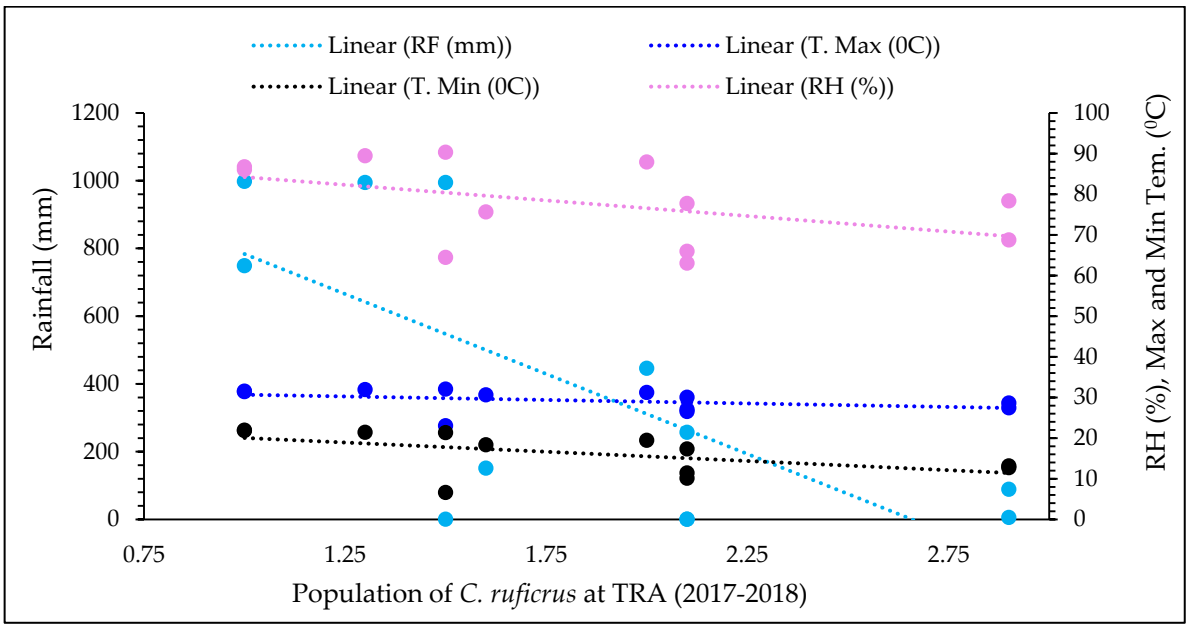


Fig. 5.4.2: Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2017-2018 at TRA experimental plot

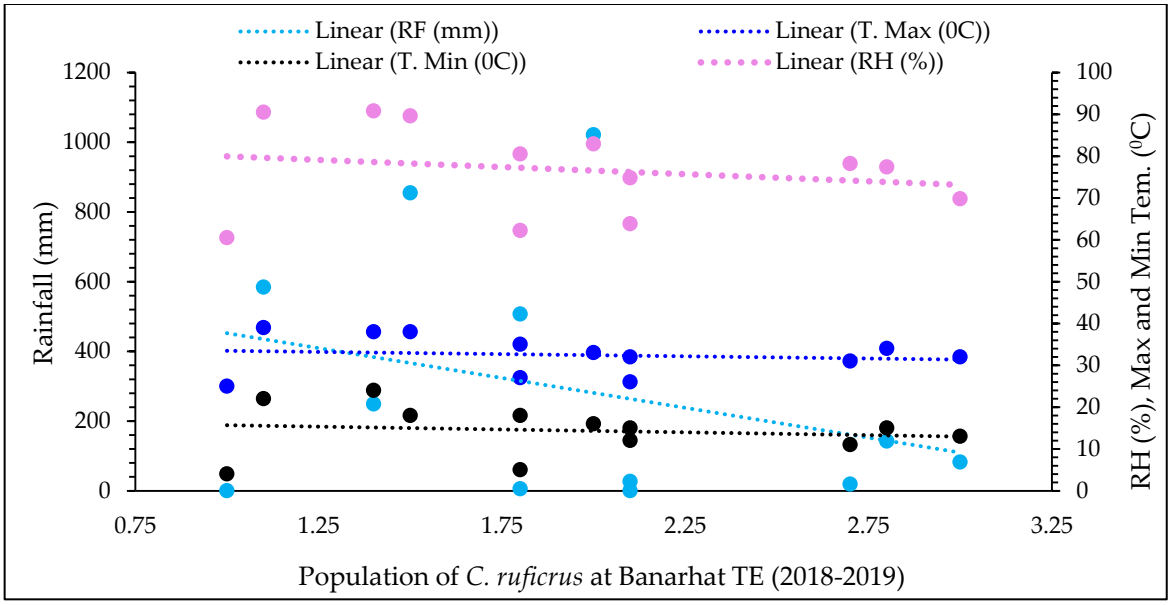


Fig. 5.4.3: Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2018-2019 at Banarhat TE

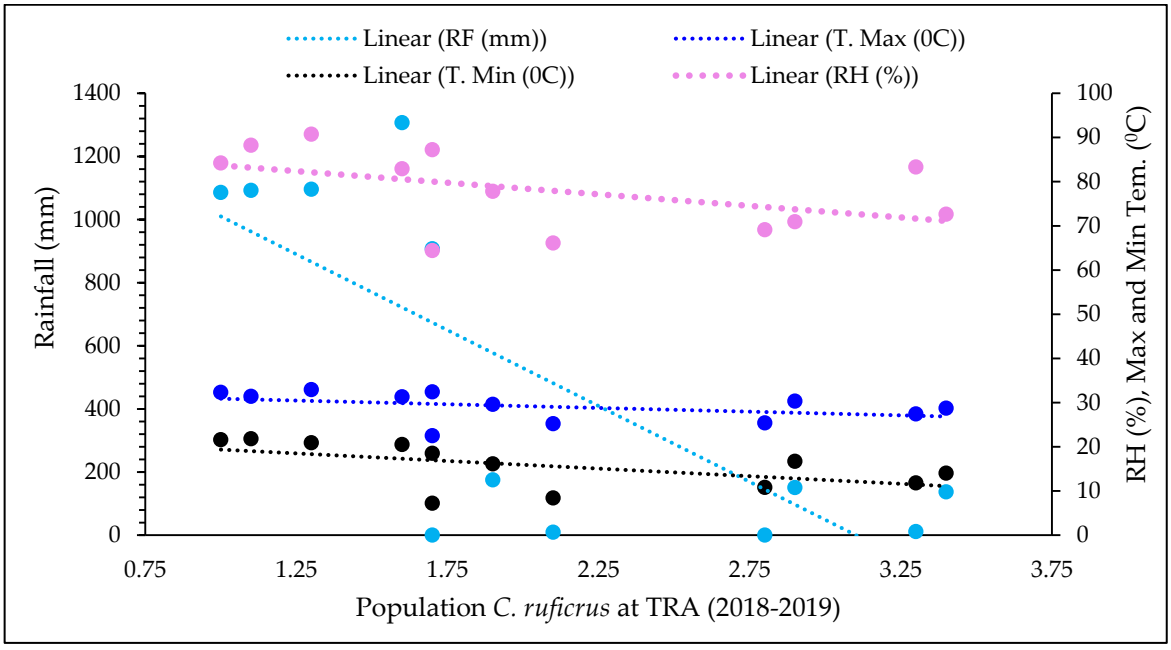


Fig. 5.4.4: Regression line representing relationship between abiotic factors and population abundance of *C. ruficrus* in the season of 2018-2019 at TRA experimental plot

4.5.4.2 During 2018-2019: Negative correlations (r=-0.2114 and r= -0.3930) were recorded between T. Max and incidence of *C. ruficrus* at both the locations L1 and L2 (Table 5.3). Like the previous year, the effect of T. Min also showed negative insignificant effect on the population dynamics of the parasitoid wasp. On the other hand, a negatively insignificant impact of rainfall was noticed with the population trends of *C. ruficrus*.

Relative humidity during the study periods was negatively influenced on the abundance of *C. ruficrus* for both the study locations L1 and L2.

Table 5.4: Correlation between *C. ruficrus* populations with climatic factors of both locations

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	-0.2114	-0.3930	-0.1449	-0.4199
T. Min	-0.3537	-0.5482	-0.1478	-0.5517
RF	-0.4812	-0.7054	-0.2030	-0.7452
RH	-0.2465	-0.4744	-0.3057	-0.4777

Values are significant at $p < .05$.

4.5.5 Regression analysis

4.5.5.1 During 2017-2018: The regression equations indicated that, all the climatic factors were negatively influenced on the population incidence of *C. ruficrus* at both the location (Fig. 5.4.1 and 5.4.2). The regression equations (Y= -1.684x+35.35, R^2=0.044 and Y= -1.724x+32.42, R^2=0.154) showed negative impact between the population of parasitic wasp and abiotic factor T. Max at L1 and L2. Similarly the T. Min. also negatively influenced the population dynamics of the wasp at both the locations. The regression equations (Y= -258.99x+754.14 R^2=0.231 and Y= -472.12x+1255.6, R^2=0.497) indicated that, rainfall showed the negative impact in the increasing trends of the parasitic wasp, noticed in both the locations, while RH also showed negative regression equations, which was worked out for L1 and L2 (Table 5.4).

4.5.5.2 During 2018-2019: The regression analysis revealed that, T. Max (Y= -1.052x+34.543, R^2=0.021 and Y= -1.676x+32.582, R^2=0.377) and T. Min. (Y= -1.136x+17.074, R^2=0.022 and Y= -3.435x+22.791, R^2=0.304) showed the negative slope which indicated the negative impact of T. Max and T. Min on the *C. ruficrus* population (Fig. 5.4.3). The regression equations (Y= -171.21x+623.3, R^2=0.093 and Y= -480.51x+149.4, R^2=0.555) for both the locations showed insignificant and negative relation between rainfall and population trends of *C. ruficrus* (Fig. 5.4.4). Whereas RH

also showed negative insignificant regression equations for L1 and L1 with *C. ruficrus* population dynamics (Table 5.6).

Table 5.6: Regression equation between *C. ruficrus* populations and climatic factors of both the locations

Parameters	Period and places of observation (s)			
	2017-2018		2018-2019	
	L1	L2	L1	L2
T. Max	Y= -1.684x+35.35, **R^2=0.044**	Y= -1.724x+32.42, **R^2=0.154**	Y= -1.052x+34.543, **R^2=0.021**	Y= -1.676x+32.582, **R^2=0.377**
T. Min	Y= -4.243x+22.679, **R^2=0.125**	Y= -4.544x+24.607, **R^2=0.300**	Y= -1.136x+17.074, **R^2=0.022**	Y= -3.435x+22.791, **R^2=0.304**
RF	Y= -258.99x+754.14 **R^2=0.231**	Y= -472.12x+1255.6, **R^2=0.497**	Y= -171.21x+623.3, **R^2=0.093**	Y= -480.51x+149.4, **R^2=0.555**
RH	Y= -4.636x+85.618, **R^2=0.060**	Y= -7.670x+91.887, **R^2=0.225**	Y= -3.411x+83.374, **R^2=0.041**	Y= -5.236x+88.938, **R^2=0.228**

4.6. Observation on the biotic interaction between the *H. talaca* and natural enemies

4.6.1 At Banarhat TE (L1)

4.6.1.1 During 2017-2018: At L1, during February, initially, the incidence of *H. talaca* population was 6.4 individuals/bush. A steady upsurge of the pest population was noted. Maximum incidence of *H. talaca* was observed at June with 13.1 individuals/bush. A steady decline of population was then observed. Dynamics of *S. collaris* (Fig.6.1.1), *E. furcellata* (Fig.6.1.3) and *C. ruficrus* (Fig.6.1.5) had shown a density dependent variation in relation to number of larvae of *H. talaca* per bush. Population of *H. talaca* and its predators and parasitoid (*S. collaris*, *E. furcellata* and *C. ruficrus*) were closely correlated to each other.Regression equation and correlation were worked out between the population trends of *H. talaca* and its natural enemies (Fig. 6.1.2, 6.1.4 and 6.1.6). The result showed that the population dynamics of *S. collaris* had significantly positive correlation (r=0.6117) with the population dynamics of *H. talaca*, whereas *E. furcellata* (r=0.2567) and *C. ruficrus* (r=0.2236) had insignificantly negative correlation (Table 6.3 and 6.4).

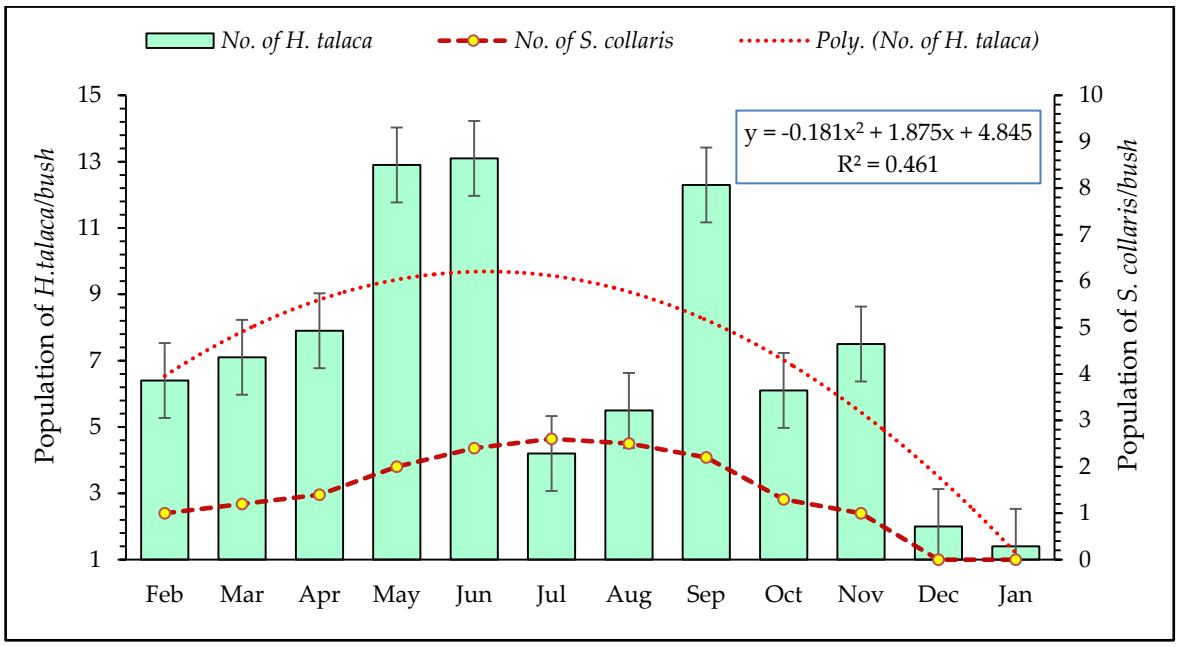


Fig. 6.1.1: Population dynamics of *S. collaris* in respect to densities of *H. talaca* at Banarhat TE (2017-2018)

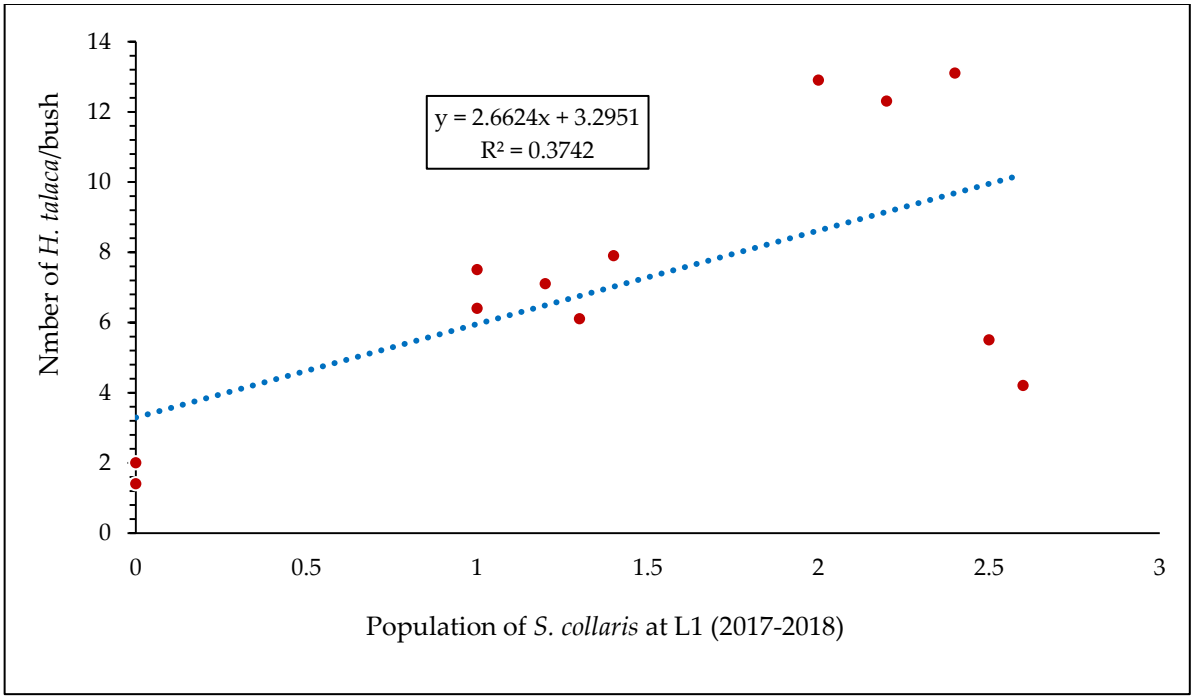


Fig. 6.1.2: Regression line representing relationship between the incidence of *H. talaca* and *S collaris* at Banarhat TE (2017-2018)

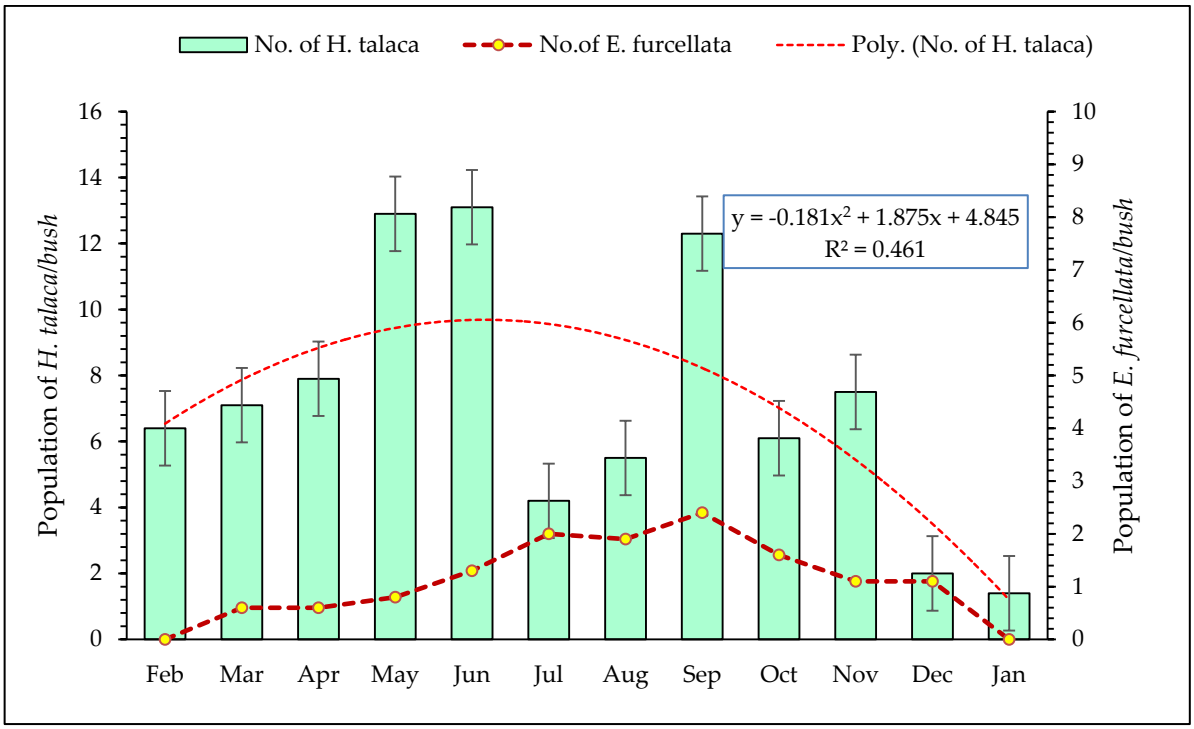


Fig. 6.1.3: Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at Banarhat TE (2017-2018)

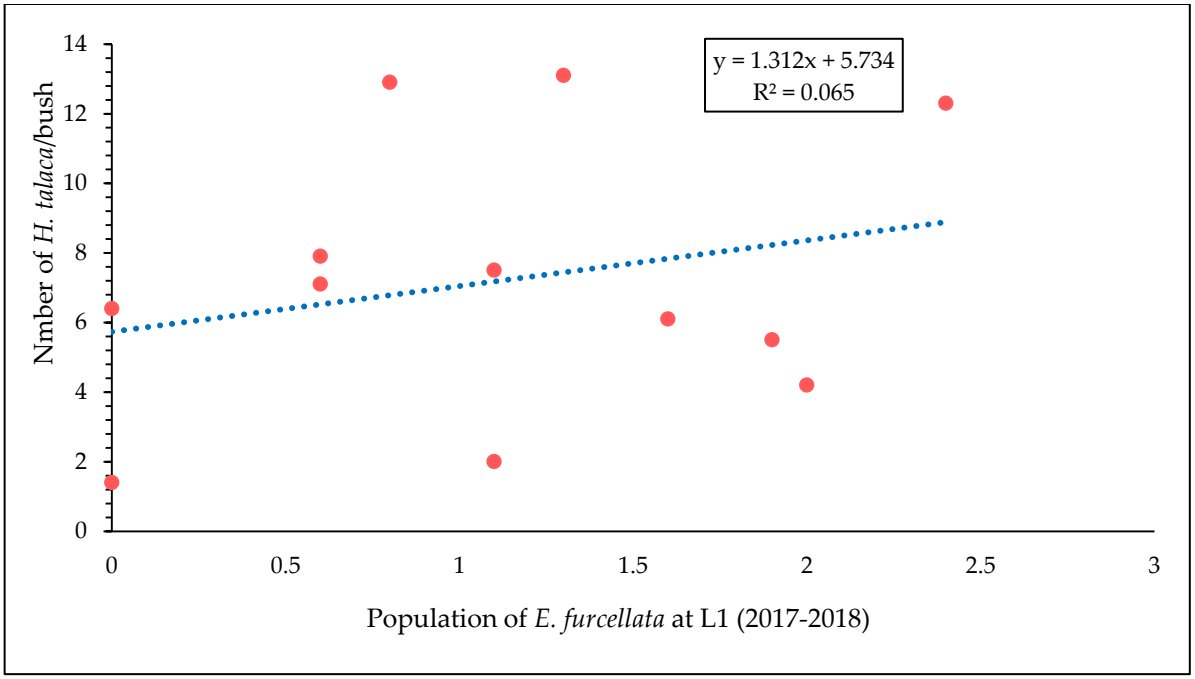


Fig. 6.1.4: Regression line representing relationship between the incidence of *H. talaca* and *E. furcellata* at Banarhat TE (2017-2018)

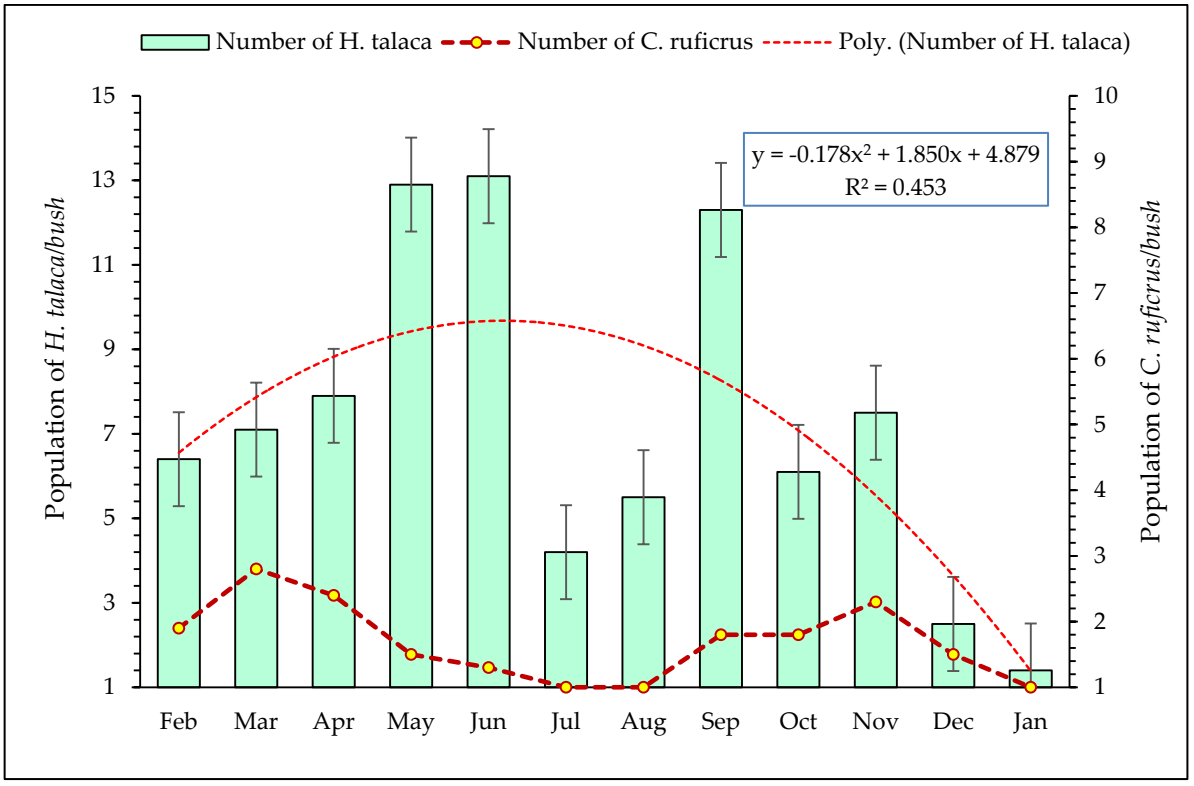


Fig. 6.1.5: Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at Banarhat TE (2017-2018)

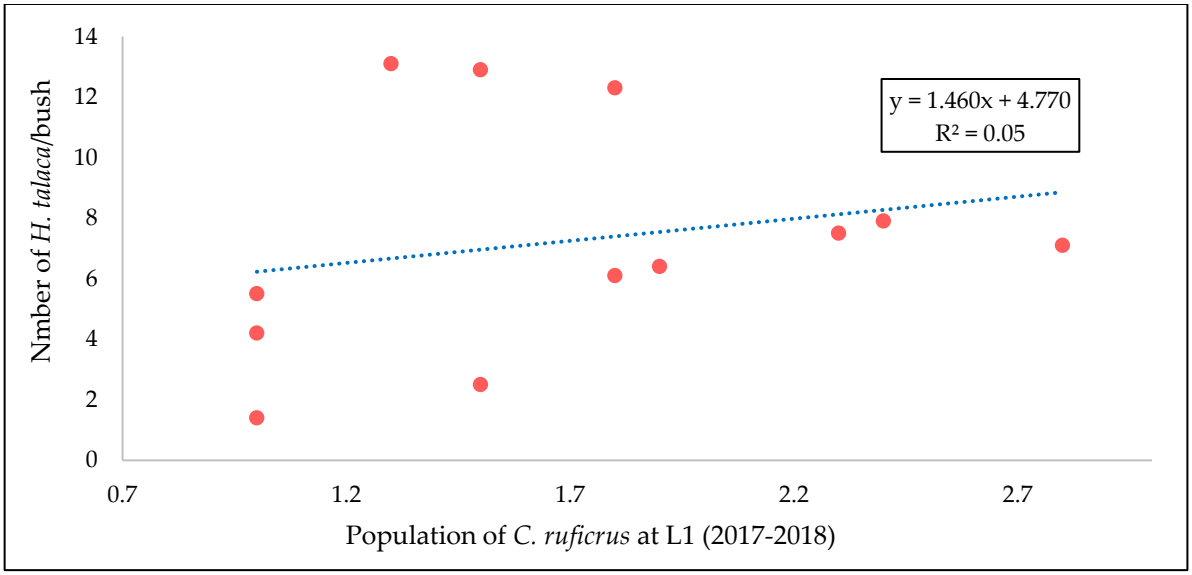


Fig. 6.1.6: Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at Banarhat TE (2017-2018)

4.6.1.2 During 2018-2019: Extent of increase of *H. talaca* population was comparatively higher during 2018-2019 than 2017-2018. The dynamics of *S.collaris*, *E. furcellata* and *C. ruficrus* had shown parity in relation to the incidence of *H. talaca* population in all cases (Fig.6.1.2.1 and 6.1.2.3). Both the predator population had increased in parity to the population of *H. talaca*. But the incidence of *C. ruficrus* was gradually decreased with the increasing temperature from March onwards (Fig. 6.1.2.5). The result exhibited that the population dynamics of *S.collaris* had significantly positive correlation with the population dynamics of *H. talaca* (r=0.4347), whereas *E. furcellata* (r=0.2846) and *C. ruficrus* (r=0.1246) had insignificantly negative correlation (Fig.6.1.2.2, 6.1.2.4and 6.1.2.6)

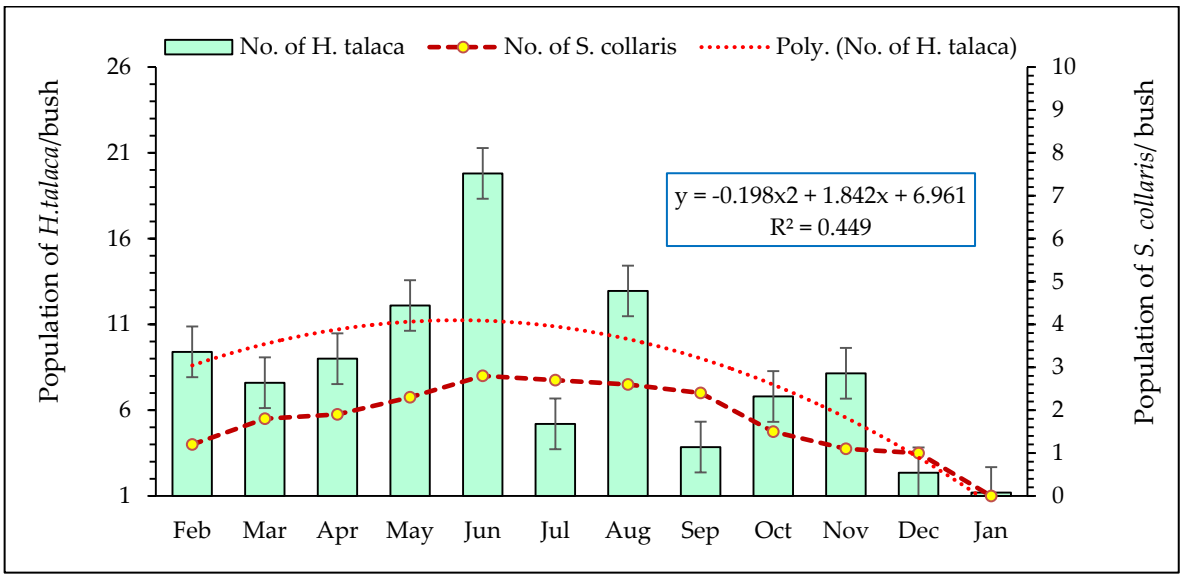


Fig. 6.1.2.1: Population dynamics of *S. collaris* in respect to densities of *H. talaca* at Banarhat TE (2018-2019)

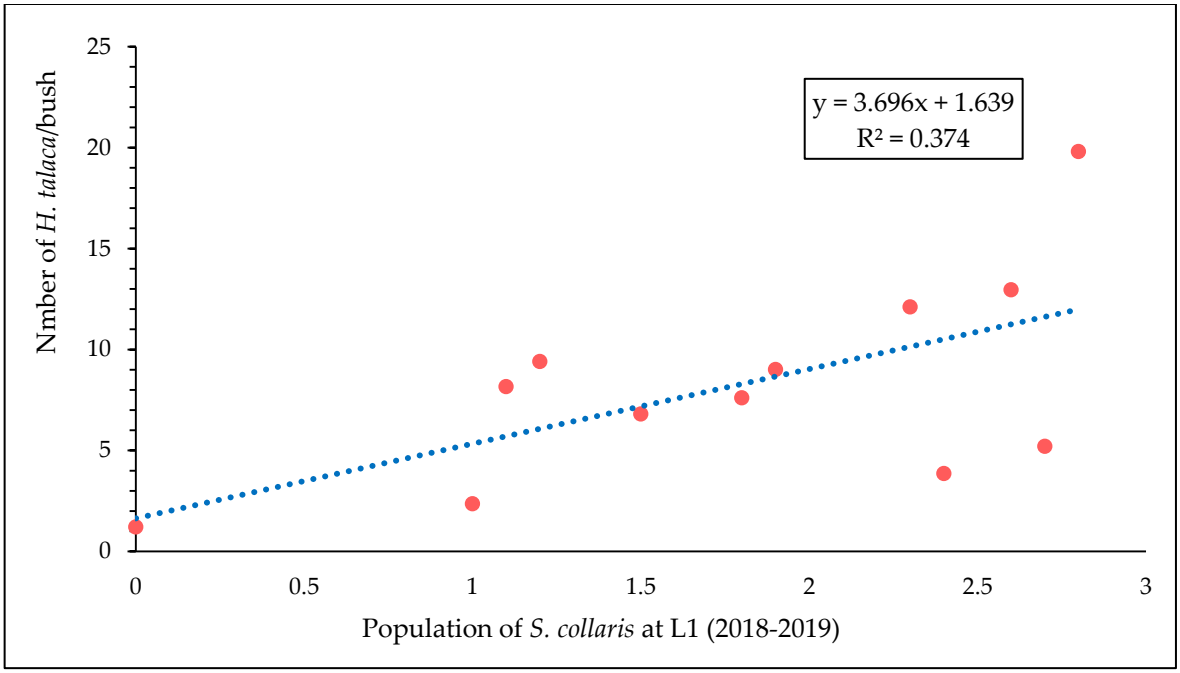


Fig. 6.1.2.2: Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at Banarhat TE (2018-2019)

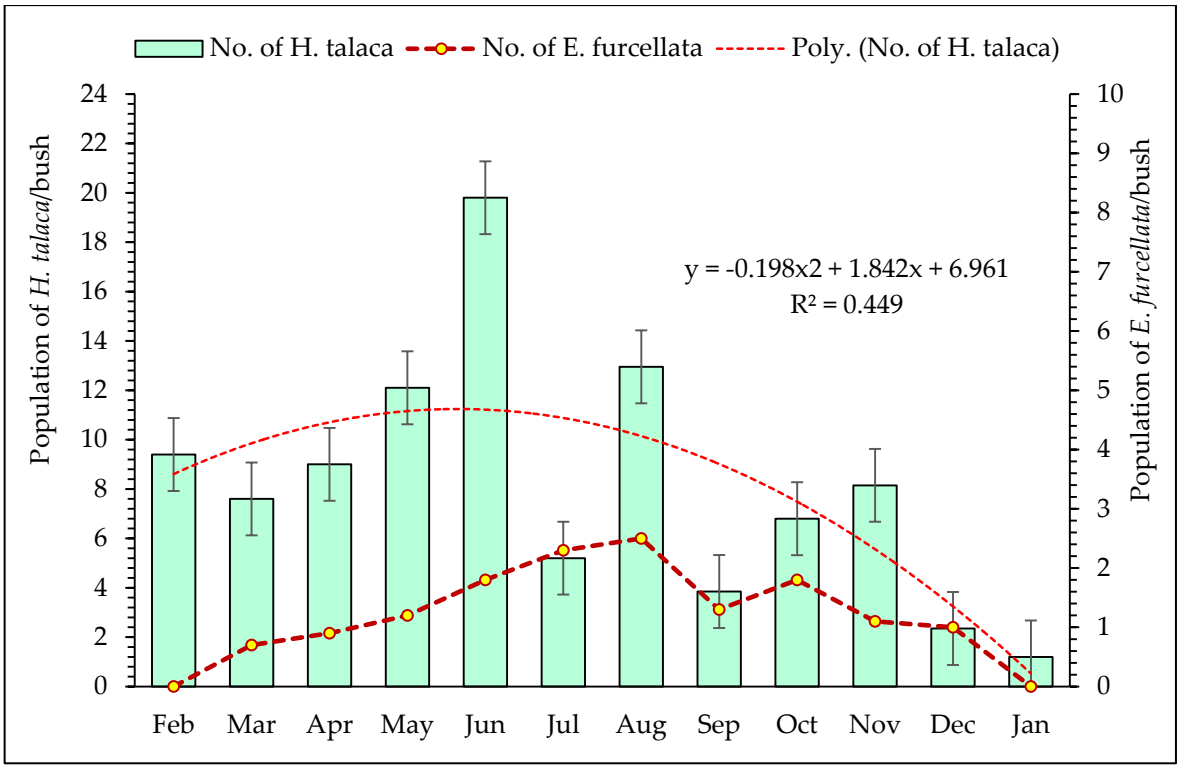


Fig. 6.1.2.3: Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at Banarhat TE (2018-2019)

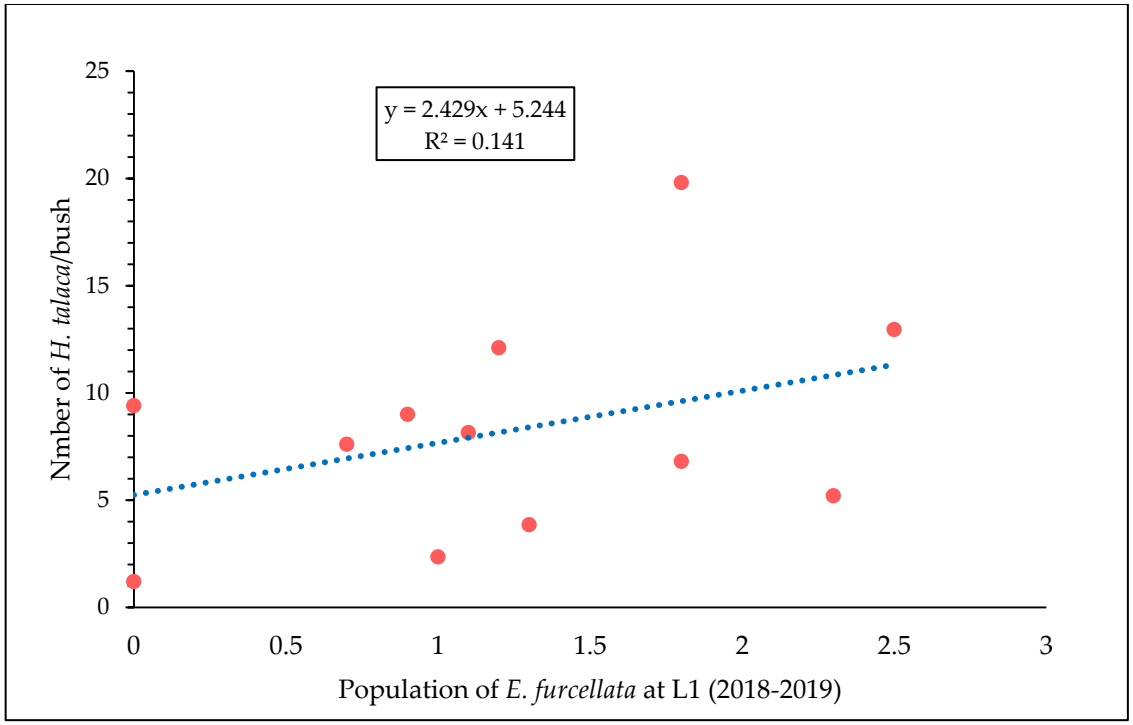


Fig. 6.1.2.4: Regression line representing relationship between population abundance of *H. talaca* and *E. furcellata* at Banarhat TE (2018-2019)

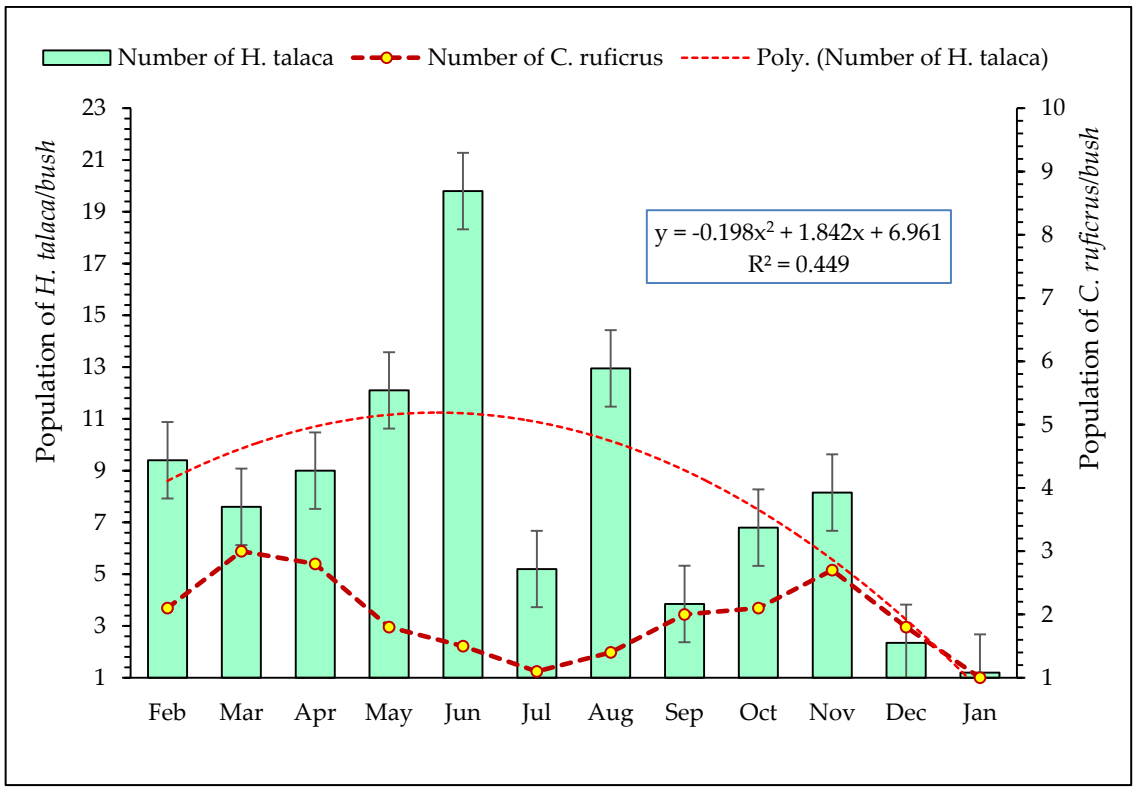


Fig. 6.1.2.5: Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at Banarhat TE (2018-2019)

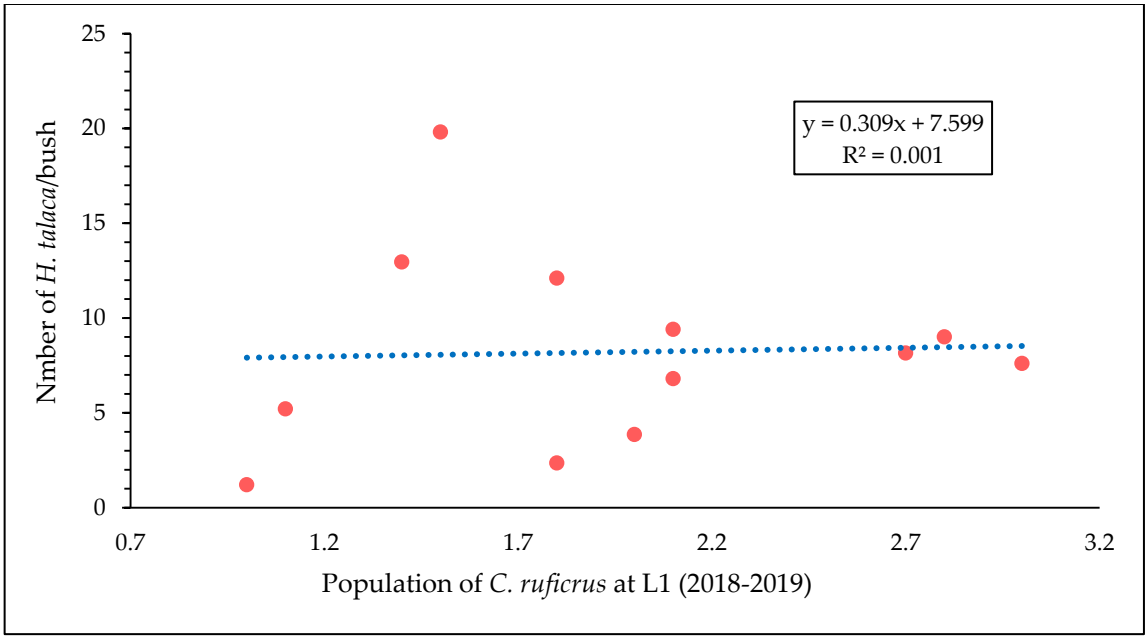


Fig. 6.1.2.6: Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at Banarhat TE (2018-2019)

4.6.2 At TRA experimental plot (L2)

4.6.2.1 During 2017-2018: At the beginning of the season the occurrence of *H. talaca* was 5.3 individuals/bush at L2 which was increasing steadily up to June and then got down. Dynamics of *S.collaris* had shown a variation in relation to dynamics of *H. talaca* (Fig. 6.2.1 and 6.2.2). Initially at February the incidence was 0.8individuals/bush. A gradual increase of the population was noted attaining the maximum abundance in August with 2.5individuals/bush. Incidence of *E.furcellata,* in the similar manner, had started to increase gradually from February. The interaction between *S. collaris* and *H. talaca* was also positive. The population then sloped down at first gradually and then abruptly attaining the minimum at December which coincided with the numerical abundance of *H. talaca* (Fig.6.2.3 and 6.2.4). Incidence of *C. ruficrus* then had gained momentum from February, the first peak of incidence was noted in March followed by a rapid fall of population (Fig. 6.2.5 and 6.2.6).Very marginal population was noted in July. The seasonality of *S. collaris* (r=0.6116), *E. furcellata* (r= 0.3760) and *C. ruficrus* (r= 0.0391) expressed positive correlation with the population trends of *H. talaca* (Table 6.3 and 6.4).

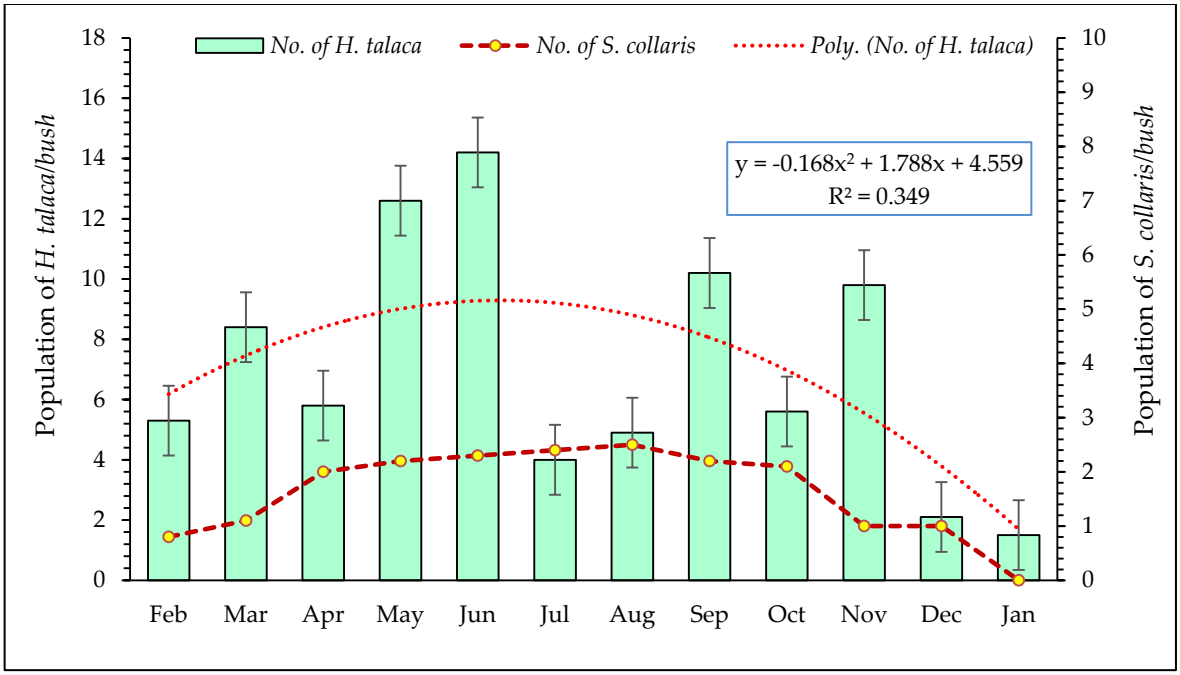


Fig. 6.2.1: Population dynamics of *S. collaris* in respect to densities of *H. talaca* at TRA Experimental plot (2017-2018)

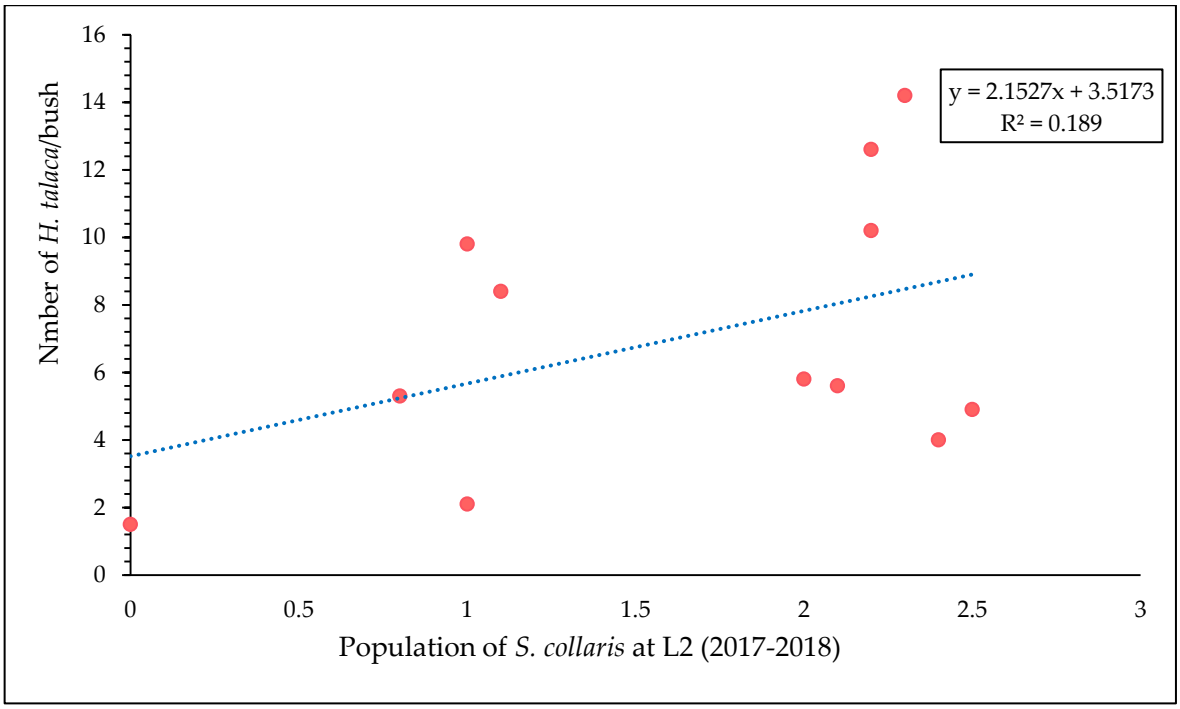


Fig. 6.2.2: Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at TRA experimental plot (2017-2018)

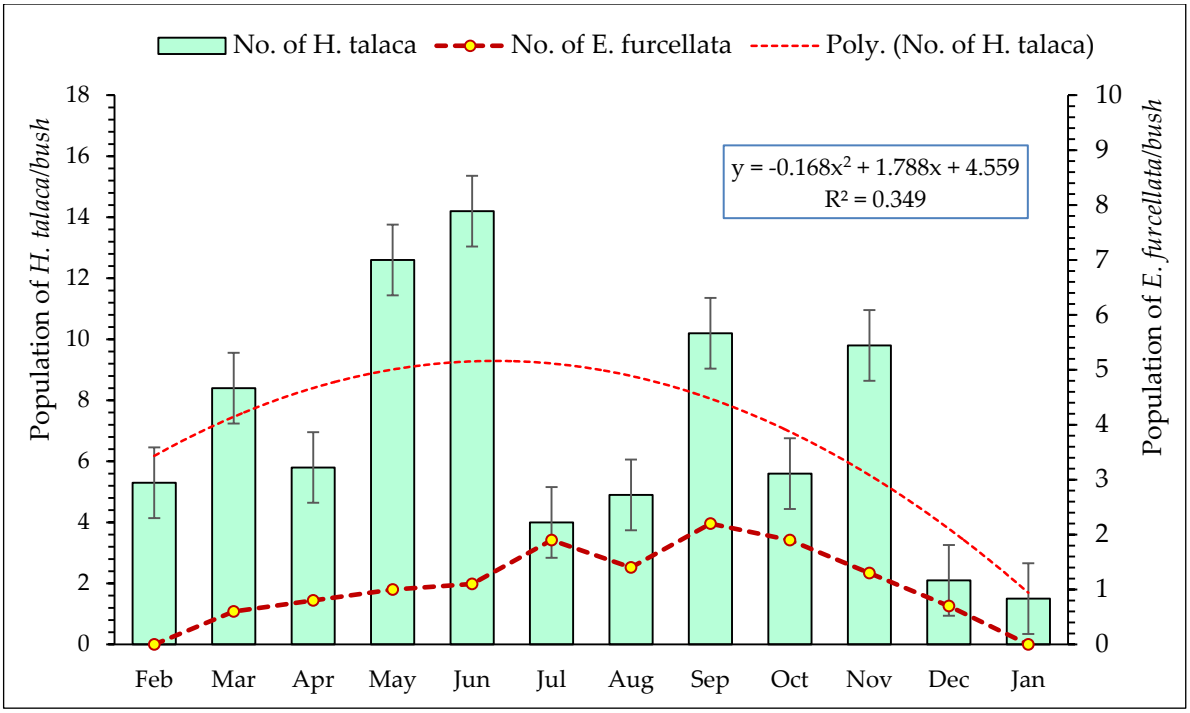


Fig. 6.2.3: Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at TRA experimental plot (2017-2018)

