THE ENTOMOLOGICAL SOCIETY OF INDIA

New Delhi, 110012

ESI- BEST Ph.D. THESIS AWARD 2021

1. Name of the applicant: **Yana Venkanna**
2. Year of the award: **2021**
3. Date of birth: **09-11-1975**
4. Field of specialization: **Biological Control**
5. Mode of award collection: **In person**
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7. Educational qualifications beginning with the first-degree or equivalent (in a tabular form)

S.No.	Degree	Institution	Year
1	BSc Ag	Acharya NG Ranga Agricultural University, A.P.	2001
2	MSc Ag., Entomology	Acharya NG Ranga Agricultural University, A.P.	2003
3	PhD in Entomology	ICAR-Indian Agricultural Research Institute, New Delhi.	2021

8. Date on which qualifying examination passed: **28-11-2019**
9. Transcript of the course work done, if any, as part of the Ph.D. degree programme. (**Enclosed**)
10. Was the thesis submitted in partial fulfillment of the requirement of the Degree? **Yes**
11. Date on which successfully completed thesis viva voce examination: **20-01-2021**
12. Date of the Degree/provisional certificate: **12-02-2021**
13. Have you received best thesis award earlier? **No**

14. Details of the thesis
    (i) Title of the thesis: **Predatory behaviour of coccinellid beetle, *Cheilomenes sexmaculata* (Fab.) and its predation risk on prey**
    (ii) Department/Division/Institution where research work was done: Biological Control Laboratory, Division of Entomology, PG School, **ICAR-Indian Agricultural Research Institute**, New Delhi.
    (iii) Institution/University to which thesis was submitted as a part of the Ph.D. degree programme: **PG School, ICAR-Indian Agricultural Research Institute, New Delhi.**
    (iv) Name and designation of the thesis supervisor:
    Dr. Sachin Suresh Suroshe
    Principal Scientist
    Division of Entomology
    ICAR-IARI, New Delhi.

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

Coccinellid beetles are the most important predators which are being used against many soft bodied pests due to their voracious feeding potential (FP) and rapid numerical response (NR) in many agricultural and horticultural ecosystems. Introduction and augmentative releases of these beetles were proved for their efficacy to suppress certain crop pests. These traditional biological control methods mostly depend on feeding potential of predator on its prey. Recent advances in biological control studies have brought certain tri-trophic interactions related aspects such as non-consumptive effects of predator on its prey, indirect defense of plants through Herbivore Induced Plant Volatiles (HIPVs), induction of indirect defense through synthetic elicitors and development of genetically modified crops which change behavioral response of pest by release of olfactory cues (EBF-Wheat).

In order to have a robust and sustainable bio-control strategy, we must strive to decipher predator-prey relationship at each level, so that, the effect of biological control could be enhanced to maximum fold. Despite of its scope in biological and bio-rational method of pest control, a comprehensive study on predator-prey relationship and chemical mediated tri-trophic interactions on a particular crop-pest-predator is lacking.

Hence, the present investigations were conducted using a versatile native coccinellid species, *Cheilomenes sexmaculata* (Fab.) which is known to remains active throughout the year with a wide geographic distribution and vast host range in India. Cotton aphid, *Aphis gossypii* Glover has taken as prey being a key pest of many agri-horticultural crops with a wide host range of about 320 plant species covering 46 families. As it is known worldwide as a key pest of cotton, *Gossypium hirsutum* L., was taken as host plant.

Biological suppression of pest is a complex phenomenon which greatly determined by the foraging behaviour of its predator. A simplified depiction of prey population dynamics under predation of each stage of predator can provide information on effective stages of predator and their efficiency. To realize the concept like non-consumptive effect of predator on prey, a deep understanding of oxidative stress levels and its biological effects on prey must be worked out to explore and develop new tools for the insect pest suppression. Assessment of risk effect through bio-chemical oxidative stress markers can reveal possible mechanisms involved in non-consumptive effects.

Predator-prey interactions are strongly influenced by herbivore induced plant volatiles (HIPVs) released from the host plant which plays a crucial role in attraction of predators towards the habitat and pest's (prey) colonies. The chemicals involved in the tri-tropic interactions can alter the behavior, physiology and population buildup of prey and might be exploited to develop formulations to attract predatory beetles to a particular crop ecosystem for their further conservation.

Keeping this in view and the availability of scanty information, the present studies were conducted with the following objectives.

a) To study the predatory behaviour of *C. sexmaculata* against cotton aphid, *A. gossypii.*

b) To assess the predation risk induced by *C. sexmaculata* on the cotton aphid, *A. gossypii.*

c) To study the orientation response of *C. sexmaculata* towards the prey and host plant extracts.

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

Biology of *C. sexmaculata* on *A. gossypii* was studied at controlled conditions of 25±1 °C, 65±5% RH and 14 hr of photo period in environmental chambers (Oliveira *et al*., 2010). Cut leaf of cotton was used as substrate by keeping in a Petri plate. Aagarose based Hoagland's media containing essential plant nutrients was used to keep the prolonged freshness of leaf (Nazarideljou *et al*. 2019). Biological and morphometrical observations were recorded on each stage of predator.

Feeding potential and life table studies were conducted in the Biological Control Laboratory, Division of Entomology, ICAR-IARI, Pusa at controlled conditions similar as followed for biology. Number of preys consumed was worked out by deduction of remaining aphid count and control mortality from the total number of aphids (Fand *et a*l. 2010a). Feeding potential throughout the life of predator was analysed through 'CONSUME-MSChart' (Chi 2012a) to display age-specific consumption (kx), age-stage-specific consumption (Cxj) and the net consumption rate (C0). Data on duration, mortality and number of eggs laid was subjected to the construction of age-stage and two-sex life tables using TWOSEXMS-Chart (Chi 2012b).

A functional response study at various densities of aphid was conducted (Omkar, 2013). The polynomial logistic regression of the proportion of aphid killed in relation to the initial numbers was carried out for an insight about the type of functional response (Trexler and Travis, 1993; Juliano, 2001). As the consumed prey was not replaced during the foraging period, Roger's random attack equation (Rogers-II functional response equation) was used to fit the curve and estimate the functional response parameters (Royama, 1971; Rogers, 1972). Whereas, the numerical response determined by using a method given by Veeravel and Baskaran (1997).

Finite rate of increase (λ) of aphid per day was calculated from the constructed fecundity-life table (Fand *et al*. 2010b). The total response of predator was taken as a product of functional response and numerical response. All the parameters *viz*., finite rate of increase of prey (λ), functional response (FR), numerical response (NR) and total response (TR) of predator were assessed as a function of single factor *i.e*., initial prey density (N_0) by keeping the duration *i.e*., total time (Tt) as one day. The change in aphid population was projected graphically by simulating the respective equations for the different instars of grub, male and female of *C. sexmaculata*.

For non-consumptive effect studies, developed a simple method of aphid rearing on Mesta seedlings to get sufficient population, clear visibility for counting and to minimize the disturbance to the study organism (*A. gossypii*). A container was designed with a double cylinder system using Petri dishes and iron meshes for the treatment impose. Superoxide dismutase activity (SOD) was quantified following the method given by Lukasik *et al*. (2012). Catalase (CAT) activity (Aebi, 1984) and Malondialdehyde (MDA) content (Halliwell & Gutteridge, 1990) was assessed based on protein content determined using Bradford (1976) method.

