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Extent and Pattern of Occurrence of Natural Enemies of Lac Insect around the Kuldiha Wildlife Sanctuary, Odisha

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ABSTRACT

The extent and pattern of occurrence of natural enemies of Lac insect (*Kerria lacca* (Kerr.) during the rainy seasons (Katki crop) of 2017-2018 around the Kuldiha Wildlife Sanctuary, Odisha was studied. Three sites viz., agricultural fields/agroforestry, strips along the roads, and village commons (complex landscapes) differing in the degree of disturbance/landscape were chosen. Palash tree (*Butea monosperma* (Lam.) Taub) was the host plant for rangeeni strain of *K. lacca* where we observed 7 enemies (3 predators and 4 parasitoids) belonging to 06 families infesting on the lac insect. The village commons landscape had maximum number of natural enemies (predators and parasitoids) with mean number of individuals of natural enemies per 30 cm of stick lac whereas it was the least from the agricultural fields. During 2017 the prevalence of *Eublemma amabilis* showed the highest peak density (11.08/30 cm stick lac) in village commons followed by *Pseudohypatopa pulverea* (8.03/30 cm stick lac) and *Chrysopa* spp. (5.13/30 cm stick lac). Among the four parasitoids *A. purpureus* had the highest density (7.65/30 cm stick lac) as the major parasitoid whereas, *Tachardiphagus tachardiae*, *E. tachardiae* and *Parechthrodryinus clavicarnis* were minor parasitoids with a peak population density of 2.77, 1.77 and 1.00 per 30 cm stick lac, respectively, in village commons. However during 2018, *A. purpureus* was also recorded as the major parasitoid with a peak population density (6.96 per 30 cm stick lac), whereas *Tachardiphagus tachardiae*, *E. tachardiae* and *Parechthrodryinus clavicarnis* were the minor parasitoids in the village commons.

Key words: *Kerria lacca*, natural enemies, host plants, katki crop, predators, parasitoid

INTRODUCTION

Lac insect (*Kerria lacca* (Kerr.) family Tachardiidae, superfamily Coccoidea of the order Hemiptera*)* is one of the most valuable insects that produces lac, a valuable non-timber forest produce (NTFPs). Lac is a natural commercial resinous (polymer) secreted by *K. lacca* and thus, is of animal origin. Lac is biodegradable, non-poisonous and non-injurious to humanbeings and has the composition of natural resins produced by scale insects (Mohanasundaram et al. 2022). It provides regular income, in the absence of other cash crops particularly in rainfed areas particularly to the tribes, landless, women and other unprivileged rural poor. In several Indian states lac cultivation is an efficient activity for enhancing livelihood of sub-forest, forest and rainfed areas (Jaiswal et al. 2012). Lac based farming is a low-input natural resource-based enterprise that provides additional income (Jaiswal et al. 2006, Pal et al. 2010).

Lac has substantial uses in printing, paints and polishes, fruit coating, cosmetics, pharmaceuticals and various similar applications. However, the extensive requirements for natural products in worldwide increases the numerous uses of lac products in food, chocolate and pill coatings, soft drink formulations, confectionery, and colouring of wool and silk. The versatile uses of lac in food and pharmaceutical industries, and other uses such as making paints, adhesives, jewellery, cosmetics, perfumes, polishes, varnishes and in textile dye due to its non-toxic nature, durability and magnificent adhesive characteristics (Srivastava and Jeet 2020, Thombare et al. 2022, Mohanasundaram et al. 2022) make it very demanding. The promotion and influence for lac cultivation eliminates environmental degradation, build up the ecological balance and also conserve endangered lac insects, associated fauna and flora (Sharma et al. 2008). In India available lac insect genetic resources are under threat due to loss of indigenous populations and associated fauna or its habitat destroyed (Mohanta et al. 2014). Hence, promoting and strengthening lac culture not only eliminate environmental deterioration but also sustain the associated fauna and flora for the future generations.

Sarvade et al. (2018) reported that there are a total of 9 genera and 99 species of lac insects all over the world out of which 2 genera and 26 species are found in India. *K. lacca* (*Kerr*.) is the most extensively and lucratively economically important Indian lac insect native in tropical or subtropical regions which is represented by two different strains, namely Rangeeni and Kusumi that produces two crops in a year of bivolatine characteristics (Ramani and Sharma 2016). Lac strains are distinguished on the basis of differences in lifecycle, their respective host plant preference and the quality of lac produced. Kusmi has equi-durational life cycle (6 months each) whereas Rangeeni is characterized by unequal duration of bivoltine life cycle per year namely katki (rainy season crop - 4 months) and baisakhi (summer season crop - 8 months). Rangeeni strain contributes about 90% of lac production and remaining 10% by kusumi crop. Due to their genetic differences in response to temperature variation these two forms of strains differ in lifecycle patterns. However, Kusumi strain is superior because of the lighter colour of resin, and it fetches better price (Yogesh et al. 2018).

Lac production and productivity depends upon distribution of suitable host plants, their sustainable management and quality of brood lac use, institutional linkages, climate change and anthropogenic disturbance activities (Shah et al. 2015), settlement of live lac insects in tender shoots (Saha et al. 2014) till the lac crops are harvested. These insects are phytosuccivorous and thrive well on specific plants, which are called as lac hosts, for their survival and growth. They remain attached to the host plant across their lifespan apart from crawler and adult male stages. Lac insects survive on more than 400 plant species which are reported as a host plants for lac insects from different parts of the country. Some researchers have claimed that these sap suckers grows well on a range of 250 host plants (Mohanta et al. 2012, Shah and Thomas 2018).

The production of lac is significantly altered by the major meteorological factors such as temperature, rainfall, humidity, wind velocity etc. Temperature is the foremost climatic factor influencing lac production. While intense heat of summer temperature reduced the annual national lac production from 20,050 tons in 2003-04 to 16,495 tons in 2009-10 (Pal et al. 2010), heavy rainfall during the month of July reduced lac insect settlement (Patel et al. 1997). Most of the biological systems are severely affected due to climate change including long-term shifts in rainfall patterns, persistent droughts and floods, raised intensity and frequency of extreme coldness, epidemic of insect pests and diseases (Anonymous 2007) and lac sub-sector is also adversely affected due to these global factors. It is estimated that the extent of loss of the viable lac crops are around two-thirds, and only one-third surviving is providing the yield (Mohanasundaram et al. 2016a).