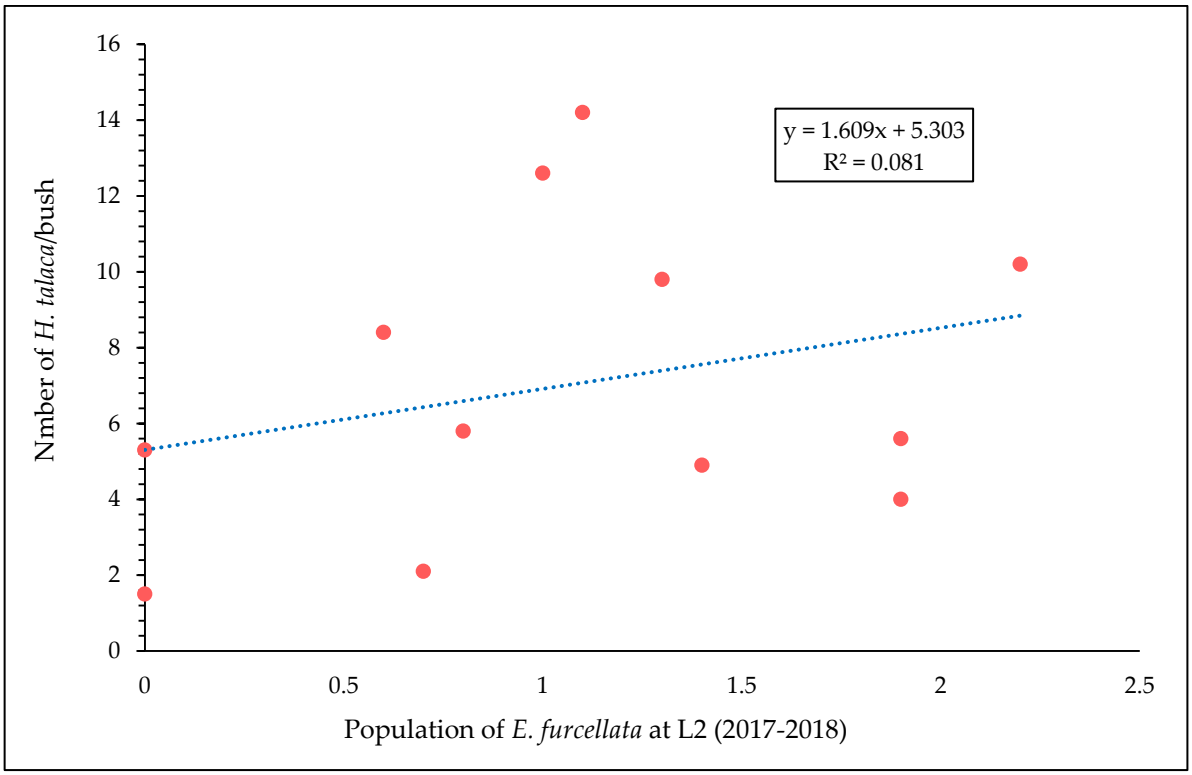


Fig. 6.2.4: Regression line representing relationship between population abundance of *H. talaca* and *E. furcellata* at TRA experimental plot (2017-2018)

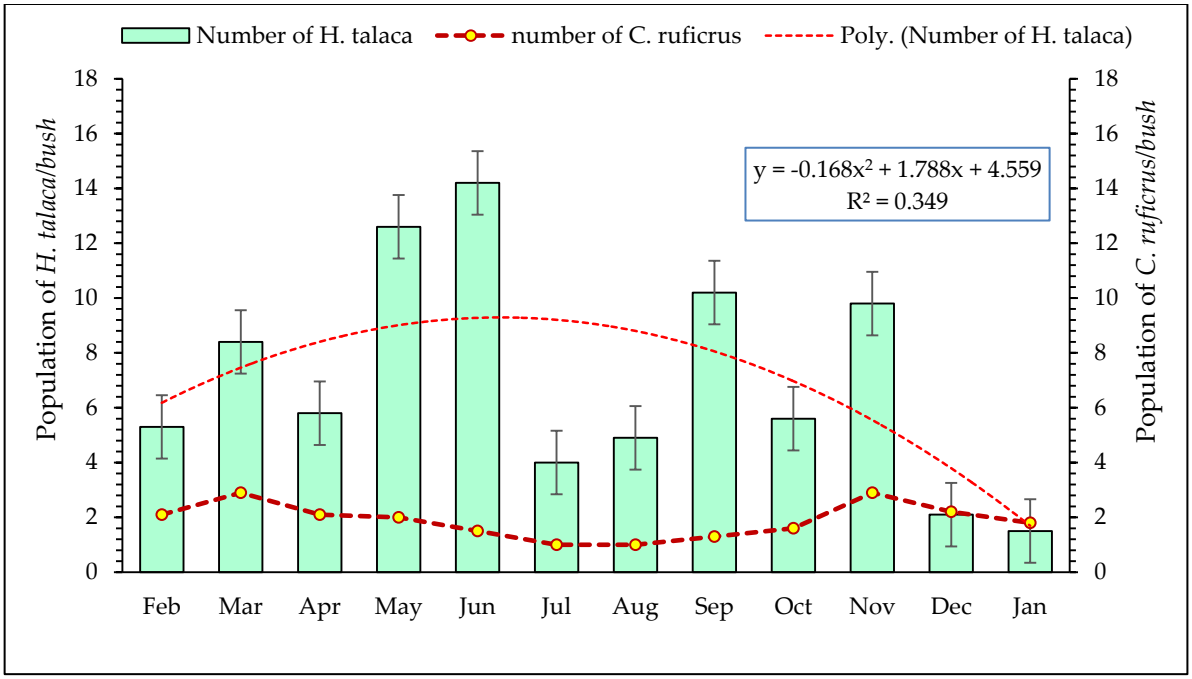


Fig. 6.2.5: Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at TRA experimental plot (2017-2018)

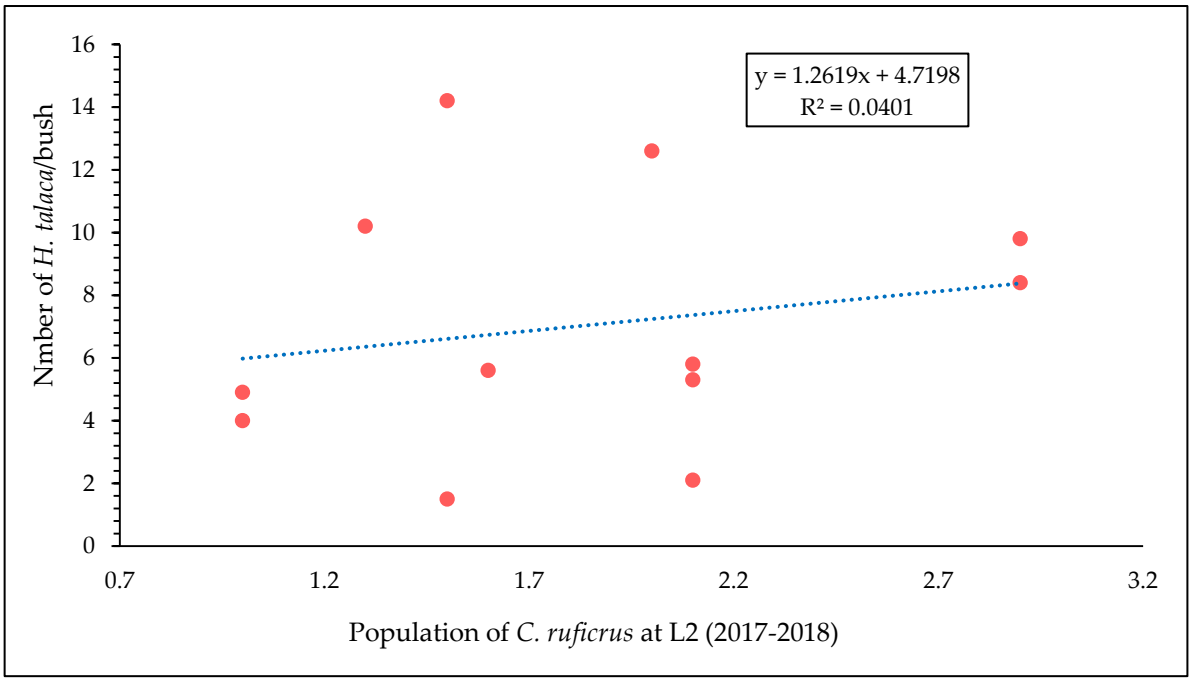


Fig. 6.2.6: Regression line representing relationship between population abundance of *H. talaca* and *C. ruficrus* at TRA experimental plot (2017-2018)

4.6.2.2 During 2018-2019: During 2018-2019, the population of *H. talaca* had initiated with 6.6 individuals/bush. The population then started to increase from March and that was continued up to June. Considerable fluctuation of population was then noted. Variation of *S.collaris* was observed in relation to the dynamics of *H. talaca* (Fig. 6.2.2.1

and 6.2.2.2).The incidence of *E. furcellata* had also exhibited parity with *H. talaca* pest population (Fig. 6.2.2.3 and 6.2.2.4). *C. ruficrus* attained peak incidence in March with 3.4 cocoons/bush. A steady decline of population was then recorded. The population of *C. ruficrus* was also related to the population trends of *H. talaca* (Fig. 6.2.2.5 and 6.2.2.6). Collectively, the population of *C. ruficrus* (r=0.5147), *E. furcellata* (r= 0.1916) and *C. ruficrus* (r= 0.0815) exhibited positive relation with *H. talaca* population (Table 6.3 and 6.4).

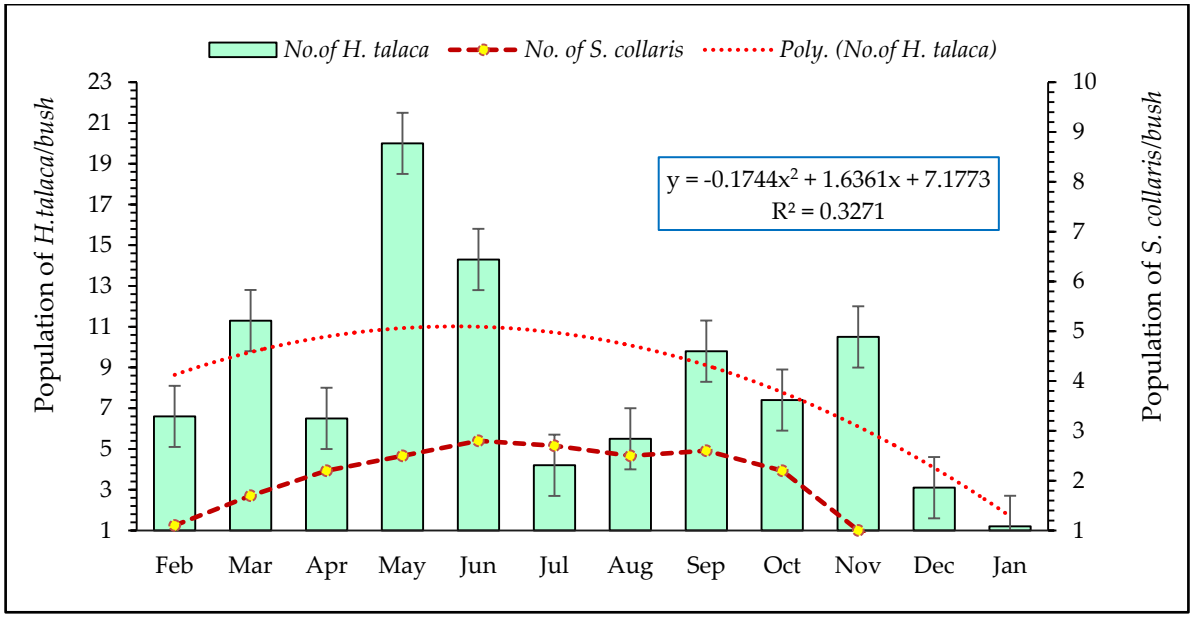


Fig. 6.2.2.1 Population dynamics of *S. collaris* in respect to densities of *H. talaca* at TRA Experimental plot (2018-2019)

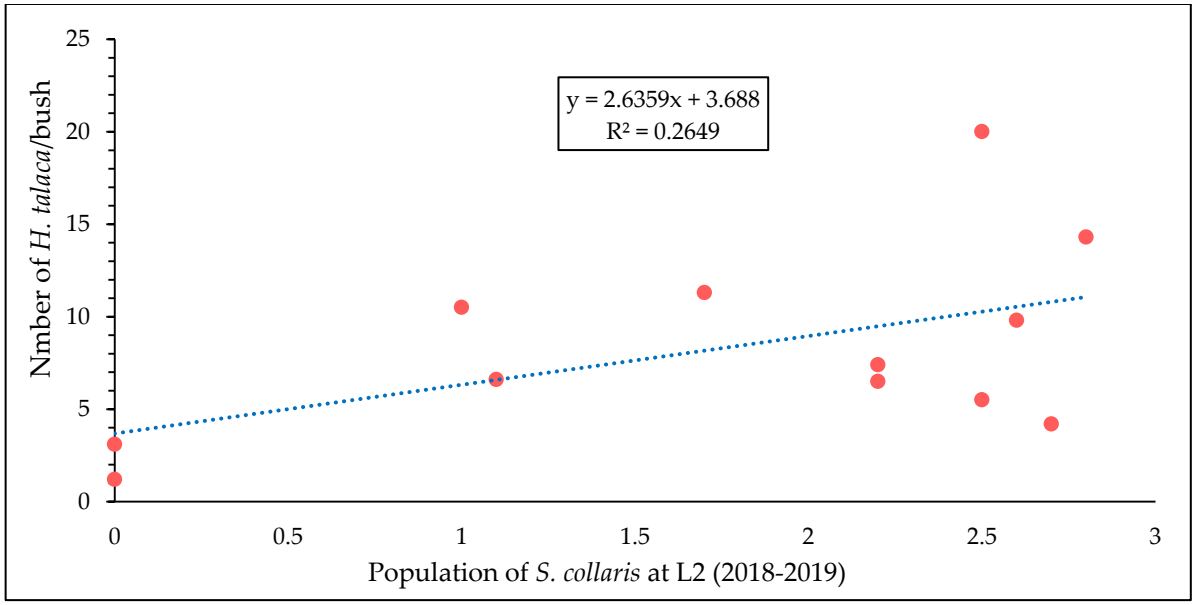


Fig. 6.2.2.2: Regression line representing relationship between population abundance of *H. talaca* and *S collaris* at TRA experimental plot (2018-2019)

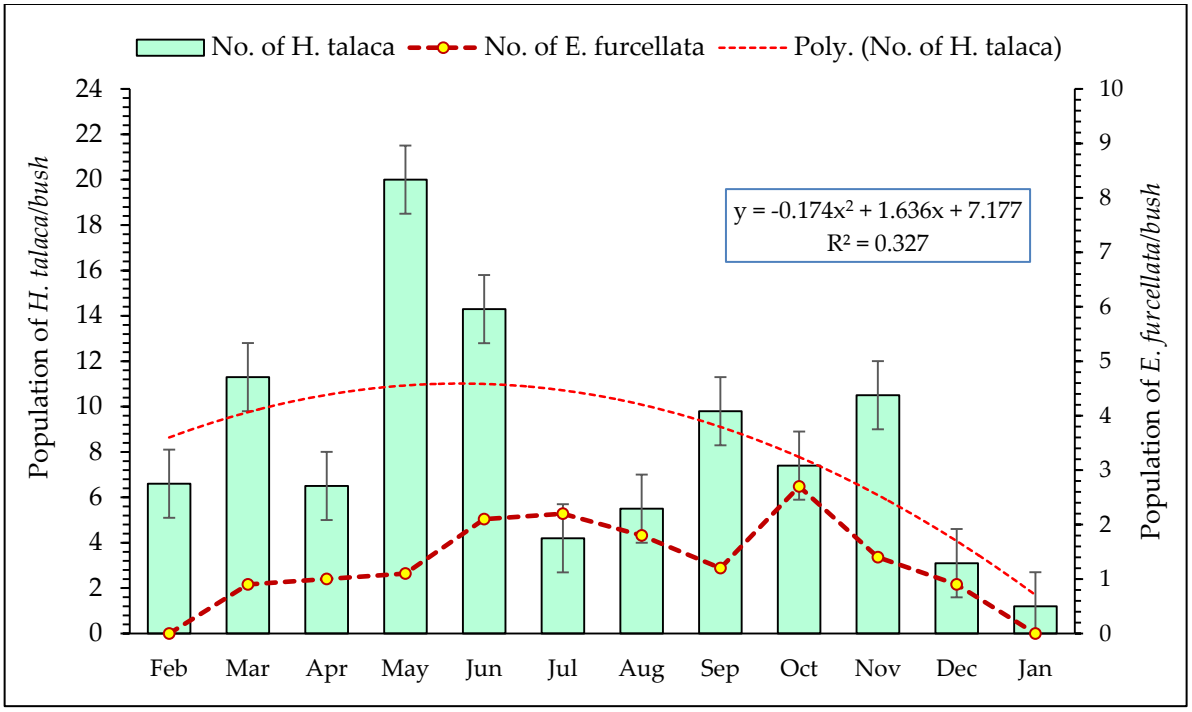


Fig. 6.2.2.3: Population dynamics of *E. furcellata* in respect to densities of *H. talaca* at TRA experimental plot (2018-2019)

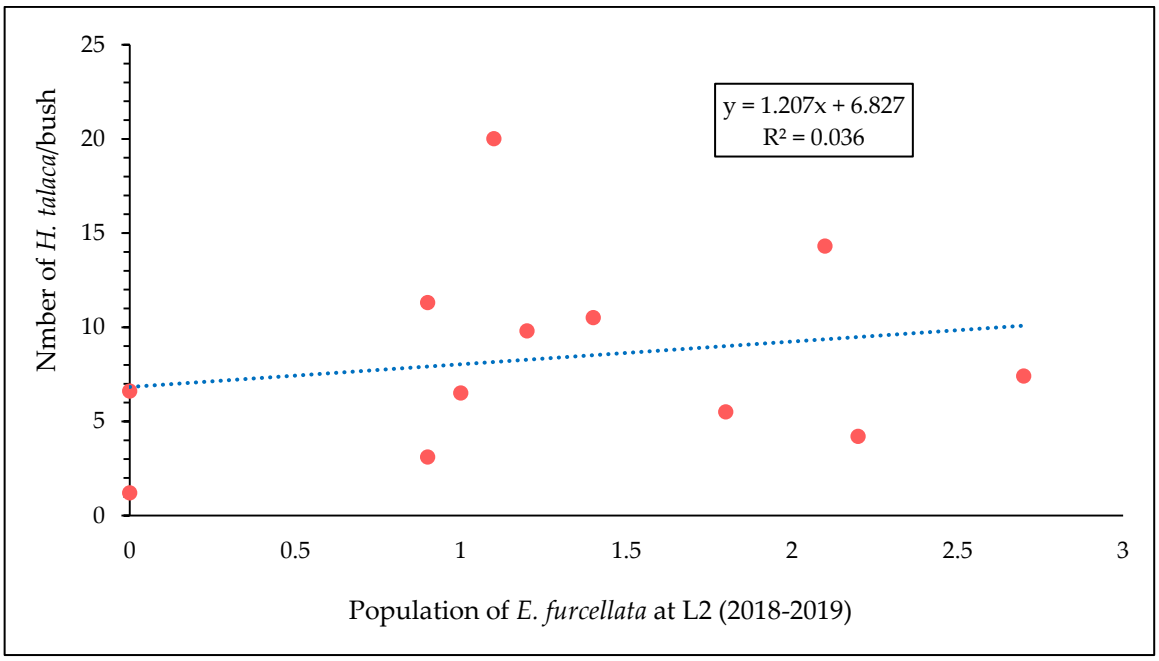


Fig. 6.2.2.4: Regression line representing relationship between population abundance of *H. talaca* and *E. furcellata* at TRA experimental plot (2018-2019)

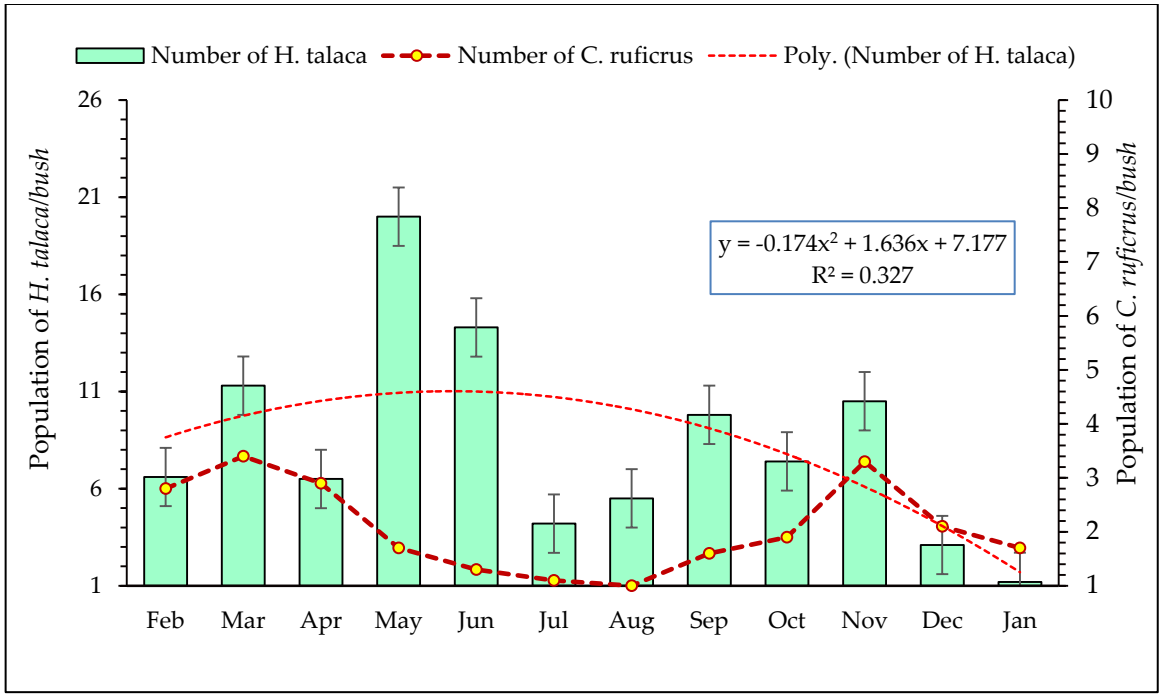


Fig. 6.2.2.5: Population dynamics of *C. ruficrus* in respect to densities of *H. talaca* at TRA experimental plot (2018-2019)

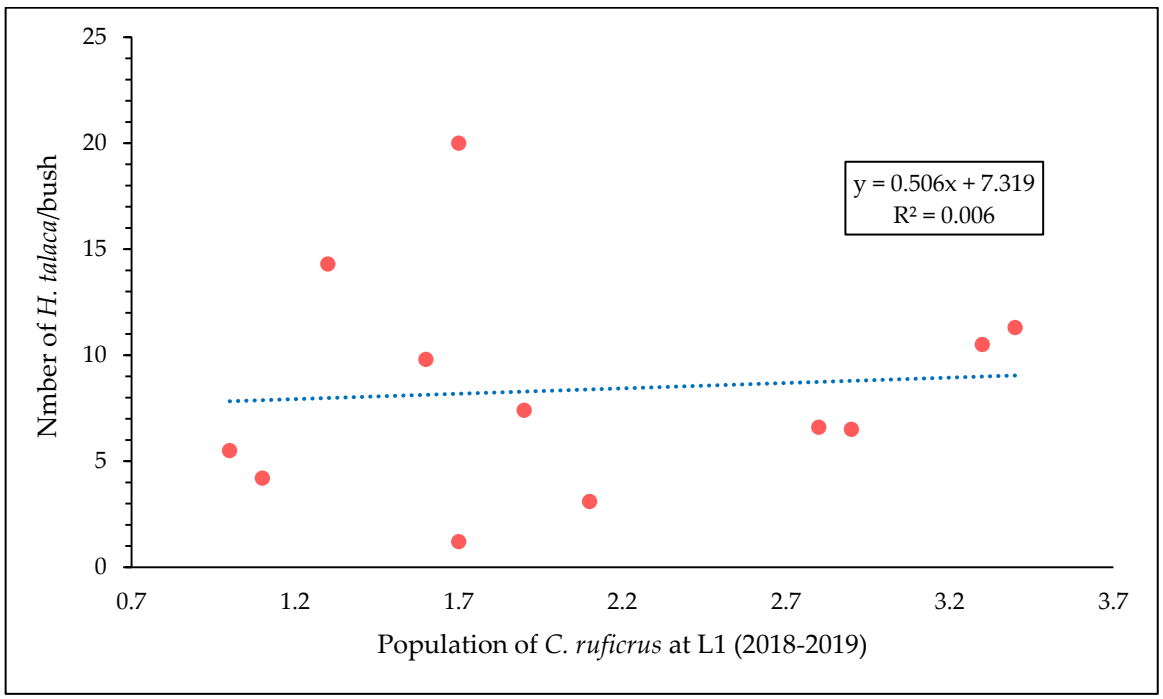


Fig. 6.2.2.6: Regression line representing relationship between population abundance of H. talaca and C. ruficrus at TRA experimental plot (2018-2019)

Table 6.3: Correlation between the population dynamics of *H. talaca* and its natural enemies

Natural enemies	Places of observation with correlation value*			
	2017-2018		2018-2019	
	L1	L2	L1	L2
S. collaris	0.6117	0.4347	0.6116	0.5147
E. furcellata	0.2567	0.2846	0.3760	0.1916
C. ruficrus	0.2236	0.1246	0.0391	0.0815

*L1: Banarhat TE, L2: TRA experimental plot

Table 6.4: Regression equations between the population of *H. talaca* and its natural enemies

Natural enemies	Places of observation with correlation value*			
	2017-2018		2018-2019	
	L1	L2	L1	L2
S. collaris	y = 2.66x + 3.29, **R^2 = 0.3742**	y = 2.15x + 3.51, **R^2 = 0.189**	y = 3.69x + 1.63, **R^2 = 0.3741**	y = 2.63x + 3.68, **R^2 = 0.2649**
E. furcellata	y = 1.31x + 5.73, **R^2 = 0.0659**	y = 1.60x + 5.30, **R^2 = 0.081**	y = 2.42x + 5.24, **R^2 = 0.1414**	y = 1.20x + 6.82, **R^2 = 0.0367**
C. ruficrus	y = 1.46x + 4.77, **R^2 = 0.05**	y = 1.26x + 4.71, **R^2 = 0.0401**	y = 0.30x + 7.59, **R^2 = 0.0015**	y = 0.50x + 7.31, **R^2 = 0.0066**

*L1: Banarhat TE, L2: TRA experimental plot

4.7. Study on the biochemistry of tea leaves and susceptibility index of selected tea clones against *H. talaca*

4.7.1 Observations on the tea leaf biochemistry

4.7.1.1. Analysis of primary metabolites: Among all the primary metabolites protein, lipid, carbohydrate and chlorophyll play the important role in the building of plant body. In the different selected cultivars of tea the amount of protein, lipid and carbohydrate were varied (Table 7.1).

4.7.1.1.1. Carbohydrate: Total carbohydrate of the selected tea leaves was estimated using the standard calibrating curve (Fig. 7.1.1.1). TV1 was characterized with high carbohydrate (0.737±0.003mg/g) followed by K1/1, TV26, B157, HP12, TV16, TV22, SNT8, TV20 and TS-520.

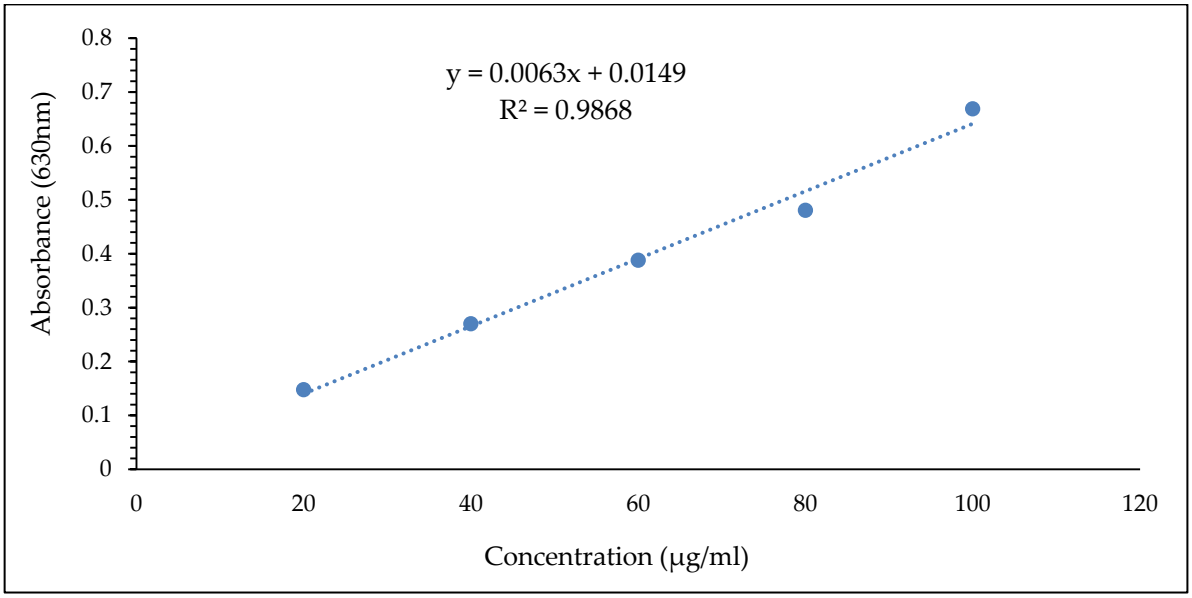


Fig. 7.1.1.1. Standard curve of carbohydrate

4.7.1.1.2. Protein: Protein imparts a major role in the biosynthesis of hormones, enzymes, membrane channels and pumps. Total protein of the selected tea cultivars was estimated by using the standard curve derived from known concentration of Bovine Serum (Fig. 7.1.1.2). For this reason high amount of protein in the tea cultivar of TV20 (10.40±1.2mg/g) and TV1 (10.10±1.1mg/g) compared with the other selected cultivars was noted. Comparatively low amount of protein was recorded in TS-520 (6.31±0.6mg/g).

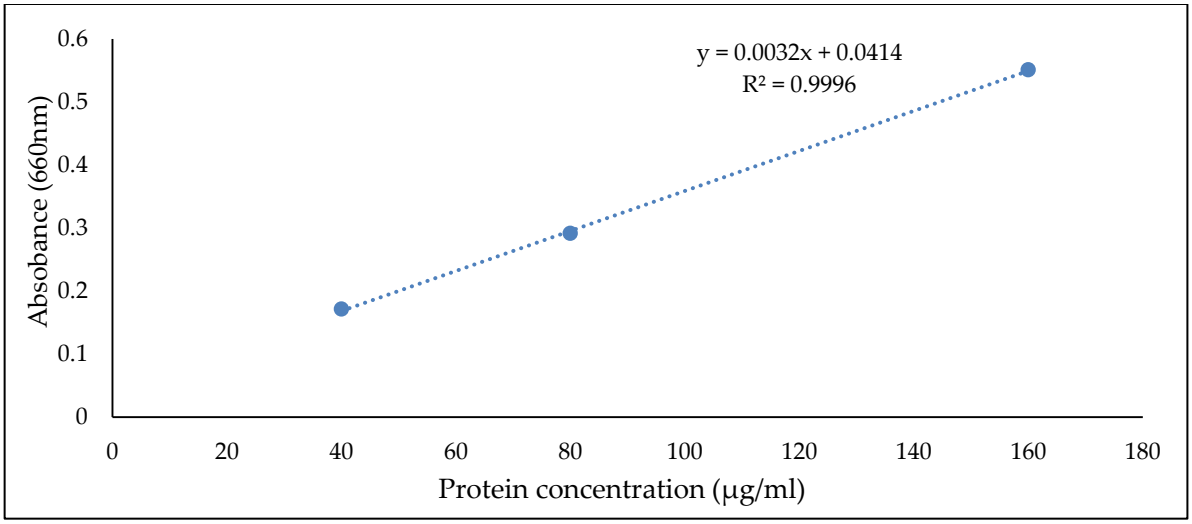


Fig. 7.1.1.2. Standard curve of protein.

4.7.1.1.3. Lipid: Lipid also play an important role in the plant health by providing the energy for metabolic processes, structural components for membranes, and intracellular signals. The amount was observed high in the cultivars of TV20 (14.6±1.4mg/g) and TV1 (14.2±1.5mg/g). TV22 contained low amount of total lipid (10.8±1.8g/mg) compared the other selected cultivars.

4.7.1.1.4. Chlorophyll: The quantity of chlorophyll was recorded comparatively high in K1/1(0.946±0.9mg/g) and TV20 (0.912±0.8mg/g). Based on the primary metabolites, food consumption of looper varied. Less amount was found in TV16 (0.678±0.07 mg/g).

4.7.1.1.5 Correlation regression: The regression revealed that significantly positive correlation of protein (r=0.6351), lipid (r= 0.6223), carbohydrate (r=0.5767) with the food consumption of looper on selected tea cultivars were recorded (Table 7.1.2.6). Correlation coefficient (r= 0.1414) between chlorophyll and the larval food consumption though positive but non-significance (Fig. 7.1.1).

4.7.1.2. Analysis of secondary metabolites: Food consumption of looper were found to be influenced by quantity of total phenols, total alkaloids, total flavonoids, carotenoids of tea leaf (Table 7.1).

4.7.1.2.1 Total polyphenol: Total polyphenol of selected tea cultivars was computed by the standard curve (Fig. 7.1.2.1), wherein the highest concentration was observed in the tea cultivar of TS-520 (270.2±10.2mg/g) followed by TV1, SNT8, TV16, HP12, TV20, TV22, TV26 and K1/1. The lowest quantity was observed in B157 (190.9±15.5mg/g).

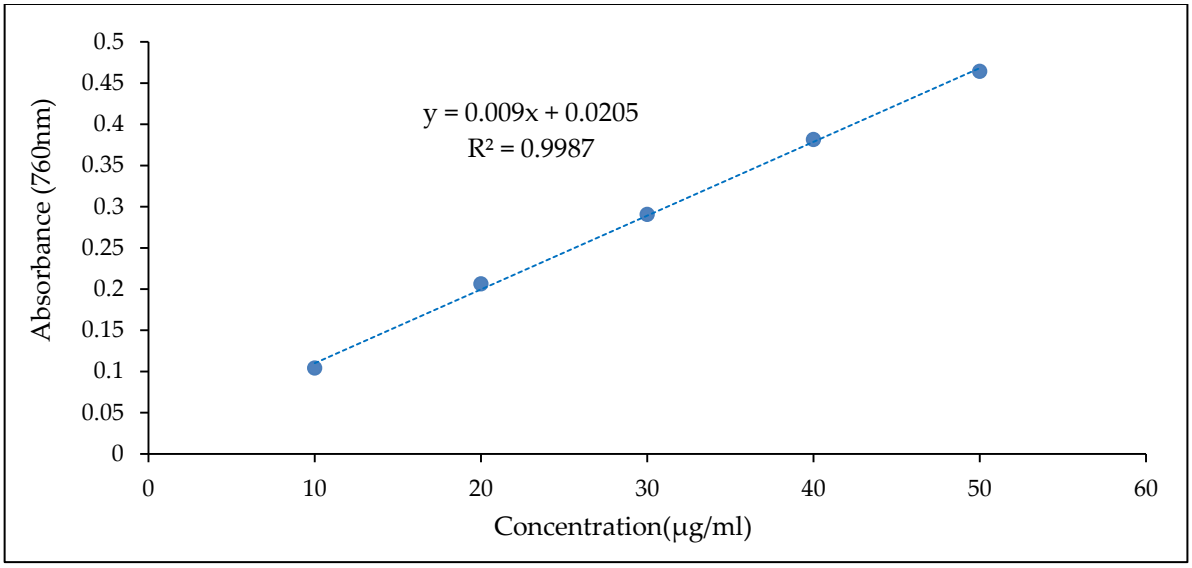


Fig. 7.1.2.1 Standard curve of polyphenol

4.7.1.2.2 Total alkaloid: The highest amount of total alkaloid was present in B157 (35.7±2.8mg/g) followed by SNT8, TV16, TV26, TV22, TS-520, K1/1, HP12, and TV1. Whereas the lowest quantity was recorded in TV20 (25.6±5.2 mg/g).

4.7.1.2.3 Total Flavonoid: Flavonoid plays a crucial role in indirect defense of plant against insect herbivores. Among all of the selected tea cultivars highest quantity was recorded in B157 as (0.15±0.003mg/g). TV26, SNT8, TS-520, HP12, TV1, TV16 and TV20. The lowest quantity was recorded in K1/1 (0.10±0.005 mg/g). Total flavonoid was estimated by using standard calibration curve (Fig. 7.1.2.3).

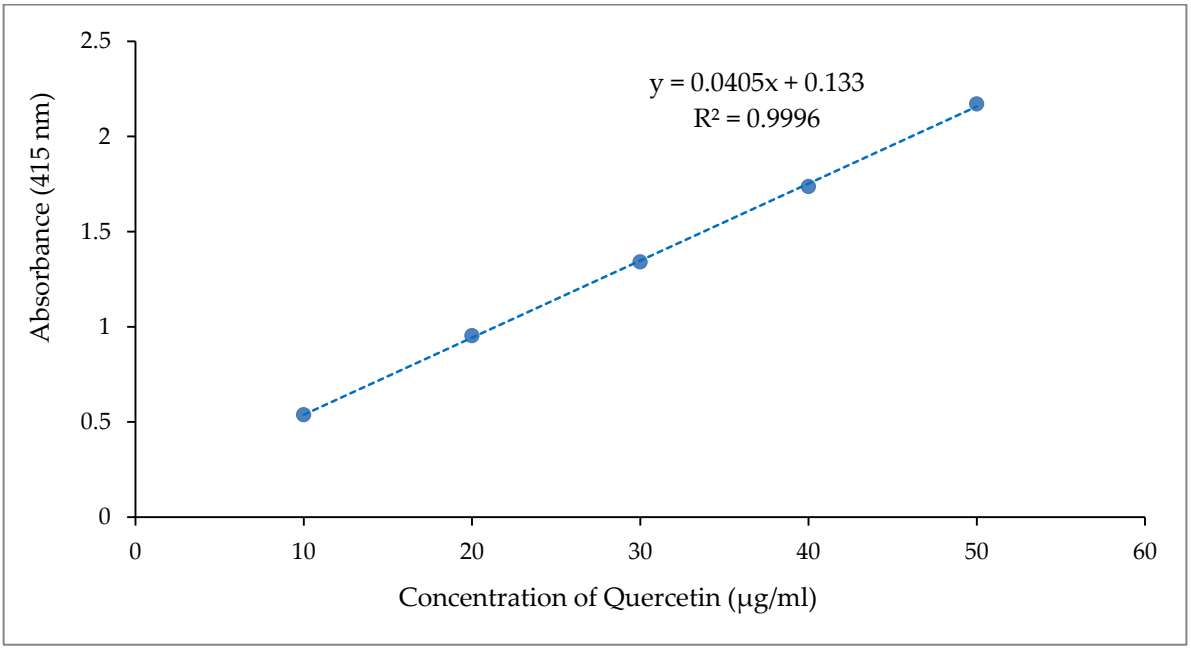


Fig. 7.1.2.3 Standard curve of Quercetin.

4.7.1.2.4 Carotenoids: Among all the tested tea cultivars, presence of highest amount of carotenoids was recorded in K1/1(0.277±0.03 mg/g). This was followed by TV20, TV22, B157, TV26, HP12, SNT8, TV16 and TS520. The lowest quantity was present in TV1 (0.178±0.03 mg/g).

Table 7.1: Quantitative estimation of tea leaf primary and secondary metabolites

Cultivars	Total phenols (mg/g)	Total alkaloids (mg/g)	Total flavonoids (mg/g)	Carbohydrate (mg/g)	Protein (mg/g)	Lipids (mg/g)	Chlorophyll (mg/g)	Carotenoids (mg/g)
TV20	228.7±21.1	25.6±5.2	0.12±0.007	0.687±0.05	10.40±1.2	14.6±1.4	0.912±0.08	0.267±0.04
TV1	266.6±15.2	25.8±3.8	0.13±0.004	0.786±0.003	10.10±1.1	14.2±1.5	0.604±0.06	0.178±0.03
K1/1	205.4±15.0	27.4±3.7	0.10±0.005	0.774±0.005	7.71±0.9	12.4±1.2	0.946±0.09	0.277±0.03
TV22	213.9±11.3	29.8±2.9	0.11±0.005	0.756±0.008	9.26±0.9	11.3±1.8	0.889±0.08	0.256±0.04
TV26	217.2±17.3	30.4±3.5	0.14±0.001	0.698±0.006	10.83±1.8	12.8±1.2	0.821±0.07	0.233±0.02
TV16	259.2±20.1	31.8±3.5	0.13±0.003	0.678±0.001	9.42±1.9	12.3±1.1	0.678±0.07	0.201±0.03
SNT8	264.2±21.3	33.8±4.2	0.14±0.001	0.643±0.002	7.21±0.7	12.4±1.2	0.788±0.08	0.218±0.02
TS-520	270.0±10.2	29.4±2.9	0.14±0.004	0.664±0.003	6.31±0.6	9.4±0.8	0.711±0.09	0.198±0.01
HP12	241.±14.5	26.8±2.6	0.14±0.003	0.583±0.007	8.35±0.8	12.2±1.2	0.746±0.06	0.220±0.02
B157	190.9±15.5	35.7±2.8	0.15±0.003	0.703±0.007	7.20±0.8	11.2±1.2	0.838±0.08	0.241±0.02

Values are representing mean ± SD of five replications.

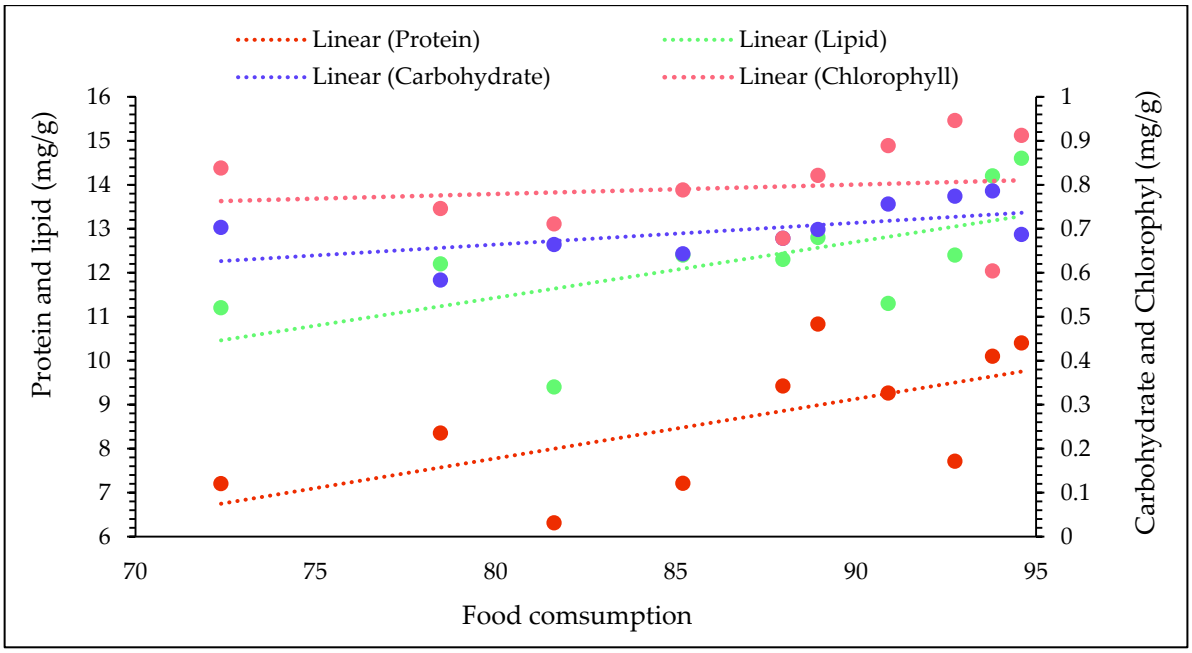


Fig. 7.1.1: Regression line showing correlation between food consumption of *H. talaca* and tea leaf primary metabolites

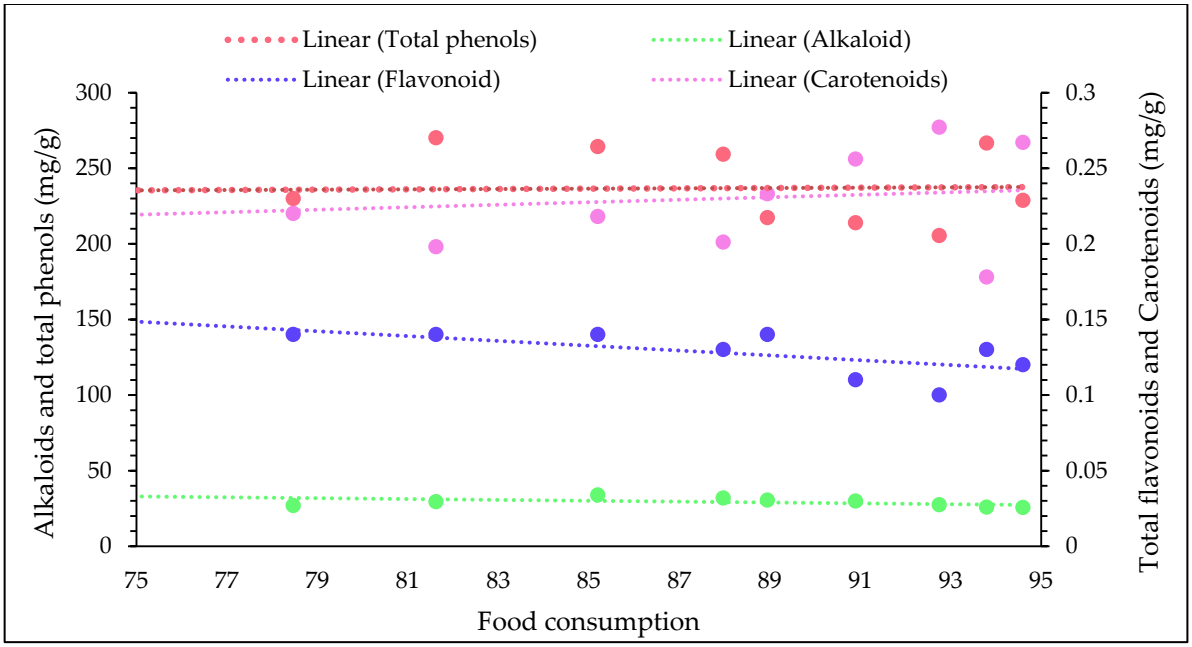


Fig. 7.1.2: Regression line showing correlation between food consumption of *H. talaca* and tea leaf secondary metabolites

4.7.1.2.5 Individual Catechins and Caffeine: The HPLC analysis showed that, highest quantity of EGC was found in TV20 (4.382%) compared with the other cultivars, while the lowest value was observed in TV16 (2.480%). Catechins was found in all the selected cultivars with variation, wherein highest quantity was observed in TV16 (1.794%) and the lowest quantity was seen in K1/1(0.714%). The results revealed that, the maximum EC was noticed in TV22 (1.855%) and minimum quantity in B157 (0.942%). Whereas EGCG contents was highest in K1/1 (11.31%) and lowest in HP12 (6.633%) compared with the other cultivars. The highest quantity of ECG was recorded in TV16 (4.929%) followed by other cultivars, where, the HP12 contains the lowest quantity. Among all the selected cultivars TV16 (3.625%) contained highest and TV16 (2.519%) lowest caffeine quantity. Gallic acid present in high quantity in B157 (0.199%) followed by other cultivars, while the lowest quantity was observed in HP12 (0.162%).

4.7.1.2.6 The correlation coefficient: Secondary metabolites alkaloids (r= -0.6137) and flavonoids (r= -0.7403) showed negative correlation with food consumption of looper (Table 7.1.2.6). Polyphenol and carotenoid were positively correlated with food consumption of looper (Fig. 7.1.2). The correlation coefficient of all types of Catechins (EGC, Catechin, EC. EGCG, ECG) and Caffeine with the feeding of looper on the selected cultivars were positively correlated (Fig. 7.1.2.6). Whereas, Galic acid showed the negative correlation (r= -0.5610) with food consumption of looper (Table. 7.1.2.8).

Table 7.1.2.6: Correlation between food consumption of *H. talaca* and biochemical compositions tea leaves

Metabolites	Components	Correlation coefficient (r)	Regression equation
Primary	Protein	0.6351*	y = 0.1352x - 3.036, **R^2 = 0.403**
	Lipid	0.6223*	y = 0.127x + 1.265, **R^2 = 0.387**
	Carbohydrate	0.5767*	y = 0.005x + 0.269, **R^2 = 0.332**
	Chlorophyll	0.1414	y = 0.002x + 0.608, **R^2 = 0.02**
Secondary	Polyphenol	0.1356	y = 0.1093x + 227.21, **R^2 = 0.001**
	Alkaloid	-0.6137*	y = -0.2866x + 54.489, **R^2 = 0.376**
	Flavonoid	-0.7403*	y = -0.0016x + 0.2681, **R^2 = 0.548**
	carotenoids	0.1874	y = 0.0008x + 0.1574, **R^2 = 0.035**

*Values are significant at $p < .05$.