Cotton leaves collected from different treatments were extracted for volatiles using two different solvents, n-Hexane and Dichloromethane (DCM). Extracts were analyzed by GC-MS for the identification of HIPVs (Magalhaes *et al*., 2018). Orientation response of *C. sexmaculata* to the HIPVs was studied using Y-tube olfactometer (Oliveira and Pareja, 2014).

Data was analyzed through R software (R-Core Team 2020) using FRAIR package (Pritchard *et al*., 2017) for functional response. Feeding potential was analyzed through 'CONSUME-MSChart' (Chi, 2012a). Data on duration, mortality and number of eggs laid was subjected to the construction of age-stage and two-sex life tables using TWOSEX-MS Chart (Chi, 2012b).

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

Host suitability and biology of *C. sexmaculata*: Cotton aphid *A. gossypii* was found to be the most suitable host for *C. sexmaculata* as evidenced by faster development (6.21±0.03 days) and more longevity of female (67±4.7 days) with high fecundity (756.5 eggs/ female). These positive biological attributes of *C. sexmaculata* on *A. gossypii* could contribute to its mass production for augmentative biological control.

Foraging behaviour of *C. sexmaculata*: For the grub stage, highest feeding potential (101.43 ± 3.04 aphids) was observed for the fourth instar which was higher than the gross feeding potential of all other instars. Among the adults, female recorded high feeding potential with a mean daily consumption of 43.13 ± 0.54 aphids. Life table studies showed intrinsic rate of increase (r) of 0.22 with the mean generation time of 27.29 days. The foraging behaviour studies revealed that, all the grub stages and adults displayed a type-II functional response. The IV instar grub has shown the lowest handling time with highest maximum predation (96.1aphids/day), followed by female (94.6), male (82.6) and other stages. However, female depicted a rapid extinction of aphid by keeping it below 25, as against fourth instar grub and male which affected extinction by keeping it below 30. So, the releases of fourth instar grub and female of *C. sexmaculata* could be advocated for the augmentative biological control of *A. gossypii*.

Oxidative stress in aphid under predation risk: We found that the oxidative stress is induced by olfactory cues, and even short duration exposure could raise antioxidant enzyme levels in the cotton aphid. Aphid's antioxidant mechanism uses up regulation of superoxide dismutase (SOD) and catalase (CAT) but not sufficiently to offset the oxidative damage that led to increased Malondialdehyde (MDA) content. SOD activity was significantly higher for active predation (9.75 ± 0.60 units/mg protein) and risk of predation (9.30 ± 0.40 units/mg protein) over controls (5.39 ± 0.13 units/mg protein). Catalase (CAT) showed highest activity in the aphids exposed to active predation (78.12 ± 5.26 H2O2 decomposed in µM/min./mg protein) followed by risk of predation (62.62 ± 5.22) and no-predation (26.48 ± 5.99) with significant differences between each other. A similar trend was also observed for Malondialdehyde (MDA) content as recorded 3.41 ± 0.30, 2.73 ± 0.39 and 1.40 ± 0.04 nM/mg protein in aphids exposed to active predation, risk of predation and no-predation, respectively. It is a clear indication of oxidative stress induction through the olfactory cues released by the predator as expressed stress enzyme levels with the same magnitude under active and risk of predation without significant differences between them.

Non-consumptive effects (NCEs) of *C. sexmaculata* on *A. gossypii*: NCEs did not influence the longevity, mortality and developmental period of aphids as there is no significant difference between the treatments and control. NCEs did have significant effects on the reproduction of aphids with reduced reproductive period and reduction in the number of nymphs produced per female during the total life span. A significant decrease in reproduction was recorded in aphids under active predation (32.35 ± 4.65 nymphs/female) as well as risk of predation (30.00 ± 4.40 nymphs/female) compared to the no-predation treatment (41.62 ± 5.60 nymphs/female). Both the active predation and risk of predation treatments resulted in a similar trend in lowering aphid reproduction, albeit with no significant difference between them. Despite the fact that there was no influence of NCEs on mortality and developmental period of nymphs produced by the parthenogenetic adults of *A. gossypii* which were exposed to predators, exposure clearly paved the way for the production of winged morphs. There was more than three-fold increase in the per cent of winged morphs produced by the aphids under predation-risk compared to the control. However,

there was no significant difference observed for winged morphs between the active-predation and risk-predation treatments (Fig. 1).

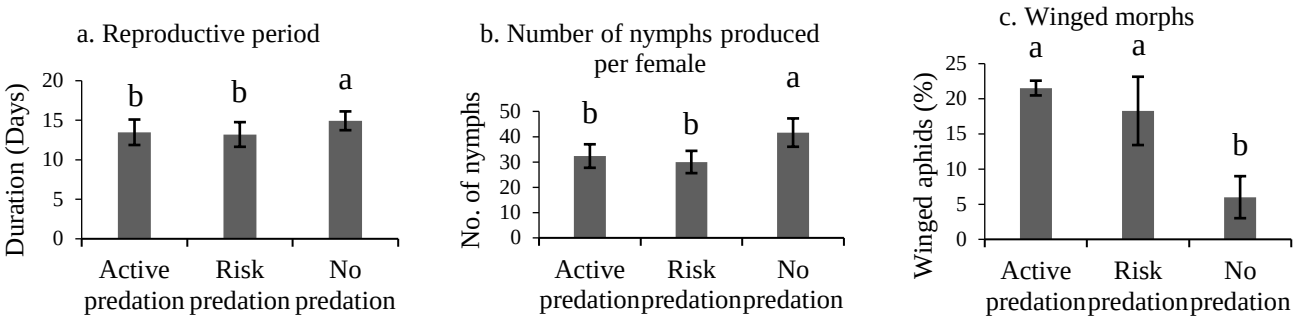

Fig. 1: Biological parameters differentially expressed by cotton aphid, *A. gossypii* under predation-risk of *C. sexmaculata*

A simple rearing technology of *A. gossypii*: Seeds of mesta, *H. cannabinus* grew well on absorbent cotton with germination per cent more than 90. In just three days after sowing, the seedlings with fully opened cotyledonary leaves were ready to host the aphids. Each Petri plate (10 cm Ɵ) could accommodate a stand of 25 seedlings. These seedlings supported the population buildup of *A. gossypii* up to 33 days after sowing. Nymphal population increased geometrically from first day to about 12 days after releasing, then increased exponentially up to 21-24 days and thereafter a faster decline was observed. The highest value of 568.9±24.8 nymphs per seedling was recorded at 24 ^{0}C and lowest at 27 ^{0}C (312±11/plant). Wingless adult population was obtained from sixth day after releasing at 24 and 27 ^{0}C whereas, it was observed from 12th day after releasing at 18 and 21 ^{0}C. The adult population was noticed highest at 24 ^{0}C (30±1.8) followed by 21 (27.3±0.9), 27 (22.2±3.4) and 18 ^{0}C (19.2±3.0) at 21, 24, 15 and 24 days after release, respectively. The cumulative total for winged adults was higher at 27 ^{0}C, which significantly differed with all other temperatures.