In India during the past few years lac production trends showed a retrograde trend in production which is greatly affected by biotic stress (predators and parasitoids) as well as abiotic (adverse climatic factors) causing hindrance in lac culture. Moreover, natural lac insect ecosystem is a complex multi-trophic web and maintains a variety of flora and fauna. It is characterised by a rich biodiversity of lac insects, lac host plants, and several predators of lac insects, parasites, microbes and host plants pests. Like other agricultural crops lac is vulnerable to be infected by many insect pests such as predators, parasitoids and diseases which cause huge loss to the lac crops. Lac pests cause more damage to lac crops as compared pest damage to agricultural crop (Singh et al. 2011). Among these, major harmful parasitoids of lac insects such as *Aprostocetus* (*Tetrastichus*) *purpureus* (Cameron), *Tachardiaephagus tachardiae* (Howard), and *Parechthrodryinus clavicornis* (Cameron) are responsible for majority of loss (Sarvade et al. 2018). *A. purperous* alone has acquired the most dreaded pest of lac insect (Mohanasundaram et al. 2016a). However, Sharma et al. (2006) and Mohanasundaram et al. 2022) reported 20 predators of lac insects, comprising of the major predators such as *Eublemma* *amabilis* Moore (white moth), *Pseudohypatopa pulverea* Meyr (black moth), *Chrysopa lacciperda* Kimmins and *C. madestes* Banks (green lace wing). The larvae of these predators made tunnels into the lac encrustations, nourished on the lac insects and found restrained within that resinous exudation. In lac production 35 to 40% losses are caused by predators (Jaiswal et al. 2008, Sarvade et al. 2018) and 5 to 10% by parasitoids (Varshney 1976). But in recent past, these insect pests cause economic losses due to the infested lac crops. One of the reasons of decline in lac production is attributed to increased incidence of predators and parasitoids. During the life cycle of the lac insect it takes up only a short time of active movement and subsequently attains a complete immobile life, therefore they are susceptible to be invaded by various types of insect predators and parasitoids, which bring about significant loss to the lac crop both in qualitatively and quantitatively (Singh et al. 2011). To minimize the lac crop yield loss, many authors have also suggested application of biopesticides and other control measures (Jaishwal and Singh 2016, 2018, Jaishwal et al. 2018).

The share of rangeeni lac was 80% to the national lac crop production and has showed significantly diminishing trend in the last few years. During rainy season rangeeni lac (katki crop) insect was found to be severely damaged by mortality, leading to entire crop loss. Like the quality and quantity of food available to the insect are important in determining their survival and reproductive rate, the growth and development of parasitoids are determined by feeding of host plants by herbivores. There is a vast range of predators and parasitoids associated in lac production (Sharma et al. 2008). Sharma et al. (2007) reported that 26 and 18% parasitization in rangeeni and kusmi strains, respectively, during the rainy season. They also noticed up to 9 and 6 parasitoids in a single cell of rangeeni and kusmi strains, respectively.

In Balasore district of Odisha, lac culture is traditionally practiced in some pockets as the agro-climatic conditions of region is suited for lac cultivation. Nilgiri block of Balasore is historically a major lac producing area in the north-eastern India. Most of the villages of this block have abundant host trees naturally growing on the on borders of paddy fields (bunds), road sides and barren lands in clusters. All three major host trees such as Ber, Kusum and Palash are found abundantly in these areas. Some of the tribal households' practice management of host trees for lac cultivation. There is non-availability and scanty knowledge among lac cultivators about the conservation of their natural habitat, lac insect enemies, interactions and causes for its occurrence. The seasonal incidence of the parasites and predators were studied along with the fluctuation in their population level and peak incidence period. Since, this information is required for developing a lac pest management programme, the study aimed to find variation in emergence profile of lac associated fauna in relation to lac host plants and their crop seasons. Palash trees (*Butea monosperma* (Lam.) Taub. commonly known as the flame of the forest) the major host plants were tremendously infested by rangeeni strain lac insect *K. lacca* during July 2017 to November 2018 in Nilgir block of Odisha. The same strain of lac insect also uses *Zizyphus mauritiana* (Lam.) trees as host and thus provides lot of scope for exploitation in different parts of the state for commercial production of the lac. Therefore, an attempt has been made to record the naturally occurring commercial host plants, and natural enemies (both predators and parasitoids) of lac insects prevailing around the Kuldiha Wildlife Sanctuary, Odisha.

MATERIAL AND METHODS

Field surveys were conducted during July 2017 to November 2018 in five major lac growing villages namely Tiakata, Garadihi, Chaindar, Balichua and Chekamara of Garadihi Gram Panchayat to record data in all the possible habitats such as agricultural field/agroforestry (AF), strips along the road side (SAR), village commons (VC) around the Kuldiha Wildlife Sanctuary (KWLS) of Balasore district, Odisha. Prior to undertaking the study, reconnesence survey of the area and a thorough discussion was made with the local authorities of forest and environment department, Government of Odisha. Information was also gathered from lac traders and farmers in the blocks. Population seasonality of associated fauna, natural enemies (predators and parasitoids) of lac insect (Table 1) were recorded

Table 1. Natural enemies associated with lac insect collected from around the Kuldiha Wildlife Sanctuary, Balasore district of Odisha

