

**Diversity and Morpho-taxonomic Studies of Major Predators of Lac
Insect, *Kerria lacca* (Kerr) in Arid Western Plains**

पश्चिमी शुष्क मैदानी क्षेत्र में लाख कीट, *Kerria lacca* (Kerr) के प्रमुख
परभक्षियों की विविधता एवं बाह्य-वर्गिकी का अध्ययन

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Master of Science in Agriculture

(Entomology)



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**DEPARTMENT OF ENTOMOLOGY
RAJASTHAN COLLEGE OF AGRICULTURE
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND
TECHNOOLOGY UDAIPUR-313001(RAJASTHAN)**

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Thesis

Submitted to

Maharana Pratap University of Agriculture and Technology, Udaipur

In partial fulfillment of the requirements for the Degree of

Master of Science in Agriculture

(Entomology)



By

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2023

CERTIFICATE-I

CERTIFICATE OF ORIGINALITY

The research work embodied in this thesis titled “**Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect, *Kerria lacca* (Kerr) in Arid Western Plains**” submitted for the award of degree of **Master of Science in Agriculture** in the subject of **Entomology** to Maharana Pratap University of Agriculture and Technology, Udaipur (Raj.), is original and bonafide record of research work carried out by me under the supervision of **Dr. Hemant Swami**, Assistant Professor, Department of Entomology, Rajasthan College of Agriculture, Udaipur. The contents of the thesis, either partially or fully, have not been submitted or will not be submitted to any other Institute or University for the award of any degree or diploma.

The work embodied in the thesis represents my ideas in my own words and where others ideas or words have been included. I have adequately cited and referenced the original source. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/ source in my submission. I understand that any violation of the above will be cause for disciplinary action by the University and can also evoke penal action from the sources which have thus not been properly cited of from whom proper permission has not been taken when needed.

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This is to certify that this thesis entitled “**Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect, *Kerria lacca* (Kerr) in Arid Western Plains**” submitted for the degree of Master of Science in Agriculture in the subject of Entomology, embodies bonafide research work carried out by **Ms. Dipali Samridhi** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of this thesis was also approved by the advisory committee on / /2023.

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This is to certify that **Ms. Dipali Samridhi** student of Master of Science in Agriculture; **Department of Entomology** has made all the corrections/modifications in the thesis “**Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect, *Kerria lacca* (Kerr) in Arid Western Plains**” which were suggested by the external examiner and the advisory committee in the oral examination held on ___/___/2023. The final copies of the thesis duly bound and corrected were submitted on ___/___/2023 are enclosed here with for approval.

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1. INTRODUCTION

Scale insects or coccoids belong to superfamily *Coccoidea* (Hemiptera: Sternorrhyncha) which consists of almost 7,500 species belonging to more than 20 family (Resh and Carde, 2009). Lac insect is a scale insect belonging to family Tachardiidae (=Lacciferidae) of order Hemiptera and superfamily Coccoidea are important species for commercial production of dye, resin and wax (Mohanasundaram *et al.*, 2019). Lac is a resin, naturally secreted by an insect (*Kerria lacca*) which feeds and thrives on the tender portion of twigs of specific host trees. Distribution of lac insect is confined to subtropical and tropical areas of south and south-east Asia (Ramani *et al.*, 2007). Across the globe, 9 genera & 99 species of lac insects are reported of which 2 genera & 26 species are recorded in India. There are two subfamilies *viz.*, Tachardiinae (true lac insect with resinous cell) & Tachardininae (pseudo-lac insect with non-resinous cells) (Mohanasundaram *et al.*, 2019). *Rangeeni* and *Kusumi* lac are the two types of lac insect strains recorded in India (Janghel *et al.*, 2014). *Kusumi* strain completes two life cycles per year with each crop having six month duration namely *Aghani* (winter crop) and *Jethwi* (summer crop). In the same way, *Rangeeni* strain completes its two unequal cycles per year namely *Katki* (rainy crop of 4 months) and *Baisakhi* (summer crop of 8 months) (Mohanasundaram *et al.*, 2018). Indian lac insect *Kerria lacca* (Kerr) contributes to more than 80% of the overall lac production (Roonwal *et al.*, 1958; Sharma *et al.*, 1997). Lac insect depends on host plants for their food requirements. Earlier only 4 species of lac host plants were known but recently more than 400 plant species have been found to be lac insect hosts, globally, which are divided into 3 categories as per their suitability and distribution *i.e.* common, occasional, and rare. The *Flemingia spp.*, Ber, Palas and Kusum host plants are considered important for lac production (Bashir *et al.*, 2022).