Orientation response of *C. sexmaculata* to the aphid induced HIPVs of cotton: Female and male beetles of *C. sexmaculata* have not shown any significant attraction to the un-infested leaf (UL) of neither DCM nor n-Hexane extractant at any of the tested concentration. Among the other extracts, infested leaf with aphid (WA) extracted with DCM as well as n-Hexane have shown significant attraction for both female and male beetles at all the concentrations. In the remaining extracts, aphid only (AO) and infested leaf without aphid (WOA) have shown significant attraction at one or other concentrations. Among all the extracts which have shown significant attraction over control, DCM-WA 5% was attracted the highest number of female beetles (83.8±3.24%) followed by Hexane-WA 5% (72.5±2.50%) and others. Similarly, male beetles were also mostly attracted to DCM-WA 5% (72.5±3.66%) and Hexane-WA 5% (70.0±4.23%). Male beetle has shown significant variation to the concentration gradient of WA by displaying 1, 5 and 10% on par with each other. Whereas, female has shown significant variation to the concentration gradient of both WA and aphid only (AO) extracts with higher number of groups with significant difference. Whereas, the extracts drawn from MeSA sprayed plants have not shown any significant attraction of beetles.

GC-MS analysis of different extracts: Volatile profile of extracts extracted through DCM exhibited an increase in number as well as abundance of certain compounds on infestation of aphid. It displayed 27 compounds by un-infested leaf (UL), increased to 38 for infested leaf with

aphid (WA) and 34 for infested leaf without aphid (WOA). Whereas, aphid only (AO) extracts could record only 22 compounds. UL and WOA have shown similarity in compounds and their abundance. Whereas, aphid infested leaf (WA) depicted a different pattern with the highest quantity of 3-Carene (20.15±1.56%) followed by (E)-β-Caryophyllene (13.06±1.51%), 1,4,7-Cycloundecatriene-1,5,9,9-tetramethyl-,Z,Z,Z- (8.98±0.38%), α-Bulnesene (4.89±0.96%) and 3-Hexenal (4.88±0.54%).Similar trend of increase in number of compounds was also recorded from the extracts drawn through the other solvent n-Hexane. n-Hexane extracts of WA resulted additional compounds *viz*., Heptane (17.36±5.09%), Pentadecane (10.39±5.21%), 3-Hexenal (7.93±1.79%), 2-Hexenal (7.09±0.89%) and α-Linolenic acid (2.79±0.99).

Comparative analysis of extracts revealed certain compounds as aphid induced HIPVs as they found in the extract of infested leaf but not in un-infested one. The DCM extract showed 14 additional compounds as HIPVs in which 3-Carene was found as predominant. Similarly, n-Hexane extract displayed 11 additional compounds as HIPVs in which Pentadecane was the highest. With the obtained results and analysis of volatile profile of different extracts, some of the compounds were identified as major aphid induced HIPVs namely, 3-Carene, Heptane, Pentadecane, 3-Hexenal, α-Copaene and α-Linolenic acid (Fig. 2). A blend of aphid induced HIPVs consisting of six major and eleven minor compounds was assumed to be responsible for the higher attraction of ladybird beetle, *C. sexmaculata* (Fig.3).

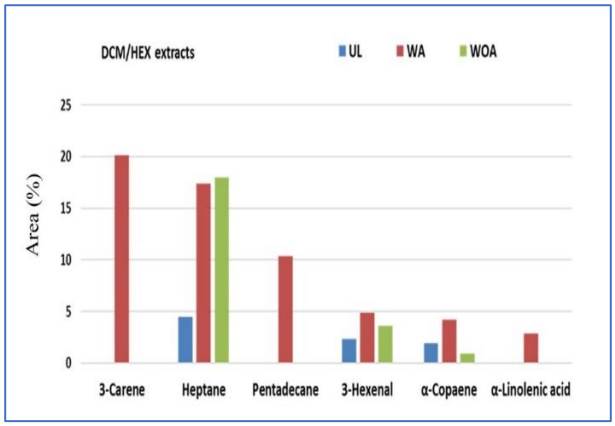

Fig. 2. Major aphid induced HIPVs identified through comparative analysis of different extracts for volatiles with their relative abundances [UL-Un infested leaf, WA-Infested leaf with aphid, WOA-Infested leaf without aphid]

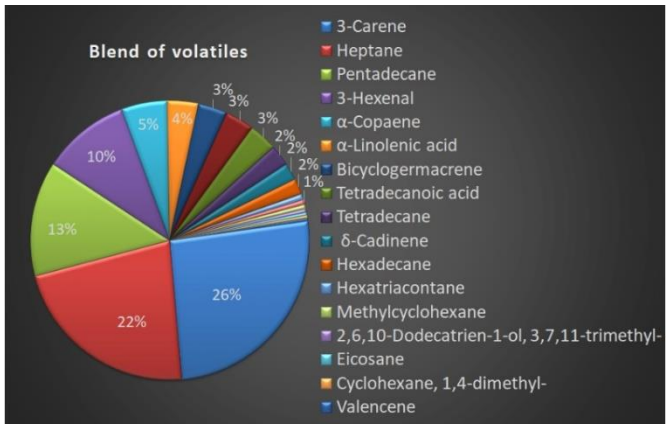

Fig. 3. Proposed blend of volatile compounds assumed to be responsible for higher attraction of *C. sexmaculata*adults

Volatile profile of the extracts collected from MeSA sprayed plants revealed that the emission profile at 2 and 4 h after spraying is very closure to that of un-infested plant as it has shown similarity in the number of compounds and their abundance. Whereas, the number of compounds increased from 20 to 29 at 10 h after spraying in which 13 compounds are additionally released after MeSA spraying. Among the additional compounds elicited by the MeSA, 3-Carene, Tetra decanoic acid, 3-Hexenal and Pentadecane were found common with that of aphid infested HIPVs. However, the MeSA elicited volatiles have not shown any significant attraction of *C. sexmaculata* beetles.

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

These positive biological attributes of *C. sexmaculata* on *A. gossypii* could contribute to its mass production for augmentative biological control.

Fourth instar grub, female and male of *C. sexmaculata* are found to be the effective stages against *A. gossypii* as it exhibited rapid reduction of prey with high attack rate and low handling time. Female beetles, in addition to their immediate functional response also contribute to the prolonged numerical response. So, the use of female and fourth instar grub could be advocated for the release towards the augmentative biological control of *A. gossypii*.

In the present investigations, we found that the NCEs resulting from predation-risk by *C. sexmaculata* on cotton aphid, *A. gossypii* was likely transmitted through olfactory cues, and even short exposure could raise the antioxidant enzyme levels in the aphids. The adult aphids exhibited antioxidant mechanisms through the up regulation of SOD and CAT but not sufficient to avoid oxidative damage that led to increased MDA content. As a result, the cost of production of SOD and CAT might have been compensated for with reduced reproduction in cotton aphid by adopting a 'sit and wait' strategy, and also by triggering winged morphs production for resorting to a 'fight or flight' strategy. Synthetic olfactory cues which mimic predator presence may act as biorational insecticide by reducing aphid population similar to non-consumptive effect found in this study.