Associated fauna	Common name	Order	Family	Genera
Predators				
Eublemma *amabilis* Moore	Big white moth	Lepidoptera	Noctuidae	1 (14.28%)
Pseudohypatopa *(=Holcocera) pulverea* Meyr.	Small black moth	Lepidoptera	Blastobasidae	1 (14.28%)
Chryosopa spp.	Green lace wing bug	Neuroptera	Chrysopidae	1(14.28%)
Parasitoids				
Tachardiaphgus tachardiae How.	—	Hymenoptera	Encyrtidae	1(14.28%)
Parechthrodryinus clavicornis Cameron	—	Hymenoptera	Encytidae	1(14.28%)
Aprostocetus purpureus Cameron	—	Hymenoptera	Eulophidae	1(14.28%)
Eupelmus tachardiae How.	—	Hymenoptera	Eupelmidae	1(14.28%)

from randomly selected 04 host plants of Palash at weekly intervals of the Rangeeni strain in Katki (rainy) crop seasons from 20th July to 12th November for four months. From inoculated Palash trees of natural stands lac insect samples (one-meter length of encrustation) were also collected randomly, initially one month after inoculation and then at every 07 days interval till crop harvest with four replications. The living lac insect encrustation along with tender host twigs were cut by secateurs and wrapped with wet cotton swab at both the ends in order to maintain the turbidity of collected samples. Simultaneously, samples were also purposively collected randomly from 04 plants (4 infested twigs from each plant) each consists of 30 cm length after removal from the host plants to record the prevalence of natural enemies of lac insect, and were caged for four months for emergence of predators and parasitoids. Caging was done in specially designed plastic jars (20 in number) for emergence of parasitoids and predators. In each jar 8-10 brood sticks were kept and the jar mouth was covered with a transparent minutely perforated polythene glass in a ballooning position. These jars containing samples of different sample locations were kept separately. The basal portion of the jar was kept dark by covering them with thick black cloth so as to induce upward movement of the predators and parasites emerging from the brood stick. The parasites or predators emerging from the sticks were collected in specimen tubes and subjected to the morphological studies. The study on the population of natural enemies of predators and parasitoids were recorded from the time of initiation of first appearance and up to completion of emergence. The counts were expressed as the number of predators and parasitoids per 30 cm lac encrustration starting from the 1st standard meteorological week (SMW) when they emerged. These emerged natural enemies were identified with using "Lac insect and associated fauna: A practical Manual" by Mohanasundaram et al. (2016b) and the evidence of population of natural enemies was maintained. These specimens were also brought to the lac insect museum cum laboratory of Lac Production and Improvement (LPI) Division of National Institute of Secondary Agriculture (NISA), Namkum, Ranchi (Formerly Indian Institute of Natural Resins and Gums and Indian Lac Research Institute) for identification confirmation. Various stages of infestation/life cycle of the predators and parasitoids are given in supplementary file (Annexure 1).

RESULTS

Extent of occurrence of natural enemies across the habitats

The predator population of *Eublemma amabilis* varied widely between the sites and years (Table 2). It ranged from 1.52 - 7.98/30 cm lac stick in AF, 0.82 - 9.44/30 cm lac stick in SAR and 1.15 - 11.08/ 30 cm lac stick in VC during 2017 and from 0.77-

Table 2. Natural enemy density (number of insects/30 cm stick lac) associated with Lac insects surroundings of KWS during 2017 and 2018

Species	Peak density						Active duration (days)						Peak active period (date)					
	2017			2018			2017			2018			2017			2018		
	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	1.52-7.98	0.82-9.44	1.15-11.08	0.77- 7.20	1.59 -9.49	2.96- 11.28	119	119	119	119	119	119	31/08	31/08	24/08	31/08	24/08	24/08
Pseudohypatopa pulverea	0.30-7.39	0.91-6.96	1.16-8.03	0.56 - 7.04	0.73 - 8.08	1.82 - 9.12	119	119	119	119	119	119	31/08	07/09	07/09	31/08	31/08	31/08
Chrysopa spp.	0.52-4.48	0.65-4.71	1.11-5.13	0.10 - 4.14	0.70 - 4.25	1.92 - 5.11	105	105	105	105	105	105	03/08	03/08	03/08	10/08	03/08	10/08
Tachardiphagus tachardiae	0.19-2.01	0.38-2.03	0.50-2.77	0.20- 2.07	0.36 - 2.58	0.67 - 2.79	91	91	91	98	98	98	09/11	09/11	26/10	26/10	02/11	02/11
Aprostochetus purpureus	0.75-5.72	1.25-6.90	1.75-7.65	1.12 - 5.07	2.80 - 6.68	3.37 -6.96	70	70	70	70	70	70	28/09	05/10	05/10	28/09	05/10	05/10
Eupelmus tachardiae	0.14-1.15	0.20-1.53	0.39-1.77	0.14 - 1.51	0.39 - 1.69	0.47 - 2.10	70	70	70	70	70	70	26/10	19/10	26/10	02/11	26/10	26/10
Parechthrodryinus clavicornis	0.53-2.65	0.71-2.50	1.00-3.25	0.42- 2.49	0.52 -2.70	0.83 -3.00	70	70	70	70	70	70	19/10	05/10	12/10	12/10	12/10	28/09

AF= (Agriculture Fields/ Agroforestry); SAR= Strips Along the Roads; VC= Village Commons

7.20/30 cm lac stick in AF, 1.59 - 9.49/30 cm lac stick in SAR and 2.96 - 11.28/30 cm lac stick in VC during 2018. While the density of *Pseudohypatopa pulverea* in AF during 2017 were 0.30 - 7.39/30 cm lac stick and 0.56 - 7.04/30 cm lac stick during 2018, In SAR it ranged from 0.91 - 6.96/30 cm lac stick during 2017 and 0.73 - 8.08/30 cm lac stick in 2018. However, in VC it ranged from 1.16 - 8.03/30 cm lac stick in 2017 and 1.82 - 9.12/30 cm lac stick in 2018. For *Chrysopa* spp. the density in AF during 2017 was 0.52- 4.48/30 cm lac stick and 0.10 - 4.14/ 30 cm lac stick in 2018, in SAR 0.65 - 4.71/30 cm lac stick and in 2018 0.70 - 4.25/30 cm lac stick. In VC during 2017 the density of *Chrysopa* spp. was 1.11 - 5.13 and in 2018 1.92 to 5.11. The density range of all predators was higher in VC than in AF and SAR. There was no distinct year wise variation in the population densities of *Tachardiphagus tachardiae, Aprostochetus purpureus Eupelmus tachardiae, Parechthrodryinus clavicornis* and *Aprostochetus purpureus* but was more prevalent in VC than SAR while AF had scanty population.