Table 7.1.2.7: percentage of weight of EGC, Catechin, EC, EGCG, ECG, Caffeine and Gallic acid

Cultivars	Catechin						
	EGC (%)	Catechin (%)	EC (%)	EGCG (%)	ECG (%)	Caffeine (%)	Gallic acid (%)
TV20	4.382	0.803	1.484	7.912	1.877	3.125	0.162
TV1	2.639	1.380	1.373	7.392	3.498	3.431	0.166
K1/1	3.837	0.714	1.210	11.31	2.174	3.394	0.176
TV22	3.927	0.980	1.855	9.793	3.397	3.331	0.175
TV26	3.255	0.753	1.278	9.504	2.353	2.519	0.182
TV16	2.480	1.794	1.645	7.575	4.929	3.625	0.172
SNT8	3.568	0.792	1.112	8.953	1.990	2.947	0.194
TS-520	3.474	0.771	1.477	9.345	2.681	3.366	0.195
HP12	3.852	0.829	1.276	6.633	1.737	2.663	0.162
B157	2.987	0.716	0.942	9.499	2.109	2.818	0.199

Table 7.1.2.8: Regression equation and correlation between food consumption and percentage of weight of EGC, Catechin, EC, EGCG, ECG, Caffeine and Gallic acid

Biochemical component of tea leaf	Correlation coefficient (r)	Regression equation
EGC	0.1852	y = 0.015x + 2.107, **R^2 = 0.034**
Catechin	0.2884	y = 0.014x - 0.272, **R^2 = 0.083**
EC	0.5149	y = 0.018x - 0.256, **R^2 = 0.265**
EGCG	0.0789	y = 0.015x + 7.475, **R^2 = 0.006**
ECG	0.2840	y = 0.039x - 0.703, **R^2 = 0.080**
Caffeine	0.4635	y = 0.023x + 1.082, **R^2 = 0.214**
Galic acid	-0.5610	y = -0.001x + 0.271, **R^2 = 0.314**

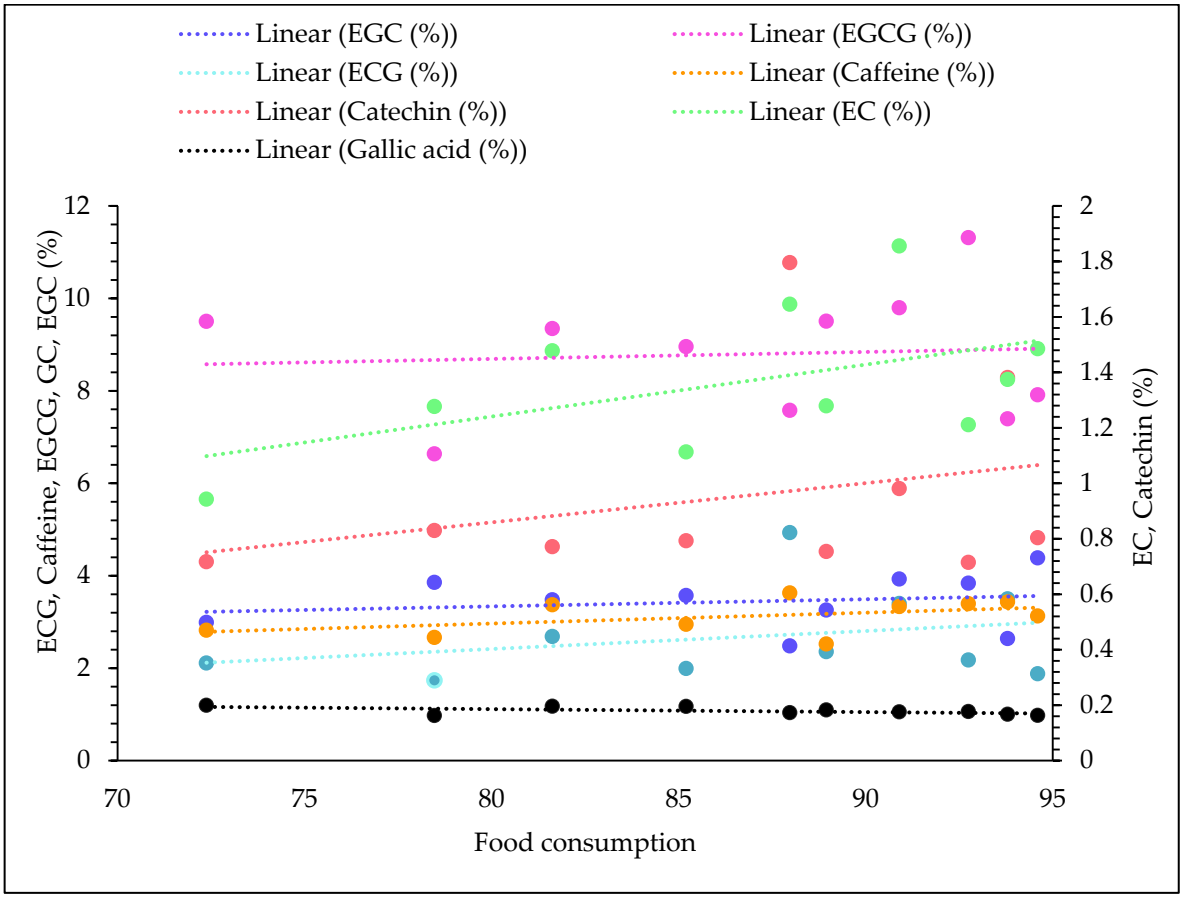
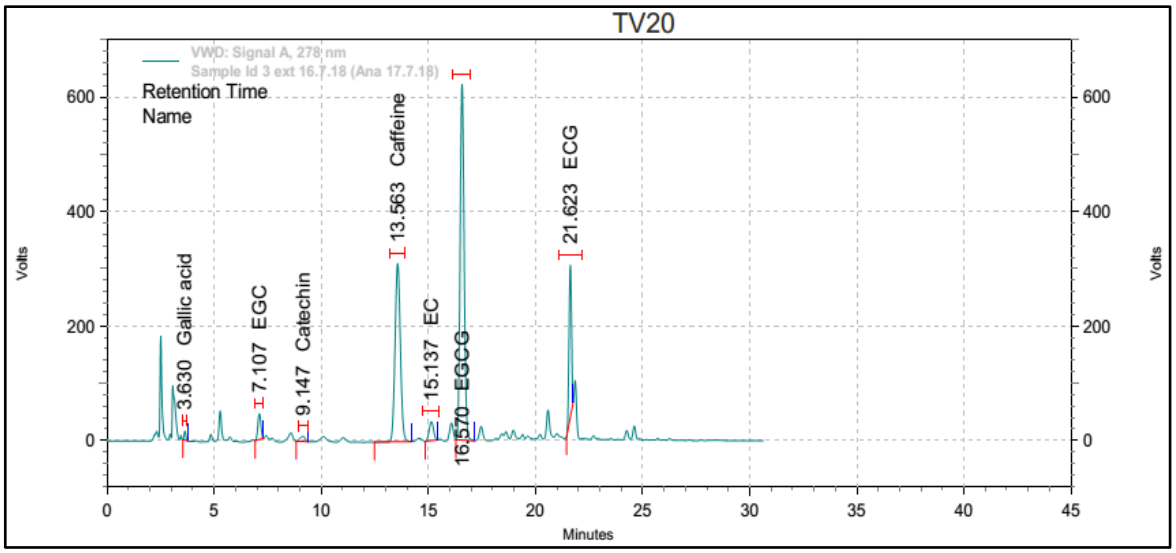
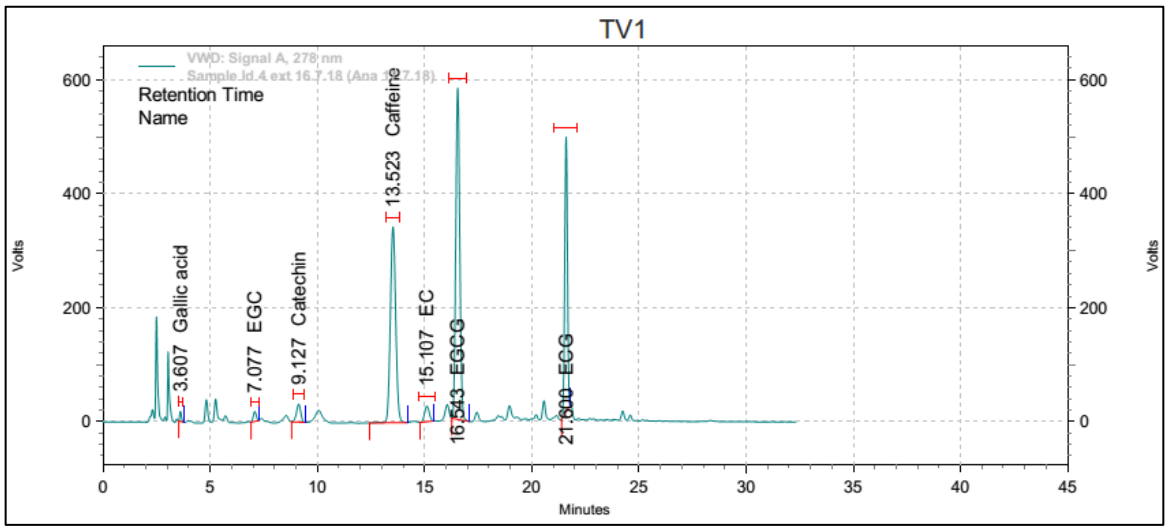
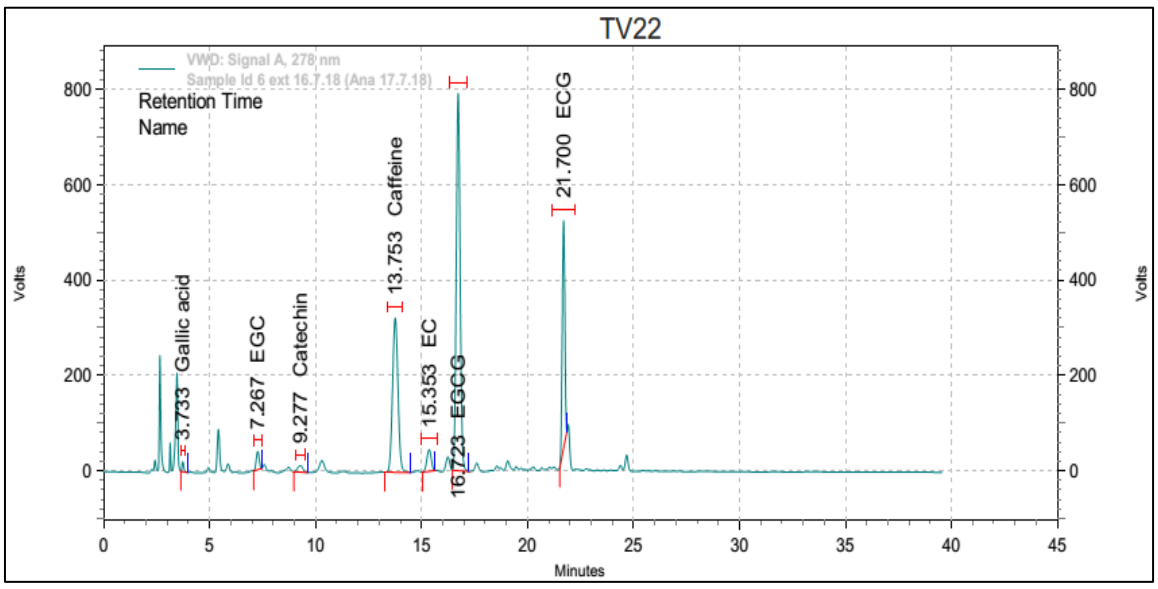


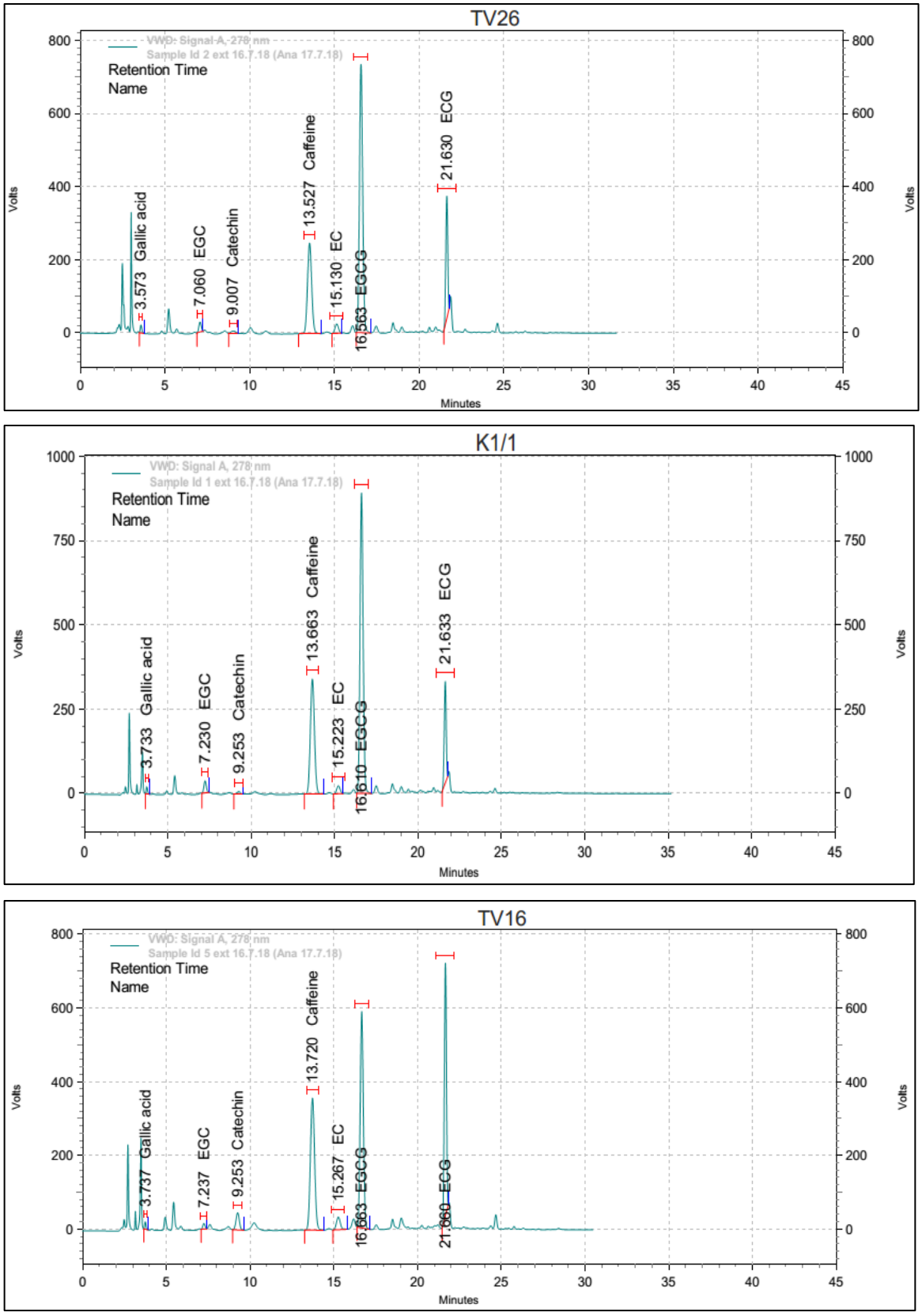
Fig. 7.1.2.6: Regression equation and correlation between food consumption and percentage of weight of EGC, Catechin, EC, EGCG, ECG, Caffeine and Gallic acid:



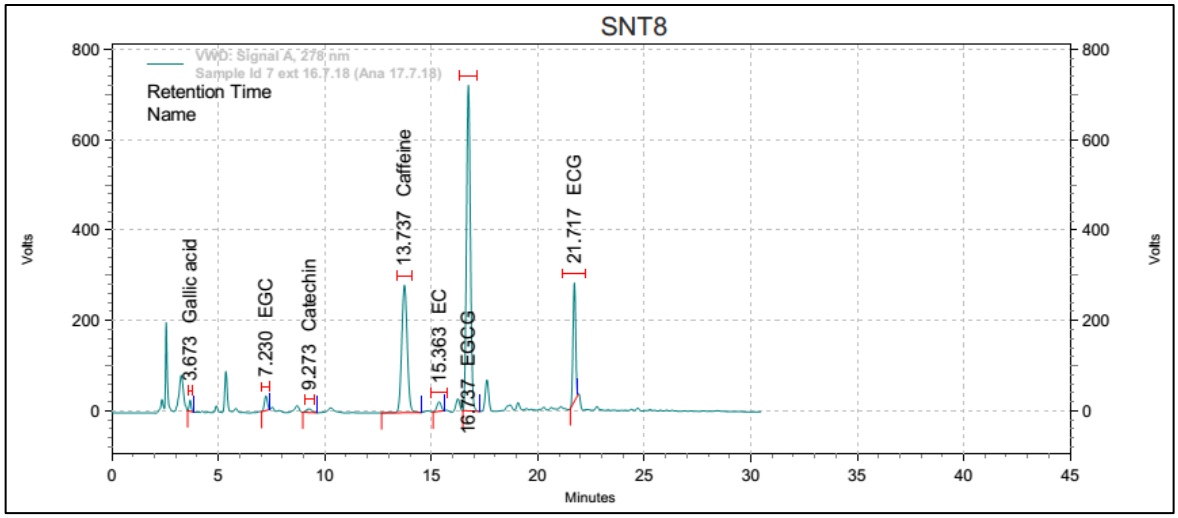


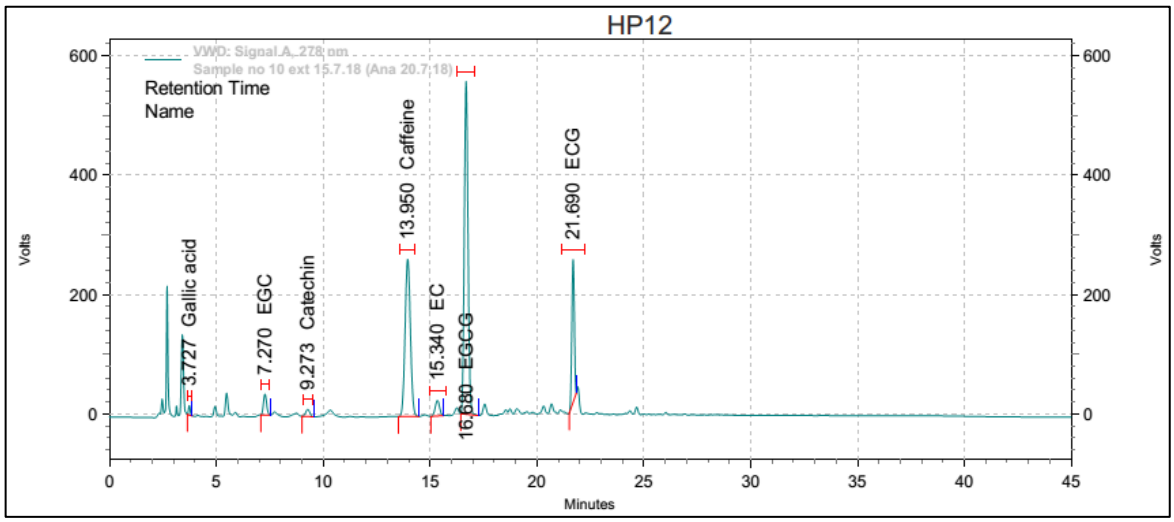


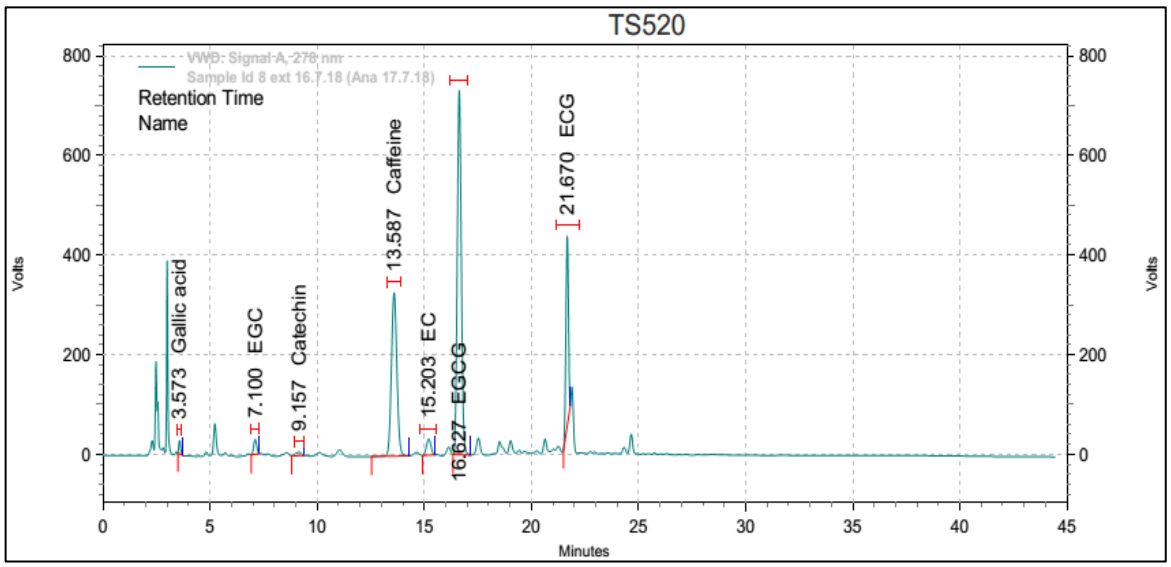
(Figure continue)



(Figure continue)







(Figure continue)

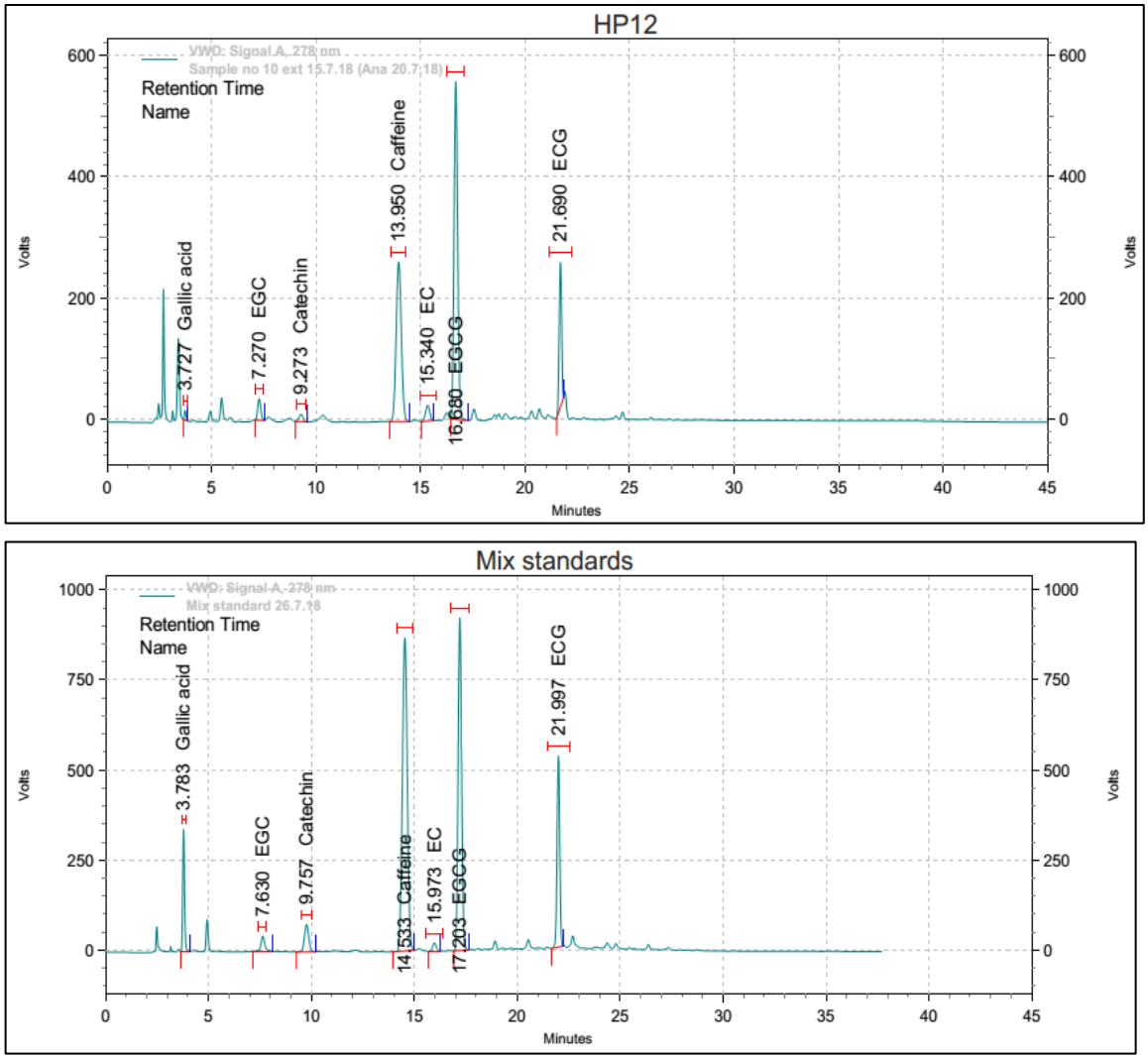


Fig 7.1.2.7: Chromatograms of green leaf of different tea cultivars and catechins mixed standard

4.7.1.3 Tea leaf biophysical characters: For the better understinding of the relationship and the performnece of direct defense of tea plant against larvae of *H. talaca*, tea leaf biophysical characters like, leaf thickness and trichome density were observed (Table 7.1.3). Tea leaf thickness of the cultivar B157 was measured as 0.248 µm, which was more thick compared to the other cultivars. The regression correlation showed negetive correlation coefficient (r= -0.7624) between the leaf thickness and food consumption of looper, which was statistically significant at $p < .05$ (Fig. 7.1.3). Trichome density was also high in the cultival of B157 (134.3±9.3/cm^2) and less in TV22 (103.3±6.0/cm^2) in the third leaf. The correlation coefficient (r= -0.8024) worked out, was showed negative relationship between trichome density and food consumption of looper (Table 7.1.4).

Table 7.1.3: biophysical characters of tea leaf

Cultivars	Leaf thickness (µm)	Trichome density (No./cm^2)
TV20	0.224±0.002	104.33±7.3
TV1	0.215±0.004	111.6±7.2
K1/1	0.235±0.002	118.0±9.9
TV22	0.227±0.001	103.3±6.0
TV26	0.212±0.002	125.3±8.6
TV16	0.223±0.005	123.0±9.6
SNT8	0.239±0.001	128.3±9.9
TS520	0.240±0.002	131.3±9.3
HP12	0.241±0.002	125.7±7.8
B157	0.248±0.002	134.3±9.3

Values are representing mean (±SE) of five replications

Table 7.1.4: Regression equation and correlation between food consumption of *H. talaca* and leaf biophysical characters

Correlation between food consumption of *H. talaca* and leaf characteristics		
Parameters	**Correlation coefficient (r)**	**Regression equation**
Thickness of leaf	-0.7624	y = -0.001x + 0.339, **R^2 = 0.581**
Trichome density	-0.8024	y = -1.203x + 224.79, **R^2 = 0.643**

Values are significant at p < .05

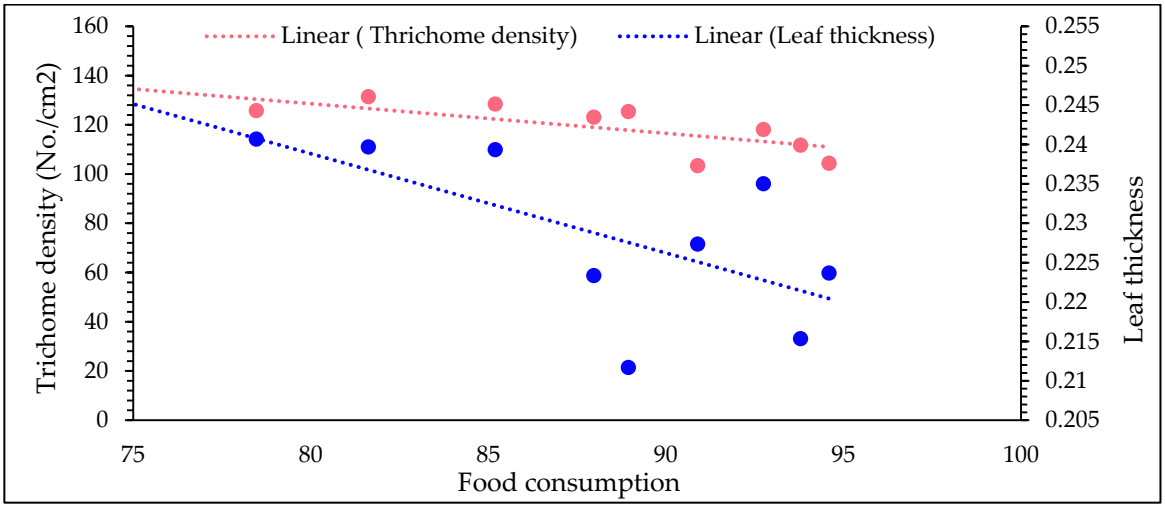


Fig.7.1.3: Regression line representing relationship between tea leaf biophysical characters and food consumption of *H. talaca*

4.7.1.4 Study on food consumption and weight gain by *H. talaca* on selected cultivars:

The gradual increase of food consumption and weight gain by the larvae of *H. talaca* were recorded. Fifth instar larvae consumed almost double amount of food compared to the young instars. The average food consumption of all instars was more on TV20 followed by TV1, K1/1, TV22, TV26, TV16, SNT8, TS-520, HP12 and B157 (Fig. 7.1.4, 7.1.5 and 7.1.6). Similar trends were also found in the weight gain by larvae. The relative

consumption rate (RCR) and relative growth rate (RGR) were noticed in decreased trends with the advanced instars gradually.

Title 7.1.5: Food consumption of *H. talaca* on tea leaves

Cultivars	Larval stages of *H. talaca*	Food consumption (mg)	Body weight gain (mg)	Nutritional indices				
				RCR	RGR	AD (%)	ECD (%)	ECI (%)
TV20	II	9.2±0.6^{a}	3.0±0.3^{a}	0.300	0.098	55.43	58.82	32.61
	III	33.6±4.0^{a}	9.8±0.7^{a}	0.300	0.088	59.50	49.00	29.17
	IV	112.0±14.2^{a}	18.2±2.2^{a}	0.252	0.040	62.60	25.92	16.25
	V	223.6±24.7^{NS}	31.0±2.0^{a}	0.084	0.011	66.18	20.91	13.86
TV1	II	9.2±0.7^{a}	3.0±0.3^{a}	0.300	0.098	55.10	59.17	32.60
	III	33.2±4.2^{a}	9.6±1.4^{ab}	0.291	0.086	59.12	48.92	28.91
	IV	111.4±12.9^{ab}	17.8±1.0^{a}	0.254	0.040	62.13	25.57	16.11
	V	222.4±21.1^{NS}	30.6±1.4^{a}	0.084	0.011	66.09	20.82	13.84
$K_{1/1}$	II	9.0±0.3^{a}	2.9±0.2^{ab}	0.292	0.095	55.00	58.58	32.22
	III	32.8±1.9^{a}	9.2±0.7^{abc}	0.290	0.083	58.53	47.92	28.00
	IV	110.2±3.0^{ab}	17.4±1.1^{a}	0.251	0.039	62.00	25.51	15.93
	V	220.0±18.4^{NS}	29.5±1.8^{ab}	0.080	0.011	65.90	20.34	13.41
TV22	II	8.0±0.5^{ab}	2.4±0.2^{abc}	0.282	0.087	54.87	54.66	30.00
	III	32.0±1.6^{ab}	8.8±0.4^{abc}	0.290	0.080	58.12	47.31	27.52
	IV	108.6±4.5^{abc}	15.2±1.4^{ab}	0.241	0.348	61.69	22.68	14.254
	V	217.0±21.0^{NS}	29.0±1.5^{ab}	0.083	0.011	65.85	20.29	13.42
TV26	II	7.1±0.7^{bc}	2.1±0.2^{bcd}	0.282	0.086	53.52	55.26	30.91
	III	30.8±1.7^{ab}	8.1±0.5^{sbcd}	0.290	0.076	57.79	45.50	26.34
	IV	103.1±2.9^{abcd}	14.3±1.0^{bc}	0.241	0.031	61.45	21.93	12.90
	V	214.8±15.0^{NS}	28.8±0.6^{ab}	0.080	0.011	64.89	20.65	13.41
TV16	II	6.9±0.5^{bc}	2.0±0.2^{cd}	0.282	0.088	52.17	55.55	31.93
	III	30.5±1.2^{ab}	8.0±0.4^{bcd}	0.290	0.076	55.40	47.33	26.22
	IV	102.0±3.9^{abcd}	13.1±0.8^{bc}	0.240	0.031	59.31	21.65	12.81
	V	212.5±14.4^{NS}	28.5±0.5^{ab}	0.080	0.011	64.47	20.87	13.43
SNT8	II	6.0±0.4^{cd}	1.71±0.2^{cd}	0.261	0.091	52.00	54.98	35.02
	III	28.8±1.8^{abc}	7.4±0.5^{cde}	0.302	0.078	54.86	46.83	25.71
	IV	98.0±3.1^{abcd}	12.0±0.9^{c}	0.240	0.029	60.20	20.33	12.20
	V	208.0±19.8^{NS}	27.0±1.8^{abc}	0.110	0.014	63.94	20.30	12.91
TS520	II	5.8±0.6^{cd}	1.65±0.2^{cd}	0.260	0.095	51.89	54.81	36.22
	III	25.7±2.4^{bcd}	6.5±0.7^{def}	0.290	0.074	54.47	46.42	25.34
	IV	95.0±5.6^{bcd}	11.5±0.4^{cd}	0.232	0.004	60.15	20.12	12.12
	V	200.0±11.8^{NS}	25.3±1.7^{bc}	0.080	0.010	63.50	19.92	12.90
HP12	II	5.0±0.4^{de}	1.41±0.2^{cd}	0.251	0.096	51.60	54.65	38.01
	III	23.4±1.7^{cd}	5.8±0.6^{ef}	0.312	0.078	54.27	45.66	24.82
	IV	91.0±8.0^{cd}	10.4±0.6^{de}	0.232	0.021	59.34	19.25	11.42
	V	194.3±15.9^{NS}	24.6±3.6^{bc}	0.080	0.009	63.04	18.44	11.64
B157	II	4.3±0.5^{e}	1.4±0.2^{d}	0.241	0.093	51.16	54.54	39.52
	III	19.3±1.2^{d}	4.9±0.4^{f}	0.282	0.071	53.93	45.15	25.43
	IV	86.7±7.0^{d}	9.6±0.6^{e}	0.250	0.021	58.82	18.82	11.12
	V	189.2±4.8^{NS}	24.1±2.6^{cd}	0.080	0.008	62.96	16.72	10.41

*Values are representing mean and standard error of 5 replications. The means followed by all the II instar (Data of food consumption and body weight gain are significant at 5% level of significance CD (0.05) = 1.455 and CD (0.05) = 0.677), III instar (Data of food consumption and body weight gain are significant at 5% level of significance CD (0.05) = 7.017and CD (0.05) = 1.974), IV instar (Data of food consumption and body weight gain are significant at 5% level of significance CD (0.05)= 16.385 and CD (0.05) = 3.145) and V instar (Data of food consumption was not significant and body weight gain are significant at 5% level of significance CD (0.05) = 5.174) the same letter are not significantly different at P = 0.05

The larvae of II, III, IV and V instars reared on the cultivar TV20 showed highest food consumption (9.2±0.6, 33.6±4.0, 112.0±14.2 and 223.6±24.7 mg per day respectively) AD (55.43, 59.50, 62.60 and 66.18 % respectively) with ECD values of

(58.82, 49.00, 25.92 and 20.9 respectively) and ECI values of (32.61, 29.17, 16.25 and 13.86). These was followed by TV1>K1/1> TV22> TV26> TV16> SNT8>TS-520>HP12. Whereas the larvae showed the lowest food consumption (4.3±0.5, 19.3±1.2, 86.7±7.0 and 189.2±4.8 mg respectively), nutritional indices like, AD (51.16, 53.93, 58.82 and 62.96 % respectively), ECD (54.54, 45.15, 18.82 and 16.72 respectively) and ECI (respectively 39.5, 25.4, 11.1 and10.4). It was interestingly observed that, the AD was gradually increased and on the other had ECI and ECD were gradually decreased (Table 7.1.5).

4.7.1.5 Susceptible index (Status of host preference on different tea cultivars by *H. talaca*): Among all the selected cultivars used in the present study, TV20, TV1, K1/1, TV22, TV26, TV16 and SNT8 were found highly susceptible to *H. talaca*, with susceptible index score ranged from 0.90 to1.07. The cultivars TS-520 and HP12 were susceptible with susceptible index score varied from 0.80 to 0.89. Only B157 was found to be moderately susceptible with susceptible index score of 0.772 (Table 7.1.6).

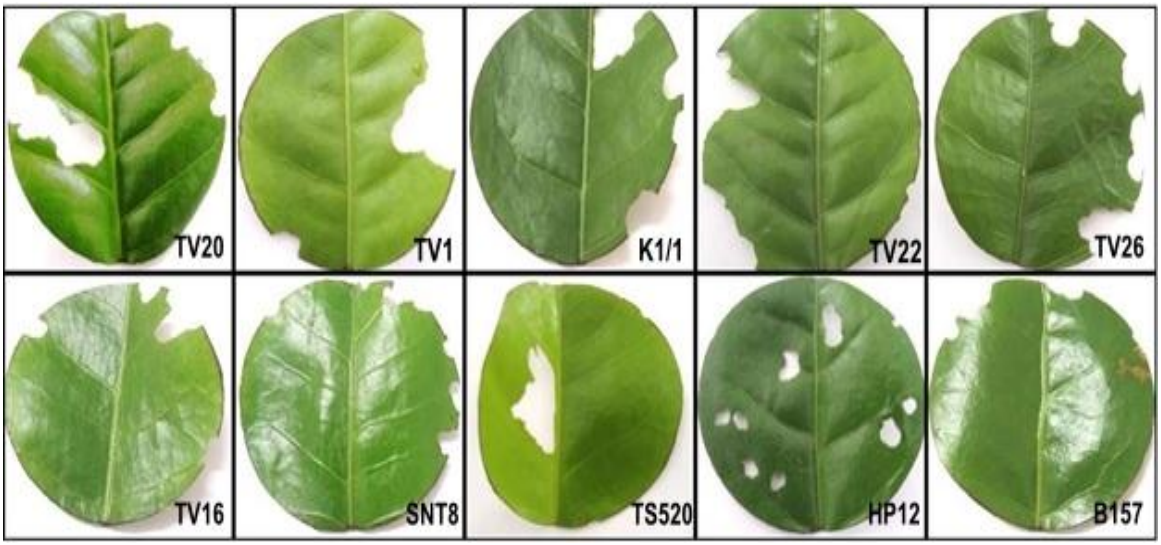


Fig.7.1.4: Leaf discs fed by II instar larvae of *H. talaca*

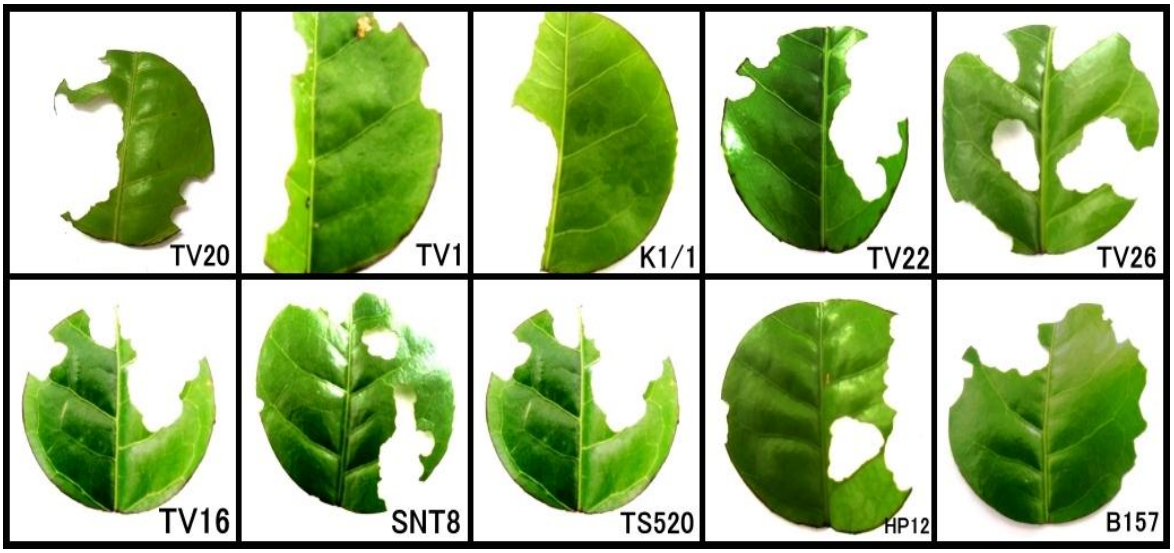


Fig.7.1.5: Leaf discs fed by III instar larvae of *H. talaca*

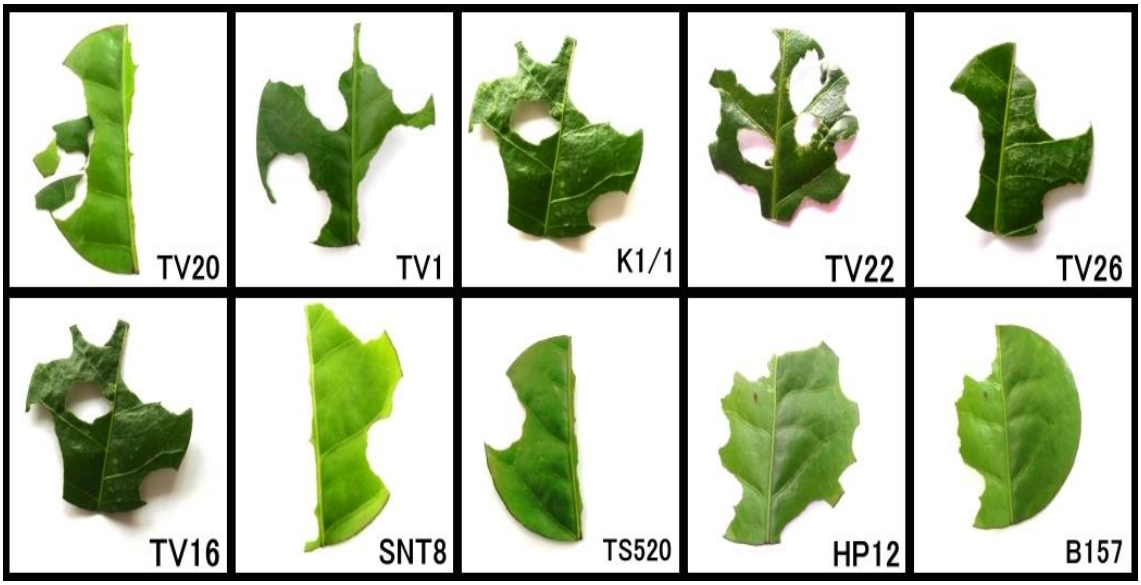


Fig. 7.1.6: Leaf discs fed by IV instar larvae of *H. talaca*

Table 7.1.6: Susceptible index (Status of host preference on different tea cultivars by *H. talaca*)

Cultivars	Susceptible index*	Status**
TV20	1.009	HS
TV1	1.000	HS
K1/1	0.989	HS
TV22	0.969	HS
TV26	0.948	HS
TV16	0.938	HS
SNT8	0.908	HS
TS-520	0.870	S
HP12	0.837	S
B157	0.772	MS

Highly susceptible (HS)= 0.90-1.0, Susceptible (S)= 0.80-0.89, Moderately Susceptible (MS)= 0.70-0.79, (Less Susceptible (LS)= 0.60-0.69, (Less Resistance (LR)= 0.50-0.59, Moderately Resistance (MR)= 0.40-0.49, Resistance (0.30-0.39) and Highly Resistance (HR)= 0.20-0.29)

4.7.1.6 Cluster analysis: Based on the nutritional indices of larvae of *H. talaca* a dendrogram was constructed (Fig. 7.1.7). The dendrogram showed A and B two distinct clusters. Cluster A was sub-clustered into A1 and A2, whereas cluster B was sub-clustered into B1 and B2. The selected tea cultivars were divided into this sub-clusters based on the nutritional indices of larvae reared on each cultivars. The cultivars TS520 and HP12 included under the sub-cluster A1 and as susceptible cultivars whereas B157 included under A2 as moderately susceptible cultivar. The cultivars included under the sub-clusters

B1 (TV22, TV16, TV26 and SNT8) and B2 (TV1, TV20 and K1/1) were considered as highly susceptible cultivars.

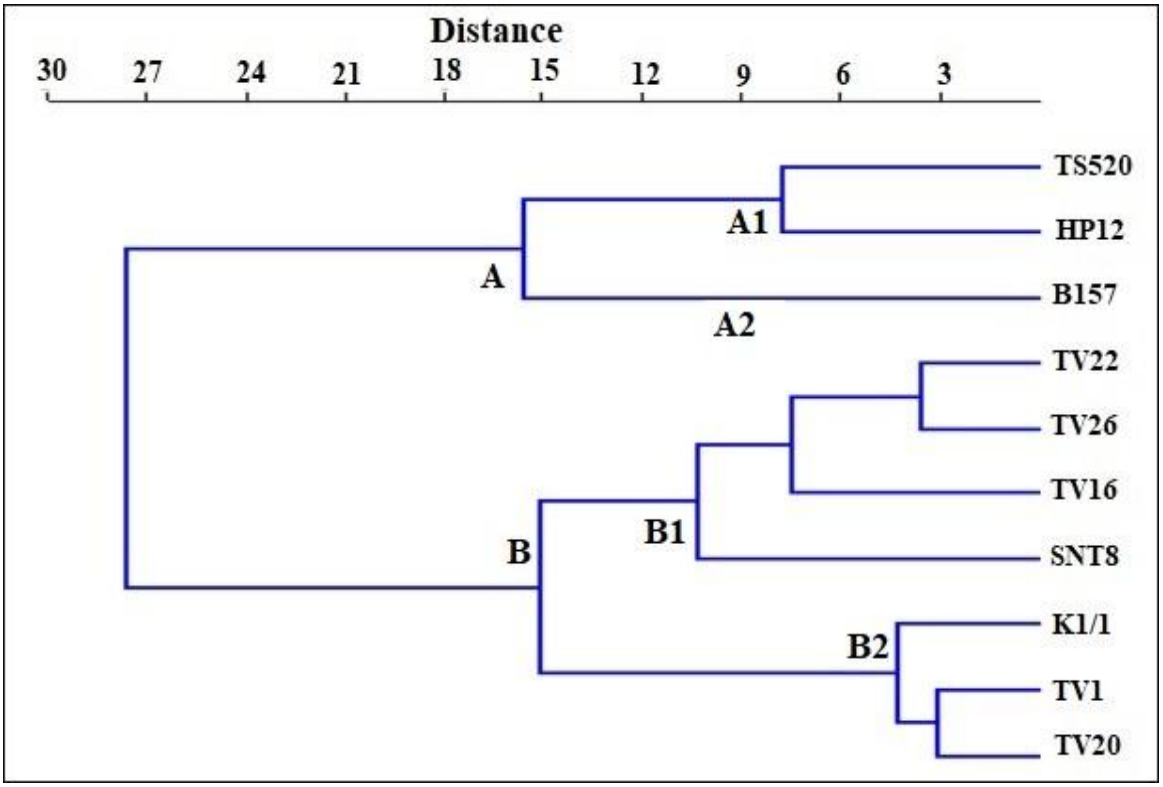


Fig. 7.1.7: Dendrogram based on the mean of all larval food consumption, body weight gain and nutritional indices of *H. tacala* fed on different tea cultivars

4.8. Study on biology and life table of *S. collaris*

4.8.1 Study on the biology of *S. collaris* on *H. talaca* and *C. cephalonica*: After mating, the female reuviid bug, *S. collaris* started to lay the first clutch of eggs (Fig. 8.1). A healthy female laid 320.4±44.2 eggs when fed on larvae of *H. talaca*. Whereas, only 282±23.9 eggs were laid when feed on larvae of *C. cephalonica*. Eggs were brown, cemented together vertically with substratum in a cluster. The incubation period was 13.6±1.1days when reared on larvae of *C. cephalonica*. But the incubation period was 11.8±2.3days while feed on *H. talaca*. Total nymphal period of *S. collaris* was 58.4±3.9 days when feed on of *C. cephalonica* larvae and comparatively longer with the duration of 64.8±4.1days when feed on *H. talaca.* In addition to this, ovipositional period of the predatory bug was 42.0±2.9 days when reared on looper and 39.6±2.3 days when reared on *C. cephalonica*. Longevity of the adult predatory bug was sex independent (Table 8.1.).

Table 8.1: Biology of *S. collaris* on larvae of *H. talaca* and *C. cephalonica*

Parameters	Developmental stages (in days) on	
	C. cephalonica	***H. talaca***
Incubation period	13.6±1.1	11.8±2.3
I instar	9.6±2.1	10.4±0.9
II instar	11.2±0.8	12.8±3.3
III instar	11.6±2.1	12.6±2.4
IV instar	12.6±0.5	14.0±2.5
V instar	13.4±2.3	15.0±1.2
Total nymphal period	58.4±3.9	64.8±4.1
Preovipositional period	9.2±0.8	9.6±2.1
Ovipositional period	39.6±2.3	42.0±2.9
Female longevity	58.2±2.0	59.4±3.4
Male longevity	41.6±1.5	42.4±2.1
Eggs/female	282±23.9	320.4±44.2
Sex ratio (F:M)	1:0.79	1:0.89

4.8.2 Study on life table of *S. collaris* reared on *H. talaca*: The survival rate (%) of the predatory reduviid bug were noted on larvae of *H. talaca*. The egg hatchibility, survival of I, II, III, IV, V instar nymphs and adult were respectively 96.7, 96.7, 92.6, 94.8, 92.7, 93.9 and 94.2% (Fig. 8.2). Highest mortality was observed in I and IV instar nymphal stages. Life table parameter like, age specific survival rate (lx), age specific fecundity rate (mx) and age specific maternity (lxmx) are worked out and presented in (Fig. 8.3) Intrinsic rate of natural increase (rm) of *S. collaris* was 0.062 day while net reproductive rate (Ro) was 252.78 female offspring/adult female. The gross reproductive rate (∑mx) was 278.98 and the finite rate of increase was 1.06 (Table 8.2).

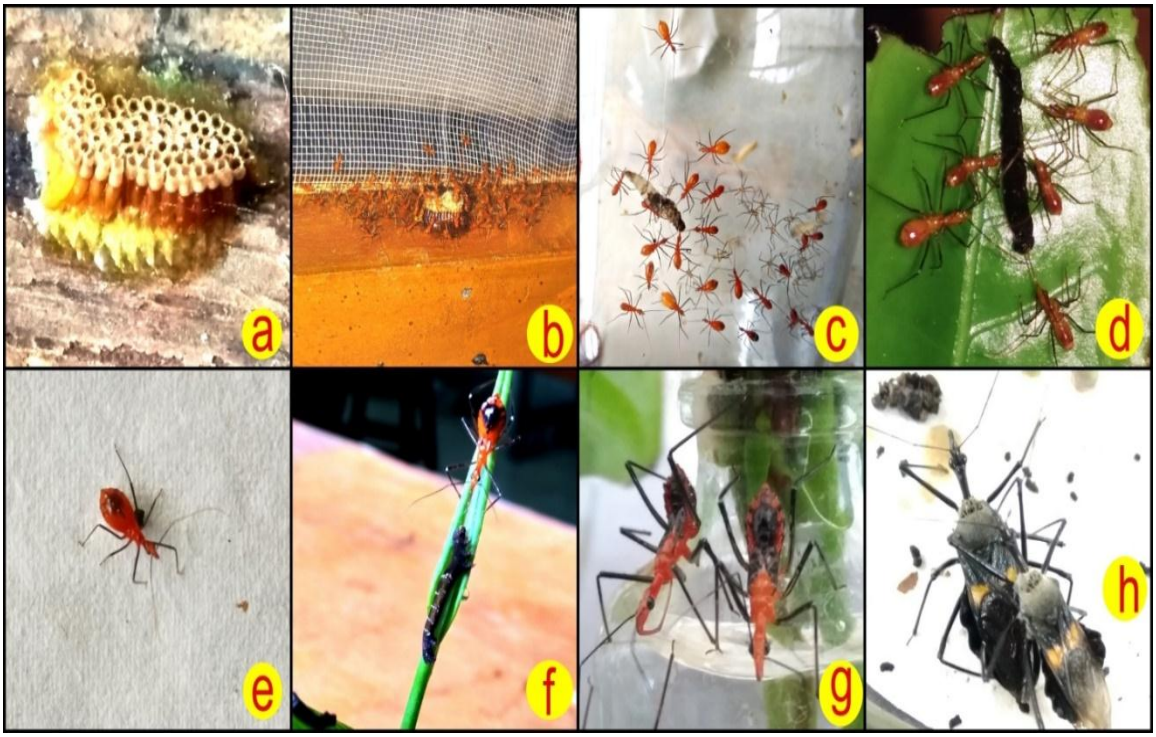


Fig. 8.1: Different life stages of *S. collaris* reared on larvae of *H. talaca* and *C. cephalonica*: (a) egg raft, (b) newly hatched nymph from egg, (c) first instar nymph, (d) second instar nymph, (e) third instar nymph, (f) fourth instar nymph, (g) fifth instar nymph and (h) adult are mating.

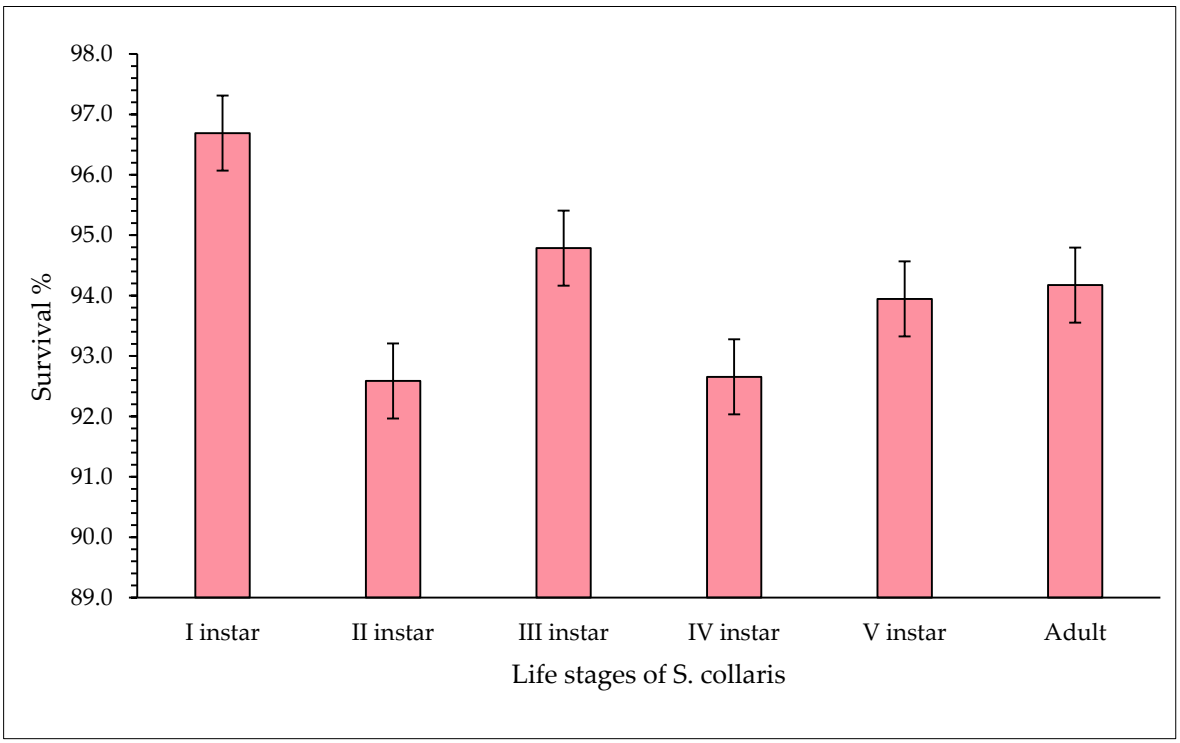


Fig. 8.2: Survival percentage of *S. collaris* reared on *H. talaca*

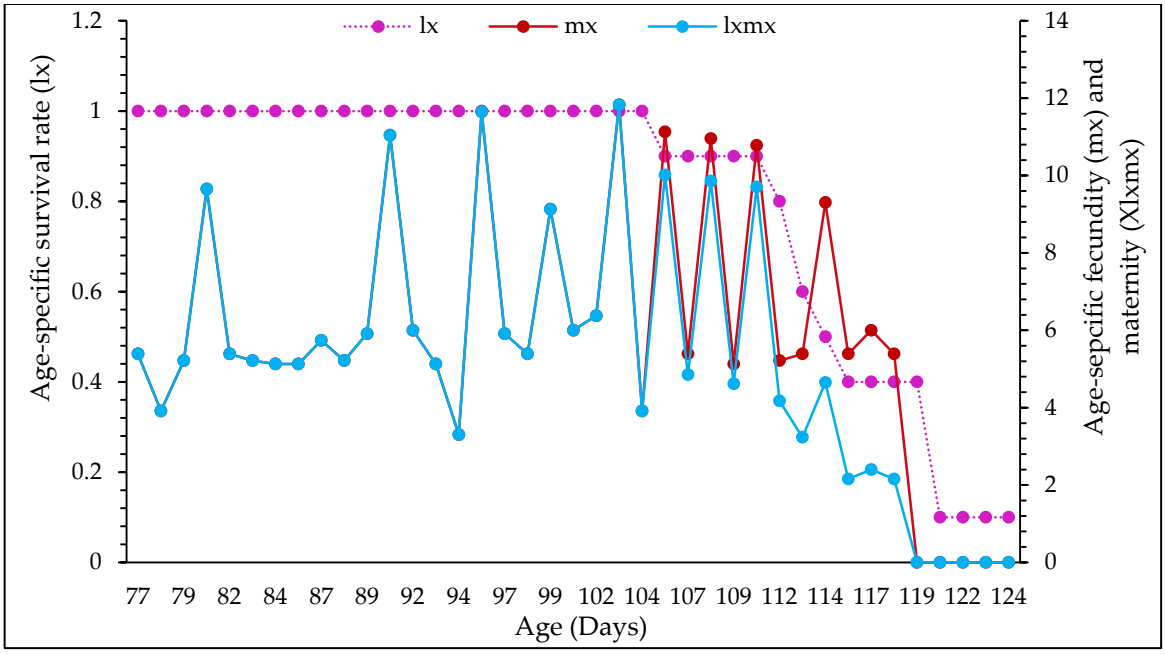


Fig. 8.3: Age specific survival rate (lx), fecundity (mx) and maternity (Xlxmx) of *S. collaris* on *H. talaca*

Table 8.2: Life table parameters of *S. collaris* reared on larvae of *H. talaca*.

Life table of *S. collaris* reared on *H. talaca*	
Parameters	**Values**
Intrinsic rate of natural increase(r_m)	0.062
Finite rate of increase(λ)	1.06
Net reproductive rate(Ro)	252.78
Mean generation time(Tc)	96.51
Corrected generation timer(T)	89.23
Gross reproductive rate (GRR)	278.98
Weekly multiplication (Wm)	1.54
Doubling time (Dt)	11.18

4.8.3 Study on predatory efficiency of *S. collaris* on larvae of *H. talaca*: The predatory potential of both the nymphs and adult of *S. collaris* was assessed in terms of the consumption capacity of the natural enemy for the pest *H. talaca* (Fig. 8.5 and 8.6). The feeding efficiency of *S. collaris* was found to be gradually increase with the development of life stages. It was also noticed that, with the advance age stages of *S. collaris* the feeding efficiency and prey preference also varied, that was assessed by 'no-choice' and 'free-choice' experiments.