We have developed a simple rearing technique of cotton aphid, *A. gossypii*s on Mesta seedlings raised in a Petri plate. It is an easy and simple method as it does away with maintenance of host plants in pots. It is very effective as we can quickly produce nymphs, wingless and winged adults in a larger number in short time. With this technique, continuous rearing is possible so that, lab studies and mass production of predators and parasitoids can be carried out easily in laboratory.

Based on the knowledge gained and comprehensive observations from the results obtained, we identified a possible blend of volatiles to be used as an effective attractant to enhance the foraging behavior of aphidophagous coccinellid beetles in the cotton crop. Proposed blend of volatile consists 17 compounds which include 3-carene (20.15%), Heptane (17.36%), Pentadecane (10.39%), 3-Hexenal (7.93%) and α-copaene (4.18%) as major compounds. It facilitates development of an attractant of coccinellid beetles using one or few of these identified compounds.

(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):

S.No.	Publication	Title	Authors	Publisher with volume	NAAS rating
1	Research Article	Biology of *Cheilomenes sexmaculata* (F.) on cotton aphid *Aphis gossypii*Glover	Venkanna, Y, Sachin S Suroshe*, Bhagyasree S N and Sweetee Kumari	Indian Journal of Entomology, 82(1): 75-79 (2020)	5.08
2	Research Article	Feeding potential and foraging behaviour of *Cheilomenes sexmaculata* (F.) on the cotton aphid, *Aphis gossypii* glover	Y. Venkanna, Sachin S. Suroshe, Subhash Chander & Sweetee Kumari	International Journal of Tropical Insect Science, 28: 1-12 (2021)	6.54
3	Research Article	Non-consumptive effects of the zigzag ladybird beetle, *Cheilomenes sexmaculata* (Fab.) on its prey, the cotton aphid, *Aphis gossypii* Glover	Y. Venkanna, Sachin S. Suroshe & Anil Dahuja	Biocontrol Science and Technology, DOI: 10.1080/09583157.2021.1937521	7.22
4	Research Article	A simple rearing technique for the cotton aphid, *Aphis gossypii* Glover	Y. Venkanna & Sachin S. Suroshe	International Journal of Tropical Insect Science (Under final review)	6.54
5	Research Article	Orientation response of *Cheilomenes sexmaculata* L. to the cotton HIPVs	Y. Venkanna, Sachin S. Suroshe & Suresh Nebapure	Communicated	-
6	Newsletter	A technique for continuous rearing of cotton aphid (*Aphis gossypii*)	Y. Venkanna & Sachin S. Suroshe	IARI NEWS, 35 (4): 4 (2019)	-

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

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.).: **No**

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.**

Dr. Y. Venkanna, Subject Matter Specialist (Entomology), Krishi Vigyan Kendra, Ramagirikhilla, Peddapally District, Telangana, has been awarded **ESI- BEST Ph.D. THESIS AWARD 2021**for Outstanding Doctoral Thesis Research in Agricultural Entomology for his doctoral thesis on the topic **"Predatory behaviour of coccinellid beetle, *Cheilomenes sexmaculata* (Fab.) and its predation risk on prey"** pursued from ICAR-Indian Agricultural Research Institute, New Delhi. Dr. Venkanna studied foraging behaviour of native coccinellid predator, *C. sexmaculata* on cotton aphid, *Aphis gossypii* with a comprehensive investigation including biology, life table, feeding potential, functional response, numerical response with which worked out total response equation and drawn prey population dynamics under predation of each stage of predator. Also studied predation risk effect through enzyme analysis of SOD, CAT and MDA content and found increased oxidative stress in aphids under predation risk of *C. sexmaculata* which ultimately effected reproductive performance of aphid and also induced the winged morphs production as a non-consumptive of predator. Identified certain volatiles as aphid induced HIPVs released by cotton and proved their attractiveness of *C. sexmaculata* beetles. Proposed a blend of volatile consisting 17 compounds includes 3-carene (20.15%), Heptane (17.36%), Pentadecane (10.39%), 3-Hexenal (7.93%) and α-copaene (4.18%) as major compounds.

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

Signature

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

Dr. Sachin Suresh Suroshe
Principal Scientist
Division of Entomology
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New Delhi-110012 (India)

Signature

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

I have forwarded students application twice to professor/Head of entomology; student has also sent mail to Prof./Head and also spoke for necessary action at Prof./Head end. But Prof/Head is not interested in forwarding application of student for Best thesis award instituted by ESI.

Name and Designation

Seal

Dr. Sachin Suresh Suroshe
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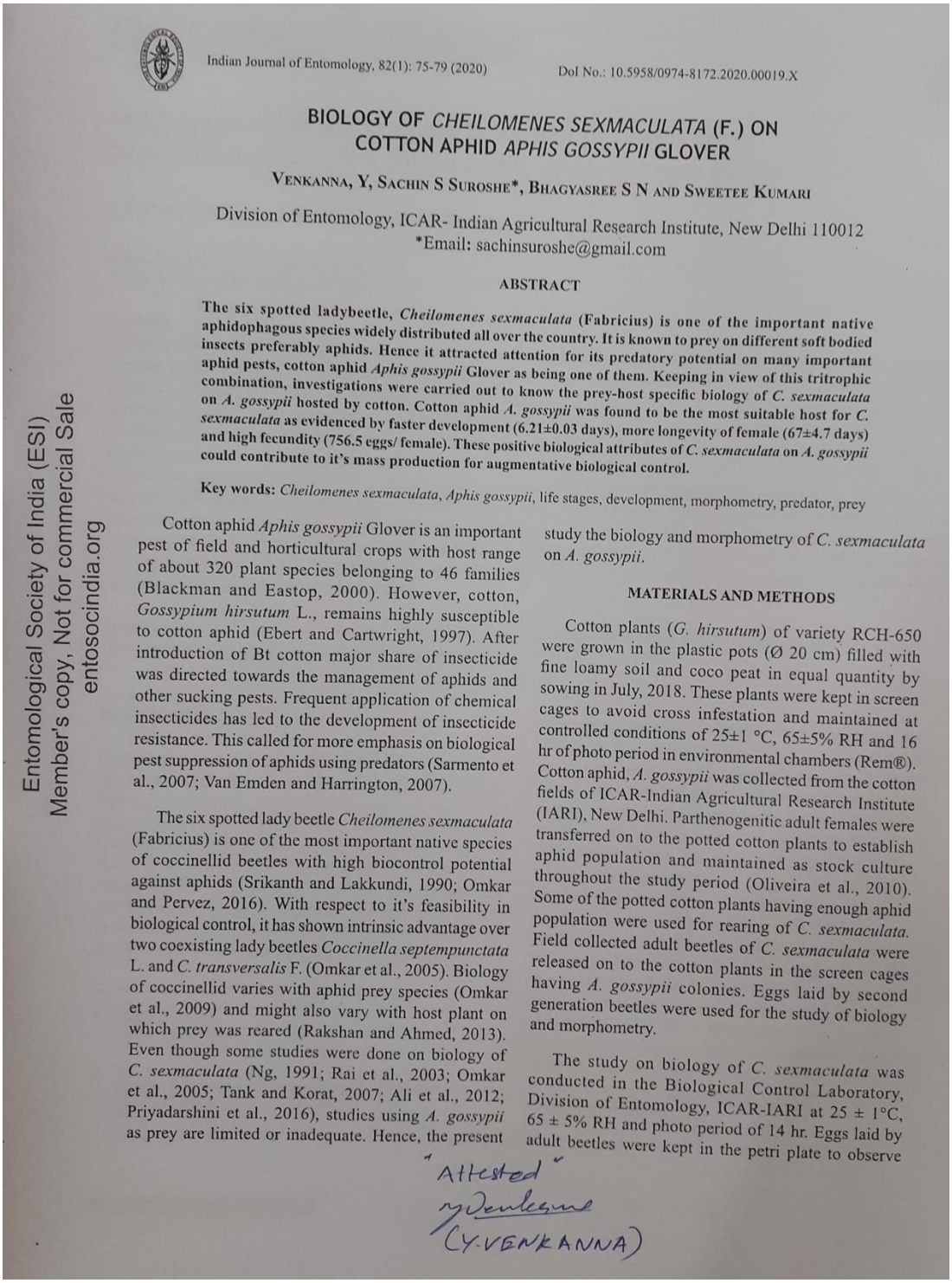
New Delhi-110012 (India)