Peak density of predator population across the habitats

The peak density of predators varied across the land use and years. In general, the peak density of predators was higher in 2017 than 2018 and showed a trend of VC>SAR>AF. Among the predators, *E. amabilis* was the dominant predator (Table 2). It showed a peak density of 7.98 and 7.20 in AF, 9.44 and 9.49 in SAR, 11.08 and 11.28 in VC during 2017 and 2018, respectively. The peak densities of other predators varied similarly (Table 2). Among the parasitoids, *T. tachardiae* population peak density during 2017 was 2.01 in AF and 2.07 in 2018. In SAR it was 2.03 during 2017 and 2.58 in 2018. In VC it was 2.77 during 2017 and 2.79 in 2018. Density of *A. purpureus* in AF during 2017 was 5.72 and 5.07 during 2018. In SAR it was 6.90 during 2017 and 6.68 in 2018 and in VC it was 7.65 during 2017 and 6.96 in 2018. For *E. tachardiae* density in AF during 2017 and 2018 was 1.15. In SAR it was 1.53 during 2017 and 1.69 in 2018 and in VC it was 1.77 during 2017 and 2.10 in 2018. Density of *P. clavicornis* in AF was 2.65 in 2017 and 2.49 during 2018. In SAR it was 2.50 in 2017 and 2.70 in 2018, and in VC it was 3.25 during 2017 and 3.00 in 2018. *A. purpureus*