4.8.3.1 No-choice condition of feeding: In a no-choice condition of feeding first instar nymph of *S. collaris* fed 2.2±0.8 second instar larvae of *H. talaca* in 24h which was found increase with the advancement of instars (p=0.05), Whereas II, III IV and V instar nymphs preferred 3.6±1.5, 5.0±1.2, 6.6±2.1 and 7.0±1.2 second instar larvae respectively (Table

8.3). Highest consumption was noticed in adult female, 11.8±2.6 larvae per day. The interesting observation was that, the number of prey consumption was reduced gradually when the feeding on advanced stages of *H. talaca*. Adult female was observed voraciously feeding on maximum fourth and fifth instar larvae of *H. talaca* per day.

4.8.3.2 Free-choice condition of feeding: The results of free-choice condition of feeding, I and II instar nymph of *S. collaris* were observed more preference towards the second and third instar larvae of *H. talaca* (Table 8.4). The III instar nymph consumed (2.0±0.7) on second instar larvae of *H. talaca* recorded at 24h intervals whereas IV and V instar nymph consumed 3.6±0.5and 4.0±1.2 larvae of *H. talaca* respectively compared to other larval instars of *H. talaca.* In both the feeding conditions, *S. collaris* showed its efficiency to consume maximum number of larvae of *H. talaca* under laboratory conditions. In free-choice condition of feeding, the predation became less compared to no-choice condition of feeding.The average feeding by the I, II, III, IV, V, male and female of *S. collaris* was recorded as 2.1, 2.9, 3.4, 4.4, 5.8, 9.3, and 11.3 per day in no choice condition and 1.3, 1.5, 1.7, 2.6, 3.1, 3.9 and 4.2 in free choice condition of feeding (Fig. 8.4).

Table 8.3: Predatory efficiency of *S. collaris* on different larval stages of *H. talaca* in No-choice feeding condition

Stages of *S. collaris*	**Feeding on larval stages of *H. talaca***			
	II	**III**	**IV**	**V**
I	2.2 ± 0.8^{d}	2.0 ± 1.0^{d}	-	-
II	3.6 ± 1.5^{cd}	2.2 ± 0.8^{d}	-	-
III	5.0 ± 1.2^{bc}	3.6 ± 1.5^{cd}	3.0 ± 1.0^{d}	1.8 ± 0.8^{c}
IV	6.6 ± 2.1^{b}	4.2 ± 0.8^{cd}	4.0 ± 1.6^{cd}	2.6 ± 0.9^{c}
V	7.0 ± 1.2^{b}	5.8 ± 1.5^{c}	5.0 ± 1.6^{c}	5.4 ± 1.1^{b}
Male	9.8 ± 1.9^{a}	8.8 ± 1.9^{b}	9.6 ± 1.8^{b}	9.0 ± 1.0^{a}
Female	11.8 ± 2.6^{a}	11.4 ± 4.0^{a}	11.8 ± 2.5^{a}	10.2 ± 1.9^{a}

Means followed by the same alphabet in a column do not differ significantly at p = 0.05 according to Tukey's multiple comparison test. (-): No food consumption was observed

Table 8.4: Predatory efficiency of *S. collaris* on different larval stages of *H. talaca* in Free-choice feeding condition

Stages of *S. collaris*	Larval stages of *H. talaca*			
	II	**III**	**IV**	**V**
I	1.4 ± 0.5^{c}	1.2 ± 0.4^{c}	-	-
II	1.6 ± 0.9^{c}	1.4 ± 0.5^{c}	-	-
III	1.8 ± 0.8^{c}	2.0 ± 0.7^{bc}	1.8 ± 0.8^{b}	1.2 ± 0.4^{b}
IV	2.2 ± 0.8^{bc}	2.4 ± 0.5^{bc}	3.6 ± 0.5^{a}	2.0 ± 0.7^{b}
V	3.0 ± 0.7^{ab}	3.2 ± 1.3^{ab}	4.0 ± 1.2^{a}	2.2 ± 0.8^{b}
Male	3.2 ± 0.8^{ab}	3.6 ± 1.1^{a}	4.2 ± 0.8^{a}	4.6 ± 1.8^{a}
Female	3.4 ± 1.1^{a}	3.8 ± 0.8^{a}	4.6 ± 1.1^{a}	5.0 ± 1.6^{a}

Means followed by the same alphabet in a column do not differ significantly at p = 0.05 according to Tukey's multiple comparison test. (-): No food consumption was observed

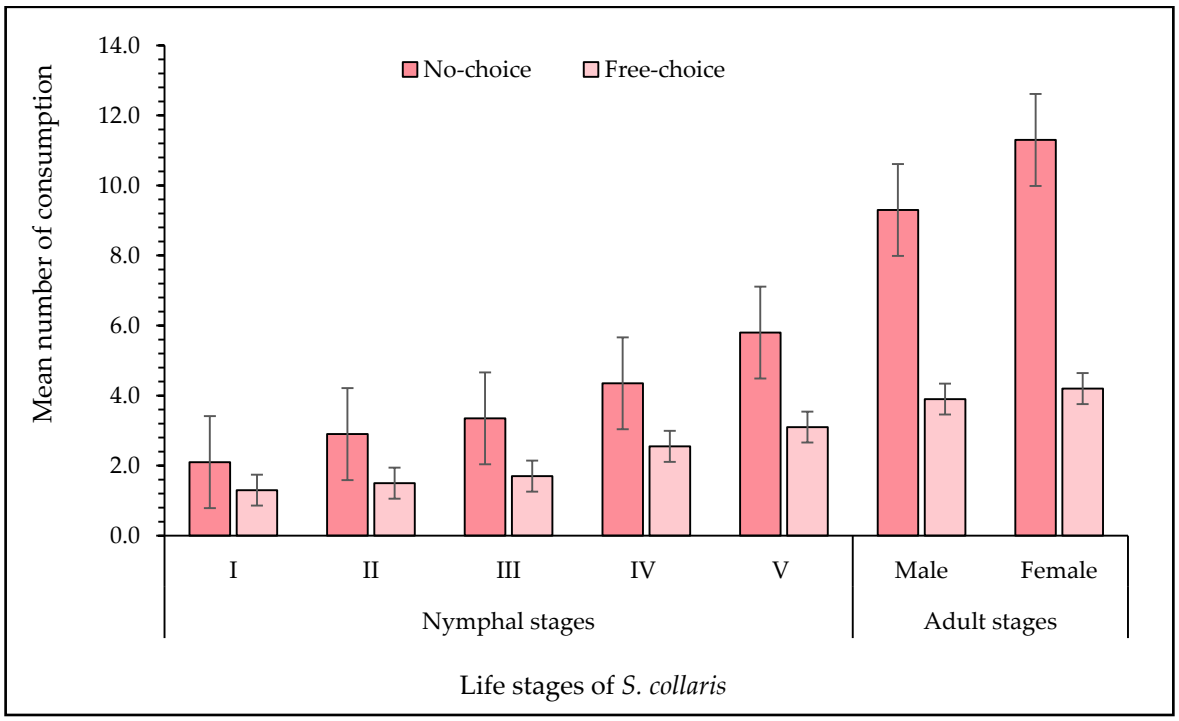


Fig. 8.4: Mean of predatory efficiency on all the larval instars by individual life stage of *S.collaris* in both no-choice and free- choice conditions

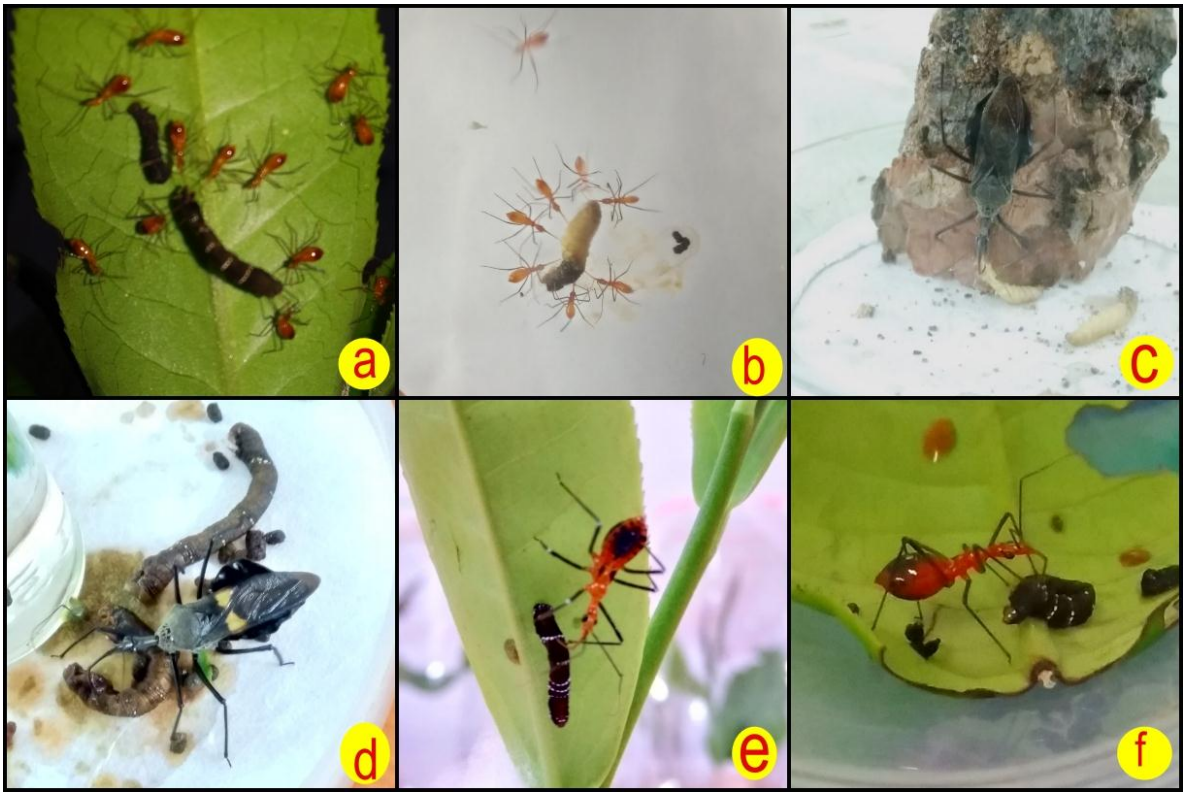


Fig. 8.5: Feeding of *S. collaris*: (a) group feeding of III instar nymph on looper and (b) on larvae of *C. cephalonica*; (c) adult female feeding on looper and (d) on larvae of *C. cephalonica*; (e) feeding of fourth instar nymph and (f) fifth instar nymph

Fig. 8.6: Condition of looper after feeding by *S. collaris*: (a) healthy looper and (b) dead looper

4.8.4 Predatory behaviour of *S. collaris* consumption on larvae of *H. talaca*: Predatory behaviour of *S. collaris* on larvae of *H. talaca* offered a visual stimulus by providing prey of different stages which lead to arouse, erect posture and extension of antennae and

rostrum of *S. collaris* towards the prey. Time taken by the different stages of *S. collaris* for approach and attacking, paralyzing and feeding were recorded during consumption. The first instar nymph of *S. collaris* took 24.0±1.0 seconds in approach attacking prey larva. Whereas II, III, IV and V instar nymphs were taken 22.0±1.0, 19.3±1.2, 17.0±1.0 and14.0±1.0 seconds. In excited condition, the predator pin the rostrum on the host body and inject the venom within 6.3±1.5 seconds to paralyze the larvae of *H. talaca*. The experimental data showed that depending on the developmental stages of *S. collaris* and the stages of host larvae the feeding time varied (Table 8.5).

Table 8.5: Predatory behaviour of *S. collaris*, feeding on larvae of *H. talaca*

Stages of *S. collaris*	Predatory activities* (in second)					
	Approach attacking	Paralyzing	Sucking (Stages of *H. talaca*)			
			II	III	IV	V
I	24.0±1.0	12.0±2.0	74.7±3.5	87.7±1.5	-	-
II	22.0±1.0	11.3±1.5	73.0±2.6	86.0±4.4	-	-
III	19.3±1.2	11.0±1.0	71.0±2.6	84.0±4.0	95.3±2.1	124.0±3.6
IV	17.0±1.0	9.7±0.6	69.0±5.5	81.7±2.1	94.0±2.0	123.0±4.6
V	14.0±1.0	9.0±1.0	68.3±1.5	80.7±6.7	93.3±3.5	120.0±4.4
Male	11.7±1.5	6.7±0.6	65.7±2.1	78.3±1.5	90.0±4.4	119.3±8.0
Female	9.7±0.6	6.3±1.5	64.3±5.9	77.3±3.8	88.0±4.6	118.3±3.1

*Means were calculated by Tukey-Kramer HSD Post-Hoc Test, significant at $p<0.05$. (-): No food consumption was observed

4.8.5 Mass rearing of *S. collaris* on *C. cephalonica*: The highest survival percentage of the predatory bug *S. collaris* reared on larvae of *C. chephalonica* revealed the successful attempt of mass rearing (Fig. 8.7). As the fecundity of healthy female reared on rice meal moth was recorded earlier, from this up to 95.24±1.0 % egg was hatched. The survival percentage of I, II, III, IV and V instar nymph were recorded as 95.52±0.8, 91.81±0.7, 94.67±2.0, 94.72±1.9 and 93.94±0.8 respectively (Table 8.6). All the nymphal instars voraciously consumed larvae of rice meal moth. The survivality of adult was 93.36±1.8%, of this 54.48±0.2% female and 46.26±3.0% male.

Table 8.6: Percentage of surviving of *S. collaris* reared on alternative host *C. cephalonica*

Parameters	Values
Hatched	95.24±1.0
I Instar	95.52±0.8
II Instar	91.81±0.7
III Instar	94.67±2.0
IV Instar	94.72±1.9
V Instar	93.94±0.8
Adult	93.36±1.8

Fig. 8.7: Mass rearing of *S. collaris*

4.8.6 Study on effect of pesticide on *S. collaris*: Among all the treated pesticides Quinalphos and Thiamethoxam are most toxic to all the life stages of *S. collaris* compared to Emamectin benzoate 5%SG, Deltamethrin 2.8EC, Bifenthrin 10%EC, Flubendiamade 20WG, Fenpyroxymate 5EC, *Beauveria bassiana* formulation and Azadirachtin 5% EC (Table 8.7). The significant effect of insecticides on immature stages was varied depend on the exposure time. Cent percent mortality was observed within 24h of the exposure of Quinalphos and Thiamethoxam. In the treatment of Bifenthrin 53.3±3.3% and 43.3±3.3 % mortality were observed after 72h of the application. Toxicity of Emamectin benzoate 5%SG, Flubendiamade 20WG and Fenpyroxymate 5EC were found low mortality after 24h of the exposure on nymph and adult. No effective mortality was observed in the treatment of *Beauveria bassiana* formulation and no toxic effect found in Azadirachtin 5% EC exposure.

Table 8.6: Toxicity of certain common used pesticides on both mature and immature stages of *S. collaris*

Treatments	Concentration	Percentage of mortality after	Percentage of mortality after		
			24h	48h	72h
Quinalphos 25EC	1:400	Nymph	100.0±0.0^{a}	100.0±0.0^{a}	100.0±0.0^{a}
		Adult	100.0±0.0^{a}	100.0±0.0^{a}	100.0±0.0^{a}
Thiamethoxam 25WG	1:4000	Nymph	100.0±0.0^{a}	100.0±0.0 ^{a}	100.0±0.0^{a}
		Adult	100.0±0.0^{a}	100.0±0.0^{a}	100.0±0.0^{a}
Emamectin benzoate 5%SG	1:2500	Nymph	10.0±0.0^{bc}	13.3±3.3^{c}	33.3±6.7^{d}
		Adult	6.7±3.3^{b}	10.0±0.0^{bc}	26.7±6.7^{c}
Deltamethrin 2.8EC	1:2000	Nymph	6.7±3.3^{c}	20.0±0.0^{b}	40.0±3.3^{cd}
		Adult	0.0±0.0^{c}	13.3±3.3^{bc}	30.0±5.8^{c}
Bifenthrin 10%EC	1:1600	Nymph	13.3±3.3^{b}	16.7±3.3^{bc}	53.3±3.3^{b}
		Adult	10.0±5.7^{b}	16.7±3.3^{b}	43.3±3.3^{b}
Flubendiamade 20WG	1:5000	Nymph	0.0±0.0^{d}	13.3±3.3^{c}	43.3±3.3^{c}
		Adult	0.0±0.0^{c}	6.7±3.3^{cd}	30.0±3.3^{c}
Fenpyroxymate 5EC	1:2000	Nymph	0.0±0.0^{d}	6.7±3.3^{d}	33.3±3.3^{d}
		Adult	0.0±0.0^{c}	6.7±3.3^{cd}	23.3±3.3^{c}
Beauveria bassiana formulation	2kg/ha	Nymph	0.0±0.0^{d}	0.0±0.0^{e}	10.0±0.0^{e}
		Adult	0.0±0.0^{c}	0.0±0.0^{d}	6.7±3.3^{d}
Azadirachtin 5% EC	1:1500	Nymph	0.0±0.0^{d}	0.0±0.0^{e}	0.0±0.0^{f}
		Adult	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{d}
Control (water)	-	Nymph	0.0±0.0^{d}	0.0±0.0^{e}	0.0±0.0^{f}
		Adult	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{d}

Means (±SD) of five replications followed by the same letter in a column do not differ significantly at p = 0.05 according to Tukey's multiple comparison test. '-': there is no recomended concentration

4.8.7 Field release of *S. collaris*: A 100 number of adult *S. collaris* was released at kurti and Hope TE (Fig. 8.9). The population trends of *H. talaca*, before and after release of predator in both the control and released plot were observed and the population was assessed by individuals/bush wise counting. The population reduction after release of adult *S. collaris* was recorded compared to the control plot. On 11th day after release of predator an average of 4.10±0.67 lopper per bush was found in released plot, whereas in control plot 7.50±1.32 looper per bush (Table 8.8). On the 13th day after exposure of the predator around 35% population reduction was noticed (Fig. 8.8).

Table 8.8: Assessment of population of *H. talaca* in both released and control plots before and after release of *S. collaris*

Days after release of *S. collaris*	Number of *H. talaca* population/ bush	
	Released plot	Control plot
Pre-released	6.17±1.24^{NS}	6.07±1.37^{NS}
1	5.30±1.28^{b}	6.70±1.35^{a}
3	4.90±1.10^{b}	6.90±1.47^{a}
5	4.53±0.94^{b}	7.10±1.52^{a}
7	4.33±0.74^{b}	7.23±1.51^{a}
9	4.23±0.59^{b}	7.40±1.4^{a}
11	4.10±0.67^{b}	7.50±1.32^{a}
13	3.80±0.61^{b}	7.47±1.36^{a}

Non-significance= NS. Values followed by the same alphabet in the same row are not significantly different at 5% level of significance according to Tukey's test

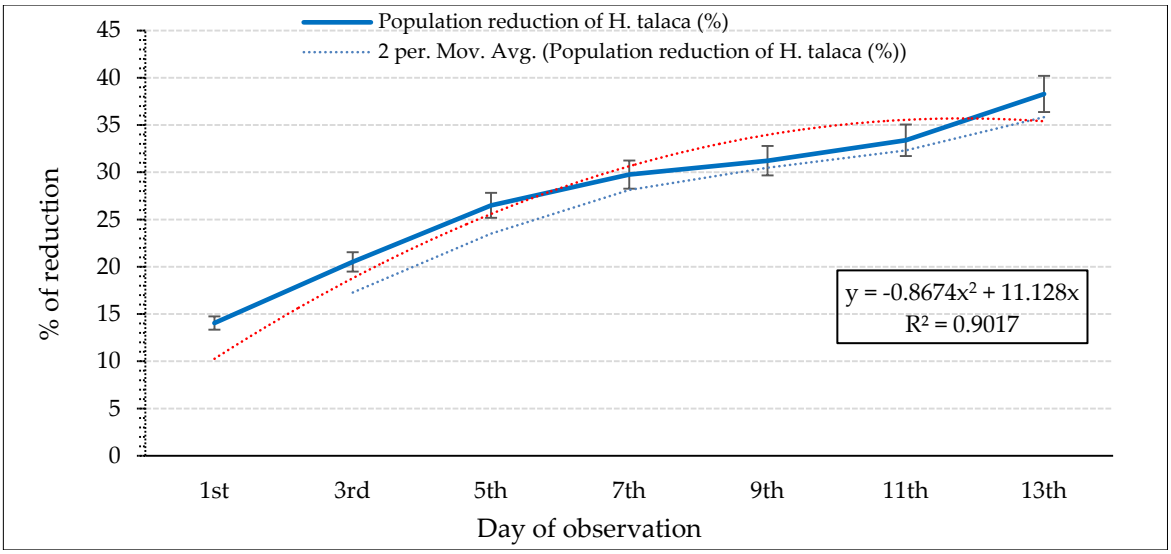


Fig. 8.8: Population reduction percentage of *H. talaca*, in the *S. collaris* released plot

Fig. 8.9: Field release of *S. collaris*: (a) at Kurti TE and (b) Hope TE

4.9. Study on biology and life table of *E. furcellata*

4.9.1 Study on biology of *E. furcellata* on *H. talaca* and *C. chephalonica*: The life stages of *E. furcellata*, consists of egg, five nymplal instars and adult (Fig.9.1). In the present investigation, the biology of stink bug *E. furcellata* on the larvae of *H. talaca* and *C. cephalonica* showed, the average number of eggs laid by the female were 276.6±15.8 and 284.6±11.8 respectively (Table 9.1). It indicates that the fecundity is little bit less when reared on *H. talaca.* Initially freshly laid eggs were whitish golden in colour, later turned into creamy to light brownish. Incubation period was little shorter (7.0±1.0) reared on *H. talaca* compared to rear on *C. cephalonica* (7.6±1.1). Total nymphal period was recorded in the culture on looper (21.8±0.7days), whereas the shorter period (18.4±1.5 days) was noticed reared on *C. cephalonoca*. Longevity of adult female was 30.8±1.9 days when reared on looper, which is shorter than the longevity of female (32.8±0.8 days) reared on *C. cephalonica*. No significant variation was observed in oviposition period between the two rearing media.

Table 9.1: Biology of *E. furcellata* on *H. talaca* and *C. chephalonica*

Parameters	**Mean duration of *E. furcellata* reared on**	
	Larvae of *H. talaca*	**Larvae of *C. cephalonica***
Incubation period	7.0±1.0	7.6±1.1
I instar	3.2±0.8	3.2±0.4
II instar	3.6±0.9	3.4±0.5
III instar	4.8±0.8	4.0±1.0
IV Vinstar	5.0±0.7	3.8±0.4
V instar	5.2±0.8	4.0±0.7
Total nymphal period	21.8±0.7	18.4±1.5
Pre-oviposition period	6.2±1.3	5.4±0.5
Oviposition period	18.4±2.3	18.0±1.6
Male longevity	27.6±1.1	30.0±1.9
Female longevity	30.8±1.9	32.8±0.8
Fecundaty /female	276.6±15.8	284.6±11.8

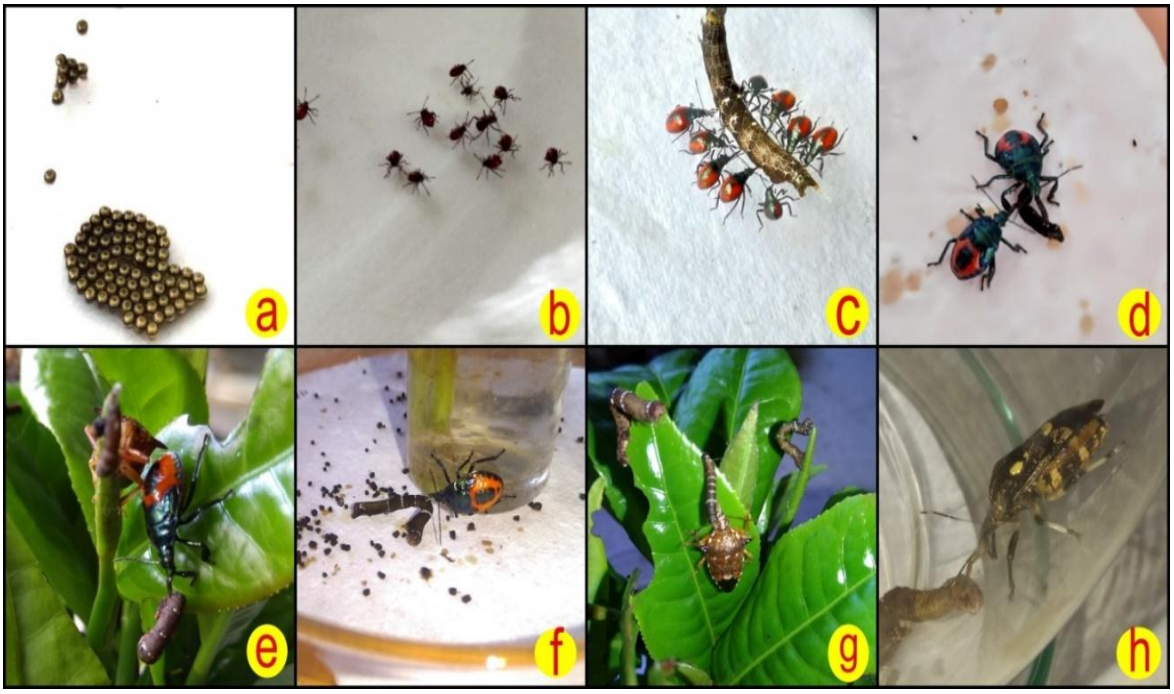


Fig. 9.1: Life stages of *E. furcellata*: (a) egg; nymphal stages of (b) first instar, (c) second instar, (d) third instar, (e) fourth instar, (f) fifth instar; (g) adult male and (h) adult female

4.9.2 Study on life table of *E. furcellata* reared on *H. talaca*: The survival trends of the stink bug were investigated when reared on larvae of *H. talaca*. The survival of different life stages of *E. furcellata* were worked out from the rearing condition under laboratory, egg hatched, I, II, III, IV, V instar nymphs and adult were 95.35, 95.35, 91.84, 92.83, 94.51, 93.25 and 95.15% (Fig.9.2). Highest mortality was observed in I instar nymphal stages.

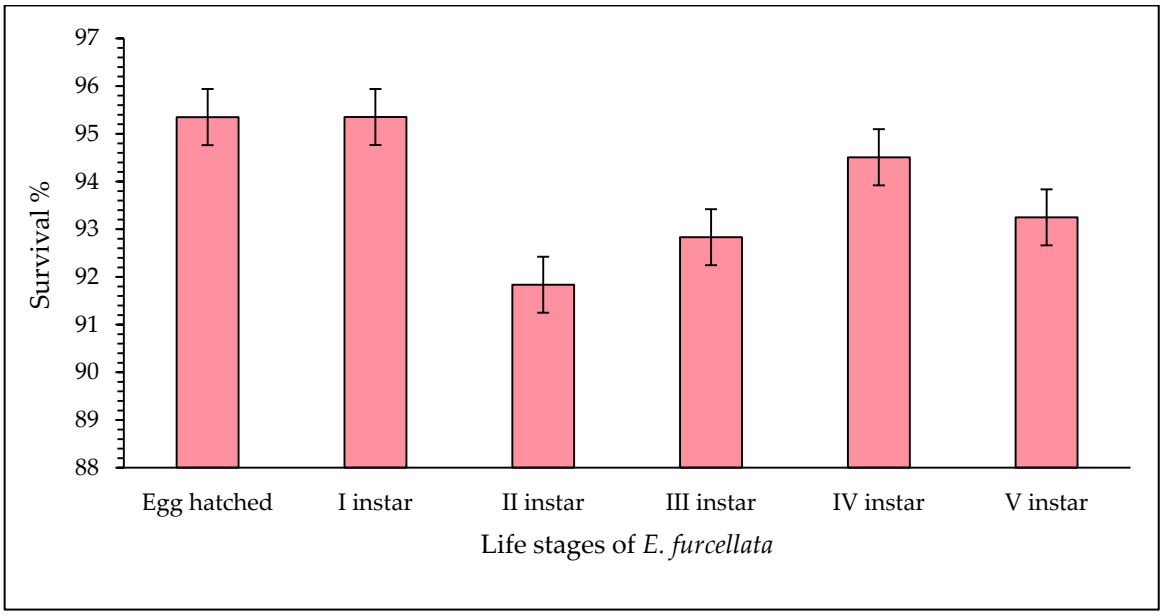


Fig. 9.2: Survival percentage of different life stages of *E. furcellata* when reared on larvae of *H. talaca*

Data was analyzed for worked out age specific survival rate (lx), age specific fecundity rate (mx) and age specific maternity (lxmx) for construct the life table of stink bug reared on the larvae of *H. talaca*, presented in (Fig.9.2) The life table parameter like intrinsic rate of natural increase (rm) of *E. furcellata* was recorded as 0.149 day^{-1} and the net reproductive rate (Ro) was 218.14 female offspring per adult female, produced during their life span expected as 276.6±15.8 eggs/ female. The gross reproductive rate (∑mx) was also recorded as 244.69 and the finite rate of increase (λ)was 1.06 (Table 9.3).

Table 9.2: Life table parameter of *E. furcellata* reared on *H. talaca*

Parameters	Values
Intrinsic rate of natural increase(r_m)	0.149
Finite rate of increase(λ)	1.161
Net reproductive rate(Ro)	218.14
Mean generation time(Tc)	35.49
Corrected generation timer(T)	35.94
Gross reproductive rate (GRR)	244.69
Weekly multiplication (Wm)	2.85
Doubling time (Dt)	4.63

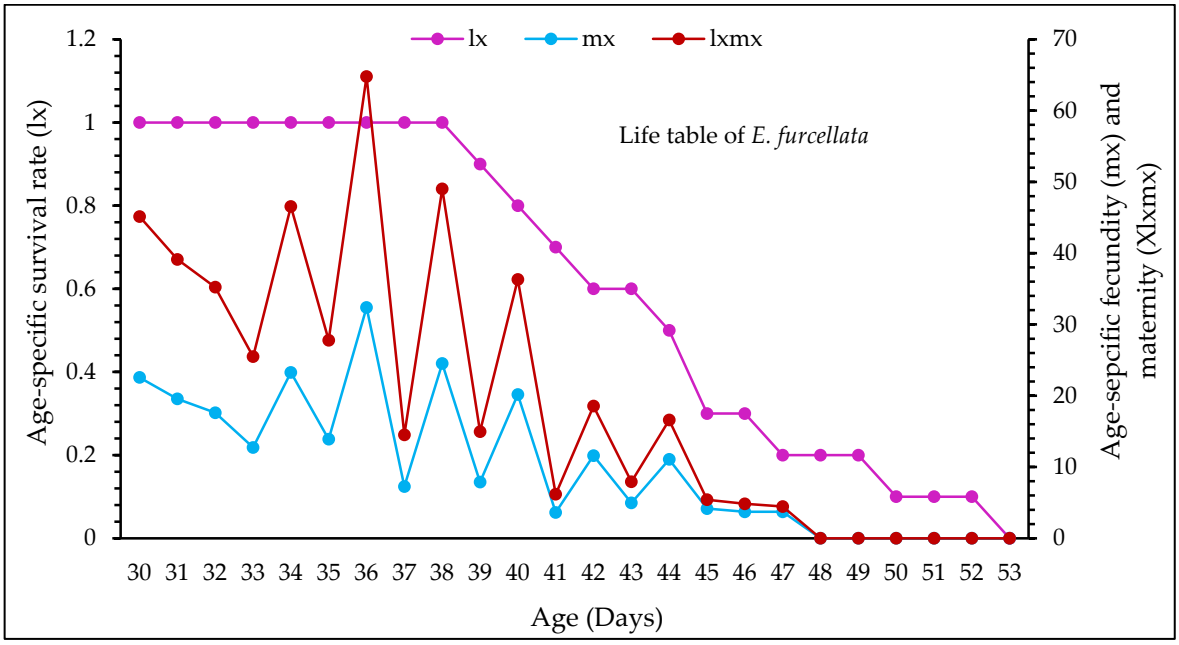


Fig. 9.3: Age-specific survival rate (lx), age-sepcific fecundity (mx) and maternity (Xlxmx) of female *E. furcellata* feeding on larvae of *H. talaca*.

4.9.3 Study on predatory efficiency of *E. furcellata* on different stages of *H. talaca*: The predatory potential of the all the life stages of *E. furcellata* was assessed by recording the total number of *H. talaca* larvae consumed per day (Fig. 9.3.2). The feeding efficiency

of *E. furcellata* was found to be gradually increase with the development and big size of life stages. It was also examined that, in each life stage the feeding efficiency and prey preference varied, that was assessed by 'no-choice' and 'free-choice' experiments.

4.9.3.1 No-choice condition of feeding: In the experiment of no-choice condition of feeding, first instar nymph of *E. furcellata* fed 1.8±0.4 second instar larvae of *H. talaca*. Whereas II, III, IV and V instar nymph predate 3.2±0.4, 4.6±1.1, 5.8±1.3 and 6.0±1.4, second instar larvae of *H. talaca* (Table 9.3.1). The adult female predated 10.2±0.8 larvae per day, which was the highest number of predation among all the life stages of *E. furcellata*. First and second instar nymph were prefer second instar larva of *H. talaca*. Whereas adult female was observed voraciously feeding on maximum fourth and fifth instar larvae of *H. talaca* per day.

4.9.3.2. Free-choice condition of feeding: In the present study of free-choice condition of feeding, the number of predation per day has been reduced compared to no-choice condition of feeding. Fifth instar nymph of *E. furcellata* was found to feed 4.8±0.8 third instar larvae of *H. talaca* followed by IV instar (4.0±1.0), III instar (3.0±1.0), II instar (2.0±0.7) and I instar (1.2±0.4) nymph (Table 9.3.2).

The average predation of rate by the I, II, III, IV, V, male and female was observed as 1.6, 2.8, 3.2, 4.3, 4.9, 7.15 and 8.4 per day in no choice condition and 1.5, ,2.3, 2.9, 3.8, 4.5, 6.5 and 7.5 in free choice condition of feeding (Fig. 9.3.2).

Fig. 9.3.1: Feeding *E. furcellata* on larvae of *H. talaca*: (a) group feeding of first instar nymph, (b) feeding of first instar nymph and (c) feeding of adult stink bug

Table 9.3.1: predatory efficiency of *E. furcellata* on different stages of *H. talaca* in no-choice condition

Stages of *E. furcellata*	Feeding on different life stages (larval) of *H.talaca*			
	II	**III**	**IV**	**V**
I Instar	1.8±0.4^{e}	1.4±0.5^{a}	-	-
II Instar	3.2±0.4^{d}	2.4±0.5^{de}	-	-
III Instar	4.6±1.1^{c}	3.2±0.8^{d}	3.0±0.7^{b}	2.0±0.7^{d}
IV Instar	5.8±1.3^{bc}	4.4±0.9^{c}	4.0±1.6^{b}	3.0±0.7^{cd}
V Instar	6.0±1.4^{b}	5.4±1.1^{c}	4.4±1.1^{b}	3.8±1.1^{c}
Male	9.2±0.8^{a}	7.6±1.1^{b}	6.2±0.8^{a}	5.6±1.1^{b}
Female	10.2±0.8^{a}	9.0±1.0^{a}	7.4±1.8^{a}	7.0±1.6^{a}

Values represent mean ±SD of five replications. Means followed by the same letter in a column do not differ significantly at p=0.05, according to Tukey's multiple comparison test. (-): No food consumption was observed

Table 9.3.2: Predatory efficiency of *E. furcellata* on different stages of *H.talaca* in Free-choice condition

Stages of *E. furcellata*	Feeding on different life stages (Larval) of *H.talaca*			
	II	**III**	**IV**	**V**
I Instar	1.8±0.4^{d}	1.2±0.4^{e}	-	-
II Instar	2.6±0.5^{d}	2.0±0.7^{de}	-	-
III Instar	4.0±1.0^{c}	3.0±1.0^{cd}	2.8±0.8^{c}	1.8±0.8^{c}
IV Instar	5.0±0.7^{bc}	4.0±1.0^{bc}	3.6±0.5^{c}	2.6±0.5^{bc}
V Instar	5.6±1.1^{b}	4.8±0.8^{b}	4.0±1.2^{bc}	3.4±0.5^{b}
Male	8.8±1.3^{a}	7.2±1.3^{a}	5.2±0.8^{ab}	4.8±1.5^{a}
Female	9.8±1.1^{a}	8.2±0.8^{a}	6.4±1.1^{a}	5.4±1.1^{a}

Values represent mean ±SD of five replications, Means followed by the same letter in a column do not differ significantly at p=0.05, according to Tukey's multiple comparison test. (-): No food consumption was observed

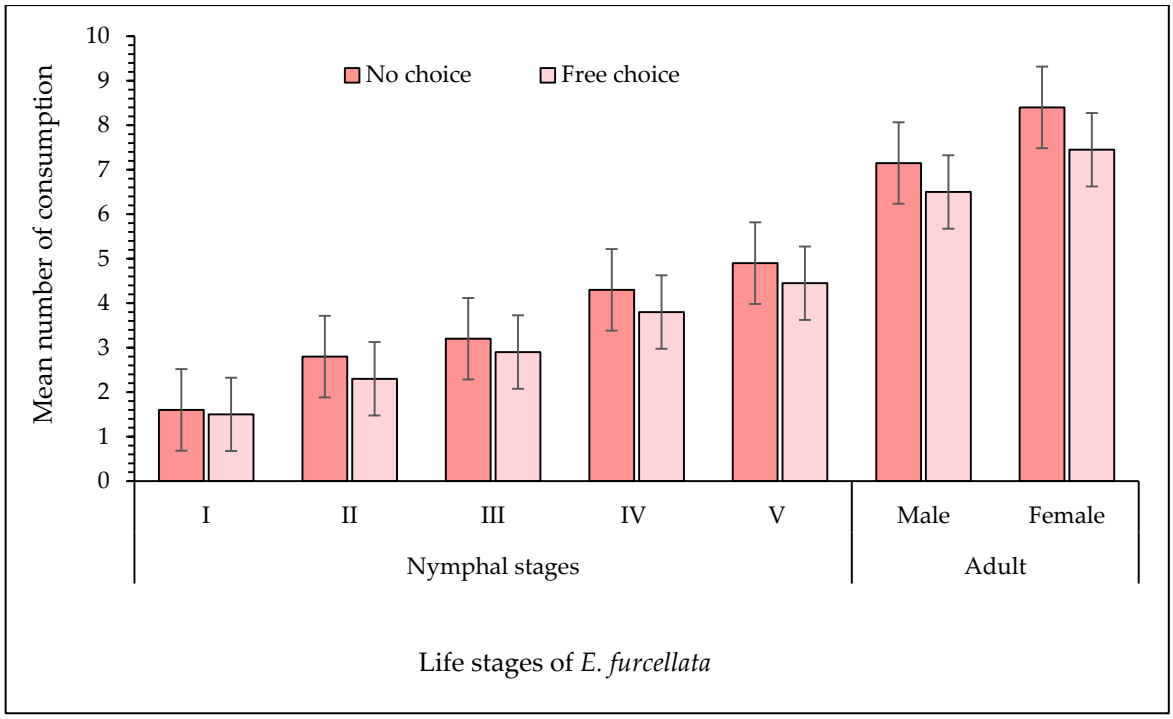


Fig. 9.3.2: Mean of predatory efficiency on all the larval instars by individual life stage of *E. furcellata* in both no-choice and free- choice conditions

4.9.4 Study on predatory behaviour of *E. furcellata* on different stages of *H. talaca*: In the experiment of predatory behaviour of *E. furcellata*, different instar of larvae of *H. talaca* were provided as a visual stimulus which lead to arouse, erect posture and extension of antennae and rostrum towards the prey. The time taken by different life stages of *E. furcellata* for approach and attacking, paralyzing and feeding were recorded during feeding (Table 9.3.3). The first instar nymph of *E. furcellata* took 17.7±2.5 seconds for approach attacking towards prey larva followed by II (16.7±0.6 seconds), III (15.3±2.1 seconds), IV (13.7±1.5 seconds) and V (11.7±1.5 seconds) instar. When female of *E. furcellata* got excited, pin the rostrum on the body of the fifth instar host larva and inject the venom within 4.7±0.6 seconds. Then the host became paralyzed and the host was sucked by the female within 95.3±5.0 seconds. For these operation other life stages of *E. furcellata* took more time.

Table 9.3.3: Predatory behaviour of *E. furcellata* feeding of different larval instars of *H. talaca*

Predatory activities of *E. furcellata* (in second)						
Stages of *E. furcellata*	**Approach attacking**	**Paralyzing**	**Sucking (Larval stages of *H. talaca*)**			
			II	**III**	**IV**	**V**
I Instar	17.7±2.5^{a}	9.7±1.5^{a}	72.3±5.1^{a}	81.0±2.6^{a}	-	-
II Instar	16.7±0.6^{ab}	8.7±1.5^{ab}	71.7±1.5^{a}	79.7±2.5^{a}	-	-
III Instar	15.3±2.1^{ab}	8.0±1.0^{ab}	67.3±2.1^{ab}	77.0±3.6^{ab}	97.3±2.1^{a}	123.3±3.1^{a}
IV Instar	13.7±1.5^{bc}	7.7±1.5^{b}	65.3±4.0^{bc}	76.0±3.6^{abc}	94.0±3.6^{ab}	118.3±4.9ab
V Instar	11.7±1.5^{cd}	7.0±1.0^{b}	60.3±1.5^{cd}	74.7±4.2^{bc}	90.3±2.5^{abc}	113.7±3.5^{b}
Male	9.7±1.5^{de}	5.0±1.0^{c}	58.3±1.5^{d}	72.0±4.4^{abc}	87.3±5.9^{bc}	103.3±5.1^{c}
Female	8.0±2.0^{e}	4.7±0.6^{c}	56.0±2.6^{d}	71.7±3.2^{c}	84.7±4.5^{c}	95.3±5.0^{c}

Values represent mean ±SD of five replications, Means followed by the same letter in a column do not differ significantly at p=0.05, according to Tukey's multiple comparison test. '-': no such kind of behaviour observed

4.9.5 Study of the toxic effect of pesticides on immature and mature stages of *E. furcellata*: In this experiment it is investigated that among all the tested pesticides Quinalphos and Thiamethoxam are most toxic in the case of all the life stages of *E. furcellata* also. Emamectin benzoate, Deltamethrin, Bifenthrin, Flubendiamade, Fenpyroxymate, *Beauveria bassiana* formulation and Azadirachtin was found to be less toxic (Table 9.4). 100% mortality was observed within 24h of the spraying of Quinalphos and Thiamethoxam. After 72h of the exposure of Deltamethrin and Bifenthrin were caused 53.3±3.3% and 50.0±5.8% mortality on nymphal stages. The significant effect of insecticides on immature stages was varied depend on the exposure time. In the treatment

with Fenpyroxymate 33.3±3.3% mortality was found in nymphal stages and 30.0±5.8% on the adult. Due to less toxic nature on insect. The treatment result of Beauveria *bassiana* formulation showed 10.0±0.0% nymphal and 6.7±3.3% adult mortality after 72h, before that no toxic symptom was noticed. No mortality was found in the treatment of Azadirachtin 5% EC exposure.

Table 9.4: Effect of certain common used pesticides on nymph and larvae of *E. furcellata*

Treatments	Concentration	Stage of *E. furcellata*	Percentage of mortality after		
			24h	48h	72h
Quinalphos 25EC	1:400	Nymph	100.0±0.0^{a}	100.0±0.0^{a}	100.0±0.0^{a}
		Adult	96.7±3.3^{a}	96.7±3.3^{a}	100.0±0.0^{a}
Thiamethoxam 25WG	1:4000	Nymph	100.0±0.0^{a}	100.0±0.0^{a}	100.0±0.0^{a}
		Adult	93.3±3.3^{a}	96.7±3.3^{a}	100.0±0.0^{a}
Emamectin benzoate 5%SG	1:2500	Nymph	16.7±3.3^{b}	16.7±3.3^{bc}	33.3±3.3^{c}
		Adult	10.0±0.0^{b}	13.3±3.3^{bc}	30.0±3.3^{c}
Deltamethrin 2.8EC	1:2000	Nymph	10.0±0.0^{c}	16.7±3.3^{bc}	53.3±3.3^{b}
		Adult	0.0±0.0^{c}	16.7±3.3^{bc}	43.3±3.3^{b}
Bifenthrin 10%EC	1:1600	Nymph	16.7±3.3^{b}	23.3±3.3^{b}	50.0±5.8^{b}
		Adult	13.3±3.3^{b}	20.0±5.8^{b}	46.7±3.3^{b}
Flubendiamade 20WG	1:5000	Nymph	6.7±3.3^{c}	20.0±5.8^{bc}	36.7±0.0^{c}
		Adult	0.0±0.0^{c}	10.0±0.0^{c}	33.3±3.3^{c}
Fenpyroxymate 5EC	1:2000	Nymph	0.0±0.0^{d}	13.3±3.3^{c}	33.3±3.3^{c}
		Adult	0.0±0.0^{c}	10.0±0.0^{c}	30.0±5.8^{c}
Beauveria bassiana formulation	2kg/ha	Nymph	0.0±0.0^{d}	0.0±0.0^{d}	10.0±0.0^{d}
		Adult	0.0±0.0^{c}	0.0±0.0^{d}	6.7±3.3^{d}
Azadirachtin 5% EC	1:1500	Nymph	0.0±0.0^{d}	0.0±0.0^{d}	0.0±0.0^{e}
		Adult	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{d}
Control (water)	-	Nymph	0.0±0.0^{d}	0.0±0.0^{d}	0.0±0.0^{e}
		Adult	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{d}

Values represent mean ±SD of five replications, Means followed by the same letter in a column do not differ significantly at p=0.05, according to Tukey's multiple comparison test. '-': there is no recomended concentration

4.10 Study on biology and life table of *C. ruficrus* on *H. talaca*

4.10.1 Study on biological parameters of *C. ruficrus* reared on *H. talaca* larvae under laboratory conditions: The results obtained from the studies on the biological parameters of *C. ruficrus* that, the duration of developmental period was found to be more in II instar (9.2 ± 0.37 days) followed by III (12 ± 0.32 days) and IV (11 ± 0.45) instars host larvae (Table 10.1). In case of II instar host larvae, the mean number of cocoon formation was comparatively very less when compared to the other stages, may be because of the body size and stage of the host larvae. A mean number of 65.2±1.85 cocoons per IV instar host larva and 27.2±3.04 cocoons per III instar host larva followed by 4.6 ± 0.68 per II instar host larva were recorded (Fig. 10.1). Pupal development of *C. ruficrus* was also varied on different host instars. Pupae which were formed from the II instar host larvae have taken more time (5.8±0.20 days) for completing the pupal duration compared with III and IV instar host larvae (Fig. 10.2).

Table 10.1: Biology of *C. ruficrus* parasitized on larvae of *H. talaca*

Biological parameters of *C. ruficrus*	Larval instar of *H. talaca* (Host)			F- value	P-value	CD (0.05)
	II	III	IV			
Larval development period (Days) *	12 ± 0.32[a]	11 ± 0.45[a]	9.2 ± 0.37[b]	13.726	0.00079	1.384
Pupal development period (Days) *	5.8±0.20[a]	4.6±0.51[ab]	4.0±0.45[b]	5.039	0.0257	1.358
Adult female longevity (Range)	4 to 6 days					
Adult male longevity (Range)	3 to 4 days					
Sex ratio (F:M)	1:0.5					
Total developmental period (Range)	19 to 24 days					

*Values represent mean ±SE of five replications followed by the same letter in a row do not differ significantly at P <0.05 (One-way ANOVA) according to Tukey's multiple comparison test

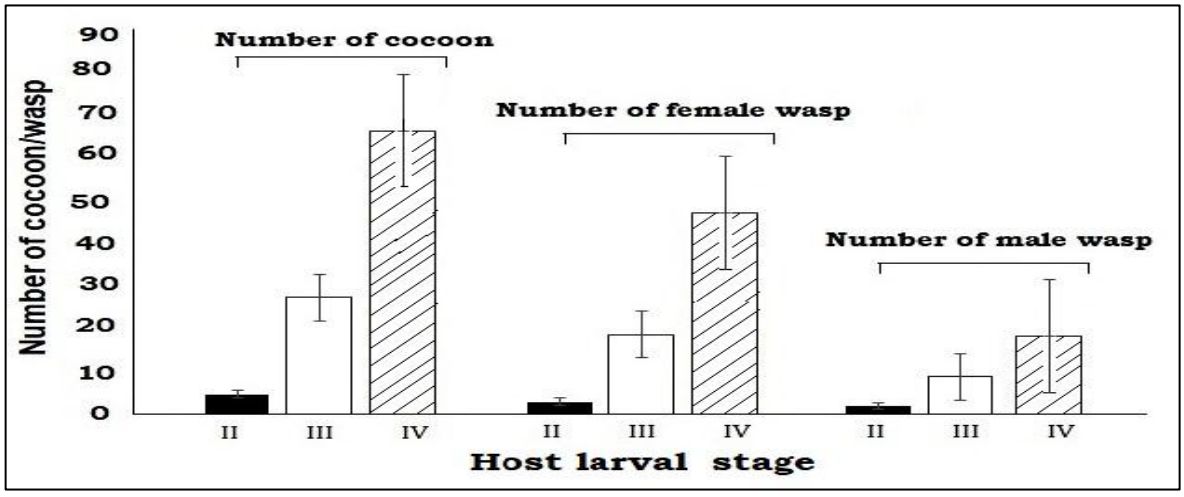


Fig. 10.1: Number of cocoon formation of *C. ruficrus*, adult (female and male) wasp emergence from a single host larva from different stages. Values are significant at P <0.05 (One-way ANOVA).

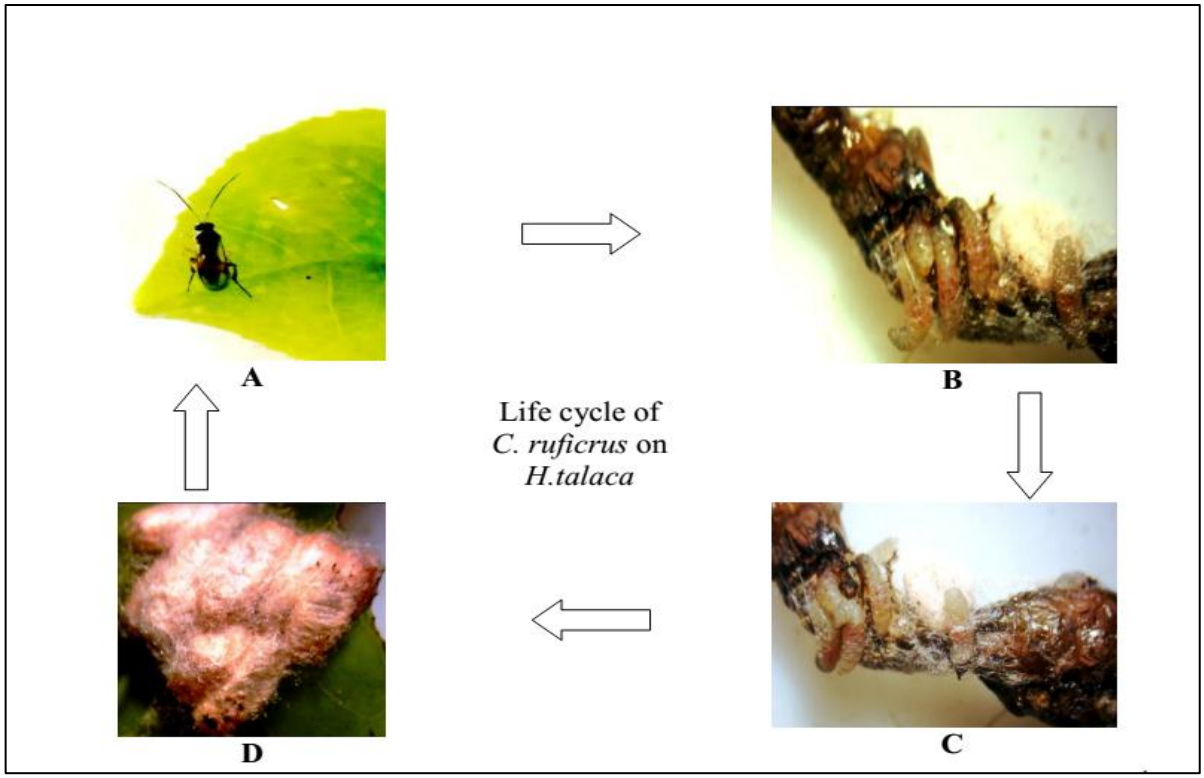


Fig. 10.2: Life stages of *C. ruficrus*: (a) adult *C. ruficrus*, (b) larvae of *C. ruficrus* emerging from host larva, (c) larvae of *C. ruficrus* forming cocoons and (d) cocoons of *C. ruficrus*

4.10.2. Study on life table of *C. ruficrus* reared on larvae of *H. talaca*: The survival rate of larva, cocoon and adult of *C. ruficrus* were 93.3±2.2, 92.9±3.5 and 92.4±1.8% in the laboratory conditions (Table 10.2). The age specific survival rate (lx), age specific fecundity rate (mx) and age specific maternity (lxmx) were worked out for construct the life table of *C. ruficrus* (Fig. 10.3). The intrinsic rate of natural increase (rm) of *C. ruficrus* was 0.203 day^{-1} and the net reproductive rate (Ro) was 41.11 female offspring/adult female when 108 eggs/ female was laid. The gross reproductive rate (∑mx) was 50.09 and the finite rate of increase (λ)was 1.23 (Table 10.3).