9

Annexures

List of self-attested scanned documents to be enclosed:

1. Publications (**First page alone**)



Indian Journal of Entomology, 82(1): 75-79 (2020) DoI No.: 10.5958/0974-8172.2020.00019.X

BIOLOGY OF *CHEILOMENES SEXMACULATA* (F.) ON COTTON APHID *APHIS GOSSYPII* GLOVER

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ABSTRACT

The six spotted ladybeetle, *Cheilomenes sexmaculata* (Fabricius) is one of the important native aphidophagous species widely distributed all over the country. It is known to prey on different soft bodied insects preferably aphids. Hence it attracted attention for its predatory potential on many important aphid pests, cotton aphid *Aphis gossypii* Glover as being one of them. Keeping in view of this tritrophic combination, investigations were carried out to know the prey-host specific biology of *C. sexmaculata* on *A. gossypii* hosted by cotton. Cotton aphid *A. gossypii* was found to be the most suitable host for *C. sexmaculata* as evidenced by faster development (6.21±0.03 days), more longevity of female (67±4.7 days) and high fecundity (756.5 eggs/ female). These positive biological attributes of *C. sexmaculata* on *A. gossypii* could contribute to it's mass production for augmentative biological control.

Key words: *Cheilomenes sexmaculata*, *Aphis gossypii*, life stages, development, morphometry, predator, prey

Cotton aphid *Aphis gossypii* Glover is an important pest of field and horticultural crops with host range of about 320 plant species belonging to 46 families (Blackman and Eastop, 2000). However, cotton, *Gossypium hirsutum* L., remains highly susceptible to cotton aphid (Ebert and Cartwright, 1997). After introduction of Bt cotton major share of insecticide was directed towards the management of aphids and other sucking pests. Frequent application of chemical insecticides has led to the development of insecticide resistance. This called for more emphasis on biological pest suppression of aphids using predators (Sarmento et al., 2007; Van Emden and Harrington, 2007).

The six spotted lady beetle *Cheilomenes sexmaculata* (Fabricius) is one of the most important native species of coccinellid beetles with high biocontrol potential against aphids (Srikanth and Lakkundi, 1990; Omkar and Pervez, 2016). With respect to it's feasibility in biological control, it has shown intrinsic advantage over two coexisting lady beetles *Coccinella septempunctata* L. and *C. transversalis* F. (Omkar et al., 2005). Biology of coccinellid varies with aphid prey species (Omkar et al., 2009) and might also vary with host plant on which prey was reared (Rakshan and Ahmed, 2013). Even though some studies were done on biology of *C. sexmaculata* (Ng, 1991; Rai et al., 2003; Omkar et al., 2005; Tank and Korat, 2007; Ali et al., 2012; Priyadarshini et al., 2016), studies using *A. gossypii* as prey are limited or inadequate. Hence, the present study the biology and morphometry of *C. sexmaculata* on *A. gossypii*.

MATERIALS AND METHODS

Cotton plants (*G. hirsutum*) of variety RCH-650 were grown in the plastic pots (Ø 20 cm) filled with fine loamy soil and coco peat in equal quantity by sowing in July, 2018. These plants were kept in screen cages to avoid cross infestation and maintained at controlled conditions of 25±1 °C, 65±5% RH and 16 hr of photo period in environmental chambers (Rem®). Cotton aphid, *A. gossypii* was collected from the cotton fields of ICAR-Indian Agricultural Research Institute (IARI), New Delhi. Parthenogenitic adult females were transferred on to the potted cotton plants to establish aphid population and maintained as stock culture throughout the study period (Oliveira et al., 2010). Some of the potted cotton plants having enough aphid population were used for rearing of *C. sexmaculata*. Field collected adult beetles of *C. sexmaculata* were released on to the cotton plants in the screen cages having *A. gossypii* colonies. Eggs laid by second generation beetles were used for the study of biology and morphometry.

The study on biology of *C. sexmaculata* was conducted in the Biological Control Laboratory, Division of Entomology, ICAR-IARI at 25 ± 1°C, 65 ± 5% RH and photo period of 14 hr. Eggs laid by adult beetles were kept in the petri plate to observe

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ORIGINAL RESEARCH ARTICLE

Feeding potential and foraging behaviour of *Cheilomenes sexmaculata* (F.) on the cotton aphid, *Aphis gossypii* glover

Y. Venkanna[1] · Sachin S. Suroshe[1] · Subhash Chander[1] · Sweetee Kumari[1]

Received: 9 May 2020 / Accepted: 26 December 2020

Abstract

Feeding potential and foraging behaviour are two important factors which determine the predator's efficiency of managing prey. Predator-prey system of *Cheilomenes sexmaculata* (Fabricius) and *Aphis gossypii* Glover was evaluated to find out the predation efficiency. Feeding potential was observed for different stages of *C. sexmaculatus* on *A. gossypii* whereas, functional and numerical responses were ascertained as a function of prey/host density. For the grub stage, highest feeding potential (101.43 ± 3.04 aphids) was observed for the fourth instar which was higher than the gross feeding potential of all other instars. Among the adults, female recorded high feeding potential with a mean daily consumption of 43.13 ± 0.54 aphids. Life table studies showed intrinsic rate of increase (r) of 0.22 with the mean generation time of 27.29 days. The foraging behaviour studies revealed that all the grub stages and adults displayed a type-II functional response. The IV instar grub has shown the lowest handling time with highest maximum predation (96.1aphids/day), followed by female (94.6), male (82.6) and other stages. However, female depicted a rapid extinction of aphid by keeping it below 25, as against fourth instar grub and male which affected extinction by keeping it below 30. So, the releases of fourth instar grub and female of *C. sexmaculatus* could be advocated for the augmentative biological control of *A. gossypii*.