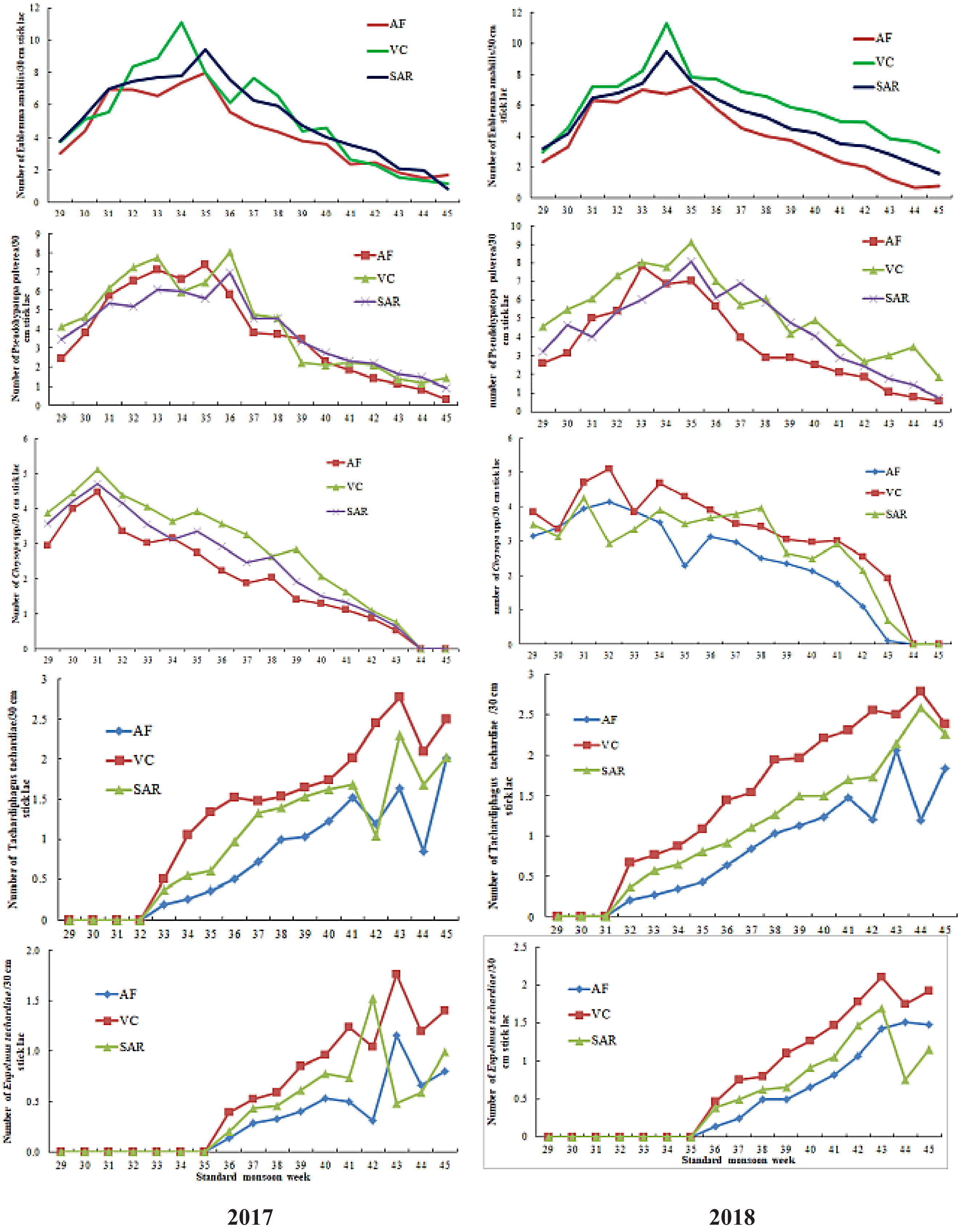

Figure 1. continued

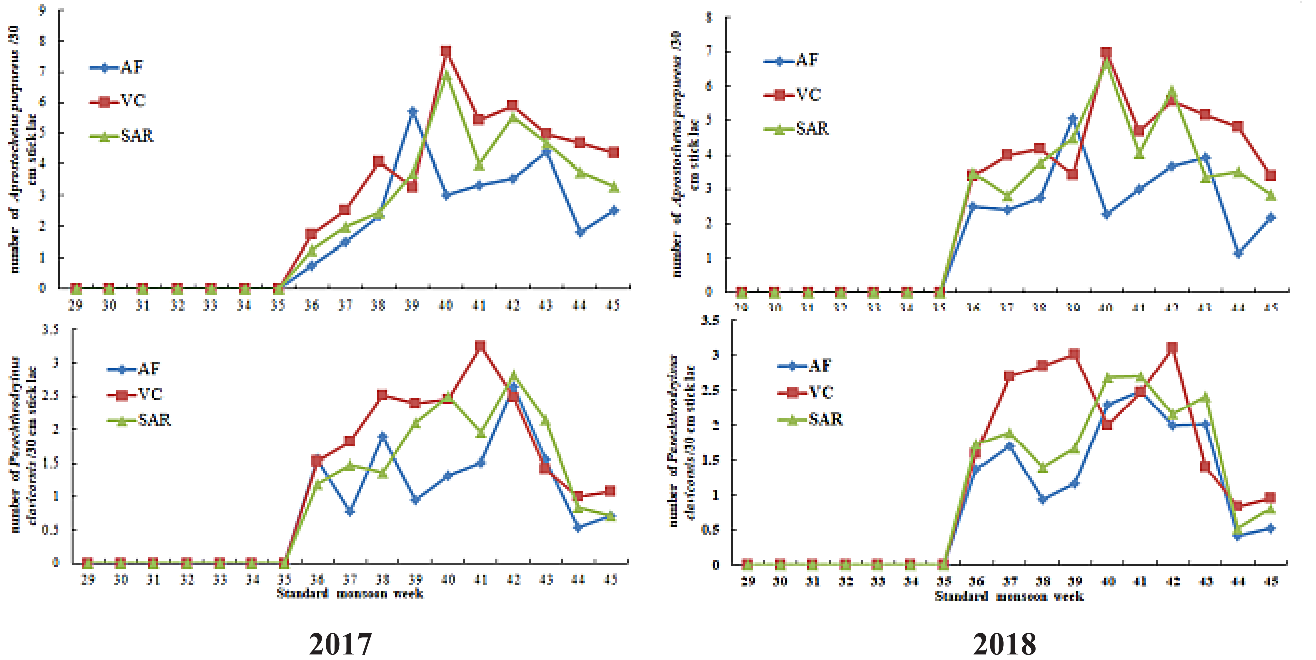

Figure 1. Pattern of occurrence of enemies across the land use during 2017 abd 2018

was found to be the dominant parasitoids which had significantly (P<0.05) higher population in VC than SAR and AF during both the years.

Pattern of occurrence of enemies

The pattern of occurrence of enemies across the land use and years are shown in Figure 1. The results reveal the enemies' peak active period differ by one to two weeks while all the species were very active from September to November. This was almost similar in both the years and for the land uses (Table 2).

Active period of predators

The active duration (days) of predators of *E. amabilis* and *P. pulverea* in all the three sites of AF, SAR and VC were 119 for both the years of 2017 and 2018. In *Chrysopa* spp. for similar three locations it was 105 days for both the yeas of 2017 and 2018.It is revealed that active duration (days) of *E. amabil* and *P. pulverea* has more active duration (days) as compared to *Chrysopa* spp. For parasitoids of *T. tachardiae* active duration (days) in all three sites of AF, SAR and VC was 91 and 98 days during 2017 and 2018, respectively. For *A. purpureus*, *E. tachardiae* and *P. clavicornis* the active duration was

Table 3. Seasonal population density (mean density/30 cm stick lac) at different sites

Species	2017			2018		
	AF	SAR	VC	AF	SAR	VC
Eublemma amabilis	4.42±0.105	5.21±0.07	5.24±0.06	3.96±0.22	4.97±0.14	6.01±0.21
Pseudohypatopa pulverea	3.77±0.06	3.91±0.08	4.24±0.07	3.65±0.14	4.42±0.13	5.35±0.05
Chrysopa spp.	2.07±0.04	2.42±0.10	2.79±0.05	2.37±0.05	2.75±0.08	3.19±0.13
Tachardiphagus tachardiae	0.73±0.03	1.01±0.05	1.33±0.05	0.82±0.06	1.12±0.06	1.47±0.1
Aprostochetus purpureus	1.70±0.06	2.21±0.0	2.62±0.08	1.70±0.07	2.40±0.03	2.68±0.07
Eupelmus tachardiae	0.30±0.02	0.40±0.02	0.59±0.02	0.49±0.02	0.54±0.02	0.79±0.06
Parechthrodryinus clavicornis	0.79±0.03	1.00±0.04	1.17±0.03	0.88±0.05	1.06±0.04	1.23±0.02

70 days for all three sites during both the years. It was found that active duration (days) of *T tachardiae* was longer among four parasitoids.

Seasonal population density

Seasonal population density (mean density/30 cm stick lac) of *E. amabilis* during 2017 in AF, SAR and VC was 4.42±0.105, 5.21±0.07 and 5.24±0.06, respectively (Table 3). During 2018 it was 3.96±0.22, 4.97±0.14 and 6.01±0.21, respectively, in AF, SAR and VC. For *P. pulverea* it was 3.77±0.06, 3.91±0.08 and 4.24±0.07 in AF, SAR and VC in 2017 and 3.65±0.14, 4.42±0.13 and 5.35±0.05 in AF, SAR, and VC, respectively during 2018. For *Chrysopa* spp. it was 2.07±0.04, 2.42±0.10 and 2.79±0.05 in AF, SAR, and VC, respectively, during 2017 and 2.37±0.05, 2.75±0.08 and 3.19±0.13 during 2018. For parasitoids *T. tachardiae* during 2017, it was 0.73±0.03, 1.01±0.05 and 1.33±0.05, respectively in AF, SAR and VC. For 2018, it was 0.82±0.06, 1.12±0.06 and 1.47±0.1, respectively. For *A. purpureus* during 2017 in AF, SAR and VC it was 1.70±0.06, 2.21±0.03 and 2.62±0.08, respectively and during 2018, 1.70±0.07, 2.40±0.03 and 2.68±0.07 in AF, SAR and VC, respectively. For *E. tachardiae* during 2017 it was 0.30±0.02, 0.40±0.02 and 0.59±0.02 in AF, SAR and VC, respectively. For 2018, it was 0.49±0.02, 0.54±0.02 and 0.79±0.06 for AF, SAR and VC, respectively. For *P. clavicornis* it was 0.79±0.03, 1.00±0.04 and 1.17±0.03 for AF, SAR, and VC in 2017. During 2018 it was 0.88±0.05, 1.06±0.04 and 1.23±0.02 in AF, SAR and VC, respectively.