Table 10.2: Survival percentage of *C. ruficrus* reared on *H. talaca*

Life stages	Survivality (%)
Larva	93.3±2.2
Cocoon	92.9±3.5
Adult	92.4±1.8

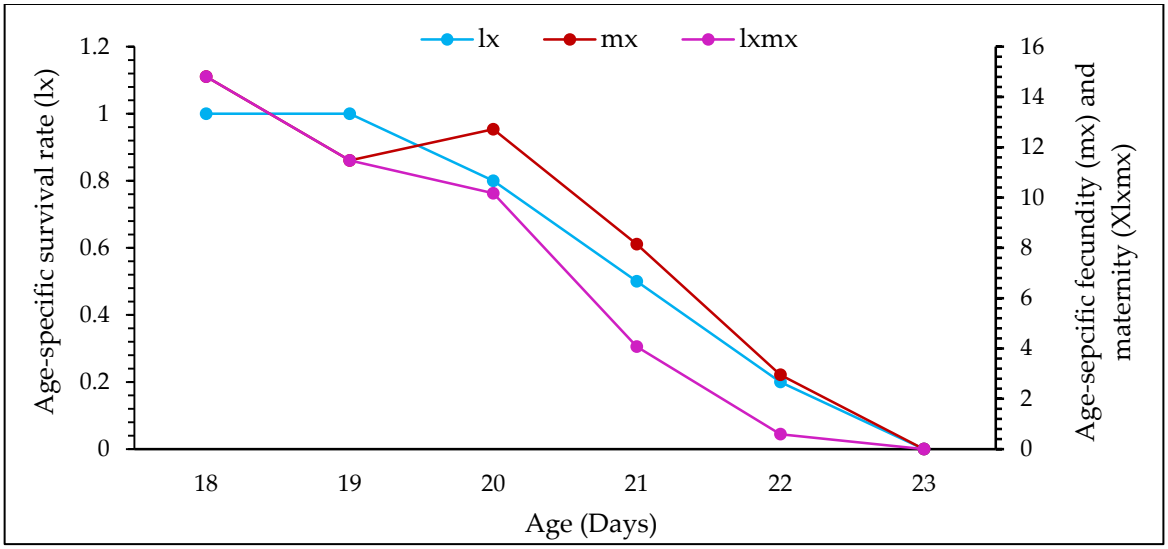


Fig. 10.3: Age-specific survival rate (lx), age-sepcific fecundity (mx) and maternity (Xlxmx) of female *C. ruficrus* parasitized on larvae of *H. talaca*

Table 10.3: Life table of *C. ruficrus* reared on *H. talaca*

Parameters	Values
Intrinsic rate of natural increase(r_m)	0.203
Finite rate of increase(λ)	1.23
Net reproductive rate(Ro)	41.11
Mean generation time(Tc)	19.13
Corrected generation timer(T)	19.13
Gross reproductive rate (GRR)	50.09
Doubling time (Dt)	3.57

4.10.3 Effect of parasitism on food consumption and growth of *H. talaca*: The food consumption of II, III and IV instar parasitized larvae were conspicuously reduced upto the egression of parasitoid when compared with the un-parasitized larvae. In the case of II instar parasitized larvae, the amount of food consumption was found to be very low during the initial two days and it gradually increased up to the 4th day of development compared to normal ones (Table 10.4). II instar parasitized larva consumed 6.1±0.8 mg of food whereas un-parasitized larva consumed 8.9±1.1mg on the second day of parasitization. On the fourth day of development of food consumption was increased very little amount in the parasitized II instar larva (6.6±0.9mg) where as in un-parasitized 10.3±0.8 mg food consumption recorded. These trends was found in both III and IV instar larvae.

Over the period, parasitoid larvae had spent days into the host larval body and consumed nutrition. On the 4th day of development the mean weight gain was recorded in second instar parasitized larva 6.1±0.2 mg and 3.4±0.7mg in un-parasitized larvae. Similarly in

the 4th day after parasitization the mean weight gain was 23.8±0.9mg by IV instar normal larva, whereas less weight gain recorded 16.0±2.9mg by parasitized larva (Table10.5).

Table 10.4: Parasitic impact of *C. ruficrus* on food consumption of host larvae (*H. talaca*)

Parasitic effect on the fitness of *H. talaca* by *C. ruficrus**						
Days of parasitization	Food consumption by the larvae (*H. talaca*) (mg)					
	II		III		IV	
	UP	P	UP	P	UP	P
1st	6.8±1.3	5.8±0.8	21.6±3	17.9±0.7	106.6±10.1	92.4±13.0
2nd	8.9±1.1	6.1±0.8	24.7±1.7	18.8±1.6	116.6±2.9	93.1±13.4
3rd	9.2±0.7	6.4±0.7	27.2±1.7	19.2±1.5	126.0±10.2	94.3±13.2
4th	10.3±0.8	6.6±0.9	29.3±1.5	19.6±1.4	134.4±7.0	95.3±13.7

*Value represented mean±SD of ten replications (UP and P) are significantly different at 1% level of significance, according to t-test. UP= unparasitized, P= parasitized

Table 10.5: Parasitic impact of *C. ruficrus* on weight gain of host larvae (*H. talaca*)

Parasitic effect on the fitness of *H. talaca* by *C. ruficrus*						
Days of parasitization	Weight gain by the larvae (*H. talaca*) (mg)					
	II		III		IV	
	UP	P	UP	P	UP	P
1st	3.0±0.7	2.9±0.5	8.1±1.0	7.8±1.0	15.2±3.1	13.9±2.9
2nd	4.4±0.5	3.0±0.8	9.0±0.8	7.9±1.1	18.5±2.6	14.3±2.9
3rd	5.2±0.4	3.2±0.6	10.1±0.8	8.0±1.2	21.3±1.5	15.1±3.0
4th	6.1±0.2	3.4±0.7	11.3±0.7	8.2±1.2	23.8±0.9	16.0±2.9

Value represented mean±SD of ten replications (UP and P) are significantly different at 1% level of significance, according to t-test. UP= unparasitized, P= parasitized

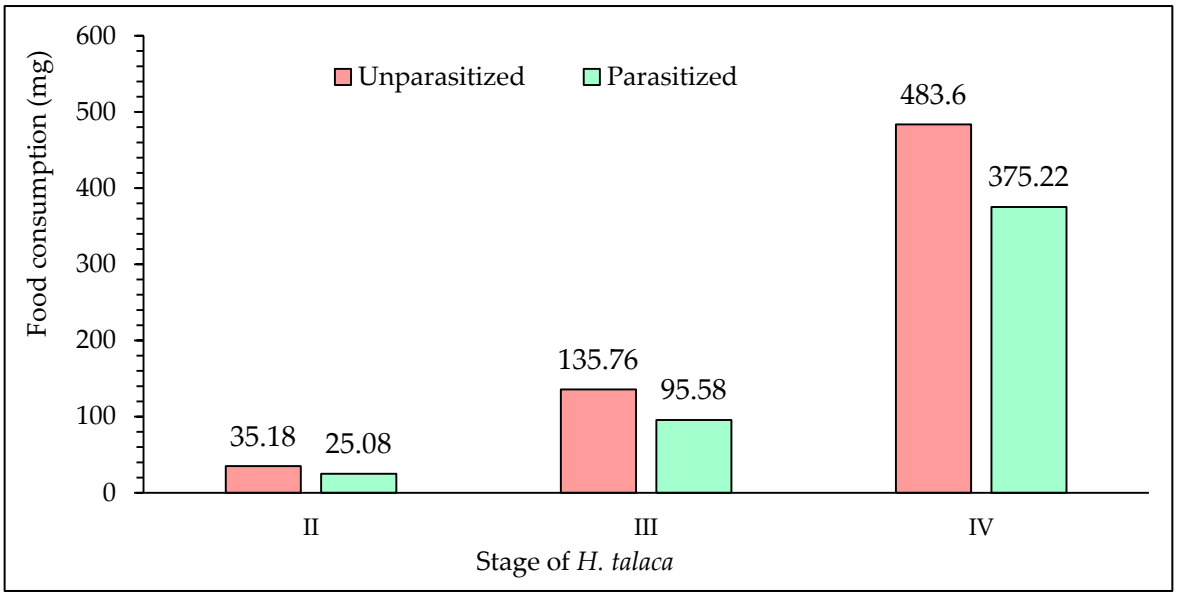


Fig.10.4 Food consumption (mg) of parasitized (white) and unparasitized (black) larvae of *H.talaca*. Values are significantly different at p<0.05 according to Tukey's HSD test

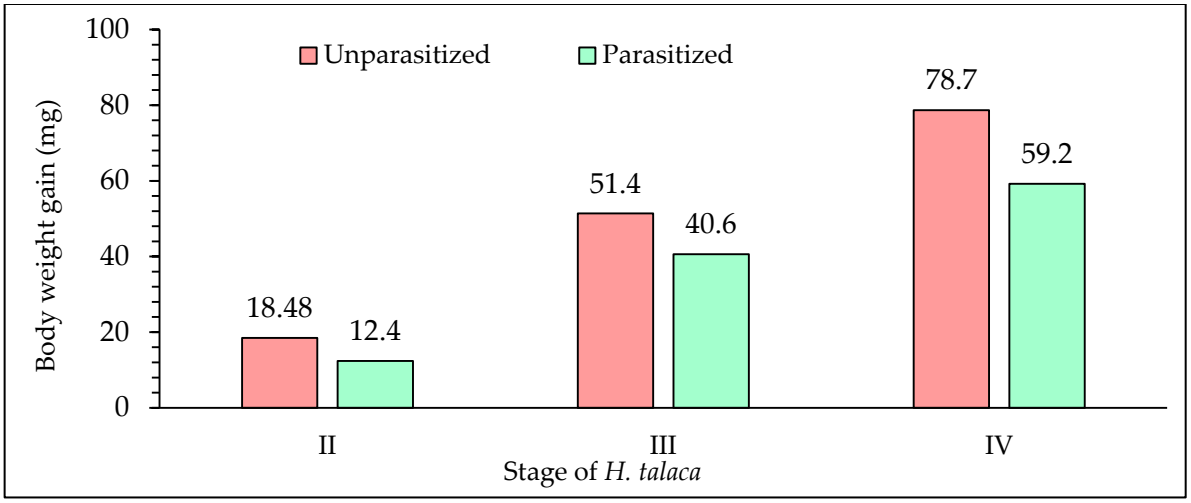


Fig. 10.5 Body weight (mg) of parasitized (white) and unparasitized (Black bar) larvae of *H. talaca.* Values are significantly different at p<0.05 according to Tukey's HSD test

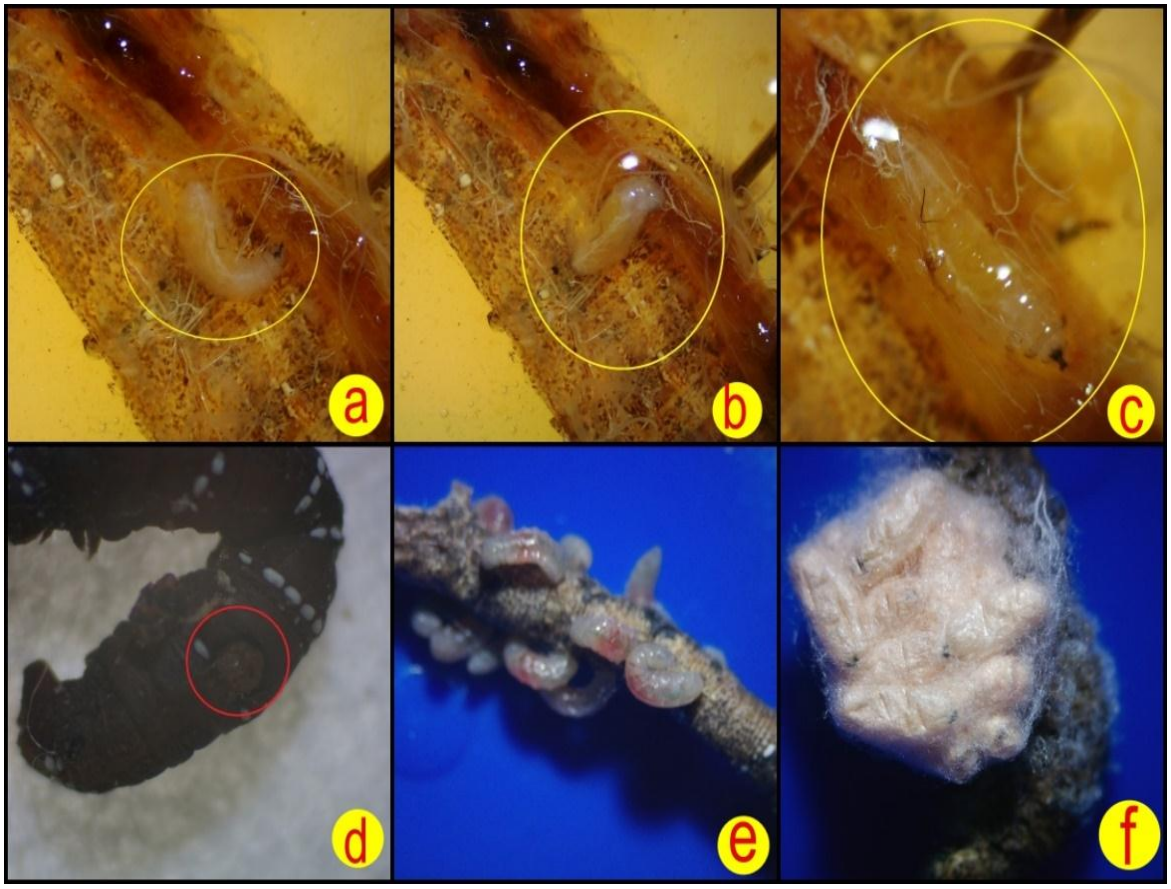


Fig. 10.6: Parasitism by *C. ruficrus* on host larva, *H. talaca*: (a-c) larva of *C. ruficrus* into the body of *H. talaca*, (d) parasitic wasp made whole on the host body, (e) larvae of *C. ruficrus* emerging from the host body and (d) cocoon formation by the parasitic larvae

4.10.4 Differential haemocyte count (DHC) and morphology of different haemocytes: There were five types of haemocytes observed in the haemolymph of *H.talaca* larvae, namely prohemocytes (PR), plasmatocytes (PL), adipohemocytes (AD), granulocytes

(GR), and oenocytoids (OE). The DHC analysis showed significant difference between parasitized and un-parasitized IV instar larvae. The percentage of PR was found to increase significantly in parasitized larvae while in case of unparasitised larvae the AD, GR, PL and OE showed significant increasing trend ($p<0.05$; $F=36.099$ and $t= 45.26$) (Table 10.6).

The morphological abnormalities in cellular diameter of different haemocytes of parasitized larvae of *H. talaca* were observed (Table 10.7). GRs were spherical or oval in shape, nucleus is oval and smaller in size and the cytoplasm is granular in un-parasitized larvae while in parasitized larvae the shape of cells were abnormal, the size of nucleus is founded to be reduced. ADs were small to large, spherical or oval cells with concave, biconvex, punctate or lobate nucleus and were mostly eccentrically located, cytoplasm contains small refringent fat droplets and vacuoles in normal larvae, however this type of features were not observed in parasitized larvae. OEs were observed as the largest haemocyte (18.67±1.1µm) with large nucleus, some droplets of fat were present in the cytoplasm but in case of parasitized larvae the shape of OEs (11.3±1.3µm) were significantly reduced ($p<0.05$) (Table 10.7). PLs were variable in shape and size and were distinguished by round or elongate nucleus and were generally centrally located with a distinct nucleolus in un-parasitized larvae but some abnormality in shape and size were observed in parasitized larvae (Fig. 10.7).

Table 10.6: Percentage of different haemocytes of normal and parasitized *H. talaca*

Haemocytes	Cellular type (%)				
	PR	GR	AD	PL	OE
Normal	41.1*	26.7*	11.1*	21.1*	3.3*
Parasitized	49.4	24.7	8.2	12.9	1.1

*Values are significantly different from each other at $p<0.05$; $F=36.099$ and $t= 45.26$ with 4 degrees of freedom

Table 10.7: Morphological analysis of different haemocytes of normal and parasitized *H. talaca*

H. talaca	Parameter	PR	GR	AD	PL	OE
Un-parasitized	C.D (µm)	7.3±1.5	9.3±1.5	13.3±1.1	14.6±1.1	18.7±1.1
Parasitized	C.D (µm)	4.7±1.1	7.3±1.1	8.7±1.1	9.3±1.1	11.3±1.1
	t (df=1)	2.8	2.1	4.9	5.6	7.7
	p	0.047	0.101	0.008	0.005	0.001

Values are presented as mean of experiments ±SD, C.D= cellular diameter $p< 0.05$ indicates significant differences between the parasitized and un-parasitized larvae (t- test)

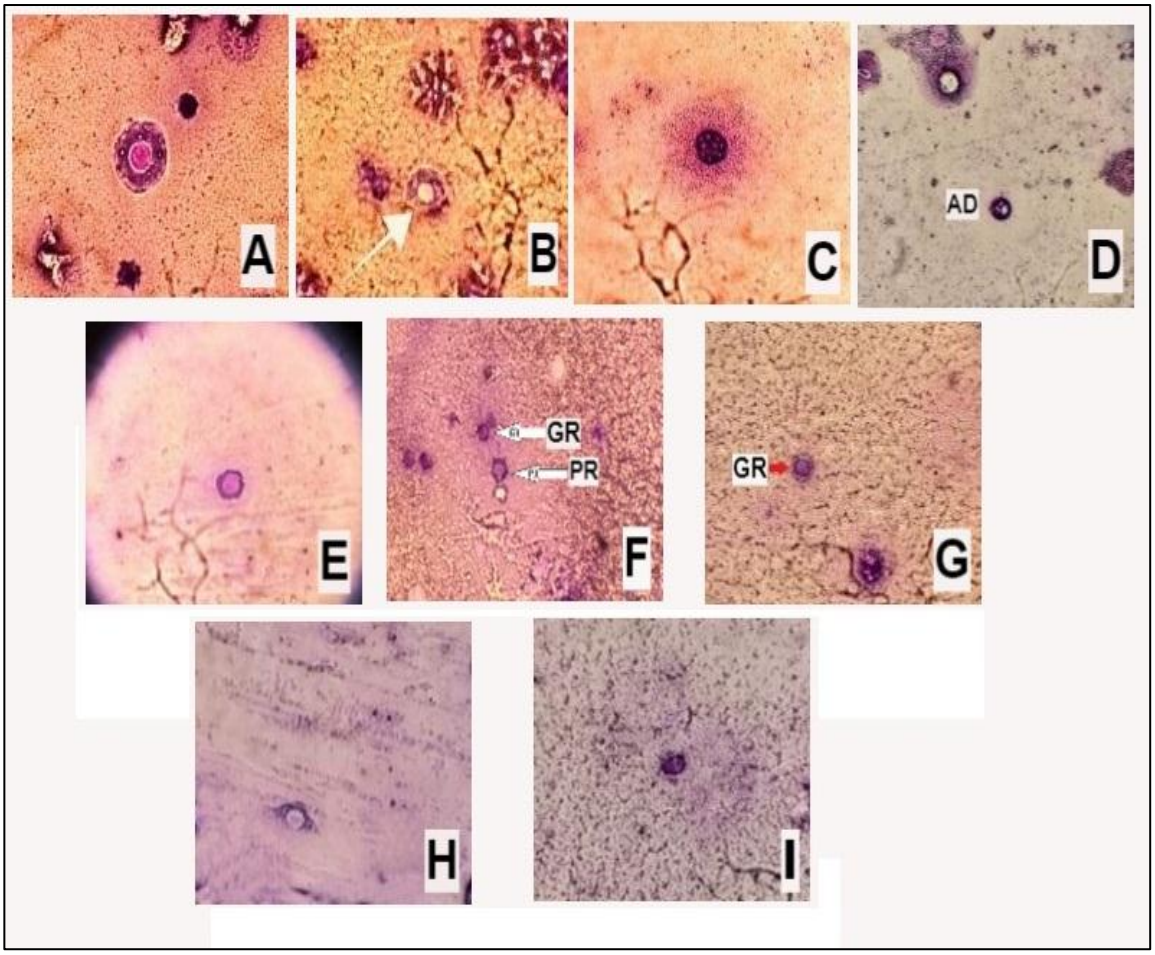


Fig. 10.7: Morphology of different haemocytes of parasitized and un-parasitized larvae of *H. talaca viz.*(A) un-parasitized OE, (B) parasitized OE, (C) un-parasitized AD, (D) parasitized AD, (E) un-parasitized PR, (F) parasitized PR and GR, (G) parasitized GR, (H) un-parasitized PL and (I) parasitized PL

4.10.5 Effect of pesticide on *C. ruficrus*: An experiment was conducted to understand the effect of use of some pesticides that are commonly applied in tea gardens, on the parasitic wasp *C. ruficrus*. The result revealed that, after 24h of the exposure of all the nine selected pesticides, highest 88.7±8.8 and 86.7±3.3% mortality were recorded in the treatment of Quinalphos and Thiamethoxam, whereas comparatively less percentage of mortality was recorded in other pesticides treatments (Table 10.8). After 72h of the exposure mortality percentage was 100%. It indicates that both the pesticides are most toxic in nature. Treatment with bifenthrin caused moderately high as 53.3±3.3% mortality after 72h followed Deltamethrin, Emamectin benzoate, Flubendiamade and Fenpyroxymate. In the treatment of Beauveria *bassiana* formulation showed 10.0±0.0% was seen after 72h of spray whereas no mortality was found in the treatment of Azadirachtin 5% EC.

Table 10.8: Effect of commonly used pesticides on *C. ruficrus*

Treatments	Concentration	Percentage of mortality after		
		24h	48h	72h
Quinalphos 25EC	1:400	88.7±8.8^{a}	97.7±3.3^{a}	100.0±0.0^{a}
Thiamethoxam 25WG	1:4000	86.7±3.3^{a}	96.7±3.3^{a}	100.0±0.0^{a}
Emamectin benzoate 5%SG	1:2500	6.7±3.3^{cd}	13.3±3.3^{c}	36.7±3.3^{cd}
Deltamethrin 2.8EC	1:2000	10.0±0.0^{c}	20.0±0.0^{bc}	43.3±3.3^{c}
Bifenthrin 10%EC	1:1600	13.3±3.3^{b}	30.0±5.8^{b}	53.3±3.3^{b}
Flubendiamade 20WG	1:5000	0.0±0.0^{d}	20.0±5.8^{bc}	30.0±5.8^{d}
Fenpyroxymate 5EC	1:2000	6.7±3.3^{d}	16.7±3.3^{c}	30.0±5.8^{d}
Beauveria bassiana formulation	2kg/ha	0.0±0.0^{e}	0.0±0.0^{d}	10.0±0.0^{e}
Azadirachtin 5% EC	1:1500	0.0±0.0^{f}	0.0±0.0^{d}	0.0±0.0^{f}
Control (water)	-	0.0±0.0^{f}	0.0±0.0^{d}	0.0±0.0^{f}

Means (±SD) of five replications followed by the same letter in a column do not differ significantly at p = 0.05 according to Tukey's multiple comparison test

Chapter-V
Discussion

DISCUSSION

5. 1 Study on the bio-ecology and seasonal incidence of *Hyposidra talaca* in relation to the climatic parameters of *Dooars* region of West Bengal

5. 1.1 Observation on bio-ecology of *H. talaca*: In the tea ecosystem interaction of *H. talaca* with different trophic component was observed and accordingly recorded in the present experimentation. *H. talaca* was observed to lay eggs on shade tree (*Melia azedarach*) and mango tree (*Mangifera indica*) that are adjacent to the tea gardens. Apart from that larvae of *H. talaca* perpetuated on goat weed (*Ageratum conyzoides*) during pruning of the tea plant. The present observation is supported by the findings of Majumder (2010) who had also reported somewhat similar ovipositional and feeding behaviour of *H. talaca* in the tea ecosystem.

5. 1.2. Seasonal abundance of *H. talaca* during the period of observation: The outbreak of *H. talaca* resulted in extensive damage in tea gardens throughout the year particularly in the area of West Bengal and Assam where tea was grown at commercial scale (Antony *et al*., 2012). In the present experiment, the population of *H. talaca* was found to fluctuate throughout the study period (2017-2018 and 2018-2019) of observation irrespective of the two locations namely, Banarhat TE and TRA experimental plot. Persistent high population of *H. talaca* was observed from February to June and August to November respectively in the present observation. The incidence of 'peak' population was noted during May at Banarhat TE and June in TRA plot respectively in both the periods of observation. Findings of the present study are in covenant with that of Das *et al*., (2010a) who had also observed that *Hyposidra* spp. remained active in March-May, June-August and September-November respectively followed by a steady decrease of population during December-February (winter months). Similar trends of the population abundance and fluctuation was observed by Majumder (2010), who had noted that looper population attained the highest incidence during summer months followed by a gradual decrease during monsoon and winter at Dooars region of the Northern parts of West Bengal.

The abundance of *H. talaca* was considerably influenced by the climatic factors. In the present observation the population showed significant positive correlation with maximum temperature and relative humidity, whereas positive but insignificant correlation was noted for minimum temperature and rainfall in the first season of the study. In the study period

of 2018-2019 same category of correlations has been noticed. Sinu *et al*., (2011) had reported that, prolonged drought and inconsistent rainfall influence the extent of infestation of *H. talaca* in tea growing area. Duration of development, survival rate, feeding rate, metabolism and fecundity of insect depends on the temperature (Cui *et al*., 2018). High temperature enhanced insect metabolism, mating and respiratory mechanism, whereas low temperature slowed down physiological activity (Kuang *et al*. 2010and Qian *et al*. 2017).

5.1.3 Biology of *H. talaca* on three alternate diets: *H. talaca* has successfully completed life cycle on all of the three selected alternative foods. The larvae of *H. talaca* was found as a defoliator of *Theobroma cacao, Cinchona* spp. and *Garciniam angostana* (Dun, 1967; Kennedy, 1996 and Intachat *et al*., 2001), *Tectona grandis* (Tripathy and Rout 2018) and *Shorea robusta* (Sen-Sharma and Thakur, 2008). Sharma *et al*., (2014) had observed that, *H. talaca* successfully completed its life cycle on *T. grandis*. The diverse host range and survival fitness offered plasticity to *H. talaca*. The pest possess detoxification capacity against plant allelochemicals and use plant nutrients to survive (Das and Mukhopadhyay, 2014). The best 'fitness' of *H. talaca*, out of the three diets, was noted on artificial diet followed by tea leaf and the least was noted for shade tree leaf. The duration of larval development was comparatively shorter on artificial diet (25.2±2.4 days) when compared to tea leaf (26.8±0.5 days) and shade tree leaf (27.6±0.9 days) respectively. The female longevity and oviposition period were 6.2±1.0 and 6.4±0.5days respectively when reared on artificial diet. However the female longevity and oviposition period were 6.0±0.8 and 6.0±0.7daysfor tea leaf. In case of shade tree leaf the values were 6.0±1.0 and 4.6±0.5days respectively. Substantial amount of secondary metabolites were present in *A. lenticularis* (Seigler, 2003 and Subhan, 2016). However, *H. talaca* could withstand the secondary metabolites of the plant for its survival and sustenance. The incubation period of *H. talaca* was 7.0±0.7, 6.4±0.9 and 7.6±0.5 days respectively when reared on tea leaves, artificial diet and shade tree leaves respectively. The duration of incubation period recorded in the current study was well in agreement with the study of Das *et al*., (2010a) and Chutia *et al*., (2012a). Sharma *et al*., (2014) had recoded that the range of total larval period as 15.24-17.14 days while female longevity as 4-8 days respectively. However, they had considered teak (*Tectona grandis*) as the dietary source of *H. talaca* in the agro-climatic region of Jammu, (J&K). The total fecundity per female, in the present study was 578.8±26.3, 589.6±15.6 and 566±18.8 when reared on tea leaves, artificial diet and shade tree leaves

respectively. Supplementary nutrients present in the artificial diet enhanced the health and development of the growing larvae and fecundity of adults. Abbasi *et al*., (2007) had also noted that the faster rate of development of related lepidopteran pest, cotton bollworm, *Helicoverpa armigera* on artificial diet supplemented with nutrients compared to its main host.

It is thus evicted that, *H. talaca* acclimatized itself on tea ecosystem apart from its original host shade tree. It can also sustain life cycle on tea leaf, may be for the high nutrient value of tea. Rearing of *H. talaca* could be possible to rear on artificial diet.

5.1.4 Survival of *H. talaca* reared on three different diets: Significant differences of the survival rate of *H. talaca* were noted on three different diets. Highest survival percentage of 98.5±0.5% was observed for artificial diet while lowest survival rate of 92.5±0.1% was noted for shade tree leaf. The artificial diet could be found more appropriate than the natural food sources under laboratory conditions (Parra 1991 and Campos *et al*., 2017).

5.1.5 Life table of *H. talaca* reared on three different diets: Higher mortality of 1st instar larva was noted on artificial diet when compared to the other instar stages, in the present study. This probably due to the time required for the 1st instar larvae to acclimatize to the artificial diet in lieu of food of natural sources. Danthanarayana and Kathiravetpillai (1969) have made similar observation on twig caterpillar *Ectropis bhurmitra* infesting tea. Gomes *et al*., (2017) and Surpur *et al*., (2018) highlighted the fitness and the survivality of the larva, thus can be ensured on appropriate artificial diet for other insects also.

The net reproductive rate (Ro) of *H. talaca*, in the present study was 462.9±22.1 when fed on artificial diet. This was followed by the main host tea leaf (396.9±16.1) and shade tree leaf (377.6±20.0) in descending order. The mean length of generation **(**Tc) was 35.3±5.4 days when reared on artificial diet. But it was recorded as 36.1±6.5 days on tea leaf and 37.1±7.2 days on shade tree leaves respectively. Although information on the life table of similar lepidopteran pests of other agro-ecosystem was availble, but study on *H. talaca* on tea was studied for the first time. References available are mostly cocerened with the insect pest of other crops of same insect order. Jha *et al*., (2012) had constructed the life table of *Helicoverpa armigera* reared on an artificial diet and recorded that 'Tc' was 36.7 days. Farahani *et al*., (2012) had reported that the mean generation time of the beet armyworm *Spodoptera exigua* on soybean was 32.0± 0.3 days. The intrinsic rate of natural increase (rm) of *H. talaca* was 0.183±0.0 days when reared on artificial diet. Whereas

comparatively shorter 'rm' was observed when reared on tea leaf (0.174±0.0) and shade tree leaf (0.164±0.0) respectively. Findings of the current study somewhat similar with the study of Farahani *et al*., (2012) who had recoreded that the 'rm' value of *S. exigua* was 0.168±0.004 when reared on soyabean. Surpur *et al*., (2018) had noted that the 'rm' value was 0.13 when *Maruca vitrata* was reared on chickpea artificial diet. The finite rate of natural increase (λ) of *H. talaca* was 1.20 female offspring per female per day when fed on artificial diet, which was greater than the other two diets that are considered in the present experiment. The life table parameters like 'rm', 'Tc' and 'λ' are useful indices of population growth in a given set of growth conditions. Shorter developmental time and high reproductive rate of any insect on a food source reflect fitness of the organism (Van Lenteren and Noldus 1990). The life table constructed with the data on the 'rm' provides the characteristic of life patterns of a particular species (Satpute *et al*. 2005). Insect growth, longevity and reproduction can be influenced by the available food sources (host plants or host prey) and also by ambient temperature (Ellers-Kirk and Fleischer 2006). The intrinsic growth rate, longevity and fecundity of *H. talaca* were more in artificial diet. However in natural condition *H. talaca* prefers to feed on tea plant as a main host and exhibits better fitness in comparison to the shade tree, the original host plant. The net reproductive rate reflects the potential population growth with shorter developmental time to complete more generations on a particular host (Liu *et al*., 2004).

5.2 Seasonal abundance of *S. collaris* during the period of observation: The population dynamics of all of the life stages of *S. collaris* were significantly correlated with *H. talaca* population at both the study areas during 2017-2018 and 2018-2019. During both summer and monsoon months the population gradually increased at both the study locations. But after October the population declined gradually. Kumaraswami and Ambrose (1994) from Melapattam Scrub jungle of Southern India had noted that the adult reduviid species, *Rhynocorism arginatus* attained peak from January onwards up to June. The immature life stages were found during the month of August and September. Threshold temperature for larval developmental and also the thermal requirements to complete the life cycle of insects totally depends on the local thermal adaptation (Kobori and Hanboosong 2017). Both biotic and abiotic factors affect the insect pest population dynamics (Kroschel *et al*., 2013). In the present study the population abundance of *S. collaris* was positively correlated with maximum temperature (r= 0.9690), minimum temperature (r= 0.9807), relative humidity (r= 0.8694) and rainfall (r= 0.7970) at TRA experimental plot during

2017-2018 at significant ($p<0.05$) level. During 2018-2019 similar trends of correlation were also found. At Banarhat TE also, the correlation of *S. collaris* with maximum temperature (r= 0.9344), minimum temperature (r= 0.9331), relative humidity (r= 0.9320) and rainfall (r= 0.8809) were significantly positive during 2017-2018. Similar trends of correlation were recorded for the second season at Banarhat TE.

Present results are in well agreement with the findings of Siddaiah *et al*., (2014). They had obtained significant positive correlation of *S. collaris* with maximum temperature (r = 0.853), minimum temperature (r = 0.932), relative humidity (r =0.850) and minimum relative humidity (r = 0.891) at Ranchi, Jharkhad, India.

In tea ecosystem life stages of *S. collaris* feed on tea red slug caterpillar, *Eterusia magnifica* in the absence of *H. talaca* larvae. This reduviid bug was observed to forage in the un-pruned plots and shade trees during winter period (December to February). Eggs were found on the bark of shade tree and sometimes in the grooves of the bark of the shade tree. The bug inhabits in small jungle trees nearer to the tea fields. Somewhat similar observation was made by Ambrose (1999) who had observed that reduviid bugs in trees and shrubs. Many species of Reduviid predators shares diverse habitats and also found in adjacent agro-ecosystems.

5.3 Seasonal abundance of *E. furcellata* during the period of observation: At both the study locations namely Banarhat TE and TRA experimental plot pentatomid predator bug first appeared in the month of March during 2017-2018 and also in 2018-2019. The incidence of bug population was very low and it was 0.6 and 0.7 bugs/bush at Banarhat TE during 2017-2018 and 2018-2019 respectively. At TRA plot the incidence of bug population was mostly similar. Chakravarty *et al.*,(2017) also had observed similar types of population trend with about 1.2 bugs/sq.m pigeon-pea. After that, the population then increase gradually attaining peak incidence of 2.5 bugs/bush of *E. furcellata* population of in August and 2.7 bugs/bush in September at Banarhat TE. Mostly similar population density was recorded at TRA plot at September with 2.2bugs/ bush and at October with 2.8 bugs/ bush during 2017-2018 and 2018-2019 respectively. Suyal *et al*., (2018) observed 3.8 bugs/ soybean plant during peak incidence in September during 2017.

For comprehensive study about the impact of temperature, rainfall and relative humidity on the population trends of *E. furcellata* the metrological data for the period was computed

against the bug population by simple correlation. Present study showed that *E. furcellata* population had exhibited significant positive correlation with maximum and minimum temperature, relative humidity and rainfall at both the places under consideration. Chakravarty *et al.*, (2017) had reported that the abundance of population was positively correlated with maximum temperature (r = 0.750) and rainfall (r = 0.725) at significant level. Whereas for other meteorological parameters the correlation was be non-significant. Pillai and Agnihotri (2011) observed that the numerical abundance of predatory sting bug of green gram was positively correlated with maximum temperature, minimum temperature and evening relative humidity respectively.

In tea ecosystem, *E. furcellata* lays eggs on the shade tree bark and also fed on the shade tree lepidopteran pest like hairy caterpillar.

5.4 Seasonal abundance of *C. ruficrus* during the period of observation: Seasonal abundance of the parasitoid wasp, *C. ruficrus* during February 2017 to January 2019 in tea ecosystem in relation to the abiotic factors was observed at both Banarhat TE and TRA experimental plots. The incidence of *C. ruficrus* was about 2.9 to 3.4 cocoons/bush in March and November respectively at both the locations during the period of observation. Present finding was partially agreed by Shankar (2004) who had studied on the incidence of *C. plutellae* and the rate of parasitization on diamondback moth larvae. In the present study the parasitoid wasp first appeared during March. The period coincides with the first flushing of tea leaf after winter dormancy. The abundance of *C. ruficrus* has gradually decreased from May onwards and increased again from September at both the study locations for two consecutive years. From Penang, Malaysia Okolle *et al*., (2006) had noted the seasonal periodicity of banana skipper, *Erionotathrax* and its all parasitoids namely *Ooencyrtu serionotae*, *C. erionotae*, *Brachymeria albotibialis*, *Elasmus* sp. and *Melaloncha* sp. Findings of the present study is similar with his study on the peak population trends of *C. erionotae*, to our findings. The occurrence of *C. ruficrus* is pest population dependent rather than climate dependent. As the numerical abundance of *C. ruficrus* was positively correlated with *H. talaca* incidence, but negatively correlated with all of the weather parameters. Successful parasitism and cocoon formation was found during October to April at both the study locations. Furlong and Zalucki, (2017) had commented that adversity of global climate change imparted detrimental effect on the host–parasitoid interactions. They further had observed a negative effect of increasing

global temperature on host–parasitoid. The optimum temperature for the survival, development and reproduction of Braconid parasitoid is lower than what was for its host as commented by Ramalho *et al*., (2011). In the present study abundant of wasp population were observed on flowering hedge plants and herbs namely *Lantana camera*, *Moringa oleifera* and *Clerodendron infortunatum* etc. associated with tea ecosystem. Lu *et al*. (2014) had pointed out that feeding on flower nectar caused an increased longevity to the parasitoids wasps *Cotesia* sp.

5.5 Interaction between *S. collaris, E. furcellata, C. ruficrus* and *H. talaca*: Our investigation explored the interaction between the natural enemies (*S. collaris*, *E. furcellata* and *C. ruficrus*) and the target pest *H. talaca*. The incidence of these natural enemies coincided with the population trends of *H. talaca* at both the study locations during the study period. The population dynamics of all the life stages *S. collaris* of were found to be significantly correlated with the *H. talaca* population at both the study area in 2017-2018 and 2018-2019. Pest and natural enemy complex associations within an agricultural field varied over the place, time and space (Kashyap *et al*., 2018). So, a periodic survey on pests and the natural enemy population is very important in IPM. The dynamics of *E. furcellata* were synchronized with *H. talaca* and were correlated at positively insignificant level. Information on the crop susceptibility to pest, biological stress and development rates and seasonal incidence of pest natural enemy complex develop the IMP system with ecological and economical balance (Pradhan et al., 2020). Chakravarty *et al.,* (2017) observed that the *E. furcellata* and *Rhynocoris fuscipes* abundant during flowering and pod initiation stage of pigeonpea crop and incidence of pod borer, *Maruca vitrata*. The present observation showed that the population dynamics of *C. ruficrus* in tea ecosystem showed positive correlation with the population of *H. talaca*. This finding is in well agreement with the report of Burgess (1987), who had observed since the first collection of C. *ruficrus* in malaise trapping and sweep net sampling the incidence of larvae of the pest *Mythimna separata* occurred on maize in New Zealand.

5.6. Study on the biochemistry of tea leaves and susceptibility index of selected tea cultivars against *H. talaca*

5.6.1 Tea leaf biochemistry:

5.6.1.1 Analysis of primary metabolites: Host plant biochemistry plays a vital role on the performance of the insect feeding. Amino-acids and proteins are the most significant

constituent of host plant (Rosenthal and Berenbaum, 1991 and Jager *et al*., 1996). In the present observation, among the selected cultivars, TV22 contains 10.83±1.8mg/g total protein and this was followed by TV20 (10.40±1.2mg/g) and TV1 (10.10±1.1mg/g)m respectively in descending order. 6.31±0.6mg/g total protein was found in TS-520 and the value was least. Sinija & Mishra, (2008) and Gayathri *et al*., (2017) showed that 15% protein of leaf dry weight was present in green tea leaf.

Presence of simple sugars plays a vital part in the formation of tea aroma (Bokuchava, 1969). Biochemical analysis showed the presence of 0.786±0.003gm/g carbohydrate in the cultivar TV1 which was followed by K1/1 and HP12 among all the selected cultivars. In parity to the present observation Gayathri *et al*., (2017) had noted 10% carbohydrates in tea leaf. Oligo-saccharides and polysaccharides are naturally occurring complex carbohydrates in tea leaf that are formed by chains of sugar residues interconnected by glycosidic linkages having biological regulatory functions (Albersheim *et al*., 1983).

Young tea leaves contain comparatively higher concentrations of phosphatidyl ethanolamine and phosphatidyl choline than mature leaves as lipids materials. Whereas, monogalactosyl diglyceride and digalactosyl glyceride were predominant in mature leaves. Whereas Phosphatidyl choline was the major lipid in tea seeds (Roberts, 1974). Lipid content increases as the leaves mature. Leaf lipid content has been related to the maturity of the chloroplast (Bhuyan *et al*., 1991). The results of the biochemical analysis revealed that, TV20 contained 14.6±1.4 mg/g of total lipids which was the highest amount among all of the tested cultivars. TV1 contained 14.2±1.5mg/g while the lowest was observed in TS-520 (6.31±0.6mg/g). Contrary to the present observation Sinija and Mishra, (2008) reported only 2% lipid contents in green tea leaves.

Chlorophyll is strongly related to the photosynthetic functioning of plants. Chlorophyll content in plant depends of the environmental and phenological conditions (Barry *et al*., 2009). Plants compensate insect induced damage by increasing relative growth rate or by enhancing photosynthetic activity (Mizumachi *et al*., 2006). In the present study, highest level of 0.946±0.09 chlorophyll content was recorded in the cultivars K1/1. In TV20 the value was 0.912±0.08mg/g. whereas in TV16 lowest amount of 0.978±0.07mg/g chlorophyll was found. Present results are in well agreement with the findings of Adhikary *et al*., (2018). The total chlorophyll content was highly variable across plant species and accordingly capacity to withstand the extent of stress differs (Cárdenas and Gallardo, 2016).

5.6.1.2 Analysis of secondary metabolites: Total phenols as secondary metabolites in tea leaves, due to its antioxidant and anti-inflammatory properties has considered as the main active components for pharmacological studies (Al-Attar and Zeid, 2013 and Adhikary *et al*., 2018). The phenol induced the defensive mechanism of plant against insect herbivory (Magalhaes *et al.*, 2008 and Scott *et al*., 2010). Among all of the selected cultivars, in the present study, TS-520 (266.6±15.2), (TV1264.2±21.3) and SNT-8 (270.0±10.2 mg/g) contained comparatively high amount of phenol. In consideration of total phenols the cultivar TV16, HP12, TV20, TV26, TV22, K1/1 and B157 ranked subsequently in descending order. Adhikary *et al*., (2018) recorded the high polyphenol content of 24.49 ±0.11 and 24.29 ±0.38% of dry weight in the cultivar of TV-26 and TV1 respectively compared to the cultivars of TS-520 (23.15 ±0.40% dry weight) and TV20 (22.32 ±0.68% dry weight). Hara *et al*., (1995) and Sinija & Mishra, (2008) reported that dried tea leaf contained 37.0% polyphenol which is marginally higher than the present findings. Amount of polyphenol was comparatively higher in the bud than the younger and older leaves (Chin *et al*., 2013).

Alkaloids are one of the largest groups of plant secondary metabolites. Alkaloids act as defensive compound against insect pests due to their toxicity (Bourgaud *et al*., 2001). In the present study, the highest amount of total alkaloids was noted in B157 with 35.7±2.8 mg/g. This was followed by the cultivar TV16 as 31.8±3.5mg/g. Chin *et al*., (2013) had reported that the average total alkaloids in old leaf, young leaf and bud collectively ranged between 20.8 to 58.1mg/g and 26.6 to 74.6 mg/g in direct extract (DE) method and in soxhlet extract (SE) method respectively. Such observation was almost similar to the present result. Lowest amount of alkaloids were found in the cultivar TV1 (25.8±3.8) which was followed by TV20 (25.6±5.2). Ramdani *et al*., (2018) reported that in green and black tea leaves the amount of alkaloid was 31.5 ± 0.31 g/kg and 28.7 ± 0.249 g/kg respectively. Alkaloids can act as antibiotic, antifungal or antiviral component and, thus, offering protection to plants from pathogens or herbivores (Bourgaud *et al*., 2001).

Flavonoids defenses plants against pathogens, herbivores, environmental stress. Flavonoids has significant contribution to plant resistance has been highlighted (Treutter, 2006). Available information about the presence of flavonoid in tea is scanty. In the present experiment cultivar B157 contained highest amount of total flavonoids as 0.15±0.0003mg/g. This was followed by HP12, TS-520, SNT8, TV26 and K1/1 respectively in descending order. Song *et al.,* (2003) and Sajilata *at el.,* (2008) studied the defensive role of flavonoid in green tea. Flavonoids as secondary metabolite offer defense

against herbivores (Feeny, 1976). In addition to that a number of insects are deterred by flavonoids during feeding (Brignolas *et al*. 1998 and Berhow and Vaughn 1999).

Carotenoids functions as antioxidant with an interactive role between herbivores and their host plants (Ahmad 1992 and Felton & Summers 1995). The result of the present study showed that K1/1 contained higher amount of carotenoids (0.277±0.03mg/g). The value was followed by TV20 (0.267±0.04mg/g) and TV22 (0.256±0.04mg/g) respectively in descending order. Lowest amount of carotenoids were present in the cultivar TS-520 as 0.198±0.01mg/g. Findings of the study are in the agreement with the study of Adhikary *et al*., (2018) who had also reported somewhat same amount of catotenoid in tea leaf.

5.6.1.3 Analysis of secondary metabolites using HPLC method: Phenolic component of tea have health benefits (Reygaert, 2017). Most important component is catechins. Among all of the fractions of catechins present in the leaf, epicatechin (EC), epicatechin gallate (ECG), epigallocatechin (EGC) and epigallocatechin gallate (EGCG) were analyzed in the present experiment. Out of the four fractions, EGCG was present in maximum quantity. EGCG was predominantly present in K1/1 sharing 11.31%. In HP12 the value was 6.63%. The presence of EGCG in tea was also recorded by Adhikary *et al*., (2018). Sinija and Mishra, (2008) analyzed green tea and had reported nearly same result. Highest amount of EGC was obtained in cultivars TV20 (4.38%) while the lowest was noted in TV16 (2.48%). Present observation is in agreement with that of Chin *et al*., (2013), Adhikary *et al*., (2018) and Ramdani *et al*., (2018). All of them had noted mostly similar observation. ECG ranked third in consideration of quantity among all of the catechins. Highest amount was recorded in TV16 (4.92%) while the lowest was scored in HP12 (1.73%). Present results are in well agreement with Reygaert (2017) and Adhikary *et al*., (2018). EC as an antioxidant catechin was found in lowest quantity. Highest quantity of catechin was noted in TV22 (1.85%) while the lowest was noted in B127 (0.94%). Schulz *et al*., (1999) had reported that the range of EC was 4.3-59.6 g/kg in green tea samples, which was comparatively, low than other catechins.

Gallic acid (GA) is one of the main phenolic components of black tea. GA is present in both free and esterified forms sharing about 5% of the weight of the tea leaf (Harbowy and Ballentine, 1997). GA has insect repellent properties (Sarvamangala *et al*., 2014). In the present investigation, GA was maximum in B157 (0.199%). Minimum GA was recorded in HP12 (0.162%). Chin *et al*., (2013) reported that the amount of GA in leaf bud, young leaf and old leaf was 5.56 mg/g, 0.01 mg/g and 0.99 mg/g respectively. Such amount is slightly higher than the present observation. Caffeine as secondary metabolites present in

tea leaves have the potential antioxidant and anti-cancerous activities Schulz *et al*., (1999). Cultivar TV16, in the present study, contained the highest amount of caffeine (3.62%) compared to TV1 (3.43%) and K1/1(3.39%). The lowest amount was recorded in TV26 (2.51%). Present observation is in consonance to the observation of Adhikary et *al*., (2018) who had noted mostly similar observation.

5.6.2 Food consumption and susceptibility index of *H. talaca* on tea leaves: Development of pest resistant crop variety is one of the helpful components in IPM programme (Wilson and Huffaker, 1976). In the present study the susceptibility levels of the selected cultivars has been evaluated in terms of food consumption and utilization by the tea looper. The lowest food consumption and utilization was noticed in young larval instars of *H talaca* fed on different tea cultivars. A gradual increase in consumption was observed with the advancement of instars. The food consumption and larval development significantly varied among the tested cultivars. The results on food consumption of the II, III, IV and V instars was recorded as 9.2±0.6, 33.6±4.0, 112.0±14.2 and 223.6±24.7 mg per day respectively. Gaining of body weight for II, III, IV and V instars was 3.0±0.3, 9.8±0.7, 18.2±2.2 and 31.0±2.0 mg per day respectively. The order of preference was respectively TV20>TV1>K1/1> TV22> TV26> TV16> SNT8>TS-520>HP12. While, the lowest consumption (9.2±0.6, 33.6±4.0, 112.0±14.2 and 223.6±24.7 mg per day respectively) and body weight gain (3.0±0.3, 9.8±0.7, 18.2±2.2 and 31.0±2.0 mg per day respectively) of II, III, IV and V instars larvae were observed on B157. Basumajumder *et al*., (2010) had studied on the growth and survival of larvae of *H. infixaria* on four different tea clones. They had observed that the larval period was significantly shortest (15. 78 d) when reared on TV25 clone. Other clones were TV1 (18. 14 days), TV9 (18. 00 days) and Teen ali 17 (17. 00 days) that ranked afterwards.

Noticeable differences were found within the nutritional indices like ECI and ECD values when *H. talaca* fed on the ten different tea cultivars. Kumar and Ahmad (2006) reported that the values of ECD depend on the amount of food intake and extent of digestibility by the larvae. In the current study, the ECD and ECI were recorded as higher in 2nd instar larva compared to the later instars. Results of the current investigations are in well agreement with the findings of Kumar and Ahmad (2006) who had reported that relatively low values of ECI was observed during advance instars. This trend was observed in the case of all the tested tea cultivars. The value of ECD and ECI were observed as high when *H. talaca* fed on TV20 followed by TV1>K1/1> TV22> TV26> TV16> SNT8>TS-520>HP12. Whereas the ECD and ECI were low when larvae of *H. talaca* were fed on

B157. The ECI values may vary with the digestibility of food and the proportional utilization of amount of the digestible portion of food which is converted to body mass that is required for the vital activities of the developing larvae (Abdel- Rahman and Al-Mozini 2007). The efficiency of conversion of ingested food (ECI) indicates the overall efficiency of the insect to utilize the food for growth and development (Nathan *et al*., 2005). The RGR and RCR values were found to decrease with the advancement of larval instars. It was observed to be high when larvae of *H. talaca* fed on the cultivar TV20 followed by TV1>K1/1>TV22>TV26>TV16> SNT8>TS-520>HP12>B157 respectively. The AD values were found to be low in 2nd instar larva and high in 5th instar larvae. The mean AD values of all the larvae were recorded as high when fen on TV20 and low on B157. Our results are in line with the results of Gurusubramanian *et al*., (1991) and Raman *et al*., (1994) had reported that the approximate digestibility (AD) and efficiency of conversion of ingested food to body substance (ECI) was inversely correlated with the larval age.

Significant variation on food consumption by II, III and IV instar larvae was observed in different cultivar chosen for the study. Based on this, susceptible index was worked out where the tea cultivar TV20 ranked top position while B157 was at the bottom. This could be attributed to the variation in the primary and secondary metabolites in the host leaves. The highest lipid content was recorded in TV20. This was followed by TV1>K1/1>TV22>TV26>TV16>SNT8>TS-520>HP12>B157 respectively. The correlation value for mean food consumption by larva with protein (r=0.6351), lipid (r=0.5767), carbohydrate (r=0.6223) and chlorophyll (r=0.1414) content showed a positive relation. However, no significant difference for food consumption of fifth instar larval was observed. Truzi *et al*., (2019) reported that the RGR, representing the amount of food ingested by the insect per day was higher for the diet with a higher protein content to meet their nutritional needs in their development. Gall and Behmer (2014) reported that herbivorous insects prefer protein biased foods when the total macronutrient content in available foods is low. Such compensatory feeding response overcomes nutritional imbalances. Plant proteins and carbohydrates exist at a variable quantity within an individual plant depending on the type of tissue in young and old leaves (Mattson, 1980; Yeoh *et al*., 1992 and Sattelmacher *et al*., 1994). Insects find and consume food which contains high concentration of proteins and carbohydrates (Gall and Behmer, 2014). In the present study, among all the secondary metabolites, alkaloid (r= -0.6137), flavonoid (r= -0.7403) and galic acid (r= -0.5610) showed a negative correlation with the larval feeding on different cultivars. It may be attributed to the variation in larval feeding on the tested

tea cultivars like TV20 to B157. Plants produce secondary metabolites like alkaloid, flavonoid, etc. when they encounter herbivores or pathogen attacks (Grayer, 2005 and Ahmed *et al*., 2017). Sarvamangala *et al*., (2014) reported that gallic acid acts as insect repellent. Ananthakrishnan, (1997) reported that gallic acid and salicylic acid play an important role in insect-plant interactions and have significant application in crop protection. The secondary metabolites like polyphenol, carotenoids, EGC, catechin, EC, EGCG, ECG and caffeine showed a positive correlation with the food consumption by larvae of *H. talaca*. *Hyposidra* spp. could utilize detoxification enzymes to overcome the secondary metabolites to complete their life cycle on the host plants *Schima wallichii* and *Camellia sinensis* and artificial diet (Das & Mukhopadhyay 2014 and Prasad & Mukhopadhyay, 2015). The trichome density (r= -0.8024) and leaf thickness (r= -0.7624) also showed a negative impact on the food consumption of *H. talaca* larva on the tested cultivars. Hägg *et al*., (2013) reported that apart from secondary metabolites plants also had morphological features like waxes, trichomes, and latices to make the feeding more difficult for the insects. Funk and Heather (2010) reported that native plant species of Fabaceae, Asteraceae and Myrtaceae generally displayed high levels of structural defense by leaf toughness and leaf thickness. Fluctuation in food consumption by larva on body weight gain was also observed.

The cluster analysis revealed that, the cultivars categorized under cluster B and sub-branched A1 might be due to their physiological and biochemical characteristics whereas B157 was categorized under sub-branch A2. The nutritional indices of larvae of *H. talaca* reared on the selected cultivars, characteristics of biochemical components and morphology of all the tested cultivars revealed that cultivars of cluster B was highly preferable than the cultivars of sub-branched A1 sub-branched and A2.

5.7.1 Biology of *S. collaris* on *H. talaca* and *C. cephalonica*: Conservation, augmentation and the utilization of reduviid predators in biological control programme to check insect pests have gained momentum in the recent years (Schaefer and Panizzi, 2000). After 9-11 days of mating, *S. collaris* started to lay the first clutch of eggs. When fed on larvae of *H. talaca*, a healthy female of *S. collaris* laid a maximum 4-6 clutches, each containing about 60-68eggs. Whereas, 3-5 clutches each with about 55- 63eggs were laid when reared on larvae of *C. cephalonica*. The incubation period was 13.6±1.1days when reared on larvae of *C. Cephalonica*. The duration was 11.8±2.3 days when reared on larvae of *H. talaca*. Total nymphal period starting from I to V instars of *S. Collaris* was 58.4±3.9 days when reared on *C. cephalonica* and 64.8±4.1 days when reared on *H. talaca*. Somewhat similar

observations were also reported by Rajan *et al.*, (2017) when the pest was reared on *C. Cephalonica* and *Spodoptera litura* respectively. Ovipositional period of *S. Collaris* was 42.0±2.9 days when reared on *H. talaca*. But it was 39.6±2.3 days when reared on *C. cephalonica*. However, longevity of male and female *S. collaris* was not significantly different when reared on the two hosts. Present observation is in parity with the observation of Rajan *et al.,* (2017). Further experiment by Vennison and Ambrose (1990) had conformity with the present study. Like other harpactorines, longevity of females is longer than males. Such strategy promotes multiple mating with males of different age groups to facilitate comparatively higher fecundity (Ambrose *et al*., 2000). Nitin *et al.*, (2017) reported that, the duration of I and V instar nymphs of closely related species of *Sycanusgal banus* were 9.24±0.18 and 16.04±0.19 days respectively when reared on larvae of *Galleria mellonella.*

Fecundity of *S. Collaris* when reared on *C. cephalonica* and *H. talaca* was 282±23.9 eggs/female and 320.4±44.2 eggs/female respectively, in the present investigation. Such finding is in well agreement to the fecundity of other reduviid bugs (Rajan *et al.,* 2017 and Sahid *et al.,* 2018). Rice meal moth *C. Cephalonica* has been further recommended as an alternative host for mass multiplication of predatory reduviid bug under laboratory conditions (George, 2000 and Rajan *et al.,* 2017).