Keywords Type-II functional response · Numerical response · Roger's random attack equation · Biological control · Age-stage-specific consumption · Predator-prey relationship

Introduction

Cotton aphid, *Aphis gossypii* Glover has been a key pest of agri-horticultural crops due its economic importance. This polyphagous aphid species is known to attack more than 300 plant species across 46 families all around the globe (Blackman and Eastop 2000) among which cotton has been the most susceptible host. Cotton aphid is the key pest of cotton and known to be a vector of leaf curl disease. The developments of pesticide resistance and associated concern about the environmental hazards caused by frequent pesticidal applications have warranted efforts on biological pest suppression, especially of aphids by the predatory beetles (Sarmento et al. 2007). Among different predators prevailed in the crop-ecosystem, the coccinellid beetles (Coleoptera: Coccinellidae) are considered as the most important group as they are known for their voracious feeding on aphids and other sucking pests both by grubs and adults (Dixon and Dixon 2000; Omkar 2016). The six spotted zigzag ladybird beetle, *Cheilomenes sexmaculatus* (F.) is one such aphidophagous coccinellid predator known to suppress the aphid population to a greater extent in nature (Reddy et al. 2001). It is a native species of India, remains active throughout the year with a wide geographic distribution and host range. It was also observed for its voracious feeding on aphids with high searching ability and could be handle with ease in the laboratory (Venkatesan et al. 2006). With respect to its feasibility as a biological control agent, it has shown intrinsic advantage over other two coexisting species viz., *Coccinella septempunctata* L. and *Coccinella transversalis* F. (Omkar et al. 2005; Rakshith et al. 2018).

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RESEARCH ARTICLE

Non-consumptive effects of the zigzag ladybird beetle, *Cheilomenes sexmaculata* (Fab.) on its prey, the cotton aphid, *Aphis gossypii* Glover

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ABSTRACT

Non-consumptive effects (NCEs) of predators include non-lethal changes in prey altering their behaviour and physiology with increased oxidative stress under predation-risk. Although prey species may exhibit a complex of antioxidant mechanisms, these may be inadequate to result in a reduction of adverse biological consequences in the prey. Reduced prey fitness may result and could contribute to enhancing biological control. Cotton aphid, *Aphis gossypii* is an important polyphagous pest predated by a variety of coccinellids and very much preferred by zigzag ladybird beetle, *Cheilomenes sexmaculata* (F.). Possible NCEs of *C. sexmaculata* on cotton aphid were studied to understand the underlying anti-oxidative mechanisms. We found that the non-consumptive effect is induced by olfactory cues, and even short-duration exposure could raise antioxidant enzyme levels in the cotton aphid. Aphids antioxidant mechanism uses upregulation of superoxide dismutase (SOD) and catalase (CAT) but not sufficiently to offset the oxidative damage that led to increased Malondialdehyde (MDA) content. Affected aphid biology with reduced reproductive performance as recorded 30.0 ± 4.40 nymphs/female under predation-risk compared to no-predation (41.6 ± 5.60). Further, the induction of winged morphs increased with active predation (21.53 ± 1.05%) and increased risk of predation (18.28 ± 4.86%) compared to aphids not exposed to predators (6.00 ± 2.99%). Antioxidant production costs were compensated by the exposed aphids directly through reduced reproduction and also triggered winged morphs in progeny. Non-consumptive effect might directly contribute to declines in aphid populations through reduced reproduction and may also stimulate dispersal of winged morphs.

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KEYWORDS
Antioxidant enzymes; Malondialdehyde; oxidative stress; predation-risk effect; superoxide dismutase; winged aphids

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Introduction

Aphis gossypii Glover (Aphididae: Homoptera) is one of the most important sucking insects damaging agriculture and horticultural crops. It is a highly polyphagous pest infesting more than 320 plant species of 46 families, and a major pest of cucurbits and

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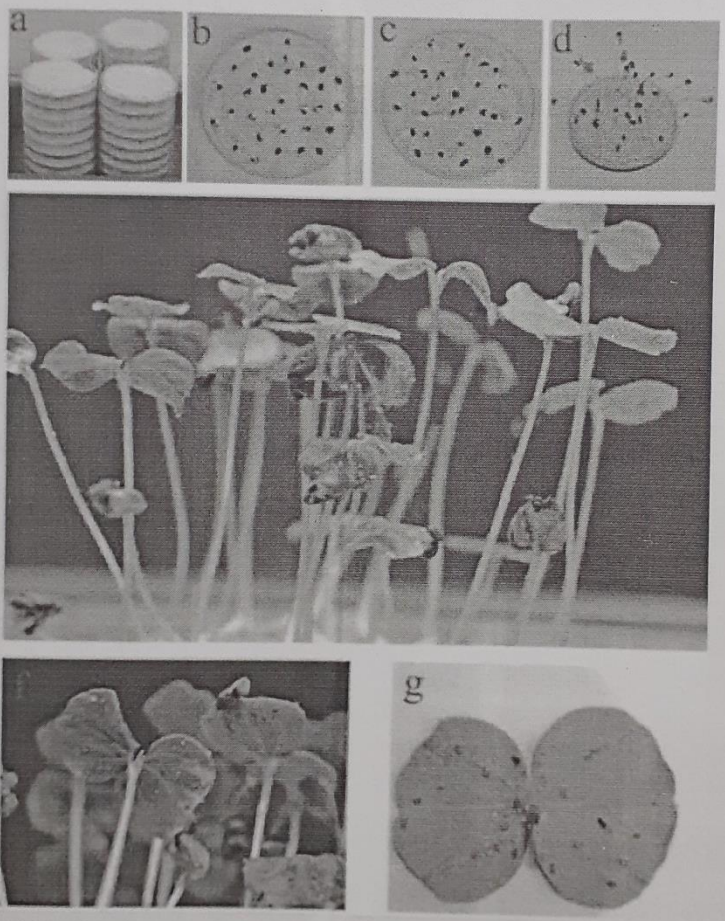
plasma isolate identified it as a member of the peanut witches' broom phytoplasma group (*Candidatus* Phytoplasma aurantifolia).

Also, on the basis of computer-simulated RFLP analysis of amplified 16S rRNA gene, assigned the peanut strain to subgroup D. This is the first report on the association of '*Ca.* P. aurantifolia' (16SrII-D subgroup phytoplasma) with peanut in India.

A Technique for Continuous Rearing of Cotton Aphid (*Aphis gossypii*)

For rearing of cotton aphid, *Aphis gossypii* potted cotton plant method has been extensively used which is a cumbersome process requires more time and space. The other methods such as rearing on excised cotton leaves and using artificial diet are also not suitable for rearing in high number for longer periods. A simple rearing technique of *A. gossypii* on a natural host system of *Hibiscus cannabinus* L. was developed in the Division of Entomology, ICAR-IARI, New Delhi. Mesta (*H. cannabinus*) was selected for rearing of *A. gossypii* based on screening of different host plants. In this period, seedlings of *H. cannabinus* were grown on absorbent cotton in a Petri plate (10 cm ɵ) as substrate. This technique was found to be effective for continuous rearing throughout the year. Among different temperatures, 24°C was found most suitable to produce nymphs and wingless adults in high number. However, for the production of winged adults, rearing at 27°C was found to be best. This technique made simple and easy to practice as it avoids growing and maintenance of host plants in pots throughout the year. It is effective as it facilitate quick start of rearing and produce nymphs, wingless adults and winged adults in high numbers and feasible for continuous rearing on *H. cannabinus* seedlings for 30 days without transfer. This technique is simple and suitable for contin-uous rearing in lab studies and mass production of predators and parasitoids would be possible for laboratory.