The peak population density (mean density/30 cm stick lac) of predators during 2017 at different sites of AF, SAR, and VC for *E. amabilis* was 7.98±0.55, 9.44±0.54 and 11.08±0.49, respectively (Table 2). During 2018 it was 7.20±0.10, 9.49±0.43 and 11.28±0.43 in AF, SAR, and VC, respectively. For *P. pulverea* it was 7.39±0.13, 6.96±0.31 and 8.03±0.19 in 2017 and during 2018 7.04±0.30, 08±0.15 and 9.12±0.26 for AF, SAR and VC, respectively. For *Chrysopa* spp. it was 4.48±0.20, 4.71±0.27 and 5.13±0.18 during 2017 and 4.14±0.17, 4.25±0.15 and 5.11±0.37 in 2018 for for AF, SAR and VC, respectively. For parasitoids, peak population density (mean density/30 cm stick lac) of *T. tachardiae* during 2017 was 2.01±0.10, 2.03±0.12 and 2.77±0.12 and 2.07±0.15, 2.58±0.15 and 2.79±0.07 during 2018 in AF, SAR and VC, respectively. For *A. purpureus* in 2017 it was 5.72±0.14, 6.90±0.09 and 7.65±0.14 and during 2018 it was 5.07±0.05, 6.68±0.05 and 6.96±0.19 in AF, SAR and VC, respectively. For *E. tachardiae* in 2017 it was 1.15±0.06, 1.53±0.17 and 1.77±0.08 and during 2018 it was 1.51±0.19, 1.69±0.12 and 2.10±0.11 in AF, SAR and VC, respectively. For *P. clavicornis* during 2017, it was 2.65±0.1, 2.50±0.3 and 3.25±0.12 and during 2018, it was 2.49±0.16, 2.70±0.24 and 3.00±0.08 in AF, SAR and VC, respectively.

DISCUSSION

Diversity, dominance of natural enemies, active period and peak density

Large number of predators and parasitoids are detrimental to the lac crop as they not only drastically reduce the production but also deteriorate the quality of the lac resin. In the present study seasonal diversity and emergence of insect predators and parasitoids associated with rangeeni strain lac insect of katki crop in rainy season indicates three predator and four parasitoids species were found on lac crops. The present study definitely indicated the occurrence of *Eublemma amabilis* Moore (Lepidoptera: Noctuidae), *Pseudohypatopa pulverea* Meyr (Lepidoptera: Blastobasidae) as major and *Cryosopa* spp. (Chrysopidae; Neuroptera) minor predator associated with the natural populations of lac insect at different agricultural landscapes on Palash trees in Nilagiri block, Balasore district of Odisha during the year 2017 and 2018 (Table 1). Sharma et al. (1997) recorded 14 species of parasitoids, among which *A. purpureus* (55.82%) and *T. tachardiae* (28.37%) were the most abundant. Bhattacharya and Yogi (2015) documented 72 insect parasitoids and predators and out of which predator *E. amabilis* and parasitoids *T. tachardiae* and *A.purpureus* as being dominant in lac. Bhattacharya et al. (2007) recorded prevalence of 14 natural enemy insects, among them *Eublemma amabilis* and *Pseudohypatopa (Holcocera) pulverea* are being the major predators. The present findings agree with the reports of Bhattacharya et al. (2007) and Jaiswal et al. (2008) who stated that *E. amabilis* Moore (Lepidoptera:

Noctuidae) and *P. pulverea* Meyr (Lepidoptera: Blastobasidae) are the two dominant predators of lac insect that bring 20 to 40% lac crop loss. Jaiswal et al. (2012) also reported the lac insect associated predators and parasitoids were noticed in limited numbers of lac cultivated regions of Odisha. Chattopadhyay (2011) found *P. pulverea* predator of lac insect is key harmful predator in all lac growing areas in India. Among the parasitiods *A. purpureus* was recorded as major potential parasitoids with peak density of 7.65 during 2017 and 6.96 during 2018 in village commons (VC) followed by strips along roads (SAR) and meagre numbers in agricultural fields (AF) whereas, *T. tachardiae, P. clavicarnis* and *E. tachardiae* was recorded as minor parasitoids. Among these parasitoids, populations of *A. purpureus* (Figs. 11, 12), *T. tachardiae* (Figs. 7, 8) and *Eupelmus tachardiae* (Figs. 9, 10) was more at crop maturity stage i.e. Oct-Nov and less in August and September. *P. clavicornis* populations were more in October and lowest in November (Figs. 13, 14). *P. clavicornis* was active from 07th September (36 SMW) to 09th November (45 SMW) and on 19th October (42 SMW) the highest mean population was noticed with 2.53 insect per 30 cm stick lac in rangeeni and katki (rainy) strains. From 07th September (36 SMW) to 09th November (45 SMW) population of lac insect parasitoid *E. tachardiae* was reported active. Its population gradually increased and reached peak on 26th October (43 SMW).