5.7.2 Predatory efficiency of *S. collaris* on larvae of *H. talaca*: The effective utilization of predator in biological control agent requires comprehensive knowledge on their predatory efficiency. The Reduviidae represents the largest family of predaceous Hemiptera enlisting potential predators of economically important lepidopteran pest (Ambrose, 1999 and Srikumar *et al*., 2017). Rajan *et al.,* (2017) reported that the feeding efficiency of *S. collaris* increased gradually with the advancement of life stages. In the present study of 'no-choice' condition of feeding, the first instar nymph of *S. collaris* fed on an average 2.2±0.8 second instar larvae of *H. talaca* per day. The rate of predation gradually increase with the advancement of instars. Adult females preferred fourth and fifth instar larvae of *H. talaca* and consumed voraciously a maximum of 11.8±2.5 and 10.2±1.9 larval individuals per day respectively. Srikumar *et al*., (2017) reported that the maximum predation by adult *S. collaris* on *Spodoptera litura* was 3.77 per day. Whereas in 'free-choice' feeding condition, the first and second instar nymph of *S. Collaris* preferred second and third instar larvae of *H. talaca*. The third instar nymph consumed

2.0±0.7 larvae of *H. talaca* per day while fourth and fifth instar nymph consumed 3.6±0.5 and 4.0±1.2 larvae per day. Such result was found to less when compared to 'no-choice' condition. Vennison and Ambrose (1992) reported that adults of *Sycanus reclinatus* consumed 2-4 fully mature *Heliothis armigera* larvae per day. Such observation is in parity to the present results of 'free choice' condition of feeding. This predatory bug was naturally found to fed on several species of economically important insect pests especially the lepidopteran larvae in several agro-ecosystem (Grundy and Mealzer, 2000; Sahayaraj, 2000).

5.7.3 Predatory behaviour of *S. collaris* fed on larvae of *H. talaca*: The present study emphasised the predatory voracious behaviour of entomophagous, crepuscular assassin bug *S. collaris*. When reduviid bugs percept a moving prey, a series of successive stages of predator-prey interactions occurs that leads to the engorging of the prey (Evangelin *et al*., 2014). Movement of *H. talaca*, visually stimulates predator. The predator responds by the unusual posture involving tibial juxtaposition that is followed by the erection of posture leading finally to the extension of antennae and rostrum towards the prey larvae. Present observation is similar to the study by Haridas and Ananthakrishnan, (1980). They had studied the predatory behaviour of reduviid predators *viz*., *Rhodniusprolixus, Rhynocoris sp. and Platymeris* sp. respectively. Venniso and Ambrose (1992) also noted somewhat same sequential predatory behaviour of *Sycanus reclinatus*, while preying on *Heliothis armigera***,** *Earia sinsulana* and S*litura* respectively. The antennal receptors of predator perceive the prey's kairomones and allomones (Hagan, 1987 and Rani and Wakamura, 1993). Such perception triggers the approach and immediately captures the prey by using the sensory hairs on the forelegs (Edwards, 1962; Ables, 1978 and Putchkova, 1979). In excited condition the predators pin the roustrum and injecte the venom to paralyze the prey larvae. The predators then ingest liquefied food by inserting the rostrum into the body of the prey and slowly emit a steady flow of venomous saliva which liquefies the body sap of the prey (Edwards, 1960; Haridas and Ananthakrishnan 1980; Sahayaraj, 1994 and Jacobson 1911). In the present investigation different developmental stages of *S. collaris* were noticed during feeding on different life stages of host larvae. Similar trends were recorded by Rajan *et al.,* (2017) during feeding of *S. collaris* on larvae of rice meal moth, *C. cephalonica* and *S. litura*. Depending on the prey size and its movement the sequential responses like time of approach attack and duration required to paralyze the prey varied (Edwards, 1962 and Ambrose, 1999). Adult male and female took 124.0±3.6, 123.0±4.6, 120.0±4.4, 119.3±8.0 and 118.3±3.1 seconds

respectively when predating on III, IV, V instar nymphs. Rajan *et al.,* (2017) reported that all of the life stages took more time to feed on larvae of *S. litura*. This study on predatory behaviour of *S. collaris* highlighted the potential role of *H. talaca* as an efficient biological control agent in tea ecosystem.

5.7.4 Survival and life table of *S. collaris* reared on larvae of *H. talaca*: In the present study, abnormal hatching and moulting caused 4-8% nymphal mortality from I to V instars. Nymphal instars had a mean survival rate of 94.14%. Nitin *et al.,* (2017) reported about 12.37% nymphal mortality of *S. galbanus* during the development period. About 96.7% nymphs of *S. collaris* emerged from eggs when reared on larvae of *H. talaca*. Rajan *et al.,* (2017) reported that, 92.11 % survival of immature stages of *S. collaris* were noted when the parasitoid feed on armyworm larvae. Better survival was also observed in other reduviids namely *S. Dichotomus* when reared on the larvae of *S. litura* and *C. cephalonica* respectively (Zulkefli *et al.,* 2004) and *R. marginatus* (Niger) on cotton leaf worm *S. litura* (George, 1999).

The net reproductive rate was measured in terms of female produced per generation. Net reproductive rate was considered as an indicator of population growth (Richard 1961 and Morris & Fulton 1970). Such property indicates the physiological capability of an organism to its reproductive capacity. The net reproductive rate (Ro) of *S. collaris* was 252.78 when reared on larvae of *H. talaca.* Such value was lesser than the gross reproductive rate (GRR) which was 278.98. Both of the values in *S. collaris* are higher than that of other reduviid species. Venkatesan *et al*., (1997) had reported that in *Cydnocoris gilvus* (Burm) the value was 31.90. George *et al*., (1998b) had noted that, due to a sharp decline in the survivorship value of the parent females, (Ro) was less than GRR, during rearing on the *Spodoptera litura*. In the present study the mean length of generation (Tc) was 96.51days, whereas corrected generation time (T) was 89.23 days. The result of the present study is in the agreement with Shahayaraj and Sathiamoorthi (2002), who studied the life table of *Rhynocorism arginatus*on larvae of *C. cephalonica*. In our study innate capacity of natural increase (rm) of *S. collaris* was 0.062, with a finite rate of increase (λ) of 1.06, the population was able to multiply 1.54 times per week on larvae of *H. talaca.* Present findings are in the line with the observation of George *et al*., (1998a) who had noted that rm was 0.043 days, 'λ' value was 1.07. The weekly multiplication value was 1.59 days. The innate capacity of natural increase (rc) was 0.192 females/female/d, with a gross reproduction (mx) of 145.2 females/female and mean length of generation (Tc) was 88.5 d of *S. collaris* (Srikumar *et al*., 2017).

5.7.5 Mass rearing of *S. collaris* on *C. cephalonica*: The fecundity of *S. collaris* was 283±23.9 when reared on alternative host larvae of *C. cephalonica*. The egg hatchability rate of *S. collaris* was 95.24±1.0% when reared on alternative host. All of the nymphal instars fed on rice meal moth larvae could fulfil daily nutritional requirements for the development. High survival rate(%) of this predatory bug was observed as 95.52±0.8, 91.81±0.7, 94.67±2.0, 94.72±1.9, 93.94±0.8 on the developmental stages of I, II, III, IV and V instar nymphs respectively. Rajan *et al.,* (2017) reported that, nymphal stages of *S. collaris* attained 92.11 % survival value when fed on leaf armyworm *S. litura* larvae. Such enhanced survival rate was also recorded by Zulkefli *et al.,* (2004) on reduviid bug, *S. dichotomus* when reared on larvae of *S. litura.* George (2000) reported somewhat similar event for the larvae of *C. cephalonica*. Adult male and female longevity of this predatory bug were also observed as similar to rearing on its natural host. Zulkefli *et al.,* (2004) and Rajan *et al.,* (2017) had concluded that *S. collaris* easily handled the natural prey, *S. litura* than the laboratory prey, *C. cephalonica*. But from the present study the conjecture is coming out that, *S. collaris* could be possible to rear on the larvae of *C. cephalonica* under laboratory conditions.

5.7.6 Effect of pesticide on *S. collaris*: In the present study, when exposed of Quinalphos and Thiomethoxam 100% mortality in both the immature and mature stages of *S. collaris* after 24h was noted. In parity to the present observation, Torres *et al*., (2003) reported high mortality of Hemipteran bug nymphs when reared on thiamethoxam-treated cotton plant. Kaushik *et al*., (2016) reported that Quinalphos 25 EC caused highly toxic to coccinellids resulting lowest population in comparison to control. De-Clercq *et al*., (1995) and De-Cock *et al*., (1996) reported that insect predators may get exposed to pesticides either by direct contact to spray applications or by indirect contact by fresh or dry residues from sprayed surfaces. Ingestion of contaminated preys or by consuming contaminated water also caused residual toxicity to natural enemies. Effective toxic impact was also seen when the *S. collaris* was treated with Bifenthrin followed by Flubendiamide, Deltamethrin, Emamectin Benzoate, Fenpyroximate, *Beauveria bassiana* formulation and Azadirachtin on both the nymph and adult stages of *S. collaris*. Zulkefli *et al.,* (2004) had commented that regular use of systemic pesticides may suppress the *Sycanus* population in oil palm field if 'poisoned' caterpillars are consumed. In field conditions, additional factors like, weather conditions and calibration of spraying equipment, etc. might be considered during calculating the mortality at field condition in comparison to laboratory condition.

5.7.7 Field release of *S. collaris*: The initial population and subsequent trend of population of tea looper *H. talaca* after the release of adult *S. collaris* in both the control and the experimental plot were assessed. The pest population was found to decrease after 13th day of release compared to the control plot at both Hope TE and Kurti TE. The most desirable characters of *S. collaris* are its predatory behaviour. Such behaviour could effectively prevent the multiplication of *H. talaca* under field conditions. The present study is similar with the findings of (Sahayaraj and Martin, 2003) who had released the predatory bug *Rhynocorism arginatus* in groundnut field which effectively reduced the lepidopteran pest population of *S. litura, H. armigera, Atractomorpha crenulata, Chrotogonoustra chypterus, Aphis craccivora, Mylabrispus tulata* and *Mylabris indica*. From the experiment it could be assumed that reduviid predator can be used as bio-control agent in the groundnut ecosystem under Integrated Pest Management (IPM) programme. Such findings also give base line information on the effective utilization of reduviid predator in biocontrol programme. Present study also emphasis on the possibility of mass rearing and subsequent field release of *S. collaris* in order to develop the biological control strategy of *H. talaca*.

5.8.1 Biology of *E. furcellata* on *H. talaca* and *C. cephalonica*: All of the parameters of *E. furcellata* and *C. cephalonica* life cycle were mostly same except the rate of fecundity. Such variation was probably due to the high feeding rate of *C. cephalonica*. Grossly, the present observation is in consonance to the study of (Lenin and Rajan, (2016) who also had noted mostly similar phenomenon when the pest was reared on *C. Cephalonica*. Kumar *et al*., (2001) used the larvae of *Spilaricta oblique* while Siddaiah and Devi (2015) had adopted vapourer tussock moth and tasar silkworm for the rearing of this pest. The total duration for the development of *E. furcellata* from incubation period to V instar nymph were 28.8 and 26.0 days respectively when reared on *H. talaca* and *C. cephalonica*. Such finding was also in parity with the observation of Ganguli *et al*., (2000); Ray & Khan, (2011) and Bhatnagar *et al*., (2019). As observed in the present study that I instar nymphs emerged from the dorsal surface of eggs after removing the upper lid, reddish with black in colour which later turned slowly into bluish and red. Ray & Khan (2011) and Siddaiah & Devi (2015) had also reported the same phenomenon. Nymphs were gregarious and found to stay together in undisturbed condition. The longevity of male and female of this stink bug was respectively 27.6± 1.1 and 30.8±1.9 days while reared on larvae of *H. talaca*. Such observation is supported by Siddaiah and Devi, (2015).

In conformity to the observation of Tuan *et al*., (2015), the duration to complete the life cycle of the pest, in the present study, is comparatively higher with 32.8±0.8 days while feeding on *C. Cephalonica.* The fecundity was also observed more when *E. furcellata* fed on larvae of *C. cephalonica* compared to *H. talaca*. This study suggests that mass culture of *E. furcellata* on the alternative host *C. Cephalonica* can be adopted for IPM programme.

5.8.2 Predatory efficiency of *E. furcellata* on larvae of *H. talaca*: Predatory role of bio-control agent could be assessed by prey consumption capacity. There is no published information on the predatory potential of *E. furcellata* on larvae of *H talaca* in tea. The predatory efficiency of this stink bug has gradually increased with the development of the life stages (Nyunt, 2008). First instar nymphs feed on II and III instar larvae of *H. talaca* in a group and did not prefer larger prey size. Smaller body size and slow motile second instar larva of *H. talaca* is more suitable as prey. Such observation has conformity with the findings of Lenin and Rajan (2016). Preference to comparatively larger prey size was noted from third instar larva. Side by side rate of individual predation was also enhanced. Such observation has similarity with the finding of Tuan *et al*., (2015). Yasuda, (2000) had reported that *E. furcellata* locate prey by sensing the chemical signals of the prey. Nyunt (2008) had conducted similar experiment on the predatory efficacy of *E. furcellata* on American bollworm feeding on four different host plants namely cabbage, cotton, chickpea and tomato plants. In both 'free-choice' as well as 'no-choice' test conditions maximum prey consumption was noted for V instar nymphal instars. Nnymphs of *E. furcellata* started feeding by injecting the rostrum and sucking of the larval haemolymph. The larvae finally skeletonized due to such continuous sucking. Kalaiyarasi *et al*., (2017) had reported similar incidence when observing the feeding of *E. furcellata* on the eggs and grubs of *Henosepilachna vigintioctopunctata*. In both 'free-choice' and 'no-choice' experiment the rate of prey consumption by *E. furcellata* depended on the life stages of the prey. Lesser the prey size higher will be the consumption rate. Kumar *et al*., (2001), in consonance to the present observation, had reported that consumption of *Spilaricta oblique* on *E. furcellata* in mulberry plantation depend on the prey size. In the current observation of free-choice condition the consumption by immature stages of II, III, IV and V instar of *E. furcellata* on II instar larvae of *H. talaca* were 1.8±0.4, 2.6±0.5, 4.0±1.0, 5.0±0.7 and 5.6±1.1 respectively. In contrary to the present study Nyunt (2008) had reported that the consumption of diamondback moth larvae by the II, III, IV and V instar

nymphs of *E. furcellata* was 4.1, 4.3, 6.0, and 8.5 larvae/day respectively when the prey density was 10 larvae. In 'no-choice' condition of feeding an adult female could consume 10.2±0.8, 9.0±1.0, 7.4±1.8 and 7.0±1.6 number of II, III, IV and V instar larvae of *H. talaca* per day respectively. Similar trends of feeding were observed by Kumar *et al*.**,** (2001) on the prey of *S. oblique*. Such feeding fulfil the daily nutritional to sustain the physiological homeostasis. The predator could consume more number of II and III *H. talaca* larvae and it is promising that *E. furcellata* prevent the pest outbreak and yield loss.

5.8.3 Predatory behaviour of *E. furcellata* on different stages of *H. talaca*:

E. furcellata get active in the presence of moving *H. talaca* larva. After getting the visual stimuli from moving prey, the stink bug raises its body from the leaf surface and holds its antennae with continuous movement and move towards the prey (Kumar *et al*.**,** 2001). Prior to capturing of the prey, the stink bug firstly approach to the prey slowly. It touches the prey, ascertains prey quality, and swiftly unfolds the rostrum from the resting position to a suitable angle (Kumar *et al*.**,** 2001 and Singh *et al*., 2019a). Then quickly pin its rostrum into the body of the prey and inject the venom affecting the central nervous system. In the present experiment, the life stages of *E. furcellata* I, II, III, IV, V instars nymph, adult male and female took 17.7±2.5, 16.7±0.6, 15.3±2.1, 13.7±1.5, 11.7±1.5, 9.7±1.5 and 8.0±2.0 seconds respectively in approach attacking towards second instar larvae of *H. talaca*. Kalaiyarasi *et al*., (2017) had noted that *E. furcellata* directly approached towards *H. armigera* larvae sustaining on cotton plants. Yasuda (1997 and 2000) had commented that, feeding by larvae on leaf chlorophyllus tissue elicits the release of (E)- phytol which intern helps *E. furcellata* to locate the prey larva. He argued that chlorophyll-rich diet is comparatively more preferable by *E. furcellata* rather chlorophyll-poor diet. In the current investigation the I, II, III, IV, V instar nymph, adult male and female of stink bug injected its venom and paralyzed the looper within 9.7±1.5, 8.7±1.5, 8.0±1.0, 7.7±1.5, 7.0±1.0, 5.0±1.0 and 4.7±0.6 seconds respectively. Singh *et al*., (2019b) noticed that *E. forcellata* takes some time to paralyze silkworm larva. The predator then inserts the proboscis on the ventral side of the silkworm repeatedly to suck haemolymph. A female stink bug took about 95.3±5.0 seconds to suck haemplymph from fifth instar looper. Singh *et al*., (2019b), on the other hand, had commented that after piercing the feeding process continues for up to 15-20 minutes. However, such time was more than the present observations.

5.8.4 Survival and life table of *E. fuecellata* reared on larvae of *H. talaca*: Information on the survival and life table of *E. fuecellata* on tea pests is scanty. In the present investigation, the egg hatchability of *E. furcellata* when reared on *H. talaca* larvae was about 95.35%. Lenin and Rajan (2016) had noted 90% egg hatchability of *E. furcellata* when reared on *C. cephalonica*. Survival rates of the nymphal stages of I, II, III, IV and V instars of this pentatomid bug was 95.35, 91.84, 92.83, 94.51 and 93.25% respectively. Whereas Nielsen *et al*., (2008) reported about 61% survival rate of closely related pentatomid bug *Halyomorpha halys* at 25^0C. The survival rate of *E. fuecellata,* in the present study, was high as *H. talaca*, was suitable food supplementing nutritional requirements. The highest nymphal mortality was observed in II instar compared to another life stages.

In the life table study of *E. furcellata* the mean generation time (Tc) was 35.49 days and corrected generation time (T) was 35.9 4days. While the finite rate of increase (λ) was1.61. The net reproductive rate (Ro) was 218.14 and the 'rm' value was 0.149. Present finding is in the agreement with the study of Tuan *et al*., (2015) who had noted that in stink bug, *Plutella xylostella*, the 'rm' is 0.138, 'λ' is 1.149 and 'Ro' is 292.4 and 'Tc' is 40.9. But all the values were found to less while rearing on the larvae of *S. litura*. Nielsen *et al*., (2008) had reported that in polyphagous stink bug *Halyomorpha halys* 'rm' is 0.07, 'Ro' is 60.02 and 'Tc' is 56.59 when reared on green bean (*Phaseolus vulgaris*), spanish peanut (*Arachis hypogaea*) and corn (*Zea mays*) . The intrinsic rate of natural increase (rm) as a key demographic parameter can be utilized to plot population growth at variable environmental conditions (Andrewartha and Birch, 1954 and Southwood and Henderson, 2000). Population growth rate of a predator is either equal or greater than its prey may have the have the potentiality to regulate the prey population (Sabelis, 1992). Potential bio-control agent with definite 'rm' value and reproductive potential can be utilized for pest-natural enemy interactions (Jervis & Copland, 1996 and Dent, 1997). However, other factors like predation potential, early detection ability and longevity may also equally contribute to the interaction between the predators and its prey (Roy *et al*., 2003). Therefore *E. furcellata* with its predatory potential and behaviour could have the ability to regulate the population of *H. talaca* in tea field.

5.9.1 Effect of parasitism on food consumption and growth of *H. talaca*: Bae and Kim (2004) had elaborated the impact of parasitism of the braconid wasp on different host larvae. In the present study, the food consumption and body weight gain of the parasitized larvae of *H. talaca* were found drastically affected in comparison to the healthy larvae. The parasitic wasp *C. ruficrus* is gregarious in habit. The female parasitic wasp laid eggs inside the growing host larvae of *H. talaca* and makes a complex association for their survival within the host haemocoel. Newly hatched parasitic larvae consume the host haemolymph for their nutrition and development which in turn put stress the food consumption rate of the host larvae. Such phenomenon consequences alteration of the body weight, growth and developmental period. These observations were in agreement with Chen *et al*., (2016) who also had studied on the parasitoid host interaction between *C. ruficrus* and *Cnaphalocrocis medinalis.* The braconid parasitism hampers the normal food consumption, growth and metamorphosis of different lepidopteran host larvae. Thompson (1982) showed the extent of host-parasitoid interaction between *Trichoplusiani* and *Hyposoter exiguae* and its consequences. Mahmoud *et al*., (2012), on the other hand, reported the parasitism of *C. flavipes* on two Crambids, *Diatraeas accharalis* and *Eoreuma loftini* with an inference on the result of parasitism on the host larva. Beckage and Templeton (1986) examined physiological changes of the host *Manduca sexta* due to parasitism by *Apanteles congregates*. Ullah *et al*., (2016) had noted a significant decrease in food consumption of different larval instar of *Pieris brassicae* after parasitized by *C. glomerata*. Shi *et al*., (2015) reported that *C. vestalis* injects neuropeptide like substances into host larvae during oviposition and resultantly suppress the immunity of host larvae. The parasitic wasp injects polydnavirus into the host larva during oviposition that regulate immune system and side by side enable the parasitic larval development on the host (Strand and Burke 2014 and Tana *et al*., 2018).

5.9.2 Differential haemocyte count (DHC) and morphology of different haemocytes: Parasitism of *C. flavipes* has led to the significant reduction of haemocytes of the host larva which play an important role in the regulation of insect physiology like cell mediated phagocytosis and encapsulation together with the transport of nutrients (Duodu and Antoh, 1984). In the present study the number of different haemocytes *viz.* GRs, ADs, OEs and PLs were significantly reduced in parasitized larvae in contrast to the healthy ones. But the number of PRs was increased and other haemocytes were decreased in parasitized larvae. In un-parasitized larvae the GRs and PLs were representing as the immuno-defensive cells. Ibrahim and Kim (2006) reported that the reduction of GR and PL number in the haemolymph of *Plutella xylostella* after the parasitization by *C. plutellae* significantly

suppressed the rate of phagocytosis response and haemocyte encapsulation. Sanap *et al*., (2016) had noted that there was a variation in the PR and GR haemocytes in *Helicoverpa armigera* larvae due to parasitization by *Chelonus blackburni* than the normal once. Reduction of haemocytes in parasitized host body, some anomalies in the function of immune system, development, metamorphosis, transportation of nutrition through the circulatory system has been found (Beckage and Kanost, 1993). In parasitized larvae, the morphological changes were observed and recorded in all five types of haemocytes. These morphologically abnormal haemocytes were not able to transport the essential nutrition through the circulatory system to the required organ and as a result the immune suppression has occurred. Tanaka (1987) observed that, the layer of the haemocyte became thinner in host larvae of *Pseudaletia separate* which was parasitized by the wasps *Microplitis mediator* and *Apanteles kariyai* and as a result the suppression of encapsulation capacity of foreign materials occured.

5.9.3 Effect of pesticide on *C. ruficrus*: IPM is an eco-friendly pest management approach that relies on a combination of chemical, physical and biological control methods. The conservation and use of insect parasitoid are important for the development of a successful IPM. Such module also incorporates the choice for pesticide and proper time of application (Smith, 1996). After 24h of the exposure, highest toxic effect on adult *C. ruficrus* was impacted by Quinalphos and Thiamethoxam with 88.7±8.8 and 86.7±3.3% mortality. Toxicity of Thiamethoxam on larval parasitoid, *Braconb revicornis* was also observed by Shankarganesh *et al*., (2017). Samanta *et al*., (2007) and Thanavendan *et al*., (2017) had reported that Quinalphos has moderate toxic effect on *B. brevicornis* and *C. blackburni* respectively. Bifenthrin caused 53.3±3.3% mortality of *C. ruficrus.* The extent of toxicity of the pesticides chronologically was Deltamethrin > Emamectin benzoate > Flubendiamade > Fenpyroxymate. Shankarganesh *et al*., (2017) had reported that Bifenthin had moderately toxic effect on *B. brevicornis*. Deltamethrin has harmful effect for adults and pupae of *Trichogramma* (Hassan, 1998). Similarly, Blibech *et al*., (2015) reported that exposure to Deltamethrin resulted in the decrease of parasitism by Trichogramma. Further harmful effect of Deltamethrin was noted on the pupae of *T. oleae* and *T. cacoeciae*, the potential parasitoids.

After 72h of spray, *Beauveria bassiana* formulation caused 10.0±0.0% mortality. Toxic effect of *B. bassiana* was also noted by Medina *et al*., (2008). Efficacy of braconid parasitoid *Psyttalia concolor* was slowed down by pesticide application. Thanavendan *et*

al., (2017) had observed that NSKE 5% (Neem Seed Karnel Extract) formulation had at all no effect against *B. brevicornis* and *C. blackburni*.

5.9.4 Biological parameters of *C. ruficrus* reared on *H. talaca* larvae under laboratory conditions: Extensive work has been done on the biological parameters of parasitoids of genus *Cotesia* and the lepidopteran hosts (Hill, 1986; Robert *et al*., 1992; Chen *et al*., 2016; Patil *et al*., 2016 and Kaiser *et al*., 2017). In the present study, longevity of *C. ruficrus* on the host larvae of *H. talaca* was recorded as 19.2-23.8 days, which is almost similar with the study of Omwega & Overholt, (1997) and Khan *et al*., (2017). They had noted the biology of *C. flavipes* and *C. sesamiae* reared on different host larvae of *Chilopartellus* sp. and gramineous stem borer respectively under laboratory conditions. Kaiser *et al*., (2017) reported that the mean longevity of *C. typhae w*as about 3 days when fed with honey at 25°C and 60% RH. Sallam *et al.,* (2002) also observed the similar condition of *C. sesamiae*. But Potting *et al.,* (1997), on the other hand, showed that the longevity of *C. flavipes* was about 5-6 days, which supports the present study. Whereas, Muirhead *et al*., (2008) reported that, the average longevity of *C. Nonagriae* was about 12 days. In the present study *C. ruficrus* used to select and parasitize more on 4th instar host larvae, compared to early instars, which could be because of fact that the early instars were not capable of supporting the successful parasitism. From the present investigation, it was evident that more number of cocoons was formed in the IV instar host larvae. Similar observation was reported by Chen *et al*., (2016). The male and female longevity of *C. ruficrus* in the present observation were less than the report of Naganagoud and Kulkarni, (1998), however, female and male ratio was high in the present study. The average larval development of *C. ruficrus* was 4 to 5 days and it varied depending on the host growth stages and physiology. These observations are in well agreement with the findings of Omwega and Overholt, (1997). The mean duration of pupa of *C. ruficrus* in the II, III and IV instar host larvae of *H. talaca* were recorded as 5.8, 4.6 and 4 days respectively. Similar results were described by Khan *et al*., (2017), who recorded the pupal duration of *C. flavipes* on III and IV larval instar larvae of *Chilopartellus* as 6.46 and 5.06 days respectively. Kaiser *et al*., (2017) also reported the similar pulal developmental duration in *C. typhae* of France strain. The number of male and female hatched out from each host was dependent on the stage, body size and health of the host. Similar study was also described by Kaiser *et al*., (2017) on *C. typhae* of France and Italian strains.

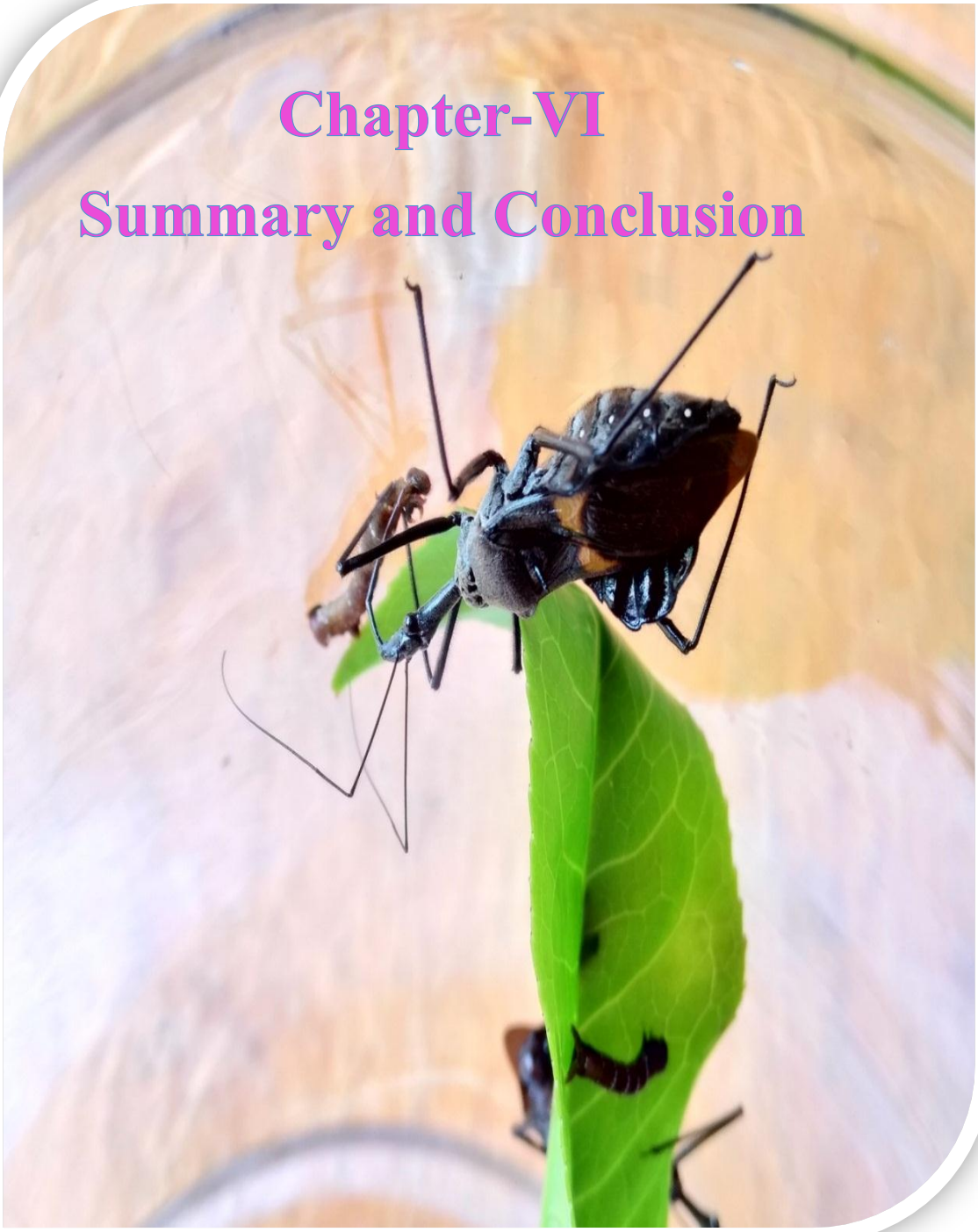
The successful parasitism by the parasitic wasp *C. ruficrus* on different stages of *H. talaca* larvae was assessed in the present study. Rahman and Bhola, (2011) reported

about 30-80% parasitism by *Apanteles taprobene* on the major tea looper *Buzura suppressaria*. Very few of the host pupated in such condition. Successful parasitism also depends on the host stage, size and immune system of the host. In our experiment, highest successful parasitism and low percentage of pupa mortality occurred in IV instar host followed by III and II instars respectively. Similar parasitic effect was observed earlier by Chen *et al*., (2016), in relation to the development time, clutch size, and survival of *C. ruficrus*.

5.9.5 Life table of *C. ruficrus* reared on larvae of *H. talaca*: Study on life table explains the survival and reproduction rate of the pests and parasitoids. Mean fitness of a pest population can further be accurately described (Southwood 1978). Life table of *C. ruficrus* on tea looper was worked out for the first time in the present study. The survival rate was 92.9±3.5% during cocoon formation. All newly emerged larvae from the host could survive 93.3±2.2%. Such observation in consonance with the study of Kaiser *et al*., 2017. The life table parameter like, intrinsic rate of natural increase (rm) was 0.203 day^{-1} and the net reproductive rate (Ro) was 41.11 female offspring per adult female in the present study. The gross reproductive rate ($\sum mx$) was 50.09 and the finite rate of increase (λ) was 1.23. The mean generation time was 19.13 while the doubling time was 3.57 days. Azad and Islam, (2016) constructed the life table of a braconid parasitoid, *Opius dissitus* (Musebeck), on leafminer, *Liriomyza sativae* and recorded that the 'rm' value was 0.255 and 'Ro'was 22.38. The mean generation time was 12.68 days while the 'λ' value was 1.29 . The present results are partly similar with such finding. Navea and Vargas (2012) reported that the intrinsic growth rate (rm) of *Aphytis iaspidis* was 0.09, Ro was 5.24, T was 16.87 and λ was1.10 respectively. However all of the parameters were comparatively less than the present observation regarding the rate of parasitization by *C. ruficrus*. Tripathi and Singh (1990) stated that in case of the faster growth rate of immature parasitoid in large hosts, the generation time 'T' decreases.Such decrease is inversely related to the intrinsic rate of increase 'rm' of the parasitoid population. Messenger, (1964) focused on the intrinsic rate of natural increase (rm) to use it as bioclimatic index for rating the parasites. *C. ruficrus* with a short larval and pupal period, life span, low mortality rate and comparatively higher survival index can effectively be utilized to parasitize *H. talaca* larva in tea ecosystem.

Chapter-VI

Summary and Conclusion



SUMMARY AND CONCLUSION

In the current study, carried out for two years at Banarhat TE and TRA experimental plot from February 2017 to January 2019. The survey was conducted on the population dynamics of the major tea looper *H. talaca* and its interaction with the ecological trophic levels of in tea ecosystem. In the similar way survey work was also conducted on the potential predators (*S. collaris* and *E. furcellata*) and parasitoid (*C. ruficrus*). These studies provide sequential information on the seasonal abundance, bio-ecology of pest and natural enemies and the impact of the abiotic factors like temperature (Maximum/Minimum), Rainfall and Relative Humidity were also worked out. A thorough information about the predatory efficiency, predatory behaviour of *S. collaris* and *E. furcellata* on the pest *H. talaca*. The current investigation also provides the evidence of the parasitic impact of *C. ruficrus* on *H. talaca*.

- Studies on the seasonal abundance and bio-ecology of *H. talaca* and its natural enemies (*S. collaris*, *E. furcellata* and *C. ruficrus*) revealed that the population dynamics of both the pest and natural enemies coincides with the recurrent oscillations. The abiotic factors like maximum and minimum temperature, rainfall and relative humidity were found to influence on the population dynamics. Both the pest and natural enemies were found foraging on alternate hosts available adjacent to tea ecosystem.

- Study on the biology and life table of *H. talaca* on tea leaf, artificial diet and shade tree leaf revealed that, a better survival fitness of *H. talaca* on artificial diet followed by tea leaf and shade tree leaf. The highest fecundity was observed when feeding on artificial diet.

- Results on the study of susceptibility of *H. talaca* on the selected tea cultivars (TV1, TV20, TV16, TV22, TV26, HP12, ST520, K1/1, SNT 8 and B157) revealed that, the highest food consumption and growth of *H. talaca* were observed when feeding on TV20 (Highly susceptible) and lowest food consumption and growth was recorded on B157 (Moderately Susceptible).

- The primary metabolites (Protein, carbohydrate, lipid and chlorophyll) of the leaves of selected tea cultivars (TV1, TV20, TV16, TV22, TV26, HP12, ST520, K1/1, SNT 8 and B157) were estimated and was found comparatively high in the

cultivars of TV20, TV1, K1/1 followed by other cultivars. Whereas the secondary metabolites (Phenol, flavonoid, alkaloid and carotenoid) were found in high quantity in B157 and HP12 compared to other tested cultivars.

- The study on biology and survival rate of the predators (*S. collaris* and *E. furcellata*) on *H. talaca* and *C. cephalonica* indicated no significant difference on the biological parameters of *S. collaris* and *E. furcellata*. However, the fecundity rate was more when reared on *H. talaca*. The high mortality rate was found for first instar nymphs. Whereas, *E. furcellata* showed high fecundity when feeding on larvae of *C. cephalonica*.

- The results of the life table study of *S. collaris* and *E. furcellata* revealed that, the intrinsic rate of natural increase "rm" as 0.062 day^{-1} and 0.149 day^{-1} while "Ro" was 252.78 and 218.14 female offspring per adult female respectively. The gross reproductive rate ($\sum mx$) was recorded as 278.98 and 244.69 while the finite rate of increase was 1.06 day^{-1} for both the predators.

- Predatory potential of both the predators (*S. collaris* and *E. furcellata*) in a free-choice and no- choice conditions showed that all the stages of the predators were voraciously feeding on the larvae of *H. talaca*. The feeding potential gradually increased with the advancement of life stages of predators. Adult female consumed more number of larvae per day compared to male. The feeding potential was found to be higher in no-choice conditions compared to free-choice condition.

- *S. collaris* and *E. furcellata* showed the predatory behaviour when offered a visual stimulus by providing different larval stages of *H. talaca*. Theses stimulus lead to arouse, erect posture and extension of antennae and rostrum of *S. collaris* and *E. furcellata* towards the prey.

- Field release experiment of *S. collaris* revealed that, the predators get established in the ecosystem which was evidenced from the reduction of pest population in the released plots compared to the control plot.

- *C. ruficrus* successfully completed its life cycle on the larvae of *H. talaca*. This parasitic wasp showed a selective preference towards IV instar larva as a suitable host for the parasitism compared to II and III instar larvae.

- Life table study showed that, the intrinsic rate of natural increase (rm) of *C. ruficrus* as 0.203 day^{-1} and the net reproductive rate (Ro) was 41.11 female offspring per adult female. The gross reproductive rate (∑mx) was 50.09 and the finite rate of increase (λ) was 1.23 day^{-1}.

- The parasitic impact of *C. ruficrus* has hampered the food consumption and growth of *H. talaca*. The haemocyte number and morphology of *H talaca* were also affected by the parasitic effect of *C. ruficrus*.

- Study on the evaluation of the impact of pesticides on the predators and parasitoid (*S. collaris*, *E. furcellata* and *C. ruficrus*) revealed that, the commonly used pesticides like Thiomethoxam and Quinalphos were highly toxic followed by Emamectin benzoate, >Deltamethrin > Bifenthrin > Flubendiamade> Fenpyroxymate> *Beauveria bassiana* > Azadirachtin.

Conclusions:

- From the present study, it is concluded that, *H. talaca* was found to successfully complete its life cycle on artificial diet. This indicates that, we can easily mass rear them under laboratory conditions for experimental purposes throughout the year. Among all the tested cultivars, B157 was found to be moderately susceptible to *H. talaca*, which specifies that, the attack of *H. talaca* on this cultivar would be less compared to other highly susceptible cultivars.

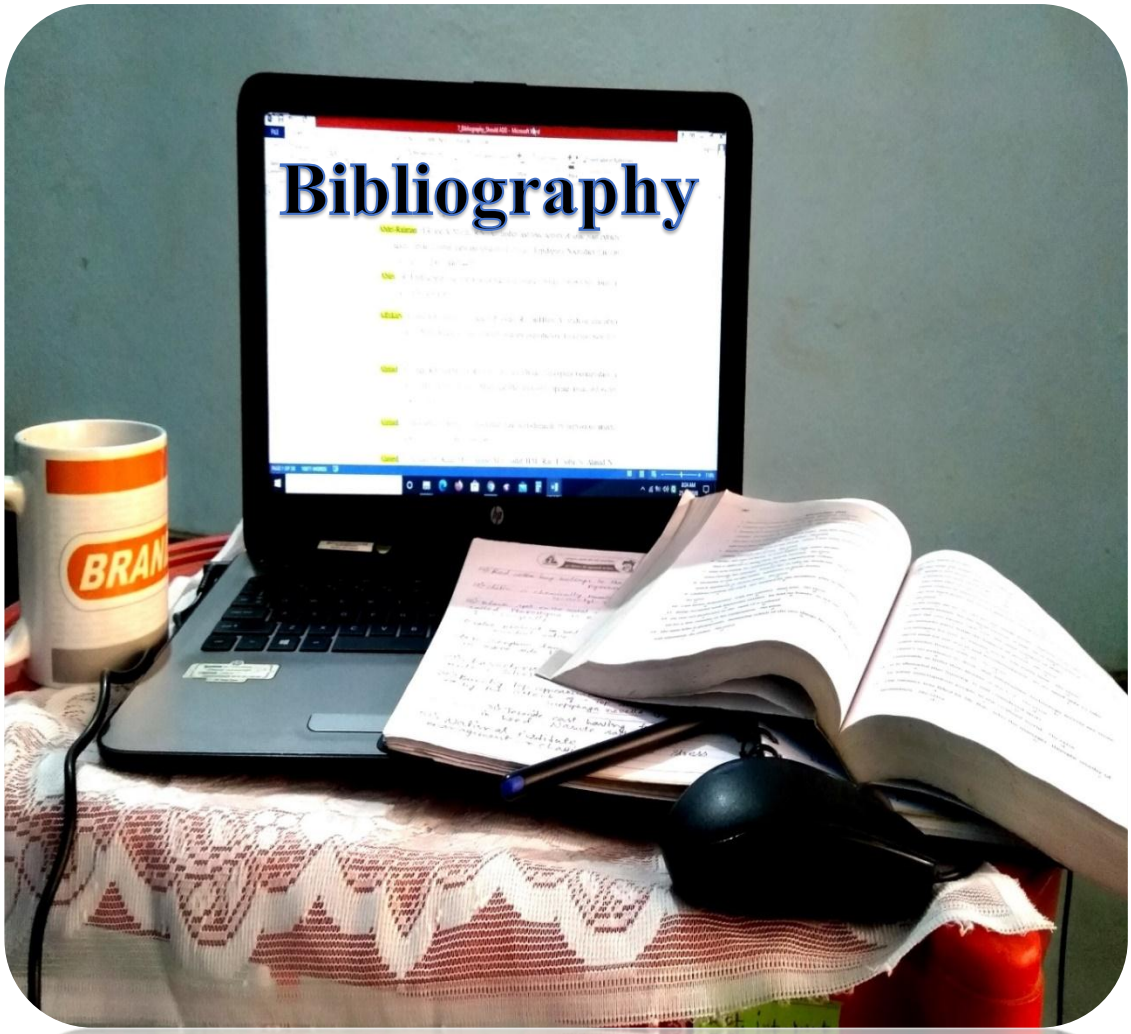
- Study on the life table parameters like, intrinsic rate of natural increase, gross reproductive rate (∑mx) and the finite rate of increase (λ) of the predators *(S. collaris* and *E. furcellata*) and parasitoid *(C. ruficrus*) indicated the ability of population build up and survival of these natural enemies, which will be helpful in developing biological control strategy for tea pests.

- The study on predatory behaviour and the potentiality under laboratory conditions specify that *S. collaris* and *E. furcellata* could be used as efficient biological control agents and can reduce the *H. talaca* population in tea ecosystem.

- The artificial rearing, field release experiments on *S. collaris* could lead to enhance the conservation, and serve as a biological control agent in tea ecosystem.

- The parasitic effect of *C. ruficrus* on the three different instars of the *H. talaca* larva has reconfirmed that, parasitism by *C. ruficrus* hamper the normal food consumption ability of the host larvae, besides retarding the growth and development of the growing host resulting in the mortality of larvae of *H. talaca*. The results on the differential haemocyte count and the morphology of the haemocyte of parasitized host larvae suggest that, successful parasitism of *C. ruficrus*, which played a vital role as a biological control agent. The aforementioned reports provide an effective suggestion to the tea industry for the eco-friendly management of *H. talaca*.

- Study on the effect pesticides on the natural enemies indicated that, Thiomethoxam and Quinalphos are very toxic to *S. collaris, E. furcellata* and *C. ruficrus*. So, the judicial use of safer pesticides may supportive to conserve the natural enemies in tea ecosystem.


Bibliography

BIBLIOGRAPHY

Abbasi, B.H., Ahmed, K., Khalique, F., Ayub, N., Liu, H.J., Kazmi, S.A.R. and Aftab, M.N., Rearing the cotton bollworm, *Helicoverpa armigera*, on a tapioca-based artificial diet, *J Insect Sci,* 7(35) (2007), 1-7.

Abdel-Rahman, H.R. and Al-Mozini, R.N., Antifeedant and toxic activity of some plant extracts against larvae of cotton leafworm *Spodoptera littoralis* (Lepidoptera: Noctuidae). *Pakistan J Biol Sci*, 10 (2007), 4467-4472.

Ables, J.R., Feeding behaviour of an assassin bug, *Zelus renardii*. *Annales Entomol Soci America*, 71(4) (1978), 476-478.

Adhikary, B., Sen, A.B., Ghosh, J.J., Tamuly, P., Gogoi, R.C. and Babu, A., Study on selected tea cultivars of North Bengal for their suitability in green tea production, *Anna Experiment Biol*, 6 (2) (2018), 32-37.

Ahmad, M., Singh, K.P. and Mishra, R., *Hyposidra talaca* Walk. (Lepidoptera: Geometridae) - a new pest of *Mallotus philippinensis* Muell. and *Murraya koenigii* Spreng, *Annals of Forestry* 112 (2003), 305-307.

Ahmad, S., Biochemical defense of prooxidant plant allelochemicals by herbivorous insects, *Biochem Syst Ecol*, 20 (1992), 269–296.

Ahmed, E., Arshad, M., Khan, M.Z., Amjad, M.S., Sadaf, H.M., Riaz, I., Sabir, S., Ahmad, N., Sabaoon, Secondary metabolites and their multidimensional prospective in plant life, *J Pharma Phytochem*, 6(2) (2017), 205-214

Akbay, P., Basaran, A.A., Undeger, U. and Basaran, N., In vitro immune modulatory activity of flavonoid glycosides from *Utricadioica* L, *Phytothera Res*, 17 (2003), 34-37

Al-Attar, A.M. and Zeid, I.A., Effect of Tea (*Camellia sinensis*) and Olive (Olea europaea L.) Leaves Extracts on Male Mice Exposed to Diazinon, *BioMed. Res Inte*, 2013, pp: 1-6.

Albersheim, P., Darvill, A.G., McNeil, M., Valent, B.S., Sharp, J.K., Nothnagel, E.A., "Oligo-saccharins: naturally occurring carbohydrates with biological regulatory functions,"in *Structure and Function of Plant Genomes,* eds O. Ciferriand L. Dure (New York, NY: Plenum Press), 1983, pp. 293–312.

Ambrose, D.P., Assassin Bugs. Oxford and IBH Publishing Company Private Limited, New Delhi, India and Science Publishers, Incorporation, Enfield, New Hampshire, U.S.A., 1999, pp. 337.

Ambrose, D.P., Claver, M.A. and Mariappan, P., Functional response of *Rhynocoris marginatus* (Heteroptera: Reduviidae) to two pests of pigeon pea (*Cajanus cajan*). *Indian J Agri Sci*, 70 (2000), 630- 632.

Ambrose, D.P., Rajan, S.J., Nagarajan K. and Krishnan. S.S., Biology, behaviour and functional response of Sphedanolestes variabilis Distant (Insecta: Hemiptera: Reduviidae: Harpactorinae), a potential predator of lepidopteran pests, *Entomol Croat,* 13(2009), 33–44.

Ananthakrishnan, T., Gallic and salicylic acids: Sentinels of plant defence against insects, *Cur Sci* 73(7) (1997), 576-579. Retrieved March 25, 2020.

Andrew, G. and Cuthbertson, S., Special Issue: Integrated Pest Management in Arable and Open Field Horticultural Crops, *Insects*, 11 (82) (2020), 1-2.

Andrewartha, H.G. and Birch, L.C., The distribution and abundance of animals. University of Chicago Press, Chicago, 1954.

Anonymous, 64thAnnual report 2017-2018. Tea Board of India, Kolkata, 2018a.

Anonymous, A note on the status of looper infestation in some of the sub-districts of Dooars in 2007. T.R.A. 2008, pp. 1-5.

Anonymous, Biochemistry of tea. *Collection of Elite Chinese Teas "Song He Crane and Pine" craneandpine.com*, (1996) http://en.craneandpine.ru/tea-biochemistry.

Anonymous, Plant Protection Code. Policy on usage of Plant Protection Formulations in Tea Plantations of India. Tea Board India. Ministry of Commerce and Industry, Govt. of India, Kolkata, West Bengal, India, 2018b.

Antony, B., Sinu, A.S. and Rehman, A., Looper Caterpillar Invasion in North East Indian Tea Agro-Ecosystem: Change of Weather and Habitat Loss May be Possible Causes? *J Tea Sci Res*, 2(1) (2012), 1-5.

Antony, B., Sinu, P.A. and Das, S., New record of nucleopolyhedroviruses in tea looper caterpillars in India, *J Inverte Pathol*, 108 (2011), 63–67.

Atwal, A.S. and Bains, S.S., Applied Animal Ecology. Kalyani Publishers, Ludhiana, (1974), Pp 128-135.

Ayyasamy, R. and Baskaran, P., Influence of certain leaf characters of brinjal accessions ith incidence of *Bemisia tabaci*, *The J Food Agri Environ*, 3(2005), 333–334.

Azad, S. and Islam, M.W., Life Table Parameters of *Opius dissitus* Musebeck (Braconidae), A Parasitoid of Leafminer, *Liriomyza sativae* Blanchard, *Advan Agri Sci*, *4*(04) (2016), 35-44.

Babu, A. Kumar, D.V., Rahman, V.K.J., Kumar, A.R. and Sundaravadivelan, C., Potential of *Mallada boninensis* Okamoto (Neuroptera: Chrysophidae), as a biocontrol agent of *Oligonychus coffeae* Nietner (Acarina: Tetranychidae) infesting tea, *J Plant Crops*, 39 (1) (2011), 193-195.

Babu, A., Barua, A., Deb, S., Gogoi, B., Rahman, A. and Sarmah, M., Growth inhibitory effect of Ponneem, a botanical pesticide against the looper *Ascotis selenaria* Hubner infesting tea in northeast India, *Two and a Bud*, 61(1&2) (2014), 68-71.

Babu, A., Deka, B. and Yadav, S.S., Laboratory production of NPV of looper (*H. talaca*) using a semi artificial diet. Tocklai news, 4 (2015a), 24.

Babu, A., Deka, B., Dhar, R., Dharmapandit, S. and Sarmah, M., Field bio efficacy of NKAE against red spider mites: A micro plot field trial. Tocklai news, 1: (2015b), pp. 24.

Babu, P.V. and Liu, D., Green tea catechins and cardiovascular health: An update, *Curr Med Chem*, 15 (2008), 1840–1850.

Bae, S. and Kim, Y., Host physiological changes due to parasitism of a braconid wasp, *Cotesia plutellae*, on diamondback moth, *Plutella xylostella*. *Compar Biochem Physiol*, *Part A*, *138* (2004), 39– 44.

Balentine, D.A., Wiseman, S.A. and Bouwens, L.C.M., The chemistry of tea flavonoids, *Critical Rev Food Sci Nutri*, 37(8) (1997), 693-704.

Banerjee, B., Arthropod accumulation on tea in young and old habitats, *Ecol. Entomol*, 18(2) (1983), 339-42.

Barman, T.S., Tea cultivars for North East India, *Sci Cul*, 77 (9–10) (2011), 391-395.

Barry, K.M., Newnham, G.J. and Stone, C., Estimation of chlorophyll content in *Eucalyptus globulus* foliage with the leaf reflectance model Prospect, *Agri Forest Meteorol*, 149 (2009), 1209-1213.

Barua, A., Babu, A. and Rajkhowa, R.C., Seasonal Abundance and Predatory Potential of *Stethorus aptus* Kapur (Coleoptera: Coccinellidae): A Biocontrol Agent of Tea Red Spider Mite *Oligonychus coffeae* Nietner (Acarina: Tetranychidae). *Preceed Zool Soci*.71 (3) (2016a), 224–228,

Barua, A., Studies on biocontrol potential of *Stethorus aptus* (Kapur) (Coleopeta: Coccinellidae) on red spider mite (RSM), *Oligonychus coffeae* (Neitner) (Acarina: Tetranychidae) infesting tea in Assam., India. Ph.D. Thesis, University of Gauhati, Assam, India, 2016b.

Barua, D. N., Science and practice in tea culture. Tea Research Association published, 1989, pp.3-27.

Basnet, K. and Mukhopadhyay, A., Biocontrol potential of the lynx spider*Oxyopes javanus* (Araneae: Oxyopidae) against the tea mosquito bug, *Helopeltis theivora* (Heteroptera: Miridae), *Inte J Tropi Insect Sci*, 34(4) (2014), 232–238.

Basu Majumdar, A. and Ghosh, P., *Hyposidra talaca* (Walker) a destructive pest of tea in Dooarstea plantations, *Two and a Bud*, 51 (2004), 49-51.

Basu Majumder, A., Bera, B. and Rajan, A., Tea statistics: Global scenario inc, *J Tea Sci*, 8 (2010), 121–124.

Basumajumdar, A. and Ghosh, P., *Hyposidra talaca* (Walker) a destructive pest of tea in Dooars tea plantations, *Two and a Bud*, 51 **(**2004), 49-51.

Basumajumder, A., Pathak, S.K. and Hath, T.K., Growth and survival of a geometrid defoliator *Hyposidra infixaria* Walker (Lepidoptera: Geometridae) on four clonal varieties of tea, *Acta entomol sinica*, 54(7) (2010), 815-819.

Beckage, N.E. and Kanost, M.R., Effects of Parasitism by the Braconid Wasp *Cotesia congregate* on Host Hemolymph Proteins of the Tobacco Hornworm, *Manduca sexta*, *Insect Biochem Molecul Biol, 23* (5) (1993), 643-653.