Lac, an unique commodity produced by an insect, is the subsidiary source of income for millions of rural mass specially tribals of the country (David and Ramamurthy, 2017). Lac makes significant contribution to the foreign exchange earnings of the country. Lac also plays an important role in the economic upliftment of around 3 to 4 million tribal people (Kumar, 2002). Cultivation of lac generates employment for both women and men (Shah *et al.*, 2015). India is a leading lac producing country contributing to 80 per cent of total lac production worldwide

(Ramani *et al.*, 2016) with an annual production of 20,000 metric tonn (Pal *et al.*, 2011) of which 75 per cent of lac is exported to more than hundred countries in semi-processed and processed form. India fetches about Rs. 120-130 crores of foreign currency through the export of lac every year. Among Indian states, Jharkhand shares 50.83 per cent of total lac production followed by Chhattisgarh, Madhya Pradesh, Maharastra, Orissa, West Bengal and Assam with 14.58, 14.14, 8.98, 4.21, 2.66 and 1.68 per cent contribution, respectively (Yogi *et al.*, 2022). Other states like Madhya Pradesh, Gujarat, Punjab, Rajasthan etc. have shown increase in production of lac recently (Pal *et al.*, 2009). According to recent data available total export of lac and its value added products in 2020 was 246543.52 tons (NISA, 2020).

Lac production in the country is limited because of abiotic and biotic factors; the major limiting biotic factors are predators and parasitoids whereas the abiotic factors are the environmental factors like drought, salinity, cold, frost, water-logging etc. (Wang *et al.*, 2003). Lac ecosystem is complex and multi-trophic web of fauna and flora. There are total of 22 species of lac predator, 30 species of primary parasites & 40 species of secondary parasites, respectively, along with fungal pathogens which represent rich biodiversity of lac associated fauna (Sharma *et al.*, 2006; Rao *et al.*, 2013). Around 35 to 40 per cent loss in lac production is caused by predators (Glover, 1937; Jaiswal *et al.*, 2008), while parasitoids cause 5 to 10 per cent loss (Varshney, 1976). *Eublemma amabilis* is a monophagus predator of lac and it causes 20 to 25% loss to the crop (Shah *et al.*, 2015) whereas *Pseudohypatopa pulverea* acts a as natural bio-agent of lac insect *Kerria lacca* (Kerr.) (Netam *et al.*, 2021). Predators and parasitoids occur regularly but their incidence may vary from one season to other, one place to other and crop to crop (Varshney, 1976) (b).

Major lac associated fauna consists of predators, primary parasitoids and hyperparasitoids. The major lac predators are *Pseudohypatopa pulverea*, *Eublemma amabilis*, *Chrysopa zastrowi*; primary parasitoids are *Aprostocetus purpureus*, *Tachardiaephagus tachardiae*, *Erencyrtus dewitzii*, *Tyndarichus clavicornis* & hyperparasitoids recorded are *Bracon greeni*, *Brachymeria tachardiae*, *Apanteles fakhrulhajiae* and *Euplemus tachardiae*. High abundance was observed for *E. amabilis* among predator, *E. dewitzii* among primary parasitoid and *E. tachardiae* among hyperparasitoid in Arid Western Plains (Swami *et al.*, 2021).

The Shannon index is a popular diversity index in ecological studies which is used to find diversity of population and Simpson's Diversity Index is used to calculate a measure of diversity, taking into account the number of species present as well as its relative abundance. It is important to calculate diversity indices as they provide information about rarity and commonness of species in community and helps in understanding community structure (Sarma and Das, 2004).

Morphometric analysis is useful for the species identification and classification. Morphometry is the study of any quantitative measurement and analysis of morphological traits affecting it (Digo *et al.*, 2015). Measurements of wings, either the length of wing or wing span, is considered as the most commonly used measure of body size in Lepidoptera (Miller, 1977). Morphology of wing span of insect is used to study the relationship between closely related taxa and it also helps in identifying the population within and between different species of insect (De la Riva *et al.*, 2001; Baylac *et al.*, 2003 and Aytekin *et al.*, 2007).

Insufficient knowledge on the incidence and identification of major predators of lac insect restricts their effective management and also hinders the lac production in the country. A proper knowledge on the incidence, abundance and morpho-taxonomic parameters will help with the effective management of major predators of lac insect and will also enhance lac production in the area. Hence, the present research work entitled, "Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect *Kerria lacca* (Kerr) in Arid Western Plains" was undertaken with the following objectives:

- 1) Survey of the prevalence and abundance of natural enemies of lac insect, *Kerria lacca* (Kerr) in different states of arid western plains on different host.
- 2) Diversity and species richness of natural enemies of lac insect.
- 3) Morpho-taxonomic studies of major predators of the *Rangeeni* strain of lac insect.