The present study also reports similar findings of Meena and Sharma (2018) who described 11 species of insect fauna associated with *Kerria lacca* from 8 families under which 3 were predator species (*E. amabilis, P. pulverea, C. zastrowi*) 4 primary parasitoids (*T. tachardiae, A. purpureus, T. clavicornis, E. dewitzi*) and 4 hyper-parasitoids (*A. fakhrulhajiae, E. tachardiae, B. greeni, B. tachardiae*) in western plains of India**.** Sharma et al. (2010) recorded a maximum of 57.6% parasitisation of lac insects is due to *A. purpureus* while hardly 20% was found nearly twenty years back. At the same time, predators are very harmful and may make loss of 35-45% annually to the lac crop. Daharia and Katlam (2013) studied the prevalent lac natural enemies in four different lac cultivated districts of Mahasamund, Jashpur, Rajpur and Kanker in Chhatisgarh. They revealed that *E. ammabilis* Moore and *P. pulverea* Meyr as the major predators in these states. However, among the parasitoids *T. tachardiae* was found as major parasitoid. *E. amabilis* is reported as a key predator of commercial *K. lacca* (Khobragade et al. 2012, Ramesh 2013), and *P. pulverea* (Kumar et al. 2007, Ghosal et al. 2010) as parasite (Kumari et al. 2012). *Chrysopa* is also a predator of *K. lacca* (Ramesh 2013). In the present study, there was meagre population of *Chrysopa* spp. This present finding is in conformity with previous experimental findings of Monobrullah et al. (2015) in which they revealed *A. purpureus* is the most alarming endoparasitoid of lac insect and determined direct correlation between low lac yield and parasitisation. Pandey et al. (2008) reported that the emergence of a greater number of natural bio-agents (predators and parasitoids) associated with lac insect *K. lacca* on *B. monosperma* in *katki* (rainy) crop than *baisakhi* (summer) crops. Predators *viz. E. amabilis* and *P. pulverea* were seen in almost all the studied areas, whereas the parasitoids (*T. tachardiae*, *T. somervilli* and *A. purpureus*) of lac insect in less numbers in the districts Allahabad and Mirzapur. Population of associated fauna varied considerably from crop to crop, place to place and in different months. The findings of the present study are similar with Sharma et al. (2007) who reported that parasitoids of lac insect make severe loss to the crop by adverse effect on the resin yield and the fecundity of the insects, mainly during rainy seasons. Due to parasitism the average decline in resin production by a single female varied between 17.25-39.80% in *Rangeeni* and 25.24-37.91% in *Kusmi* strain. Chattopadhyay (2011) also revealed that *A. purpureus* belongs to the order hymenoptera are the most prevalent lac associated parasitoids. The parasites exhibited different patterns of peak emergence. Among the parasitoids of lac insect, *Aprostocetus purpureus* and *T. tachardiae* were observed regularly in large numbers in all the four lac crops (baisakhi, katki, jethwi and aghani) by Srivastava et al. (1984). Rahman et al. (2009) noticed that the moth *E. amabilis* is very harmful to lac insect and lac encrustation. Prior to pupation a single larva injures 42-50 mature lac cells and brings more loss to the Kartki crop than to the Baishakhi crop. Variation of population was observed between different locations, the hosts and the crop seasons.

During the year 2012-2015 Mohansundaram et al. (2018) affirmed that the variations of lac insect associated predators and parasitoids population for both strains of kusmi and rangeeni. It reports *T. tachardiae* and *A. purpureus* population was 14.7 and 62.7, respectively, and maximum in ber (50.2) during katki crop. Monobrullah et al. (2015) also stated that during rainy season *(in katki* of 2013) crop, prevalence of *A. purpureus*, and *P. clavicarnis* was more during September-October, whereas *T. tachardiae* was more in October-November. Predator *(E. amabilis* and *P. pulverea)* were more abundant during crop maturity period in both the crops of *baisakhi and* katki. Srivastava et al. **(**1984) noticed that higher peak of associated parasitoid population in the katki crop accorded with the time of crop maturity period (October and November) are in conformity with the present findings.

Pattern of variation among the habitats

The higher emergence of populations of parasitoids and predators in the village commons might be due to lack of maintenance and sanitation of lac culture area. In this area, there are no operations between inoculations of brood lac on host plant and the harvest of the lac secretion produce. Intensive maintenance of lac ecosystem considered as an effective practice for controlling parasitoids and predators which includes undergrowth (ground cover) cleaning, removal of dried, dead and criss-cross branches of host plants which is seen in agricultural fields. The removal of branches to reduce crown density enhances air circulation as well as reduces humidity, the unfavourable conditions for emergence of parasitoids and predators on host plants in agricultural fields. The higher mean number of associated natural enemies of both predators and parasitoids per 30 cm lac encrustation stick in the village commons than the other locations around the KWLS could be due to variations in climatic conditions between different sites. Climate has both direct as well as indirect effect on these insects and also on the host plants on which these insects survive (Jagannathan 1956). VC has dense (thick) forest in comparison to other locations. Due to the continuity in canopy in the VC, it acts as a safeguard from the adversities of climatic factors of temperature, wind and rainfall and thus it provides favourable environment for emergence of natural enemies than other sites. Thus, the lac insects are more susceptible to natural enemies in village commons.

The present research findings further gets confirmed partly from the works of Sharma et al. (1997) where parasitoids of *A. purpureus* and *T. tachardiae* detected most abundant species comprising 55.82 and 28.37%, respectively, of the total population of parasitoids. However, this alteration may be found due to varied agro climatic conditions of the region. Mohansundaram et al. (2014) reported that rainy season crops of both strains of Kusmi and Rangeeni of *K. lacca* are severely affected fecundity and resin production due to parasitisation. Sharma et al. (2007) also stated that due to parasitism the resin produced by a single female reduced severely. Mohansundram et al. (2016) reported that the prevalence of the lac associated predators and parasitoids during *baisakhi* (summer) season crop for two consecutive years, which stated that parasitoids alone constitute 93 and 89% population, followed by predator and hyper parasitoids on ber, respectively. Similar trend was found on palash for both the years, among which, *A. purpureus* was significantly more abundant which constitute 71.56% on ber and 74.47% on palash, respectively. They further revealed that *A. purpureus* population has increased by 538% over the four decades. Maximum population of *A. purpureus* was found during the SMW 17 to 22 after inoculation. These findings reported that the emergence of *A. purpureus* as the pest of lac insect causing huge economic losses, which are more or less similar to our results.