Beckage, N.E. and Templeton, T.J., Physiological effects of parasitism by *Apanteles congregates* in terminal-stage tobacco hornworm larvae, *J Insect Physiol,* 32 (1986), 299–314.

Berhow, M.A. and Vaughn, S.F., Higher plant flavonoids: biosynthesis and chemical ecology. In: Inderjit, Dakshini KMM, Foy CL (eds) Principles and practices in plant ecology. CRC Press, Boca Raton, 1999, pp 423–438.

Berndt, LA, Wratten, S.D. and Scarratt, S.L., The influence offloral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards, *Biol Control*, 37(1) (2006), 50–55.

Bhatnagar, V.R., Maurya, R.P., Brijwal, L., Dobhal, P., Suyal, P. and Singh, N.K., Study on variability among predatory stink bug, *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae) population thriving in different agro-ecosystems of north-western Himalayas, India, *J Entomol Zool Stud*, 7(3) (2019), 726-736.

Bhuyan, L.P., Tamuly, P. and Mahanta, P.K., Lipid Content and Fatty Acid Composition of Tea Shoot and Manufactured Tea, *J. Agric. Food Chem.*, 39 (1991), 1159-1162.

Bindu, S. P. and Pramanik, A., Effect of Leaf Characteristics on Different Brinjal Genotypes and their Correlation on Insects Pests Infestation, *Int. J. Curr. Microbiol. App. Sci*, 6(11) (2017), 3752-3757.

Bjorksten, A.T. and Robinson, M., Juvenile and sublethal effects of selected pesticides on the leafminer parasitoid *Hemiptarsenus varicornis* and *Diglyphus isaea* (Hymenoptera: Eulophidae) from Australia, *J Econ Entomol*, 98 (2005), 1831–1838

Blibech, I., Ksantini, M., Jardak, T. and Bouaziz, M., Effect of Insecticides on *Trichogramma* Parasitoids Used in Biological Control against *Prays oleae* Insect Pest, *Adv Chem Engine Sci*, 5 (2015), 362-372.

Bligh, E.G. and Dyer, W, J., A Rapid method of total lipid extraction and purification. Canadian, *J Biochem Physiol*, 37 (1959), 911-917.

Bokuchava, M. A. and Skoboleva, N. I., Advances in Food Research, Academic Press, New York, 1969, pp.17:215.

Bourgaud, F., Gravot, A., Milesi, S. and Gontier, E., Production of plant secondary metabolites: a historical perspective, *Plant Sci*, 161 (2001), 839-851.

Boyd, M.L. and Boethel, D.J., Susceptibility of predaceous hemipteran species to selected insecticides on soybean in Louisiana, *J. Econ. Entomol*. 91 (1998), 401–409.

Brich, L.C., The intrinsic rate of natural increase of an insect population, *J Ani Ecol*, 17 (1948), 15-26.

Brignolas, F., Lieutier, F., Sauvard, D., Christiansen, E. and Berryman, A.A., Phenolic predictors for Norway spruce resistance to the bark beetle *Ips typographus* (Coleoptera: Scolytidae) and an associated fungus, *Ceratocystis polonica*, *Can J For Res*. 28 (1998), 720– 728.

Browne, F.G., In: An annotated list of principal species occurring in the British Commonwealth. Clarendon Press, Oxford, 1968.

Burgess, E.P.J., Population dynamics of *Mythimna separata* and its parasitoid,*Cotesia ruficrus,* on maize in New Zealand, *New Zealand J Agri Res*, 30 (1987), 203-208.

Cabrera, C., Artacho, R. and Gimenez, R., Beneficial effects of green tea—A review, *J. Am. Coll. Nutr*., 25(2006), 79–99.

Campos, L.S., JR., A.C. and Parra, J.R.P., Artificial diet for laboratory rearing of *Condylorrhiza vestigialis* (Guenée, 1854) (Lep: Crambidae). *Anais da Academia Brasileira de Ciências*, 89(1) (2017), 333-340.

Cárdenas, A.M. and Gallardo, P., Relationship between insect damage and chlorophyll content in mediterranean oak species, *Appl Ecol Environ Res*, 14(4) (2016), 477-491.

Chakravarty, S., Agnihotri, M. and Jagdish, J., Seasonal abundance of predatory bugs, *Eocanthecona furcellata* (Wolff.) and *Rhynocoris fuscipes* (F.) and its olfactory responses towards plant and pest mediated semiochemical cues in Pigeonpea ecosystem, *Legume Res*, 40 (2) (2017), 351-357.

Chen, Y., Liu, X.G., Wang, J., Zhao, J., Lu, Z.X. and Liu, Y.H., *Cotesia ruficrus* (Hymenoptera: Braconidae) Parasitizing *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae): Developmental Interactions and Food Utilization Efficiency of Hosts. *Journal of Ecological Entomology*, *109*(2) (2016), 588–593.

Chin, F.S., Chong, K.P., Markus, A. and Wong, N.K., Tea Polyphenols and Alkaloids Content Using Soxhlet and Direct Extraction Methods. *World J Agri Sci*, 9 (3) (2013), 266-270.

Chutia, B.C., Rahaman, A., Sarmah, M., Borthakur, M. and Barthakur, B.K., Biology of *Hyposidra talaca* (Walker) - A major defoliating pest of tea in North East India, *Indian J Entomol*, 73 (2012a), 106–109.

Chutia, B.C., Rahman, A., Sarmah, M., Barthakur, B.K. and Borthakur, M., *Hyposidra talaea* (Walker): A major defoliating pest of tea in North East India, *Two and a Bud*, 59 (2012b), 17-20.

Claver, M.A. and Jaiswal, P., Distribution and Abundance of Two Predatory Stink Bugs (Pentatomidae: Hemiptera) Associated with Rice Field, *Academic J Entomol*, 6 (1) (2013), 33-36,

Cloyd, R.A., Timmons, N.R., Goebel, J.M. and Kemp, K.E., Effect of Pesticides on Adult Rove Beetle *Atheta coriaria* (Coleoptera: Staphylinidae) Survival in Growing Medium, *J. Econ. Entomol*, 102(5) (2009), 1750-1758.

Cranham, J.E., Tea pests and their control, *Annu. Rev. Entomol*, 11 (1996), 491–514.

Cui, J., Zhu, S., Bi, R., Xu, W., Gao, Y. and Shi, S., Effect of Temperature on the Development, Survival, and Fecundity of *Heliothis viriplaca* (Lepidoptera: Noctuidae), *J Econo Entomol*, 111(4) (2018), 1940–1946.

Danthanarayana, W. and Kathiravetpillai, A., Studies on the ecology and causes of outbreaks of *Ectropis bhurmitra* wkr. (geometridae), the twig caterpillar of tea in Ceylon, *J Appl Ecol*, 6 (1969) 311-322,

Danzinger, H.L., Diseases and Pests of Tea: Overview and Possibilities of Integrated Pest and Disease Management, *J Agri Tropics Subtrop*, 101(2000), 13-38.

Das S, Mukhopadhyay, A. and Roy, S., Morphological diversity, developmental traits and seasonal occurrence of looper pests (Lepidoptera: Geometridae) of tea crop, *J Biopesti*, 3 (2010) 16–19.

Das, G.M., Bionomics of the tea red spider, *Oligonychus coffeae* (Nietner), *Bull Entomol Res*, 50 (1959), 265–74.

Das, G.M., Pests of tea in North East India and their control. Memorandum No. 27, Tocklai Experimental Station, Tea Research Association, Jorhat, 1965, pp. 169–173.

Das, G.M., Pests of tea in North East India and their control. Memorandum No. 27, Tocklai ExperimentalStation, Jorhat, Assam, India, (1965), pp.115.

Das, S. and Mukhopadhyay, A., Host-based life cycle traits and detoxification enzymesof major looper pests (Lepidoptera: Geometridae) of tea from Darjeeling Terai, India, *Phytoparasitica*, 42 (2014), 275–283.

Das, S., Mukhopadhyay, A. and Roy, S., Morphological diversity, developmental traits and seasonal occurrence of looper pests (Lepidoptera: Geometridae) of tea crop, *J Biopesti*, 3(1 Special Issue) (2010a), 016 – 019.

Das, S., Roy, S. and Mukhopadhyay, A., Diversity of arthropod natural enemies in the tea plantations of North Bengal with emphasis on their association with tea pests, *Curr Sci*, 99 (10) (2010b), 1457-1463.

Das, S., Sarker, M. and Mukhopadhyay, A., Changing diversity of hymenopteran parasitoids from organically and conventionally managed tea-ecosystem of North Bengal, India, *J Environ Biol*, 26 (2005), 505–509.

Das, S.C., Choice of planting Material for tea cultivation. Field Management in Tea Tocklai Experimental Station. Tea Research Association, 2006, pp. 5.

De Cock, A., De Clercq, P., Tirry, L. and Degheele. D., Toxicity of diafenthiuron and imidacloprid to the predatory bug *Podisus maculiventris* (Heteroptera: Pentatomidae), *Environ. Entomol*. 25 (1996), 476-480.

De-Clercq, P., De-Cock, A., Tirry, L., Vinuela, E. and Degheele, D., Toxicity of diflubenzuron and pyriproxyfen to the predatory bug, *Podisus maculiventris*, *Entomol Exp Appl*, 74 (1995), 17–22.

DeClercq, P., Predaceous Stinkbugs (Pentatomidae: Asopinae). In C. W. Schaefer and A. R. Panizzi (eds.), Heteroptera of economic importance. CRC Press LLC, Boca Raton, FL, 2000, pp. 737–789.

Deevy, E.S., Life table for natural populations of animals, *The quart Revi biol*, 22 (1947), 283- 314.

Dent, D.R., Quantifying insect populations: estimates and parameters. In: D.R. Dent and M.P. Walton (eds), Methods in ecological and agricultural entomology. CAB International, Oxford. 1997, pp. 5–98.

Devi, K.D., Nishikanta, K. and Varatharajan, R., Diversity and density of tea pests in the tea gardens of Manipur, *J Plant Crops,* 44(1) (2016), 47-51.

Dun, G.S., Cacao flush defoliating caterpillars in Papua New Guinea, *Agri Journal*, 19, (1967), 67–71.

Duodu, Y.A. and Antoh, F.F., Effects of parasitism by *Apanteles sagax [Hym.: Braconidae]*on growth, food consumption and food utilizationin *Sylepta derogata* larvae [Lep. : Pyralidae], *Entomophaga*, 29 (1) (1984), 63-71.

Dutta, M., Morphological resistance of certain tea clones to red spider mite (*Oligonychus coffeae*) in tea, *J Entomol Zool Studies*, 3(4) (2015), 454-457.

Dutta, S., Dey, P. and Chaudhuri, T.K., Quantification and correlation of the bioactive phytochemicals of *Croton bonplandianum*leaves of Sub-Himalayan region of West Bengal, *Asian J Pharmaceu Clini Res*, 6(3) (2013), 142-147

Edwards, J.S., Observations on the development and predatory habits of two reduviid Heteroptera, *Rhynocoris Carmelita* Stal and *Platymeris rhadamanthus* Gerst, *Proceedings of the Royal Society of London, Series A, Gene Entomol*. 37 (7-9) (1962), 89-98.

Edwards, J.S., Spitting as a defensive mechanism in a predatory reduviid, *Proceed Inte Congr Entomol*, 11 ed. Vienna, (1960), pp. 259-263.

Ellers-Kirk, C. and Fleischer, S.J., Development and life table of *Acalymma vittatum* (Coloptera: Chrysomelidae), a vector of *Erwinia tracheiphila* in cucurbits, *Environ Entomol*, 35(4) (2006), 875–880.

El-Wakeil, N.E., Gaafar, N. and Vidal, S., Side effect of some Neem products on natural enemies of *Helicoverpa Trichogramma* spp. and *Chrysoperla carnea*, *Archiv Phytopathol& Plant Prot*, 39 (2006), 445-455.

Engelhardt, U.H., Chemistry of Tea. In: Reference Module in Chemistry, Molecular Sciences and Chemical Engineering, Elsevier, 2013, 1–29.

Espagne, E., Douris, V., Lalmanach, G., Provost, B., Cattolico, L., Lesobre, J., Kurata, S., Iatrou, K.,Drezen, J.M. and Huguet, E., A Virus Essential for Insect Host-Parasite Interactions Encodes Cystatins, *J Virol*, 79(15) (2005), 9765–9776.

Evangelin, G., Horne, B., Muthupandi, M. and William, S.J., Feeding Behaviour of the Predatory Reduviid, *Rhynocoris kumarii* (Hemiptera: Reduviidae), *Inte J Life Sci*, 3 (2014), 64-69.

Farahani, S., Talebi, A.A. and Fathipour, Y., Life Table of Spodoptera exigua (Lepidoptera: Noctuidae) on Five Soybean Cultivars, *Psyche J Entomol*, (2012) 1-7.

Feeny, P.P., Plant apparancy and chemical defense, *Rec Adv Phytochem*, 10 (1976), 1–40.

Felton, G.W. and Summers, C.B., Antioxidant systems in insects, *Arch Insect Biochem Physiol*, 29 (1995), 187–197.

Fernandes, F.L., Bacci, L. and Fernandes, M. S., Impact and Selectivity of Insecticides to Predators and Parasitoids, *Entomo Brasilis*, 3(1) (2010), 01-10.

Funk, J.L. and Heather, L., Throop Enemy release and plant invasion: patterns of defensive traits and leaf damage in Hawaii, *Oecologia*, 162 (2010), 815–823.

Furlong, M.J. and Zalucki, M.P., Climate change and biological control: the consequences of increasing temperatures on host–parasitoid interactions, *Curr Opin Insect Sci*, 20 (2017), 1-6.

Gall, M.L. and Behmer, S.T., Effects of Protein and Carbohydrate on an Insect Herbivore: The Vista from a Fitness Landscape. *Integrat Comparat Biol*, 54(5) (2014), 942–954.

Gallo, D., Nakano, O., Silveira-Neto, S., Carvalho, R.P.L., Baptista, G.C., Berti-Filho, E., Parra, J.R.P., Alves, S.B., Vendramin, J.D., Marchini, L.C., Lopes, J.R.S. and Omoto, C., Manual de Entomologia Agrícola. Piracicaba, Fealq, 2002, pp.649.

Ganguli, J., Chandrakar, S. and Puri, C., *Canthecona furcellata* Wel. a predatory bug on caterpillars of *Clostera sp*, *Ins Environ*, 6(2) (2000), 79-80.

Gayathri, P., Anitha, T., Suganya, S., Chithra, S., Lasyaja, A.B. and Thomas, L., Comparison of biochemical, mineral and nutritive analysis of Camellia Sinensis, L. (Green Tea) with normal tea dust, *Inte J Advan Sci Res*, 2(3) (2017), 05-08.

Ge, Y., Liu, P., Yang, R., Zhang, L., Chen, H., Camara, I., Liu, Y. and Shi, W., Insecticidal Constituents and Activity of Alkaloids from *Cynanchum mongolicum*. *Molecules*, 20 (2015), 17483-17492.

George, P.J.E. and Ambrose, D.P., Impact of insecticides on the haemogram of *Rhynocoris kumarii* Ambrose and Livingstone (Hem: Reduviidae), *Journal of Applied Entomology*, 128(9/10) (2004), 600–604.

George, P.J.E., Development, life table and intrinsic rate of natural increase of three morphs of *Rhynocoris marginatus* (Fabricius) (Heteroptera: Reduviidae) on cotton leaf worm *Spodoptera litura* Fab. (Lepidoptera: Noctuidae), *Entomon*, 24(4) (1999), 339-343.

George, P.J.E., Seenivasagan, R. and Kannan, S., Biology and life table studies of *Acanthaspis pedestris* Stal. (Heteroptera: Reduviidae) population on three lepidoptern insect pest, *J Biol Control*, 12(1), (1998a), 1-6.

George, P.J.E., Seenivasagan, R. and Karuppasamy, G., Life table and intrinsic rate of increase of *Sycanus collaris* Fabricius (Heteroptera: Reduviidae), a predator of *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae), *Bioi. Control*, 12 (2) (1998b), 107-111.

George, P.J.E., The intrinsic rate of natural increase of a harpactorine reduviid *Rhynocoris kumarii* Ambrose and Livingstone on three lepidopteran insect pests, *Entomon*, 25(4) (2000) 281-286.

Gillespie, J.J., Yoder, M. J. and Wharton, R.A., Predicted secondary structure for 28S and 18S rRNA from Ichneumonoidea (Insecta: Hymenoptera: Apocrita): impact on sequence alignment and phylogeny estimation, *J Mol Evol*, 61 (2005), 114–137.

Gogoi A. S. and Borua P.K., Profiling of total polyphenols and pigments in tea (*Camellia sinensis* (L.) O. Kuntze) in various seasons for manufacturingblack tea and green tea, *Inte J Food Nutri Sci*, 6(2) (2017), 56-67.

Gomes, E.S., Santos, V. and Ávila, C.J., Biology and fertility life table of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in different hosts, *Entomol Sci*, 20 (2017), 419–426.

Goswami, B.K., Tipping and Plucking of Tea. *Tea Field Management*, Tea Research Association, Jorhat, Assam, India, 2011, pp. 80-91.

Grainge, M. and Ahmesds, A., Handbook of plant with pest control properties. John Wiley and Sons, New York, 1988, pp. 470.

Grayer, R.J., Chemotaxonomy, diversity of plant compounds and plant conservation. In Lead lay, E., Jury, S. (Eds.) Taxonomy and Conservation of Plants. Cambridge University Press, Cambridge, (2005), pp. 191-202.

Grundy, P.R. and Mealzer, D.A., Assessment of *Pristhesancus plagipennis* (Walker) (Hemiptera: Reduviidae) as an augmentated biological control in cotton and soyabean crop, *Australian j Entomol*, 39 (2000), 305-309.

Gurr, G. M., Wratten, S. D. and Altieri, M. A., Ecological Engineering for Pest Management: Habitat Manipulation for Arthropods. CSIRO Publishing, Collingwood, Australia, 2004.

Gurusubramaniam, G., Babu, A., Venkatesan, S. and Karnan. P., Improvement of growth rate, adult emergence and reproductive potential of *Heliothisarmigera* (Hubner) (Insecta: Lepidoptera: Noctuidae). An evaluation of Natural and Semi-synthetic diets. *Phytophaga,* 2(2) (1991), 121-138.

Gurusubramanian, G., Bora, S., Relative toxicity of some commonly used insecticides against adults of *Helopeltis theivora* Waterhouse (Miridae: Hemiptrra) collected from Jorhat area tea Plantations, South Assam, India. Resistance Pest Management Newsletter, 17(1) (2007), 8-12.

Gurusubramanian, G., Rahman, A., Sarmah, M., Ray, S. and Bora, S., Pesticide Usage Pattern in Tea Ecosystem, Their Retrospects and Alternative Measures, *J Environ Biol*, 29(6) (2008), 813-26.

Hafez, M., The biology and life-history of *Apanteles ruficrus* Hal. (Hymenoptera: Braconidae), *Soc Fouad Entomol Bull*, 32 (1947), 225–249.

Hagan, K.S., Nutritional ecology of terrestrial insect predators. In: *Nutritional Ecology of Insects, Mites, Spiders and Related Invertebrates*, (eds.) Slansky, F. Jr. and Rodriguez, J.G., John Wiley and Sons, New York, 1987, pp. 533-577.

Hägg, J.F., Zagrobelny, M. and Bak, S., Plant Defense against Insect Herbivores, *The Inte J Mole Sci*, 14(5) (2013), 10242–10297.

Hailemichael, Y., Schulthess, F., Smith, J. W., and Overholt, W.A., Suitability of West African gramineous stemborers for the development of *cotesia* species, *Insect Sci Applic*, 17(1) (1997), 89-95.

Hara, Y., Luo, S.J., Wickremashinghe, R.L. and Yamanishi, T., Botany (of tea). Food Rev. Int., 11(1995), 371-374.

Harborne, J.B., Classes and functions of secondary products. In: Chemicals from Plants, Perspectives on Secondary Plant Products, eds. Walton NJ and Brown DE, Imperial College Press, 1999, pp. 1–25.

Harborne, J.B., Phytochemical methods, London. Chapman and Hall, Ltd., 1973, pp. 49-188.

Harbowy, M.E. and Ballentine, D.A., Tea chemistry, *Criti Revi Plant Sci*, 16(5) (1997), 415-480.

Harbowy, M.E. and Ballentine, D.A., Tea chemistry, *Critical Revi Plant Sci*, 16(5) (1997), 415-480.

Haridas, E.T. and Ananthakrishnan, T.N., Models for the feeding behaviour of some reduviids from south India (Insecta: Heteroptera: Reduviidae), *Proceed Indian Acad Sci (Animal Science)*, 89 (1980), 387-402.

Harvey, J.A. and Strand. M.R., The developmental strategies of endoparasitoid wasps vary with host feeding ecology, *Ecology*, 83 (2002), 2439–2451.

Hassan, S.A., The Suitability of *Trichogramma cacoeciae* as an Indicator Species for Testing the Side Effects of Pesticides on Beneficial Arthropods, Compared to Other Hymenopterous Parasitoids, *IOBC/WPRS Bulletin*, 21 (1998), 89-92.

Hazarika, L.K. and Chakraborti, S.K., Spider complex of tea ecosystem in Assam. Res. Bull. No. AAU/DA/E1, Assam Agricultural University, Jorhat, Assam, India, 1998. pp. 1-12.

Hazarika, L.K., Bhattacharrya, B., Kalita, S. and Das. P., BT as a bloclde and its role in management of tea pests, *Inte J Tea Sci*, 4(3&4) (2005) 7-16.

Hazarika, L.K., Bhuyan, M. and Hazarika, M.N., Insect pests of tea their management, *Annual Rev Entomol*, 54 (2009), 267–284.

Hedge, J.E. and Hofreiter, B.T., Carbohydrate chemistry. V-17. Academic Press, New York, 1962.

Heil, M., Extra floral nectar at the plant-insect interface: A spotlight on chemical ecology,phenotypic plasticity, and food webs, *Annual revi entomol*, 60 (2015), 213-232.

Henrichs, E.A., Medrano, F.G. and Rapusas, H.R., Genetic evaluation for insect 363 resistance in rice. IRRI, Philippines, (1985), 356.

Hill, M.G. and Atkins, A.W., Incidence of the armyworm, *Mythimna separata* Walker (Noctuidae : Lepidoptera), and its introduced parasite, *Apanteles rujicrus* Haliday (Braconidae : Hymenoptera), in maize, *New Zealand j Agri Res*, 26 (1983), 135-138.

Hill, M.G., Effects of *Cotesia ruficrus* (Braconidae: Hymenoptera) parasitism and rearing density on *Mythimna separata* (Noctuidae: Lepidoptera) food consumption,and implications for biological control, *New Zealand J Agri Res*, 29(2) (1986), 281-287.

Holloway, J.D., The Moths of Borneo: family Geometridae, subfamily ennominae, *Malayan Natu Jour*, 47(1993), 1–309.

http://www.google.com/url?sa=i&url=http%3A%2F%2Fagritech.tnau.ac.in%2Fhorticulture%2FTea%2520Board%2520of%2520India.htm&psig=AOvVaw0UJdbxaHH_JsIBTv2_w9Ci&ust=1599045739528000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCLCD7ufrx-sCFQAAAAAdAAAAABAJ.

http://www.maplandia.com/india/west-bengal/jalpaiguri/nagrakata/)

Hui, D., Iqbal, J., Lehmann, K., Gase, K., Saluz, H.P. and Baldwinet, I.T., Molecular interactions between the specialist herbivore *Manduca sexta*(Lepidoptera, Sphingidae) and its natural host *Nicotiana attenuata*: V. Microarray analysis and further characterization of large-scale changes in herbivore-induced mRNAs, *Plant physiol*, 131(4) (2003), 1877-1893.

Ibrahim, A.M.A. and Kim, Y., Parasitism by *Cotesia plutellae* alters the hemocyte population and immunological function of the diamondback moth, *Plutella xylostella*, *J insect Physiol*, 52 (2006), 943–950.

Intachat, J., Holloway, J. D. and Staines, H., Effects of weather and phenology on the abundance and diversity of geometroid moths in a natural Malaysian tropical rain forest, *J Tropi Ecol*, 17 **(**2001), 411–429.

ISO (ed.) (2005) Determination of substances characteristic of green and black tea – Part 2: Content of catechins in green tea – Method using high-performance liquid chromatography (ISO14502–2: 2005).

ISO/CD 14502 – 1.2, Tea – Methods for determination of substances characteristic of green and black tea part1. Determination of total polyphenols in tea – colorimetric method using Folin – Ciocalteu reagent, (2001).

Jacobson, E., Biological notes on the hemipteron *Ptilocerus ochraceus. Tijdschrift voor Entomologie*, 54 (1911), 175–179.

Jager, C.M.D., Butot, R.P.T., Meijden, E.V.D. and Verpoorte, R., The role of primary and secondary metabolites in chrysanthemum resistance to *Frankliniella occidentalis*, *J Chem Ecol*, 22(11) (1996), 1987-1999.

Jallow, M.F.A., Awadh, D.G., Albaho, M.S., Devi, V.Y. and Thomas, B.M., Pesticide Knowledge and Safety Practices among Farm Workers in Kuwait: Results of a Survey, *The Inte J Environ Res Pub Health*, 14(4) (2017), 340.

Jervis, M.A. and Copland, M.J.W., The life cycle. In: M. Jervis and B. Kidd (eds), Insect natural enemies; Practical approaches to their study and evaluation. Chapman and Hall, London. 1996, pp. 6–161.

Jha, R.K., Chi, H. and Tang, L.C., Life Table of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) with a Discussion on Jackknife vs. Bootstrap Techniques and Variations on the Euler-Lotka Equation, *Formosan Entomol*, 32 (2012), 355-375.

Jigisha, A., Nishant, R., Navin, K. and Pankaj, G., Green tea: A magical herb with miraculous outcomes, *Int. Res. J. Pharm.*, 3(2012), 139–148.

Johanowicz, D.L. and MitchellSource, E.R., Effects of Sweet Alyssum Flowers on the Longevity of the Parasitoid Wasps *Cotesia marginiventris* (Hymenoptera: Braconidae) and *Diadegma insulare* (Hymenoptera:Ichneumonidae), *The Florida Entomol*, 83(1) (2000),41-47.

Jung, S., Kwoen, M., Choi, J.Y., Je, Y.H. and Kim, Y., Parasitism of *Cotesia* spp. Enhances Susceptibility of *Plutella xylostella* to Other Pathogens, *J Asia-Pacific Entomol*, 9(3) (2006), 255-263.

Kaiser, L., Fernandez-Triana, J., Capdevielle-Dulac, C., Chantre, C., Bodet, M., Kaoula, F., Benoist, R., Calatayud, P., Dupas, S., Herniou, E.A., Jeannette, R., Obonyo, J., Silvain, J.F. and Le Ru, B., Systematics and biology of *Cotesia typhae* sp. n. (Hymenoptera, Braconidae, Microgastrinae), a potential biological control agent against the noctuid Mediterranean corn borer, *Sesamia nonagrioides*, *ZooKeys*, 682 (2017), 105–136.

Kalaiyarasi, L., Livingstone, A.R. and Miracline, S.F., A report on the predatory behaviour of stink bug*Eocanthecona furcellata* Wolff (Hemiptera: Pentatomidae) on the eggs and grubs of *Henosepilachna vigintioctopunctata, Inte J Recent Sci Res,* 8(8) (2017), 19550-19554.

Karban, R., The ecology and evolution of induced resistanceagainst herbivores, *Funct Ecol,* 25 (2011), 339–347.

Kashyap, N., Painkra, G.P., Painkra, K.L. and Bhagat, P.K., Insectpests succession, natural enemies and their correlation with weather parameters in mustard crop, *J of Plant Deve Sci,* 10(10) (2018), 563-568.

Katoch, M., Malladi, M.S., Pests and diseases of tea (*Camellia sinensis*), *Int J Sci, Engine Manag,* 2(7) (2017), 55-62.

Kaur, R., Gupta, A.K. and Taggar, G.K., Induced resistance by oxidative shifts in pigeonpea (*Cajanus cajan*L.) following *Helicoverpaarmigera* (Hübner) herbivory. *Pest Manage Sci,* 71 (2015), 770–782.

Kaushik, A. K., Bisht, K., Yadav, S. K. and Srivastava, P., Impact of various insecticides on natural enemies in cowpea ecosystem, *J Plant Develop Sci*, 8 (11) (2016), 547-550.

Kennedy, D.K., (ed) The Magic Mountains: Hill Stations and the British Raj. University of California Press, Berkeley, (1996), pp.264.

Khan, J., Ali, R., Blouch, A., Javed, H.I., Haq, E.U., Mehmood, T. and Rasool, A., Biological parameters of *Cotesia flavipes* reared on different larval instars of *Chilo partellus* under laboratory conditions, *J Entomol Zool Studies*, 5(3) (2017), 829-832.

Khewa, S, Mukhopadhyay, A. and Dey, D., Isolation and Characterization of two *Bacillus* strains toxic to *Hyposidra talaca* (Walker) (Lepidoptera: Geometridae) from Darjeeling Foothill Region, *J Appli Zool Res*, 25 (2014), 39–44.

Kim, Y. and Son, Y., Parasitism of *Co/esia plu/ellae* Alters Morphological and Biochemical Characters of Diamondback Moth, *Plu/ella xylos/ella*, *J. Asia-Pacific Entomol*, 9 (1) (2006), 37-42.

Kingdon-Ward, F., Does wild tea exit? *Nature*, 165 (1950), 297-299.

Kobori, Y. and Hanboosong, Y., Effect of temperature on the development and reproduction of the sugarcane white leaf insect vector, *Matsumuratettix hiroglyphicus* (Matsumura) (Hemiptera: Cicadellidae), *J. Asia-Pac. Entomol*. 20 (2017), 281–284.

Kottawa-Arachchi, J.D., Gunasekare, M.T.K., Ranatunga, M.A.B., Punyasiri, P.A.N. Jayasinghe, L. and Karunagoda, R.P., Biochemical Characteristics of Tea (*Camellia* L. spp.) Germplasm Accessions in Sri Lanka: Correlation between Black Tea Quality Parameters and Organoleptic Evaluation, *Int J Tea Sci*, 10(1) (2014), 3-13.

Kroschel, J., Sporleder, M., Tonnang, H.E.Z., Juarez, H., Carhuapoma, P., Gonzales, J.C. and Simon, R., Predicting climate-change-caused changes in global temperature on potato tuber moth *Phthorimaea operculella* (Zeller) distribution and abundance using phenology modeling and GIS mapping, *Agric. For. Meteorol*. 15 (2013), 228–241.

Kshettry, A., Vaidyanathan, S. and Athreya, V., Diet Selection of Leopards (Panthera pardus) in a Human-Use Landscape in North-Eastern India, *Tropi Conserv Sci*, 11, (2018), 1-9.

Kuang, X.J.X., Sun, H., Huang, F. and Xue, F.S., Effect of temperature on mating behavior of *Colaphellus bowringi* Baly, *J. Environ. Entomol*. 32 (2010), 307–311.

Kumar, A.G., Rajan, K., Rajan S.J. and Ambrose, D.P., Predatory behaviour of an assassin bug, *Coranus spiniscutis* (Reuter) on rice meal moth, *Corcyra cephalonica* (Stainton) and leaf armyworm, *Spodoptera litura* (Fabricius). *Insect Pest Management, A Current Scenario,* Dunston P. Ambrose, Entomology Research Unit, St. Xavier's College, Palayamkottai, India, 2011, pp. 404-408.

Kumar, M. and Ahmad, M., Quantitative study of food consumption, assimilation and growth in *Creatonotos transiens* Walker (Lepidoptera: Arctiidae) on *Paulownia fortune*, *Indian J. Agric. Res*., 40 (1) (2006), 42-46.

Kumar, S. and Singh S.V., Longevity Fecundity and Sex Ratio of *Canthecona furcellata* on Lepidopterous Insect Pests, *Annals Plant Protec Sci*, 15(7) (2007), 235-281.

Kumar, V., Morrison, M.N., Rajadurai, S., Babu, M.A., Thiagarajan, V. and Dutta, R.K., Studies on the Biology, and Predatory Behaviour of *Eocantheconafurcellata* (Wolff) Predating on *Spilarctia obliqua* (Walk.) in Mulberry Olantation, *Inte J Indus Entomol*, 2(2) (2001), 173-180.

Kumaraswami, N.S. and Ambrose, D.P., Population dynamics of five assassin bugs Melapattam Scrub jungle of Southern India, *Hexapoda*, 6(1) (1994), 1-6.

Kuriachan, I.R, Henderson L.R. and Vinson, S.B., Post-egression host tissue feeding is another strategy of host regulation by the koinobiont wasp, *Toxoneuron nigriceps*, *J Insect Sci* 11(2011), 3.

Landis, D.A., Wratten, S.D. and Gurr, G.M., Habitat management to conserve natural enemies of arthropod pests in agriculture, *The Annu Rev Entomol*, 45 (2000), 175–201.

Lavine, M.D. and Strand, M.R., Insect hemocytes and their role in immunity, *Insect Biochem Mol Biol*, 32 (2002), 1295–1309.

Lenin, E.A. and Rajan, S.J., Biology of predatory bug *Eocanthecona furcellata* Wolff (Hemiptera: Pentatomidae) on *Corcyra cephalonica* Stainton, *J Entomol Zool Studies*, 4(3) (2016), 338-340.

Levin, D. A., The role of trichomes in plant defense, *Quarterly Rev Biol*, 48 (1973), 3–15.

Lichtenthaler, H., Chlorophylls and carotenoids Pigments of photosynthetic Biomembrane. *Methods Enzymol*, 148 (1987), 350-382.

Liu, Z., Li, D., Gong, P. and Wu, K., Life Table Studies of the Cotton Bollworm, *Helicoverpa armigera* (Hu¨ bner) (Lepidoptera: Noctuidae), on Different Host Plants. *Environ. Entomol*. 33(6) (2004), 1570-1576.

Lizarazo, K., Mendoza, C. and Carrero, R., Efecto de extractos vegetales de *Polygonum hydropiperoides, Solanum nigrum* y *Calliandra pittieri* sobre el gusano cogollero (*Spodoptera frugiperda*), *Agron Colomb*, 26(3) (2008), 427-434.

Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J., Protein measurement with the folin phenol reagent, *J Biologi Chem*, 193 (1951), 265–275.

Lu, Z.X., Zhu, P.Y., Gurr, G.M., Zheng, X.S., Donna M.Y. Read, D.M.Y., Kong-Luen Heong, K. L., Yan, Y.J. and Xu, H.X., Mechanisms for flowering plants to benefit arthropod natural enemies of insect pests: Prospects for enhanced use in agriculture, *Inse Sci*, 21 (2014), 1–12.

Mackauer, M., Quantitative assessment of Aphidius smithi (Hymenoptera: Aphidiidae): fecundity, intrinsic rate of increase and functional response, *Canadian Entomol*, 115, (1983), 399–415.

Magalhães, S.T., Guedes, R.N., Demuner, A.J. and Lima, E.R., Effect ofcoffee alkaloids and phenolics on egg-laying by the coffee leafminer *Leucoptera coffeella, Bulletin Entomol Res*, 98 (2008), 483–489.

Mahdavi, V., Saber, M., Rafiee-Dastjerdi, H. and Mehrvar, A., Comparative study of the population level effects of carbaryl and abamectin on larval ectoparasitoid Habrobracon hebetor Say (Hymenoptera: Braconidae), *Bio Control*, 56 (2011), 823–830.

Mahmoud, A.M.A., Santillana, E.J.D.L., Guo, X., Villanueva, F.R. and Perez, M.A.R., Development of the braconid wasp *Cotesia flavipes* in two Crambids, *Diatraea saccharalis* and *Eoreuma loftini*: Evidence of host developmental disruption, *J Asia-Pacific Entomol*, 15 (2012), 63–68.

Majumder, A. B., Studies on *Hyposidra spp.* (Lepidoptera: Geometridae): A new looper pest of tea in Dooars Tea Plantations, India. Ph.D. Thesis, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India, 2010.

Majumder, A.B., Pathak, S.K. and Hath, T.K., Evaluation of some bio-rational insecticides against the looper complex, *Hyposidra* spp. in tea plantations of Dooars, West Bengal, *J Biopesti*, 5(1) (2012), 91-95.

Majumder, A.B., Pathak, S.K. and Hath, T.K., Growth and survival of a geometrid defoliator *Hyposidra infixaria* (Lpidoptera: Geometridae) on four clonal varieties of tea. *Acta Entomol Sinica*, 54(7) (2011), 815-819.

Manske, R.H.F., The Alkaloids. Chemistry and Physiology. Volume VIII. – New York: Academic Press, (1965), pp. 673.

Mattson, W.J., Herbivory in relation to plant nitrogen content, *The Annual Revi Ecol Evol System,* 11(1980), 119–61.

McCutcheon, G.S., Salley, W.Z. and Turnipseed, S.G., Biology of *Apanteles ruficrus*, an Imported Parasitoid of Pseudoplusia includens, *Trichoplusia ni*, and *Spodoptera frugiperda* (Lepidoptera: Noctuidae), *Environmental Entomology*, 12(4) (1983), 1055-1058.

Medina, P., Corrales, E., González-Nuñez, M., Guy Smagghe, G. and Viñuela, E., Effects of *Beauveria bassiana*, Heterorhabditis bacteriophora, *H. megidis* and *Steinernema feltiae* on the Mediterranean fruit fly Ceratitis capitata and the very sensitive braconid *Psyttalia concolor* in the lab, *Pesticides and Beneficial Organisms IOBC/wprs Bulletin,* 35 (2008), 113-121.

Messenger, P.S., Use of life tables in bioclimatic study of an experimental aphid Braconid wasp host parasite system, *Ecology,* 45 (1964), 119-131.

Michael, W., Introduction: Biochemistry, Physiology and Ecological Functions of Secondary Metabolites. Biochemistry of Plant Secondary Metabolism, Second Edition, 40 (2010), 1-19.

Mith ̈ofer, A., and Boland, W., Plant Defense Against Herbivores: Chemical Aspects Axel, *Annu. Rev. Plant Biol*, 63 (2012), 25.1–25.20.

Mitra, B., Shah, S. K., Mishra, P., Insect Fauna associated with the Tea Ecosystem of North Bengal, India, *Recor zool Surv India.* 118(2) (2018), 178-193.

Mizumachi, E., Mori, A., Osawa, N., Akiyama, R. and Tokuchi, N., Shoot development and extension of *Quercus serrata* saplings in response to insect damage and nutrient conditions, *Anna Bot*, 98 (2006), 219-226.

Morais, M.R., Zanardi, O.Z., Rugno, G.R. and Yamamoto, P.T., Impact of five insecticides used to control citrus pests on the parasitoid Ageniaspis citricola Longvinovskaya (Hymenoptera: Encyrtidae), *Ecotoxicology*, 25(5) (2016), 1011-20.

Morris, R.F. and Fulton. N.C., Models for the development and survival of *Hyphantria cunea* in relation to temperature and humidity, *Mem Entomol Soc Can*, 70 (1970), 1-60.

Muirhead, K.A., Austin, A.D., Sallam, M., The systematics and biology of *Cotesia nonagriae* (Olliff) stat rev (Hymenoptera: Braconidae: Microgastrinae), a newly recognized member of the *Cotesia flavipes* species complex, Zootaxa 1846 (2008), 35–46.

Mukhopadhyay, A., Sannigrahi, S. and Biswas, G., Colonization and utilization of young tea plants by some insects and mites in Darjeeling foothills. Ecology and evolution of plant- feeding insects in natural and manmade environments: 1997, pp. 59-69.

Muraleedharan, N. and Chen, Z.M., Pests and diseases of tea and their management, *J. Plant Crops*, 25 (1997), 15–43.

Muraleedharan, N., Selvasundaram, R. and Radhakrishnan, B., Natural Enemies of Certain Tea Pests Occurring in Southern India, *Int. J. Trop. Insect Sci*., 9 (1988), 647-54.

Muraleedharan, N., Selvasundaram, R. and Radhakrishnan, B., Parasitoids and predators of tea pests in India, *J Plant Crops*, 29(2) (2001), 1-10.

Naganagoud, A. and Kulkarni, K.A., Biology of *Cotesia ruficrus* (Haliday) (Hymenoptera: Braconidae), a parasitoid of sorghum armyworm, *Mythimna separata* (Walker), *Bioi. Control.* 12(1) (1998), 43-45.

Naganagoud, A. and Kulkarni, K.A., Effect of Temperature and Relative Humidity on the Biology of *Cotesia ruficrus* (Haliday), *Karnataka J Agri Sci*, 13(1) (2000), 55-59.

Nagarkatti, S., Sankaran, T. and Manjunath, T. M., Natural control of the scale *Fioriniatheae* Green (Coccoidea: Diaspididae) in Assam, *Prot. Ecol*., 1 (1979), 179-84.

Nagrare, V.S., Kranthi, S. Kranthi, K.R., Naik, V.C.B., Deshmukh, V., Naikwadi, B. and Dahekar, A., Relative toxicity of insecticides against cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera:Pseudococcidae) and its fortuous parasitod *Aenasius bambawalei* Hayat (Hymenoptera: Encyrtidae), *J Appl Natural Sci*, 8 (2) (2016), 987 – 994.

Nair, N., Sekh, K., Debnath, M.R., Dhar, P.P. and Somchoudhury, A.K., 'Biology of *Hyposidra infixeria* Walk. (Lepidoptera: Geometridae), a Resurgent Looper pest of tea', *J Entomol Res*, 32 (2008), 67-70.

Nathan, S.S., Chung, P.G. and Murugan, K., Effect of biopesticides applied separately or together on nutritional indices of the rice leafolder *Cnaphalocrocis medinalis*. *Phytoparasitica* 33 (2005), 187-195.

Navarajanpaul, A.V., Biological control of lepidopteran pests using important predators, Proceedings of the symposium on biological control of lepidopteran pests, Bangalore, 2002, pp. 19–28.

Navea, O.D. and Vargas, R.M., Parasitoidism rate and life table parameters of *Aphytis iaspidis* (Howard) (Hymenoptera: Aphelinidae) and *Hemiberlesia lataniae* (Signoret) (Hemiptera: Diaspididae), *Chilean J Agri Res, 72*(3) (2012), 335-344.

Nguyen, H.T., Oo, T.T., Ichiki, R.T. Takano, S., Murata, M., Takasu, K., Konishi, K., Tunkumthong, S., Chomphookhiaw, N. and Nakamura, S., Parasitisation of Tetrastichus brontispae (Hymenoptera: Eulophidae), a biological control agent of the coconut hispine beetle Brontispalongissima (Coleoptera: Chrysomelidae), *Biocon Sci Technol,* 22(8) (2012), 955-968.

Nielsen, A.L., Hamilton, G.C. and Matadha, D., Developmental Rate Estimation and Life Table Analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae), *Environ Entomol,* 37(2) (2008), 348-355.

Nitin, K.S., Bhat, P.S., Raviprasad, T.N. and Vanitha, K., Biology, Behaviour and predatory efficiency of *Sycanus galbanus* Distant. Hemiptera: Reduviidae: Harpactorinae recorded in Cashew plantations, *J Entomol Zool Studies*, 5(2) (2017), 524-530.

Nyunt, K.T., Potential of the predatory pentatomid *Eocanthecona furcellata* (Wolff) as a biocontrol agent on American bollworm in cotton in Myanmar. Faculty of Agricultural Sciences Georg-August University Go¨ttingen, Germany, 2008, pp. 16-21.

Okolle, J.N., Mansor, M. and Ahmad, A.H., Seasonal abundance of the banana skipper, *Erionota thrax* (Lepidoptera: Hesperiidae) and its parasitoids in a commercial plantation and a subsistenc farm in Penang, Malaysia, *Inte J Tropi Insect Sci*, 26(3) (2006),197–206.

Omwega, C.O. and Overholt, W.A., Progeny production and sexratios of field populations of the parasitoids *Cotesiaflavipes* and *Cotesiasesamiae* reared from gramineousstemborers in coastal Kenya, *Insect Sci its Appli*, 17 (1997), 137-142.

Orre Gordon, G., Wratten, S., Jonsson, M., Simpson M. and Hale, R., 'Attract and reward': combining a herbivoreinduced plant volatile with floral resource supplementation– Multi-trophic level effects, *Biol Control*, 64(2) (2013), 106–115.

Pant, C.P., Some aspects of bionomics of *Erias* spp. at Kanpur, *Agra Univ.* J. *Res. (Sci)*, 9 (1960), 31-40.

Park, K.T., Kang, T.M., Kim, M.Y., Chae, M.Y., Ji, E. M. and Bae, Y.S., Discovery of the Ten Species of Subtropical-moths in Is. Daecheong, Korea, *Korean J Appli Entomol*, 45(3) (2006), 261-268.

Park, Y.S., Jung, S.T., Kang, S.G., Heo, B.K., Arancibia-Avila, P., Toledo, F., Drzewiecki. J., Namiesnik, J. and Gorinstein, S., Antioxidants and proteins in ethylene-treated kiwifruits, *Food Chem*, 107 (2008), 640–648.

Parra, J.R.P., Consumo e utilização de alimento por insetos. In: Panizzi AR, Parra JRP (eds) Ecologia Nutricional e Suas Implicações no Manejo de Pragas, Manole, São Paulo, 1991, pp. 9–65.

Patil, S.S., Chandani Kamble, C. and Sathe, T.V., Biocontrol potential of *Cotesia ruficrus* Hal. (Hymenoptera: Braconidae) against different Lepidopterous pests, *Biolife*, 4(2) (2016), 343-346.

Perera, D.R., Armstrong, G., Naylor, R.E.L. and Senanayake, N., Response of *Chrysodeixis eriosoma* (Doubleday), *Plutella xylostella* L. and the parasitoid, *Cotesia plutellae* (Kurdjumov) to feeding deterrents, *Tropical Agric Res*, 12 (2000), 186-198.

Pillai, K.A. and Agnihotri, M., Population dynamics of the predatory bug *Eocanthecona furcellata* (Wolff.). Indian, *J Appl Entomol*, 25 (2011), 162-163.

Poelman, E.H., Oduor, A.M.O., Broekgaarden, C., Hordijk, C.A., Jansen, J.J., Loon, J.J.A.V., Dam, N.M.V., Vet. L.E.V. and Dicke, M., Field parasitism rates of caterpillars on *Brassica oleracea* plants are reliably predicted by differential attraction of *Cotesia* parasitoids, *Functional Ecology*, 23 (2009), 951–962.

Potting, R.P.J., Overholt, W.A., Danso, F.O. and Takasu, K., Foraging behaviour and life history of the stemborer parasitoid *Cotesia flavipes* (Hymenoptera: Braconidae), *J Insect Behav*, 10 (1997), 13–29.

Powell, J.E., Food consumption by tobacco budworm (Lepidoptera: Noctuidae) larvae reduced afterparasitization by *Microplitis demolitor* or *M. croceipes* (Hymenoptera: Braconidae), *J Econ Entomol*, 82(1989), 408–411

Prasad, A.K. and Mukhopadhyay, A., Fitness traits of the tea defoliator, Hyposidra talaca (Walker 1860) (Lepidoptera: Geometridae) on natural and artificial diets in relation to gut enzymes and nutritional efficiencies, *Inte J Entomol*, 51(2) (2015), 145-152.

Prasad, A.K., Mukhopadhyay, A., A technique to measure the loss in tea crop by the defoliating pest (*Hyposidra talaca* Walker) on the basis of dry mass and leaf area parameters, *Inte J Bio-resour Stress Manag*, 4 (2013), 358–361.

Pratissoli, D., Milanez, A.M., Celestino, F.N., Barbosa, W.F., Vianna, U.R., Polanczyk, R.A. and Carvalho, J.R., Seletividade de inseticidas, recomendados para cucurbita´ceas para Trichogramma atopovirilia Oatman & Platner (Hymenoptera: Trichogrammatidae) em condic¸o˜es de laborato´rio, *Rev Ceres*, 58 (2011), 661–664.

Puja, D. and Sabiha, K., A field study of population dynamics of major insect pests and their natural enemies on cauliflower of Ajmer district, *Inte J Agri Sci*, 8(53) (2016) 2642-2645.

Putchkova, L.V., Adaptive features of leg structures in the Heteroptera, *Entomol Rev*, 58 (1979), 189-196.

Qian, X., Wang, Y.Y., Xie, H.H., Dou, J., Li, Z.W., Jashenko, R. and Ji, R., Effects of temperature on the activities of key enzymes related to respiratory metabolism in adults of *Gomphocerus sibiricus* (Orthoptera: Acrididae), *Acta Entomol. Sin*. 60 (2017), 499–504.

Rabindra, R.J., Sustainable pest management in tea: Prospects and challenges, *Two and a Bud*, 59 (2012), 1-10.

Radhakrishnan, B., Loganathan, S. and Murraleedharan, N., Coccinellid predators of *Toxoptera aurantii* (Boyer de Fonscolmbe) infesting tea in Southern India, *Newslet Aphidolog Society India*, 71 (1988) 7-8.

Rahman, A. and Bhola, R.K., Role of Kairomone in Parasitization Efficiency of Larval Parasitoid *Apantele staprobene* Cameron (Hym: Braconidae), in *Buzura suppressaria* a Lepidopteran Pest of Tea, *Sci Cul*, **77** (9–10) (2011), 416-418.

Rajan, S.J., Suneetha, N. and Sathish, R., Biology and predatory behaviour of an assassin bug, *Sycanus collaris* (Fabricius) on rice meal moth, *Corcyra cephalonica* (Stainton) and leaf armyworm, *Spodoptera litura* (Fabricius), *Agri Update*, 12 (5) (2017), 1181-1186.

Ramalho, F.S., Wanderley, P.A., Malaquias, J.B., Fernandes, F.S., Nascimento, A.R.B. and Zanuncio, J.C., Effect of temperature on the reproduction of *Bracon vulgaris* Ashmead (Hymenoptera: Braconidae), a parasitoid of the cotton boll weevil, *Anais da Academia Brasileira de Ciências*, 83(3) (2011), 1021-1029.

Raman, K.V.A., Mgdum, S.B. and Datta, R.K., Feeding efficiency of the silkworm *Bombyx mori* L. hybrid (NB4DC x KA), *Insect Sci Appli*, 15(2) (1994), 111-116.

Ramdani, D., Chaudhry, A.S. and Seal, C.J., Alkaloid and Polyphenol Analysis by HPLC in Green and Black Tea Powders and their Potential Use as Additives in Ruminant Diets, *AIP Confer Proceed*, 1927 (2018), 030008.

Rani, P.U. and Vukkala, I.H., Predatory and Mating Behaviour of *Eocanthecona furcellata* (Wolff.) (Heteroptera: Pentatomidae) a Promising Natural Enemy of Lepidopterous Larvae, *Biol Control*, 7 (1) (1993a), 9-11.

Rani, P.U. and Wakamura, S., Host acceptance behaviour of a predatory pentatomid, *Eocanthecona furcellata* (Wolff.) (Heteroptera: Pentatomidae) towards larvae of *Spodoptera litura* (Lepidoptera: Noctuidae), *Insect Sci Appl*, 14(2) (1993b), 141-147.

Rao, V.P, Dutta, B. and Ramaseshiah, G., Natural enemy complex of flush worm and phytophagous mites on tea in India. Tea Board, Calcutta, 1970, p.53.

Rashmi, M.A., Biology of rice moth, *Corcyra cephalonica* Stainton on foxtail millet, *Karnataka J Agri Sci,* 22(3-Spl.Issue) (2009), 674-675.

Ray, S.N. and Khan, M.A., Biology of predatory bug, *Canthecona furcellata* Wolff. (Hemiptera: Pentatomidae) on poplar defoliator, *Clostera fulgurita* Walker (Lepidoptera: Notodontidae), *J biopesti*, 4(2) (2011), 109-111.

Reygaert, W.C., An update on the health benefits of green tea. *Beverages*, 3(6) (2017), 2-14.

Richard, O.W., The theoretical and practical study of natural insect populations, *Annu Rev Entomol*, 6 (1961), 147-162.

Robert, N. Wiedenmann, J.W. Smith, J.R. and Darnell, P.O., Laboratory Rearing and Biology of the Parasite C*otesia flavipes* (Hymenoptera: Braconidae) Using *Diatraea saccharalis* (Lepidoptera: Pyralidae) as a Host, *Biolog Cont*, 21(5) (1992), 1160-1167.

Roberts, G.R., Polar lipid compositions of the leaves and seeds from the tea palnt (*Camellia sinensis* L.). *J. Sci. Food Agric*, 25, (1974), 473-475.

Rosenthal, G. A. and Berenbaum, M.R., Herbivores. Their Interactions with Secondary Plant Metabolites, 2nd ed., Vot. 1, The Chemical Participants. Academic Press, San Diego, 1991.

Roy, M., Brodeur, J. and Cloutier, C., Effect of temperature on intrinsic rates of natural increase (rm) of a coccinellid and its spider mite prey, *Bio-control*, 48 (2003), 57-72.

Roy, S, Mukhopadhyay, A. and Gurusubramanian, G., Varietal Preference and Feeding Behaviour of Tea Mosquito Bug (*Helopeltis theivora* Waterhouse) on Tea Plants (*Camellia sinensis*), *Academic J Entomol*, 2 (1) (2009), 01-09.

Roy**, S.** Das, S., Handique, G., Mukhopadhyay, A. and Muraleedharan, N., Ecology and management of the black inch worm, *Hyposidra talaca* Walker (Geometridae: Lepidoptera) infesting *Camellia sinensis* (Theaceae), *J Inte Agri*, 16(10) (2017), 2115-2127.

Roy, S., Mukhopadhyay, A., Soma Das, S. and Gurusubramanian, G., Bioefficacy of coccinellid predators on major tea pests, *J Biopesticides*, 3(1 Special Issue) (2010), 033 – 036.

Roy, S., Muraleedharan, N., Pujari, D., A catalogue of arthropod pests and their natural enemies in the tea ecosystem of India, *Two and a bud*, 61(1&2) (2014), 11-39.

Roy, S., Prasad, A. K., Pradhan, B., Mukhopadhyay, A., Pestiferous Red Slug Caterpillars of *Eterusia aedea* (Lepidoptera: Zygaenidae): Status, Bioecology and Management in Tea Plantations of India, *J Lepidopt' Society,* 72(1) (2018), 87–95.

Roy, S., Talukdar, T., Saha, A.S., Banerjee, D.K, Sannigrahi, S. and Gurusubramanian, G., Species richness and seasonal abundance ofspider and lady bird fauna in tea eco-systemofNorth Bengal, *In* Proc. 34th Tock. Conf., Tea Research Association, Tocklai Experimental Station, Jorhat, 2005, pp. 347-51.

Sabelis, M.W., Predatory arthropods. In: M.J. Crawley (ed), *Natural enemies. The population biology of predators, parasites and disease.* Blackwell, Oxford. 1992, pp. 22–264.