Seed kept for germination: (a-d) 0, 1, 2 and 3 days after keeping for germination. (e) Aphid establishment at 18 days after release, (f) Aphid on both sides of leaf, (g) Different stages of aphid on underside of leaf.

Procedure of new rearing method of Aphid

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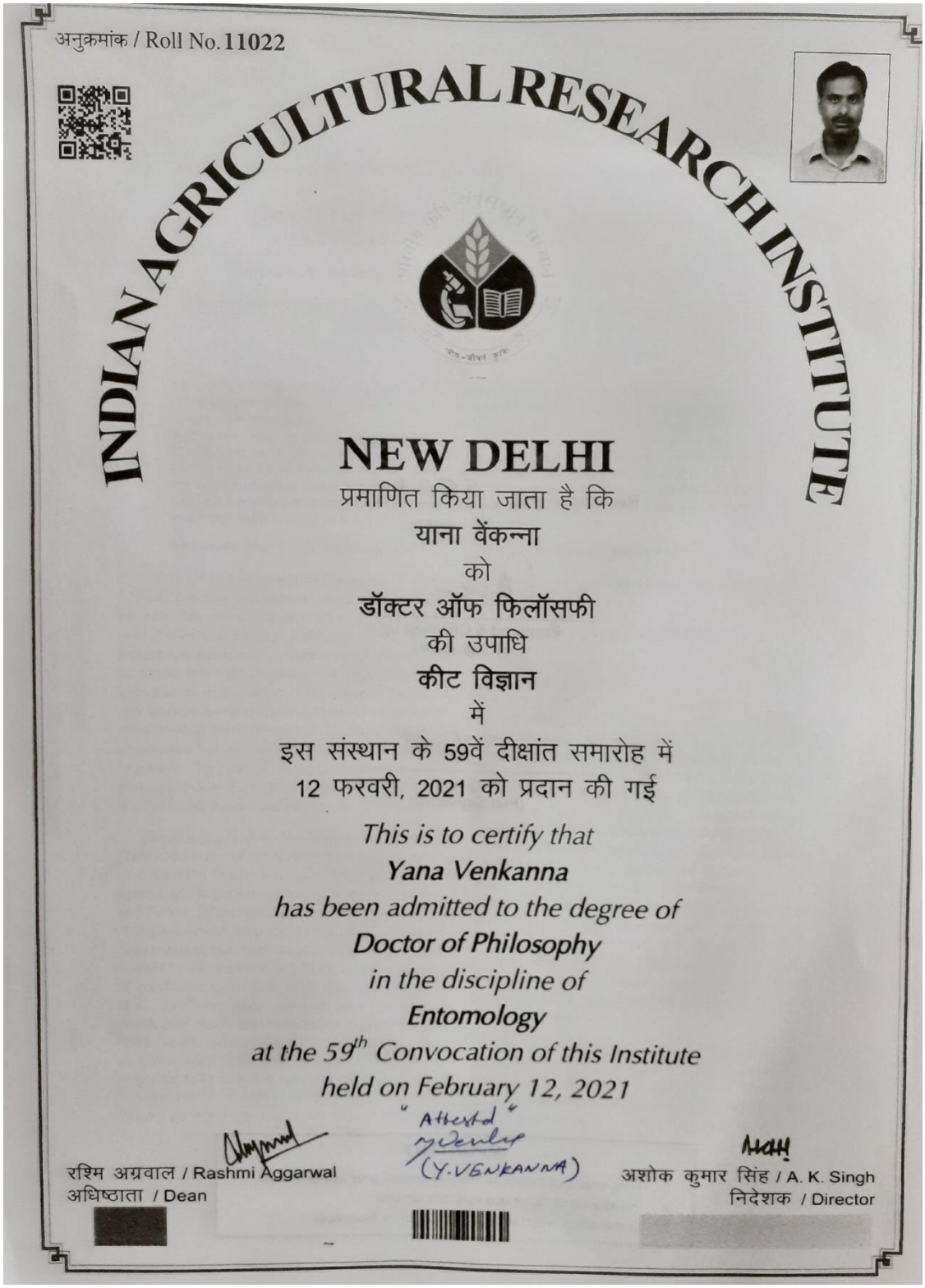
2. Photo copy of PhD degree



अनुक्रमांक / Roll No. **11022**

INDIAN AGRICULTURAL RESEARCH INSTITUTE

NEW DELHI

प्रमाणित किया जाता है कि

याना वेंकन्ना

को

डॉक्टर ऑफ फिलॉसफी

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इस संस्थान के 59वें दीक्षांत समारोह में

12 फरवरी, 2021 को प्रदान की गई

This is to certify that

Yana Venkanna

has been admitted to the degree of

Doctor of Philosophy

in the discipline of

Entomology

at the 59th Convocation of this Institute

held on February 12, 2021

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(Y. VENKANNA)

रश्मि अग्रवाल / Rashmi Aggarwal
अधिष्ठाता / Dean

अशोक कुमार सिंह / A. K. Singh
निदेशक / Director

3. Age proof

4. Best passport size photograph

5. Thesis (soft copy) (Enclosed pdf file)

Predatory behaviour of coccinellid beetle, *Cheilomenes sexmaculata* (Fab.) and its predation risk on prey

BY

VENKANNA. Y

A Thesis Submitted to the Faculty of Post-Graduate School,
ICAR-Indian Agricultural Research Institute, New Delhi
in partial fulfillment of the requirements
for the award of the degree of