Management strategies

The production of lac is one of the major interventions for livelihood support to the resource constraints farmers around the KWLS. The natural enemies of lac insect **(***K. lacca*) therefore should be sustainably managed by adopting suitable biocontrol/ novel biopesticides through broodlac treatment (Malhotra and Katiyar 1975, Singh et al. 2013, Singh and Jaiswal 2018) to improvise lac yield. The density of settlement of larvae and subsequent mortality due to the natural enemies nevertheless affect the production of lac. Under excess brood condition 'crowding effect' was observed in rangeeni strain which cause higher mortality due to insufficient availability of space and nutrition. Among the lac predators *E. amabilis* alone is reported to cause 20-25% damage to the crop (Narayanan 1962) and *T. tachardiae* is the most abundant and damage causing lac parasites. The loss of lac spores to the natural enemies could be reduced through timely and effective management.

CONCLUSIONS

Fast disappearance of forest resources is a major hazard for the preservation of the biodiversity of lac insects. Lac crop being susceptible to both biotic and abiotic factors contribute in declining of the yield up to 50%. The temperature is the foremost abiotic factor affecting lac production to the greatest extent. Erratic rainfall pattern, intense cold waves are also among the other abiotic factors adversely affecting lac insects. Rangeeni crop is more threatened to associated pest attack in lac insects and destruction is more in the rainy season crop which results the severe crop loss. This loss can be reduced through proper identification of lac insect pests and their effective management approaches. The current investigation determines that adequate pest management strategy to be followed for specific crop season depending upon the nature of emergence profile of lac associated fauna of key parasitoid/ predators. Populations' variation of parasitoid and predator was found in palas of katki crop season. Among the parasitoids, *A. purpureus* was the most key parasitoids followed by *T. tachardiae* and *P. clavicornis*. In katki lac, crop maturity period is regarded as the most vulnerable phase which reduced quality of broodlac. During this period increased incidence of parasitoids and predators may induce to entire crop failure. Since, this knowledge pertaining to the most critical stage of associated fauna in lac ecosystem, required for developing a pest management programme among the lac growing farmers and researchers.

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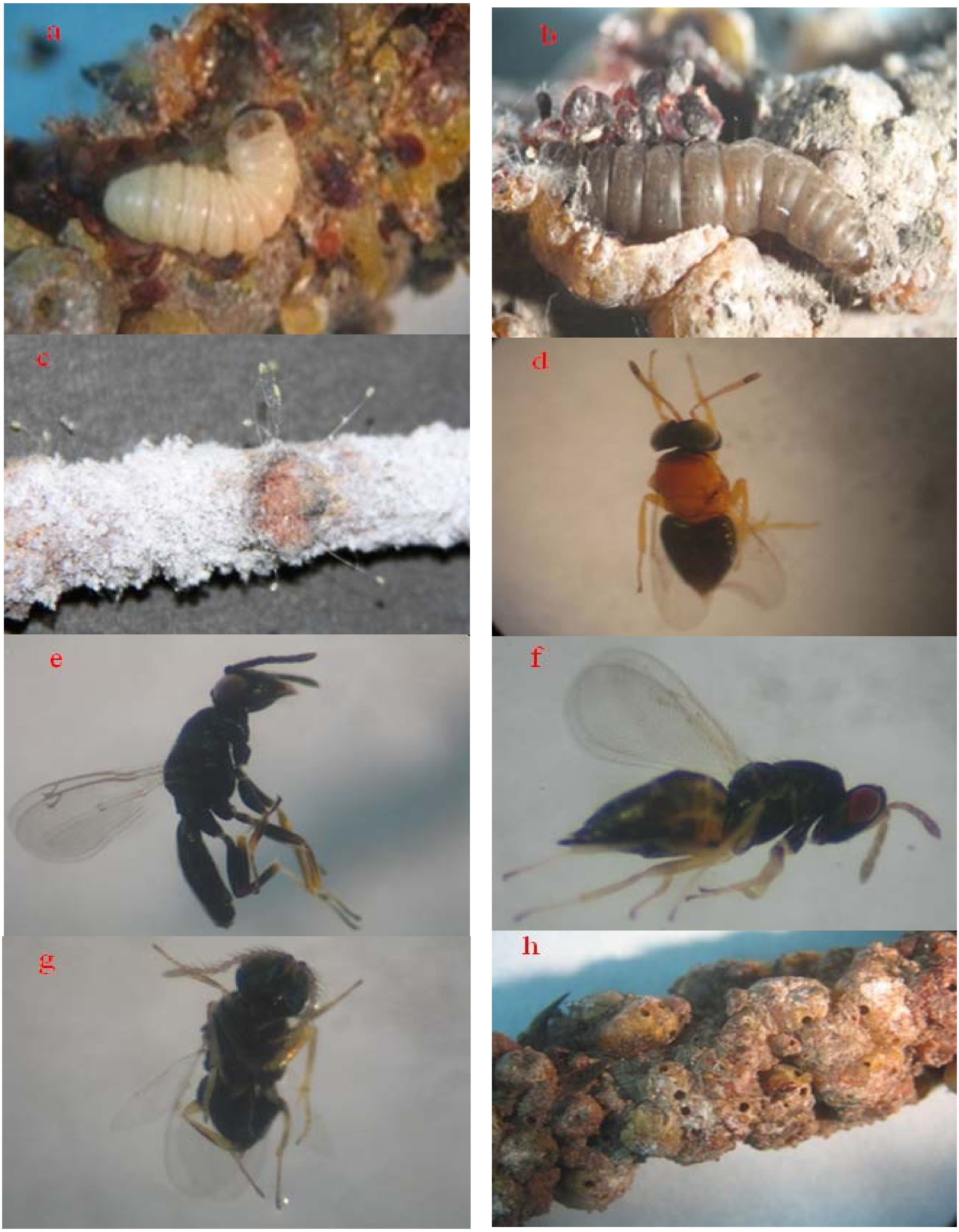
Annexure 1



Predator: (a) *Eublemma amabilis*, (b) *Pseudohypatopa pulverea*, (c) *Chrysopa* spp.; Parasitoid: (d) *Tachardiphagus tachardiae*, (e) *Eupelmus tachardiae*, (f) *Aprostochetus purpureus*, (g) *Parechthrodrynus clavicornis*; (h) Symptoms of infestation by natural enemies