Sahayaraj, K. and Martin, P., Assessment of *Rhynocoris marginatus* (FAB.) (Hemiptera: Reduviidae) as augmented control in groundnut pests, *J Cent European Agri*, 4(2) (2003), 103-110.

Sahayaraj, K., Artificial rearing on the nymphal developmental time and survival of three reduviid predators of Western Ghats, Tamil Nadu, *J Biopesti*, 5(2) (2012), 218-221.

Sahayaraj, K., Capturing success by reduviid predators *Rhynocoris kumarii* and *R.marginatus* on different age groups of *Spodoptera litura*, a polyphagous pest (Heteroptera: Reduviidae), *J Ecobi*, 6(3) (1994), 221 - 224.

Sahayaraj, K., Evaluation of biological control potential of *Rhynocoris marginatus* on four groundnut pests under laboratory condition. International Arachis Newsletter, 20 (2000), 72-73.

Sahayaraj, K., Small scale rearing of reduviid predator, *Rhynocoris marginatus* F. (Hemiptera: Reduviidae) on *Crocyra cephalonica* Stainton by larval card method, *J Cent European Agri*, 3(2002), 137–147.

Sahid, A., Natawigena, W.D., Hersanti and Sudarjat., Laboratory rearing of *Sycanus annulicornis* (Hemiptera: Reduviidae) on two species of prey: Differences in its biology and efficiency as a predator of the nettle caterpillar pest *Seto thosea asigna* (Lepidoptera: Limacodidae), *European J Entomol*, 115 (2018), 208–216.

Sajilata, M.G., Bajaj, P.R. and Singhal, R.S., Tea polyphenols as nutraceuticals. *Compreh Revi Food Sci Food Saf*, 7(3) (2008), 229-254.

Salah, N., Miller, N.J., Paganga, G., Tijburg, L., Bolwell, G.P. and Rice-Evans, C.A., Polyphenolic flavanols as scavengers of aqueous phase radicals and as chain breaking antioxidants, *Arch Biochem Biophys.* 322 (1995), 339-346.

Sallam, M.N.S., Overholt, W.A., Keiru, E., Intraspecific and interspecific competition between *Cotesia flavipes* and *Cotesia sesamiae* (Hymenoptera: Braconidae), gregarious larvalendo parasitoids of lepidopteran stemborers, *Biocon Sci Technol*, 12 (2002), 493–506.

Samanta, A., Chakraborthy, K., Somchoudhury, A.K. and Jana, S.K., Persistent toxicity of different insecticides of Trichogramma and Bracon on Guava leaves, *Pestic. Res. J*., 19 (1) (2007), 59-62.

Sanap, Y., Dawkar, V.V., Giri, A.P., Sen, A. and Pandit, R.S., Parasitism by *Chelonus blackburni* (Hymenoptera) affects food consumption and development of *Helicoverpa armigera* (Lepidoptera) and cellular architecture of the midgut, *J Asia-Pacific Entomol*, 19 (2016), 65–70.

Sarkar, S., Babu, A. Chakraborty, K. and Deka, B., Study on the Biology, Feeding Behaviour and predatory Potential of *Sycanus collaris* (Fabricius) (Heteroptera: Reduviidae), a new Predator of Hyposidra talaca (Walk.) (Lepidoptera: Geometridae), a major Tea pest and mass Rearing on *Corcyra cephalonica* (Stainton) in Laboratory, *Inte J Curr Advan Res*, 08(06) (2019), 19258-19262.

Sarma, P.V., Possibilities for integrated control of major pests of tea in India, *PANS Pest Articles & News Summaries*, 25(3) (1979), 237-45.

Sarvamangala, D., Sharma, G.V.R., Prasad, K.R.K., Srinivas, K., Krishnarao, V. and Udaybhaskar, K., Novel herbal formulation with insect repellent activity, *Int. J. LifeSc. Bt & Pharm. Res*, 3(4) (2014), 118-122.

Satpute, N. S., Deshmukh, S.D., Rao, N.G.V. and Nimbalkar, S.A., Life tables and the intrinsic rate of increase of *Earias vittela* (Lepidoptera: Noctuidae) reared on different hosts, *Inte J Topi Insect Sci*, 25(2) (2005), 73–79.

Sattelmacher, B., Horst, W.J., Becker, H.C., Factors that contribute to genetic-variation for nutrient efficiency of crop plants, *Zeitsch fur Pflanzenerna Bodenk*, 157 (1994), 215–24.

Satyagopal, K., Sushil, S.N., Jeyakumar, P., Shankar, G., Sharma, O.P., Sain, S.K., Boina, D.R., Chatopadhyay, D., Sunanda, B.S., Asre, R., Murali, R., Arya, S., Kumar, S., Roy, S., Rai, H.K., Hath, T.K., Laskar, N., Roy, A., Khalko, S., Sathyanarayana, N. and Latha, S., AESA based IPM package for Tea. 2015, pp 54.

Saunders, J.A., O'neill, N.R. and Romeo, J.T., Alkaloid Chemistry and Feeding Specificity of Insect Herbivores. In: Pelletier S.W. (eds) Alkaloids: Chemical and Biological Perspectives. Alkaloids: Chemical and Biological Perspectives, Springer, New York, NY, 8 (1992), pp. 151-196.

Schaefer, C.W. and Panizzi, A.R., Heteroptera of economic importance. CRC press, Boca Raton, FL, 2000, pp.828.

Schmelz, E.A., Engelberth, J., Alborn, H.T., Tumlinson, J.H. and Teala, P.E.A., Phytohormone-based activity mapping of insect herbivore-produced elicitors, *Proceedings Nation Acad Sci*, 106(2) (2009), 653-657.

Schulz, H., Engelhardt, U.H., Wegent, A., Drews, H.H. and Lapczynski, S., Application of Near-Infrared Reflectance Spectroscopy to the Simultaneous Prediction of Alkaloids and Phenolic Substances in Green Tea Leaves, *J. Agric. Food Chem.*, 47, (1999), 5064-5067.

Schuman, M.C., Barthel, K. and Baldwin, I.T., Herbivory-induced volatiles function asdefenses increasing fitness of the native plant *Nicotiana attenuata* in nature, *ELife*, 1 (2012), 1-29.

Scott, M.I., Thaler, S.J. and Scott, G.F., Response of a generalist herbivore*Trichoplusia ni* to jasmonate-mediated induced defense in tomato, *J Chem Ecol*, 36 (2010), 490–499.

Seal, D.R., Klassen, W. and Kumar, V., Biological parameters of *Scirtothripsdorsalis* Hood on selected hosts, *Environ.Entomol*, 39 (2010), 1389–98.

Seeram, N.P., Henning, S.M., Niu, Y., Lee, R., Scheuller, H.S. and Heber, D., Catechin and caffeine content of green tea dietary supplements and correlation with antioxidant capacity, *J Agri Food Chem*, 54 (2006), 1599-1603.

Segoli, M. and Rosenheim, J.A., Spatial and temporal variationin sugar availability for insect parasitoids in agriculturalfields and consequences for reproductive success, *Biol Control*, 67(2) (2013), 163–169.

Seigler, D.S., Phytochemistry of *Acacia—sensu lato*, *Biochem Systemat Ecol*, 31 (2003), 845–873.

Sen-Sharma, P.K., Thakur, M.L., Pests of dipterocarpaceae and their management, pp.165–187, *In Forest Entomology* (edited by L. K. Jha and P. K. Sen-Sharma). APH Publishing, New Delhi, 2008.

Shah, S., Yadav, R.N.S. and Borua, P.K., Biochemical defense mechanism in *Camellia sinensis* against *Helopeltis theivora, Inte J Plant, Animal Environ Sci*, 4(3) (2014), 246-253.

Shah, S.K. and Mitra, B., Moth (Insecta: Lepidoptera) Fauna and their Insect Predators Associated with the Tea gardens and the surrounding Natural Ecosystem Environs in Northern West Bengal, India, *J Zool Stu*, 2(6) (2015), 01-05.

Shahayaraj, K. and Sathiamoorthi, P., Influence of different diets of *corcyra cephalonica* on life history of a reduviid predator *Rhynocoris marginatus* (Fab.), *J Cent European Agri*, 3(1) (2002), 53-62.

Shankar, U., Seasonal abundance of *Cotesia plutellae* Kurdjumov and its parasitization on Diamondback moth larvae, *Ann. Pl. Protec. Sci*. 12(1) (2004), 193-242.

Shankarganesh, K., Paul, B. and Naveen, N.C., Eco-Toxicological Effect of Insecticides on the Larval Parasitoid, *Bracon brevicornis* Wesmael (Hymenoptera: Braconidae). *African Entomol, 25*(2) (2017), 367-374.

Sharma, A.K., Important consideration in pruning and skiffing. *Tea Field Management*, Tea Research Association, Jorhat, Assam, India, 2011, pp. 92-103.

Sharma, S., Tara, J.S., Bhatia, S., Ferozl, M., Sharma, J. and Gupta, M., Biology of *Hyposidra talaca* Walker (Lepidoptera: Geometridae), a major defoliating pest of teak (*Tectona grandis*) in Jammu, (J&K), *J Environ Bio-Sci*, 28 (2) (2014), 183-186.

Sharmaa, H.C., Sullivanb, D.J. and Bhatnagar, V.S., Population dynamics and natural mortality factors of the Oriental armyworm, *Mythimna separata* (Lepidoptera:Noctuidae),in South-Central India, *Crop Protec*, 21 (2002), 721–732.

Shi, M., Dong, S., Li, M., Yang, Y., David Stanley, D. and Chen, X., The Endoparasitoid, *Cotesia vestalis*, Regulates Host Physiology by Reprogramming the Neuropeptide Transcriptional Network, *Sci Rept*, 5 (2015), 8173.

Siddaiah, A.A., and Devi, A.R., Biology of a predatory bug *Eocanthecona furcellata* Wolff (Hemiptera: Pentatomidae) on Vapourer tussock moth larvae: a major pest of tasar silkworm food plants, *Int. J. Indust. Entomol*. 30(1) (2015), 26-30.

Siddaiah, A.A., Prasad, R., Rai, S., Dubey, O., Satpaty, S., Sinha, R., Prsad, S. and Sahay, A., Influence of abiotic factors on seasonal incidence of pests of tasar Silkworm *Antheraea mylitta* D, *Int. J. Indust Entomol*, 29 (1) (2014), 135-144.

Simmonds, M.S.J., Blaney, W.M., Delle Monache, F., Marini Bettolo, G.B., Insect Antifeedant activity associated with compounds isolated from species of Lonchocarpus and Tephrosia, *J Chem Ecol*, 16 (1990), 365-380.

Simpson, M., Gurr, G.M., Simmons, A. T., Wratten, S.D., James, D.G., Leeson, G. and Nicol, H.I., Insect attraction to syntheticherbivore-induced plant volatile-treated field crops, *Agric For Entomol*, 13(1) (2011), 45–57.

Singh, A.P., Bahuguna, K. and Ramola, G.C., New host records of polyphagous Lepidoptera on Ban Oak *Quercus leucotrichophora* A. Camus (Fabaceae) in the Garhwal Himalaya, India, *J Threat Taxa*, 11(5) (2019a), 13579–13591.

Singh, A.P., *Sycanus collaris* Fab. (Reduviidae: Hemiptera), a new predator of *Clostera* spp. on *Populusdeltoid, J Entomol Res*, 124 (1998), 172.

Singh, I. D., Selection and testing field performance of candidate tea clones in India, *IJTS*, 5 (2006), 1–12.

Singh, K.P., Singh, S., *Hyposidra talaca* Walk. (Lepidoptera: Geometridae). A new pest of *Quercus incana* Roxb. *Indian Forester*, 130(2) (2002), 231-232.

Singh, S., Jigyasu, D.K., Roy, D., Shabnam, A.A. and Das, R., Feeding Behaviour of Two Important Predator Bugs *Eocanthecona furcellata* Wolff and *Sycanus collaris* Fabricius in Muga Ecosystem, *Res J Agri Sci*, 10 (1) (2019b), 185-188.

Sinija, V.R. and Mishra, H.N., Green tea: Health benefits, Review, *J Nutri Environ Medicine*, 17 (2008), 232–242.

Sinu, P.A, Antony, B. and Mallick, S., The occurrence of nucleopolyhedrovirus infecting *Hyposidra talaca* (Geometridae: Lepidoptera), a tea defoliator from North- East India, *Biocon Sci Technol*, 21 (2011a), 999–1003.

Sinu, P.A, Mandal, P., Antony, B., Range expansion of *Hyposidra talaca* (Geometridae: Lepidoptera), a major pest, to Northeastern Indian tea plantations: change of weather and anti-predatory behaviour of the pest as possible causes, *Int J Tropi Insect Sci*, 31(4) (2011b), 242–248.

Sinu, P.A., Mandal, P., Banerjee, D., Mallick, S., Talukdar, T. and Pathak, S.K., Moth pests collected in light traps of tea plantations in North East India: species composition, seasonality and effect of habitat type, *Curr Sci*, 104 (5) (2013), 645-651.

Sivapalan, P. and Seneratne, K.A.D.W., Some aspects of the biology of the tea termite *Glyptotermes dilatatus*, *PANS*, 23 (1997), 9-21.

Smilanick, J.M., Zalom, F.G. and Ehler, L.E., Effect of metamidophos residue on the pentatomid egg parasitoids *Trissolcus basalis* and *T. utahensis*, *Biol Control*, 6 (1996), 193-201.

Smith, S. M., Biological Control with *Trichogramma*: Advances, Successes and Potential of Their Use, *Annu Revi Entomol*, 41 (1996), 375-406.

Song, G., Lin, J., Qu, F. and Huie, C.W., Extraction of catechins and caffeine from different tea leaves and comparison with micellar electrokinetic chromatography, *Chinese Sci Bull*, 48(22) (2003), 2438-2443.

Southwood, T.R.E. and Henderson, P.A., Ecological methods. Kluwer Academic Press, London, 2000.

Southwood, T.R.E., The construction, description and analysis of age- specific life-tables. In: Southwood TRE (ed) Ecological methods with particular reference to the study of insect population. Champ and Hall, London, 1978, pp. 356- 387.

Srikumar, K.K., Smitha Sukumaran, S., Bastian, S., Kumar, B.S. and Radhakrishnan, B.J., Life History and Functional Response of Two Species of Reduviids (Hemiptera: Reduviidae: Harpactorinae) in Tea, *Agric Urban Entomol*, 33 (2017), 44–56.

Strand, M.R. and Burke, G.R., Polydnaviruses: Nature's genetic engineers, *Annu Revi Virol*, 1 (2014), 333–354.

Subhan, N., Phytochemical and pharmacological investigations of Australian *Acacia*: An ethnomedicine-guided bioprospective approach. Ph.D Thesis, School of Biomedical Sciences, Churles Sturt University, 2016.

Sudhakaran, R. and Muraleedharan, N., Biologyof *Helopeltis theivora* (Hemiptera: Myridae) infesting tea, *Entomon*, 31(3) (2006), 165-80.

Suh, C.P., Orr, D.B. and Van Duyn, J.W., Effect of insecticides on *Trichogramma exiguum* Preimaginal development and adult survival, *J Econ Entoml*, 93 (2000), 577-583.

Sultana, N., Effects of Parasitism on the Development and Food Consumption of Larva of *Spilosoma obliqua* (Walker) by its Parasitoid *Apanteles obliquae* Wilkinson, *Journal of Biological Sciences*, 3 (2003), 466-473.

Sundararaju, D., and Sundara Babu, P.C., *Helopeltis* spp. (Heteroptera: Miridae) and their management in plantation and horticultural crops of India, *J Plant Crops*, 27(1999), 155–74.

Sundararaju, D., Studies on cashew pests and their natural enemies in Goa, *J Plant Crop*, 12(1) (1984), 38–48.

Surpur, S., Yelshetty, S., Sreenivas, A.G. and Patil, B.V., Life table and biotic potentialof *Maruca vitrata* (Geyer) (Lepidoptera: Crambidae) on chickpea artificial diet, *JEZS*, 6 (4) (2018), 892-896.

Suyal, P., Gaur, N., Rukesh, P.K N. and Devrani, A., Seasonal incidence of insect pests and their natural enemies on soybean crop, *JEZS*, 6(4) (2018), 1237-1240.

Taggar, G.K., Gill, R.S., Gupta, A.K. and Sandhu, J.S., Fluctuations in peroxidase and catalase activities of resistant and susceptible black gram (*Vigna mungo* (L.) Hepper) genotypes elicited by *Bemisia tabaci* (Gennadius) feeding, *Plant Signal Behav*, 7 (2012), 1321–1329.

Tana, C.W., Peiffera, M., Hoovera, K., Rosab, C., Acevedoa, F.E. and Feltona, G.W., Symbiotic polydnavirus of a parasite manipulates caterpillar and plant immunity, *Proceed Nation Academy Sci*, *115*(20) (2018), 5199-5204.

Tanaka, T., Morphological changesin haemocytes of the host, pseudaletia separata parasitizedby*Microplitis mediator* or *Apanteles kariyai*, *Develop Compar Immunol*, ii (1987), 57-67.

Thanavendan, G., Jeyarani, S. and Kennedy, J.S., Safety of selected botanical and synthetic insecticides against braconid parasitoids of vegetable ecosystems, *Inte J Plant Protec*, 10(1) (2017) 174-180.

Thapa, R.B., Pesticide pollution and integrated pest management. In: F. P. Neupane (ed.) Integrated Pest Management in Nepal. Proc. Natl. Sem. IPM in Nepal, 25-26 Sept. 2002. HIRI, Ktm, Nepal, 2003, pp. 175-194.

Thompson, S.N., Effects of parasitization by the insect parasite *Hyposoter exiguae* on the growth, development and physiology of its host. *Trichopl ni Parasitol*, 84 (1982), 491-510.

Thungrabeab, M. and Tongma, S., Effect of entomopathogenic fungi, *Beauveria bassiana* (Balsam) and *Metarhizium anisopliae* (Metsch*)* on non-target insects, *KMITL Sci. Tech. J*, 7(S1) (2007), 8-12.

Tiwari, S., Mayuri, R.P. and Pandey, A.K., Effect of different insect hosts on biology and predation efficiency of *Eocanthecona furcellata* Wolff (Hemiptera: Pentatomidae), *The bioscan*, 12(1) (2017), 193-197.

Torres, J.B., Silva-Torres, C.S.A., and Barros, R., Relative effects of the insecticide thiamethoxam on the predator, *Podisus nigrispinus* and the tobacco whitefly, *Bemisia tabaci* in nectaried and nectariless cotton, *Pest Manag. Sci.* 59 (2003), 315–323.

Torres, J.B., Silva-Torres, C.S.A., Oliveira, M.R. and Ferreira. J., Compatibilidade de inseticidase acaricidas com o percevejo predador *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) em algodoeiro, *Neotrop. Entomol*. 31 (2002) 311-317.

Treutter, D. Significance of flavonoids in plant resistance: a review. *Environ Chem Lett*, 4 (2006), 147–157.

Tripathi, R.N. and Singh, R., Fecundity, reproductive rate, longevity and intrinsic rate of increase of an aphidiid parasitoid *Lysiphlebia mirzai* Shuja-Uddin, *Entomophaga*, 34 (1990), 601-610.

Tripathy, M.K. and Rout, M., Diversity of Insect Pests and their Natural Enemies Infesting Teak (*Tectona Grandis*, Verbenaceae) in Coastal Odisha, *Int J Cur Microbiol App Sci*, 7(11) (2018), 1421-1432.

Truzi, C.C., Holzhausen, H.G., Álvaro, J.C., Laurentis, V.L., Vieira, N.F., Vacari, A.M. and Bortoli, S.A.D., Food Consumption Utilization, and Life History Parameters of *Helicoverpa armigera* (Lepidoptera: Noctuidae) Reared on Diets of Varying Protein Level, *J Insect Sci*, 19(1) (2019), 1–7.

Tschopp, A., Riedel, M., Kropf, C., Nentwig, W. and Klopfstein, S., The evolution of host associations in the parasitic wasp genus *Ichneumon* (Hymenoptera: Ichneumonidae): Convergent adaptations to host pupation sites, *BMC Evolution Biol*, 13 (2013), 74.

Tuan, S., Yeh, C., Atlihan, R. and Chi, H., Linking Life Table and Predation Rate for Biological Control: A Comparative Study of *Eocanthecona furcellata* (Hemiptera:Pentatomidae) Fed on *Spodoptera litura* (Lepidoptera:Noctuidae) and *Plutella xylostella* (Lepidoptera: Plutellidae), *J Econo Entomol*, 109(1) (2016), 13–24.

Tuan, S.J., Yeh, C.C., Atlihan, R., and Chi, H., Linking Life Table and Predation Rate for Biological Control: A Comparative Study of Eocanthecona furcellata (Hemiptera: Pentatomidae) Fed on Spodoptera litura (Lepidoptera: Noctuidae) and Plutella xylostella (Lepidoptera: Plutellidae), *J Econo Entomol*, 1–13 (2015) 1-12.

Ullah, M.I., Arshad, M., Ali, S., Iftikhar, Y., Jaime, M.O. and Foster, J.E., Host Utilization of the Endoparasitoid, *Cotesia glomerata* L. (Hymenoptera: Braconidae) in Different Instars of *Pieris brassicae* L. (Lepidoptera: Pieridae), *The Egyptian J Biol Pest con*, *26*(3) (2016), 625-629.

Ulubelen, A., Meriçli, A.H., Meriçli, F., Kilinçer, N., Ferizli, A.G., Emekci, M. and Pelletier, S. W., Insect repellent activity of diterpenoid alkaloids, *Phytother Res*, 15(2) (2001), 170- 171.

Usha Rani, P. and Ha vukkala, I., Predatory and Mating Behaviour of *Eocanthecona furcellata* (Wolff.) (Heteroptera: Pentatomidae) a Promising Natural Enemy of Lepidopterous Larvae, *Biol Control*, 7 (1) (1993), 9-11.

Uthamasamy, S., Influence of leaf hairiness on the resistance of bhendi or lady,s finger, *Abelmoschus esculentus*(L.) Moench, to the leafhopper, *Amrasca devastans* (Dist.), *Trop. Pest Manag*, 31 (1985), 294-295.

Van Lenteren, J.C. and Noldus, L.P.J.J., Whitefly-plant relationship: Behavioural and ecological aspects. In D Gerling (ed.). *Whiteflies: Their bionomics, pest status and management*. Hampshire, Intercept Ltd., 1990, pp. 47–89.

Vanitha, K., Raviprasad, T.N. and Shwetha, V., Life cycle of Eocanthecona furcellata Wolff. (Hemiptera: Pentatomidae) a predatory bug in cashew plantations, upon rearing on wax moth larvae, *J Entomol Zool Stu*, 6(2) (2018), 3007-3010.

Vasanthkumar, D., Roobakkumar, A., Rahaman, V.K.J. and Babu, A., Impact of temperature and pesticide applications on the prey consumption of *Mallada Desjardins* (Navas) (Neuroptera: Chrysopidae), a predator of red spider mite infesting tea, *Two and a Bud*, 59 (2011), 43-48.

Venkatesan, S., Seenivasagan, R. and Karuppasamy, G., Influence of prey species on feeding response, development and reproduction of the reduviid, *Cydnocoris gilvus* Burm. (Reduviidae: Heteroptera), *Entomon*, 22(1) (1997), 21 - 27.

Vennison, S.J. and Ambrose D.P., Biology, Behaviour and Biocontrol Efficiency of a Reduviid Predator, *Sycanus reclinatus* Dohrn (Heteroptera: Reduviidae) from Southern India, *Mitteilungen aus dem Zoologischen Museum in Berlin*, 68 (1) (1992), 143-156.

Vennison, S.J**.** and Ambrose, D.P., Biology of anassassin bug *Velitra sinensis* Walker (Insecta:Heteroptera: Reduviidae) from South India, *Indian J Entomol*, 52 (1990) 310-319.

Volkmar, C., Schumacher, K. and Müller, J., Impact of low-input pesticides usage on spider communities with special regards to accumulated effects, *Pesticides and Beneficial Organisms IOBC/ Wprs Bull*, 35 (2008), 18-25.

Wa¨ckers, F.L., Romeis, J. and Van Rijn, P.C.J., Nectar and pollen feeding by insect herbivores and implications for multitrophic interactions, *Annu Rev Entomol*, 52 (2007), 301–323.

Waldbauer, G.P., The consumption and utilization of food by insects, *Advan Insect Physiol*, 5 (1968), 229-288.

Watt, G., and Mann, H.N., The Pests and Blights of the Tea Plant. Calcutta: Gov. Printing Press, 1903, pp.429.

Wight, W., Tea classification revised, *Current Sci*, 31(1962), 298-299.

Wilson, F. and Huffaker, C.B., The physiology, scope and importance of biological control. In: Huffaker CH, Messenger PS, editors, *Theo Pract Biol Cont*. 1976, pp. 3-15.

Wu, J. and Baldwin, I.T., New insights into plant responses to the attack from insect herbivores. *Annual Rev Gen*, 44 (2010), 1-24.

Yasuda, T., Chemical cues from the *Spodoptera litura* larvae elicit preylocating behavior of generalist predatory stink bug *Eocanthecona furcellata, Entomol Exp Appl*, 82 (1997) 349-354.

Yasuda, T., Effects of (E)-Phytol of several lepidopteran species in prey locating behaviour of generalist predatory stink bug *Eocanthecona furcellata* (Heteroptera: Pentatomidae), *Entomol Sci*, 1(1998), 159-164.

Yasuda, T., Role of semiochemicals in prey- locating behavior of a generalist predatory stink bug *Eocanthecona furcellata* (Heteroptera: Pentatomidae), *Japan Agric Res Quart*, 34 (2000), 15-20.

Yeoh, H.H., Wee, Y.C. and Watson, L., Leaf protein contents and amino acid patterns of dicotyledonous plants. *Biochem Systemat Ecol*, 20 (1992), 657–63.

Zhao, L.Y., Chen, J.L., Cheng, D.F., Sun, J.R., Liu, Y. and Tian, Z., Biochemical and molecular characterizations of *Sitobion avenae*-induced wheat defense responses, *Crop Protection*, 28 (2009), 435–442.

Zhu, P., Wang, G., Zheng, X., Tian, J., Lu, Z., Heong, K.L., Xu, H., Chen, G., Yang, Y. and Gurr, G.M., Selective enhancement of parasitoids of rice Lepidoptera pests by sesame (*Sesamum indicum*) flowers, *Bio Control*, 60 (2015), 157–167.

Zulkefli, M**.,** Norman, K. and Basri, M.W., Life cycle of *Sycanus dichotomus* (Hemiptera: Pentatomidae) – A common predator of Bagworm in oil palm, *J Oil Palm Res*, 16(2) (2004), 50-56.

Appendices

Appendix-I

Publications from thesis

Name of the journal	International Journal of current advance research
ISSN number	(O)-2319-6475, (P)-2319-6505
DOI	http://dx.doi.org/10.24327/ijcar.2019. 19262.3705
Indexed in	**SCOPUS, WoS, Indian Citation Index, PUB MED Central, ELISVER**

International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: 6.614
Available Online at www.journalijcar.org
Volume 8; Issue 06 (D); June 2019; Page No.19258-19262
DOI: http://dx.doi.org/10.24327/ijcar.2019.19262.3705

Research Article

STUDY ON THE BIOLOGY, FEEDING BEHAVIOUR AND PREDATORY POTENTIAL OF *Sycanus* collaris (FABRICIUS) (HETEROPTERA: REDUVIIDAE), A NEW PREDATOR OF *Hyposidra talaca* (WALK.) (LEPIDOPTERA: GEOMETRIDAE), A MAJOR TEA PEST AND MASS REARING ON *Corcyra cephalonica* (STAINTON) IN LABORATORY

Suman Sarkar[1], Azariah Babu[1], Kaushik Chakraborty[2] and Bhabesh Deka[1]

[1]Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India
[2]Entomology Laboratory, Department of Zoology, University of Gour Banga, Mokdumpur, Malda, West Bengal, 732103, India

ARTICLE INFO

Article History:
Received 10th March, 2019
Received in revised form 2nd April, 2019
Accepted 26th April, 2019
Published online 28th June, 2019

Key words:

Sycanus collaris, predatory potential, tea looper, *Hyposidra talaca,* biological control agent.

ABSTRACT

The sustainable utilization of biological control agents in agro-ecosystems depend on the data on biology, bio-ecology and feeding behaviour of that biological control agents on their main or alternative host. In the present study, the biology, feeding behavior and predatory potential of a newly recorded reduviid predator *Sycanus collaris*, from tea ecosystem found predating on one of the major tea pests *Hyposidra talaca,* have been observed under laboratory conditions. The incubation period, duration of the nyphal stages and longevity of adult stages were observed both on *Corcyra cephalonica* (rice meal moth) and on *H. talaca.* The incubation period was recorded as 13.6±1.1 and 11.8±2.3, duration of nymphal stages as 58.4 ±3.9 and 64.8±4.1, adult longevity 99.8±3.5 and 108.6±2.8 days respectively on rice meal moth and tea looper respectively. The fecundity (total number of eggs laid /female) was found to be 282.0± 23.9 and 320.4± 44.2 eggs/female when feed on larvae of *C. cephalonica* and *H. talaca* respectively. Predatory potential of the reduviid bug *S. collaris,* has been studied by providing larvae of tea looper, *H. talaca* in laboratory. The predator *S. collaris* attacked more prey to satiate itself at a given point of time. In the case of free choice feeding condition, wherein the adult males consumed a 4.6±1.8 fifth instar larvae of *H. talaca* while the adult female consumed 5.0±1.6per day. However, the nymphal consumption varied between 3.2±1.3 on third instar and 2.2±0.8 fifth instar of looper. The feeding behaviour of the predator such as the time taken for approach and attacking, paralyzing, sucking on the prey were also recorded. The adult female could paralyze a grown-up looper within 5-8 seconds and sucked the body sap within 119-121 seconds. First instar nymph of the reduviid bug preferred only second instar larvae of looper and group feeding was observed whereas, with the advancement of the nymphal instar they prefer to predate on later stages of looper (fourth and fifth instars) when compared to the early instars.

INTRODUCTION

Reduviidae a large family belongs to the order Hemiptera, found to be efficient predators of different insect pest, preferably lepidopteran larvae (Ambrose *et al*., 2009). *Sycanus collaris*, known as assassin bug, all of its life stage efficiently feed on the target insect. Depending on the feeding on different insect the developmental period and fecundity rate is also different when fed on different hosts (George, 2000).The perennial monoculture crop tea (*Camellia sinensis* L.), provides a stable shelter, food and microenvironment for breeding for divers species of arthropod throughout the year (Babu *et al.,* 2014). Among them, some arthropods are considered as pest and some are considered as biological control agents. In the tea ecosystem of Dooars and Darjeeling regions of West Bengal among different *Sycanus* species of Reduviidae family of order Hemiptera only *Sycanus croceovittatus* (Dohrn) have been reported (Das *et al.,* 2010 and Mitra *et al*., 2018). The sequential predatory behaviour of the Genus *Sycanus* on its prey is very active (Ambrose, 1999). Sahayaraj, (2012) developed a rearing technique of reduviids using meat-based artificial diets which couldbe useful for mass rearing and pest management programme. There is no information available on *Sycanus collaris* as a predator of *H. talaca* in tea ecosystem of West Bengal and North East India

Corresponding author:* **Suman Sarkar
Department of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India

Name of the journal	International journal of Scientific Research
ISSN number	2277 - 8179
DOI	10.36106/ijsr
Indexed in	International Scientific Indexing, Indian Citation Index, UGC Sr.No.49217

ORIGINAL RESEARCH PAPER

Volume-9 | Issue-3 | March-2020 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

PREDATORY BEHAVIOUR OF EOCANTHECONA FURCELLATA ((HEMIPTERA: PENTATOMIDAE) FEEDING ON LARVAE OF HYPOSIDRA TALACA (LEPIDOPTERA: GEOMETRIDAE), A MAJOR TEA PEST OF NORTH EAST INDIA

Zoology

Suman Sarkar — Department Of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India.

Azariah Babu* — Department Of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India. *Corresponding Author

Kaushik Chakraborty — Department Of Zoology, Raiganj University, Uttar Dinajpur, West Bengal, 733134, India.

Bhabesh Deka — Department Of Entomology, Tea Research Association, North Bengal Regional R & D Centre, Nagrakata, Jalpaiguri, West Bengal, 735 225, India.

ABSTRACT

Eocanthecona furcellata (Wolff.) is an important predator of several pets associated with agricultural crops, especially lepidopteran pest. The predatory behaviours of this insect such as approach and attacking, paralyzing, sucking were recorded. The adult female could paralyze a larvae in 4.7±0.6 seconds and suck the body sap within 95.3±5.0 seconds. First instar nymph preferred only second instar larvae of looper and group feeding was observed. The incubation period was recorded as 7.6±1.1days and total duration of nymphal stages was 18.4±1.5days. The longevity of adult male and female were recorded as 30.0±1.9 days and 32.8±0.8 days respectively. The hatchibility rate of egg was 94.5% with 96.2% adult survival rate was recorded, when reared on *Coeryra cephalonica*. Moreover this study revealed that, in the absence of main host, *C. cephalonica* could be used as alternative host to mass rear *E. furcellata,* successfully for field release.

KEYWORDS

Predatory Behaviour, *Eocanthecona furcellata*, Tea Looper.

INTRODUCTION:

Perennial monoculture crop tea (*Camellia sinensis* L.), provides shelters, food, microenvironment for breeding for divers species of arthropod throughout the year (Babu *et al.,* 2014). Tea plant foliage is infested by about 167 arthropod species in the tea belt of Northeastern regions of India (Mukhopadhyay and Roy, 2009). The looper stage of the lepidopteran pest *Hyposidra talaca* have migrated and adapted in tea growing area of Darjeeling Terai and the Dooars and Assam causing substantial damage to the crop (Basumajumdar and Ghosh, 2004). Among them some arthropods are considered as pest and some are considered as biological control agents. In the tea ecosystem of Dooars and Darjeeling regions of West Bengal there are 29 species belonging to 28 genera of hemipteran bugs, among them the highest species is of family Pentatomidae have been recorded (Mitra *et al.,* 2018). In order to concise the application of synthetic chemical pesticides, in the tea gardens for the management of lepidopteran tea pests especially *H. talaca*, biological control measures are being adopted worldwide (Mobed *et al*., 1992 and Gillespie *et al*., 2000). *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae) is one of the important predator that has recently included in the field of biological control due to its potential to prey different orders of insect pests such as, lepidoptera, coleoptera and heteroptera (De Clercq, 2000). This predacious stink bug *E. furcellata* (Wolff) is efficient lepidopteran caterpillar predators in the field of, soyabean, beans, vegetable and forest ecosystems found to feeding on fall army worm, *S. frugiperda* in maize (Navarajanpaul, 2002). In the present study, predatory behaviour and stage specific predation of this stink bug while feeding on larvae of *H. talaca* and biology and survival rate on alternative host were studied.

MATERIALS AND METHODS:

REARING OF HOSTS AND PREDATOR:

Field collected healthy moths of *H. talaca* were, put them into mating and egg laying chamber (glass chimney) with 10% honey solution as food source. After hatching of the eggs, larval stages were reared on tea leaves preferably using TV1 (Tocklai Vegetative 1) under the laboratory conditions (27± 2°C, 70-80% RH and 16:10 LD photoperiod) by following the methodology developed by Babu *et al.,* (2014). Eggs of rice meal moth of *Corcyra cephalonica* were collected from Uttar Banga Krishi Viswavidlaya, Coochbihar, India and reared on plastic container containing maize powder under the same laboratory conditions as an alternative host of *E. furcellata*. Adult stink bug were collected from the TRA (Tea Research Association) experimental plot and kept into glass chimney for mating and laying eggs containing few tea shoots along with larvae of *H. talaca*. Shade tree barks were kept inside the mating chamber for egg laying and the egg masses were transferred into separate chamber. Newly hatched first instar and then second instar nymphs of the predator were reared in group. Third, fourth, fifth and adult stages were put into separate Tarson sample container (Diameter 4.3, height 5.4cm) to avoid cannibalism following the method of Lenin and Rajan, (2016) with slight modifications.

PREDATORY BEHAVIOUR OF *E. FURCELLATA*:

In order to record the predatory behaviour of all the life stages of *E. furcellata* on the different larval instars of *H. talaca*, an experiment was conducted using large petridish (14.5cm in diameter). Each life stage of *E. furcellata* were maintained for 1.5h starved condition and then placed into that petridish with different larval instars of *H. talaca* separately. The time taken by the stink bug for approach attacking, paralyzing and sucking the prey by different life stages of were recorded (Rajan *et al.,* 2017). Mean were calculated by Tukey-Kramer HSD Post-Hoc Test.

STAGE SPECIFIC PREDATION:

Selection of specific stage of larvae of *H. talaca* and predation by different life stage *E. furcellata* were also studied under the same laboratory conditions. Different larval instars like, II, III, IV and V of *H. talaca* were provided to the individual stages of *E. furcellata*. The maximum number of prey consumption and type of feeding were observed at 24h interval.

STATISTICAL ANALYSIS:

Mean of the experiment of predatory behaviour was analyzed by Tukey's multiple comparison test at $p<0.05$.

REARING OF *E. FURCELLATA* ON ALTERNATIVE HOST:

From the laboratory rearing conditions 100 eggs were separately put into glass chimney and observed carefully till hatched. Newly hatched first instar nymphal instars were transferred into individual container and head crushed larvae of *C. cephalonica* were provided as food source from the laboratory stock culture. Every nymphal instars were carefully maintained till moulted into adult. Ten pairs of saults were separately put into glass chimney along with sufficient larvae of rice meal moth. After laying eggs onto the previously provided shade tree bark, it was collected and put into separate chimney. The incubation period, each nymphal duration for development, mortality and survival rate of each life stages were recorded at 24h intervals.

Name of the journal	Journal of Biopesticides
ISSN number	(P) 0974-391X, (O) 2230-8385
Citation in	Web of Science
Indexed in	SCOPUS – Elsevier, Index Copernicus, SCImago, Zoological Record-ISI, Thomson Reuters

Biology and life history of *Cotesia ruficrus* (Hymenoptera: Braconidae) a potential parasitoid of *Hyposidra talaca* (Lepidoptera: Geometridae) larvae, a major tea pest

Suman Sarkar*[1], Azariah Babu[1], Kaushik Chakraborty[2] and Bhabesh Deka[1]

ABSTRACT

The black inch looper, *Hyposidra talaca* is considered as a major pest in tea in northern part of West Bengal and North East India. Among the natural enemy reported, *Cotesia ruficrus* is considered as one of the most gregarious endo-parasitoid wasps. In order to assess the potential of this natural enemy, a study on the biological parameters of *C. ruficrus* was evaluated on the different developmental stages (second, third and fourth instars) of the host larvae, *H. talaca*. The results indicated that, the mean duration of larval development was 12.0 ± 0.32, 11.0 ± 0.45 and 9.2±0.37 days in second, third and fourth instar host larvae respectively. The pupal period of *C. ruficrus* was found to be significantly different among the different larval stages of *H. talaca*. The successful parasitism of *C. ruficrus* and the number of cocoon formation of the parasitic wasp was reliant on the stage, body size and the physiological conditions of host larvae that it parasitizes. A maximum of 65.2±1.85 cocoons were formed when the fourth instar host larvae parasitized, followed by 27.2±3.04 in the third instar and 4.6±0.68 in the second instar host larvae. The number of females and males hatched out from each clutch was compared to the different host stages. .

Key words: Black inch looper, *Hyposidra talaca,* Parasitic wasp, *Cotesia ruficrus,* Tea, Parasitism.

MS History: 12.04.2020 (Received)-05.05.2020 (Revised)- 10.05.2020 (Accepted).

Citation: Suman Sarkar, Azariah Babu, Kaushik Chakraborty and Bhabesh Deka. 2020. Biology and life history of *Cotesia ruficrus* (Hymenoptera: Braconidae) a potential parasitoid of *Hyposidra talaca* (Lepidoptera: Geometridae) larvae, a major tea pest. *Journal of Biopesticides,* **13**(1):79-84.

INTRODUCTION

The black inch looper, *Hyposidra talaca* (Lepidoptera: Geometridae), considered as a major tea pest, which causes considerable damage to tea plantations leading to loss in yield and the quality of manufactured tea as well. In general, chemical insecticides are being used for the control of tea pests including this black inch looper (Hazarika *et al*., 2009) by the tea planters. Hence the use of chemical pesticides has many negative impacts such as development of resistance in insects, abolition of natural enemies, imbalance in natural ecosystems and increasing environmental contamination besides causing ill-health to human beings. Therefore, non-chemical control measures are extremely important for the management of this destructive pest (Deka *et al*., 2017; Nguyen *et al*., 2018). Biocontrol agents play a vital role for the management of pests, especially lepidopteran pests with a well-balanced ecological systems, by helping in the reduced use of pesticides in major agricultural crops, including tea.

The tea ecosystem, which is considered as a semi-forest ecosystem, harbor more than 1034 arthropod species associated within (Hazarika *et al*., 2009). Among the diversity of arthropod natural enemies in sub-Himalayan tea growing region of northern part of West Bengal, parasitoid groups belonging to the families such as Braconidae and Ichneumonidae are dominant ones. Among the parasitoids,

Appendix-II

Seminar attended certificate

AMITY UNIVERSITY CHHATTISGARH

ST. XAVIER'S COLLEGE (AUTONOMOUS)
PALAYAMKOTTAI
(Recognized as 'College with Potential for Excellence' by UGC)
(Re-accredited by NAAC with 'A' Grade with a CGPA of 3.50)

Sponsored by
Chhattisgarh Council of Science & Technology

6TH BIOPESTICIDE INTERNATIONAL CONFERENCE (BIOCICON-2019)
06th – 08th MARCH, 2019

Certificate

This is to certify that Dr./Mr./Ms./Mrs . Suman Sarkar ..... has Participated/Presented a paper/oral/e-poster entitled Impact of Parasitism on the developmental disruption change in no. & morphology of haemocytes of a major tea defoliator Hyposidra talaca In 6th Biopesticide International conference (BIOCICON-2019) held at Amity University Chhattisgarh, Raipur .

Organizing Secretary
Dr. K. Sahayaraj Dr. Piyush Parkhey

Prof (Dr) Ravikant Singh

Convener
Rev. Dr. V. Britto, S.J.

TOCKLAI TEA RESEARCH INSTITUTE
Tea Research Association, Jorhat : Assam

35th Tocklai CONFERENCE
February 22-23, 2019 | Jorhat, Assam

SustainabiliTea challenges & the way forward

Certificate of Participation

This is to certify that Prof./Dr./Mr./Ms. ....Suman Sarkar..... has participated/presented oral/poster paper in the 35th Tocklai Conference held on 22-23 February, 2019 at Tocklai Tea Research Institute, Jorhat

S. P. Baruah
Organising Secretary

S. Roy
Organising Secretary

A. K. Barooah
Director

National Seminar
on
"Recent Advances in Bio-Sciences"
&
Annual General Meeting of Zoological Society of Assam
21st & 22nd September, 2018
organised by **Department of Zoology, Pragjyotish College, Guwahati**
in association with Zoological Society of Assam (ZSA)

Certificate of Participation

This is to certify that Prof. /Dr./Mr./Ms. Suman Sarkar
of North Bengal Regional R & D Centre *attended and participated as Keynote Speaker/Invited Speaker/Chairperson/Paper Presenter/Poster Presenter/Other registered participant in the National Seminar on "Recent Advances in Bio-Sciences" & Annual General Meeting of Zoological Society of Assam, held on 21st & 22nd September, 2018 at Pragjyotish College, Guwahati - 781009, Assam, India.*

(Priyabrata Lahkar)
President
ZSA

(Jogen C. Kalita)
General Secretary
ZSA

(Jayanta Deka)
Organising Secretary
National Seminar

National Level Seminar on
Current Research in Biological and Biomedical Sciences
February 9, 2016
Organized by
The Department of Zoology
University of Gour Banga
Malda-732103

Certified that Prof./Dr./Mr./Ms ..... Suman Sarkar .....
of ..... Tea Research Association North Bengal Regional Centre ....., India
~~participated~~/presented a ~~Key Note Address~~ /~~Plenary Lecture~~ /~~Lead Lecture~~/ Paper(Oral/~~Poster~~)
entitled .....
.....
in the National Level Seminar on Current Research in Biological and Biomedical Sciences organized by the Department of Zoology, University of Gour Banga, on February 9, 2016.

Dr. Shyamapada Mandal
Organising Secretary &
Head, Department of Zoology, UGB

Professor Gopalchandra Misra
The Vice-Chancellor, UGB

Appendix-III

SUMAN SARKAR

CURRICULUM VITAE

PROFILE

A dedicated and capable research fellow with four years of research experience in Entomological field, especially in tea field. Experience in biochemical analysis of tea leaf and insect gut enzyme. Seeking a project development position, where there is a need for a biological management of insect pest. Good communication and organizational skills. A confident presenter at

CONTACT

PADMAPUKUR MORE, BALURGHAT, DAKSHIN DINAJPUR, WB, INDIA

PADMAPUKUR MORE, P.O- BALURGHAT, WB, INDIA, 733101

sumanrb25@gmail.com

+91 9932097107

+91 9932097107

ACADEMIC

***Perusing Ph. D** from Tea Research Association (NBRRDC) in collaboration with University of Gour Banga,
Session of Registration: 2016-2017

University: University of Gour Banga
Session: 2012-2014
Course: Master of Science
Subject: Zoology (Specialization- Entomology)

College: Raiganj SN Mahavidyalaya
Session: 2009-2012
Course: Bachelor of Science
Subject: Zoology (Honours) (General-Botany and Chemistry)

School: Balurghat LMAU Vidyalaya
Session: 2006-2008
Course: Higher Secondary
Subject: Physics, Chemistry, Mathematics, Biology, English and Bengali

RESEARCH EXPERIENCE

- **Project Scientist** in Entomology Department of Tea Research Association under EID PARRY (I) Pvt. Ltd., Chennai, funded research project from November 2016 to December 2019.
- **Junior Research Fellow** in Microbiology and Mycology Department of Tea Research Association under DST Kolkata, funded research project from April 2016 to October 2016.
- **Junior Research Fellow** in Entomology Department of Tea Research Association under DST Kolkata, funded research project from August 2015 to March

WORK EXPERIENCE

Microbiologist from September, 2014 to July, 2015
Matri Water Products Pvt. Ltd. Malda, West Bengal, India

- Work with senior Quality Developer
- Carry out quality assurance for optimizing use

SKILLS

- Insect rearing under laboratory conditions developing artificial diets
- Field survey for insect pest and natural enemy assessment
- ELISA technique for insect gut enzyme analysis
- Plant leaf biochemical analysis using UV-spectrometry technique
- Data analysis and representation

RESEARCH INTEREST

- Insect-Host-Parasitoid/Predator tri-trophic interactions
- Mass rearing of insect natural enemies in laboratory
- Development of a biological pest management technique

PUBLICATIONS

- International peer reviewed journal- 7
- National journal- 1
- Book chapter-1

Appendix-IV

Identification certificate of *S. collaris*

Crop Protection Research Centre (CPRC)
Department of Advanced Zoology and Biotechnology,
St.Xavier's College (Autonomous),
Palayamkottai - 627 002, Tamil Nadu, India.

Dr.K.Sahayaraj, M.Sc., M.Phil., Ph.D., PGDCA
Director

Ref. No: Date : .....

Ref No. KSR/Inlden/05/2018 20/11/2018

TOWHOM SOEVER IT MAY CONCERN

We received the insect specimens in good condition. Considering the taxonomical features of the insect, it is identified as a reduviid predator namely, *Sycanus collaris* Fab. (Insecta: Hemiptera: Heteroptera: Reduvioidea: Reduviidae).

With Kind Regards,
K.Sahayaraj

To
Dr. A. Babu
Deputy Director (Research),
Tea Research Association,
North Bengal Regional R & D Centre,
Nagrakatas, Jalpaiguri District,
West Bengal-735225
India.

Off: 0462- 2560744, Fax: 91-0462-2561765; Res: 0462-2542303; e-mail:ttn_ksraj@sancharnet.in / ksraj42@gmail.com.

Appendix-V

Certificates from authority of Tea Estate

QUALITY TEA PLANTATIONS PRIVATE LIMITED

KURTI TEA ESTATE, P. O. **NAGRAKATA** - 735 225, DIST. JALPAIGURI (W.B.)
PHONES : (OFFICE) +91-3563-200109, (MGRS BUNG)+91-3563-200112 E-mail : kurtitea@gmail.com
CIN NO. U01132WB1989PTC047068 GSTIN : 19AAACQ0597K1Z0

16th March, 2020

CERTIFICATE

It gives me immense pleasure to learn that, Mr. Suman Sarkar has successfully completed mass rearing of a predatory bug *Sycanus collaris* belongs to the order Hemiptera of the family Reduviidae, a voracious predator of larvae of *Hyposidra talaca* (Lepidoptera: Geometridae) and an attempt has been made to release 100 adult bugs in my garden.

This is a part of work of Mr. Sarkar's Ph. D programme. He is pursuing Ph.D from Tea Research Association (NBRRDC) affiliated to the University of Gour Banga under the guidance of Dr. Kaushik Chakraborty and Dr. Azariah Babu.

Mr. Sarkar has done the experiment on the predatory potentiality on larvae of *H. talaca* under laboratory and based on the outcome of experimental results, he has confidently released them in tea field to study its establishment. This predatory bug is not found to be harmful to tea plant and human as well.

It is hoped that, this work will provide an excellent idea to improve IPM tools for controlling tea looper pest biologically.

Manager
Kurti Tea Estate
Manager
Kurti Tea Estate

502, Mangalam- 'A', 24 Hemanta Basu Sarani, Kolkata - 700 001, India
Phones : +91-33-22304273 / 8994 / 22435274 Fax : +91-33-2243016
E-mail : qtpltea @gmail.com / info@qtplt.com

HOPE TEA GARDEN
P.O. : Nagrakata-735 225
Dist : Jalpaiguri
Phone: (03565) 270202 (O)
(03565) 270201 (R)

Certificate

I am very happy to see that, about 120 predatory bugs, *Sycanu scollaris* belongs to the order Hemiptera of the family Reduviidae are going to release in my garden with the direction of Dr. Azariah Babu. *S. collaris* is a predator of larvae, which was reared on larvae of *Hyposidra talaca*, a major tea pest and mass produced under laboratory conditions by Mr. Suman Sarkar,TRA,Nagrakata.

This research work is a part of Mr. Sarkar's Ph. D., programme. He is pursuing Ph.D from Tea Research Association (NBRRDC), affiliated to the University of Gour Banga under the guidance of Dr. Kaushik Chakraborty and Dr. Azariah Babu.

Based on the laboratory study, Mr. Sarkar reported that, all the life stages of *S. collaris* predate on all the larval stages of *H. talaca*. *S. collaris* has no harmful character on tea plant and human being.

I deeply appreciate and all the success of this preliminary work, which has given an indication that conservation of such natural enemies in tea ecosystem, is mandatory for successful management of *H. talaca* in an eco-friendly manner.

MANAGER
HOPE TEA GARDEN
MANAGER
HOPE TEA GARDEN

GOODRICKE GROUP LIMITED
Regd.Office : "Camellia House", 14, Gurusaday Road, Kolkata-700 019
A Camellia Plc. U.K. Group Company

Appendix-VI

Plagiarism checking report

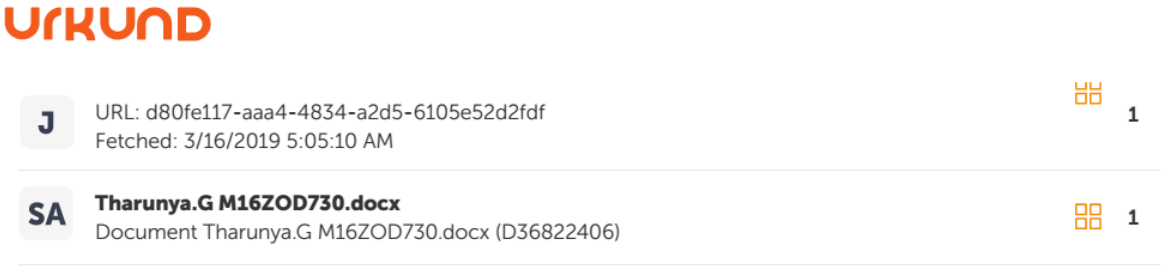
URKUND

Document Information

Analyzed document	File_for_Plagiarim.docx (D77347782)
Submitted	7/31/2020 11:53:00 AM
Submitted by	MR. AJAY MISRA
Submitter email	ajaymisrachs@gmail.com
Similarity	6%
Analysis address	ajaymisrachs.raiuni@analysis.urkund.com

Sources included in the report

W	URL: https://docplayer.net/91640407-Journal-of-integrative-agriculture-2017-16-0-availa ... Fetched: 7/31/2020 11:56:00 AM	2
W	URL: https://www.researchgate.net/publication/259431063_Egg-laying_pattern_of_Hyposidra ... Fetched: 7/31/2020 11:56:00 AM	1
W	URL: https://en.wikipedia.org/wiki/Hyposidra_talaca Fetched: 7/31/2020 11:56:00 AM	1
SA	**THESIS Sree Chandna P.docx** Document THESIS Sree Chandna P.docx (D75796648)	1
SA	**Archita Barua_Zoology.docx** Document Archita Barua_Zoology.docx (D19532374)	20
W	URL: https://www.researchgate.net/publication/334537385_Study_on_the_Biology_Feeding_Be ... Fetched: 7/31/2020 11:56:00 AM	1
W	URL: https://journalijcar.org/sites/default/files/issue-files/9616-A-2019_0.pdf Fetched: 7/31/2020 11:56:00 AM	44
W	URL: https://archive.org/stream/ArtificialRearingReduviidae2016/%5BK._Sahayaraj%2C_R._B ... Fetched: 11/13/2019 4:00:28 PM	1
W	URL: https://www.researchgate.net/publication/334801166_Effects_of_Entomopathogenic_Fun ... Fetched: 7/29/2020 8:32:05 AM	1
SA	**Shabistana Nisar (DD1578) - Thesis.docx** Document Shabistana Nisar (DD1578) - Thesis.docx (D29445863)	1
W	URL: https://www.researchgate.net/publication/260228286_Comparative_biology_and_product ... Fetched: 5/2/2020 3:45:02 AM	3
SA	**L. KALAIYARASI.pdf** Document L. KALAIYARASI.pdf (D60943373)	1
	Development of weather based forewarning model for major pests of rice	


URKUND
J
URL: d80fe117-aaa4-4834-a2d5-6105e52d2fdf
Fetched: 3/16/2019 5:05:10 AM
1
SA
Tharunya.G M16ZOD730.docx
Document Tharunya.G M16ZOD730.docx (D36822406)
1