DOCTOR OF PHILOSOPHY

IN

ENTOMOLOGY

2020

Approved by:
Advisory Committee

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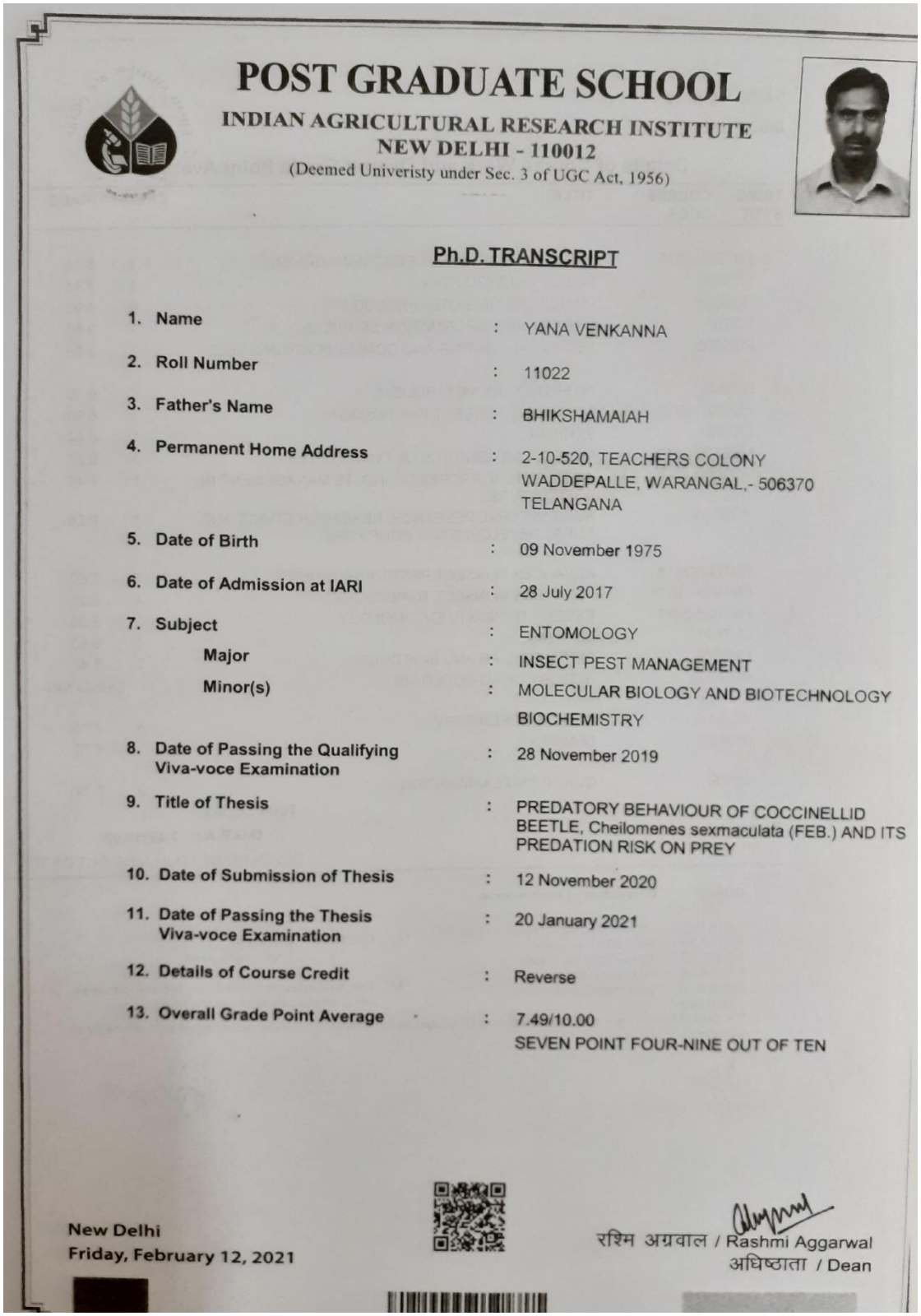
6. Transcript of the course work done, if any, as part of the Ph.D. degree programme. (Enclosed)



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Ph.D. TRANSCRIPT

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Major	:	INSECT PEST MANAGEMENT
Minor(s)	:	MOLECULAR BIOLOGY AND BIOTECHNOLOGY BIOCHEMISTRY
8. Date of Passing the Qualifying Viva-voce Examination	:	28 November 2019
9. Title of Thesis	:	PREDATORY BEHAVIOUR OF COCCINELLID BEETLE, Cheilomenes sexmaculata (FEB.) AND ITS PREDATION RISK ON PREY
10. Date of Submission of Thesis	:	12 November 2020
11. Date of Passing the Thesis Viva-voce Examination	:	20 January 2021
12. Details of Course Credit	:	Reverse
13. Overall Grade Point Average	:	7.49/10.00 SEVEN POINT FOUR-NINE OUT OF TEN

New Delhi
Friday, February 12, 2021

रश्मि अग्रवाल / Rashmi Aggarwal
अधिष्ठाता / Dean

NAME: YANA VENKANNA **ROLL NO:**11022

DISCIPLINE: ENTOMOLOGY

Details of Course Work and Overall Grade Point Average

TRIME-STER	COURSE CODE	TITLE	CREDIT	GRADE
I				
	ENT503-2017	PRINCIPLES OF INSECT PEST MANAGEMENT	3	8.14
	ENT606	INSECT BIOCHEMISTRY	3	7.43
	MBB501	PRINCIPLES OF BIOTECHNOLOGY	4	6.95
	PGS501	LIBRARY AND INFORMATION SERVICES	1	9.80
	PGS502	TECHNICAL WRITING AND COMMUNICATION SKILLS	2	8.80
II				
	BIO606	INTERMEDIARY METABOLISM	3	6.00
	ENT607-2017	ADVANCES IN INSECT PHYSIOLOGY	3	6.90
	ENT691	SEMINAR	1	8.44
	MBB505-2017	MOLECULAR GENETICS OF EUKARYOTES	3	6.20
	PGS503	INTELLECTUAL PROPERTY AND ITS MANAGEMENT IN AGRICULTURE	1	7.45
	PGS505	AGRICULTURAL RESEARCH, RESEARCH ETHICS AND RURAL DEVELOPMENT PROGRAMES	1	8.25
III				
	ENT603-2018	ADVANCES IN INSECT PEST MANAGEMENT	3	7.60
	ENT605-2017	ADVANCES IN INSECT TOXICOLOGY	4	8.25
	ENT608-2017	RECENT TRENDS IN ENTOMOLOGY	3	8.35
	ENT691	SEMINAR	1	8.85
	MBB506	BIOSAFETY, IPR AND BIOETHICS	2	7.40
	PGS-506	HISTORY OF AGRICULTURE		Satisfactory
IV				
	BIO501	BASIC BIOCHEMISTRY	5	6.75
	BIO691	SEMINAR	1	8.72
VII				
	QVVE	QUALIFYING EXAMINATION	2	7.14

Total Credits: 46

O.G.P.A.: **7.49 /10.00**

Remarks: SEVEN POINT FOUR-NINE OUT OF TEN

Note:

	OGPA	Description of Performance
(1)	9.0 to 10.0	(90 to 100%) Ist Class with distinction
	8.0 to 8.99	(80 to 89%) Ist Class
	7.0 to 7.99	(70 to 79%) IInd Class
	6.0 to 6.99	(60 to 69%) Pass
	Below 6.00	(Less than 60%) Fail
	Incomplete	I

(2) O.G.P.A.= Total points earned / Divided by / Total credits taken

(3) One hour lecture or three hours practical per week for 12 weeks carries one credit hour.

(4) The date of Final Viva-voce Examination may be treated as the date of completion of the degree programme for all purposes.

Prepared & Checked by:

Registrar

1. Completeness of the application rests with applicant and no further additions/alterations will be entertained.
2. Complete nominations are to be submitted online at www.entosocindia.com awards section by using member login and password on or before **11.59 PM of the 21 October 2021.** No correspondence will be entertained in this regard.
3. This year we are also considering applications through email **in single PDF (not more than 50 pages)** including application form andwith all enclosures must reach by email: esiaward@gmail.com (hardcopy will not be entertained) on or before **11.59 PM of the 21 October 2021.** No correspondence will be entertained in this regard.