2. REVIEW OF LITERATURE

The available literature pertaining to the objectives of the present investigation has been compiled and presented in this chapter. There is a lack of significant work on the studies of lac insect in Arid Western Plains, particularly on natural enemies associated with lac insect and their morpho-taxonomic aspects, however, work carried out in different parts of the country have has been reviewed and compiled in this chapter under different objectives.

2.1 Prevalence and abundance of natural enemies of lac insect

Natural enemies like predators and parasitoids associated with the lac insect are one of the major biotic factors causing huge reduction in lac production in the country. Malhotra and Katiyar (1975) reported that 30-35 per cent loss to the lac crop is caused by the two major pests namely *Pseudohypatopa pulverea* & *Eublema amabilis*. After hatching from the egg, larvae of *E. amabilis* leads a cryptic mode of life as it feeds on lac insect and not on lac cells by burrowing and tunneling within the lac encrustation. There are three overlapping generations for this predator in both rainy and summer season of lac crop where it moults 10 times before it pupates.

Varshney (1976) reported 22, 30 & 45 species of predators, primary parasites and secondary parasites, respectively along with few fungal pathogens that are a part of lac ecosystem and form multi-trophic and complex web of flora and fauna which ultimately is a huge constrain in lac production.

Jaiswal *et al.* (1998) studied lac associated fauna under storage conditions. After storage period of 8 months he recorded the presence of predator: *P. pulveria* ; parasitoids: *Aprostocetus purpureus*, & *E. tachardiae* ; hyperparasitoids: *Pristomerus sulci* and a small number of *A. tachardiae* whereas predator: *E. amabilis*; parasitoids: *Tachardiaephagus tachardiae*, *Coccophagus tschirchii* & *Parechthrodryinus clavicornis* and hyperparasitoids: *B. greeni* & *Elasmus claripennis* were present initially in freshly harvested lac but were absent in the stored condition.

Bhattacharya *et al.* (2004) reported that 3 to 4 per cent of average damage is caused by the larval stages of *P. pulverea* & *E. amabilis* who acts as predator for different stages of the lac insect. Bhattacharya *et al.* (2007) also recorded that a total

loss of 4 per cent is caused alone by *E. amabilis* which thus acts as the major predator of lac insect.

Rahman *et al.* (2009) reported that *E. amabilis* is highly destructive to both lac encrustation and the lac insect. His studies further revealed that a single newly hatched larvae of *E. amabilis* enters the lac cell through one of the opening present in it or else it excavates holes in the encrustation and damages 42 – 45 matured lac cells before pupation. Predator completes six generations in a year causing more damage to *Katki* than *Baisakhi* crop.

Chattopadhyay (2011) reported that a single larvae of *P. pulverea* can destroy upto 45 to 60 matured lac cells and thus it is highly destructive to the lac crop. It is recorded in all lac growing areas and feeds both on living and dead cells of lac. A large number of this predator can also be seen in stored lac and thus it causes huge quantitative and qualitative loss to lac in stored condition.

Bhattacharya and Yogi (2015) reported that 90 per cent of lac is damaged and destroyed by the predators of lac insect. Studies carried out at IINRG have revealed that about 20 per cent of Kusum plants in *Jethwi* and 72 per cent of balia plant in *Baisakhi* is damaged by insects. Amongst the insect predators two Lepidopterans namely *E. amabilis* & *P. pulverea* and two Neuropterans *viz.* *Chrysopa madestes* & *C. lacciperda* are the most destructive ones. Among these, lepidopteran predators cause maximum damage and they must be managed and controlled for high yield and profitable lac crop.

Kalahal (2017) recorded two species of Lepidopteran predators *viz.* *E. amabilis* and *P. pulverea* and one species of Coleopteran predator namely *Oryzaephilus spp.* which contributed 0.70, 0.28 and 1.26 per cent to the total population of natural enemies, respectively. Kalahal *et al.* (2018) reported that order Hymenoptera consists of three species of parasitoids *viz.*, *T. tachardiae* Howard (5.2 per cent), *E. dewitzii* Mahd. (88.4 per cent) of family Encyrtidae and *A. purpureus* Cameron (4.2 per cent) of family Eulophidae contributed 97.8 per cent to the total natural enemies population. The two predators of lepidopteran order *viz.*, *P. pulverea* Meyrick and *Eublemma amabilis* Moore of family Blastobasidae & Noctuidae contributed 0.3 & 0.70 per cent, respectively that constitutes around one per cent to

the total population of natural enemies. *Oryzaephilus spp* (Silvanidae; Coleoptera) contributed 1.3% to the total natural enemy population.

Mohanasundram *et al.* (2018) carried out a study to find out the variation in the lac associated fauna in relation to different host plants viz., ber, palas and red gram for both *Kusumi* and *Rangeeni* strain of lac. In his study he found that the population of lac associated fauna was significantly higher on ber (*Ziziphus mauritiana*) followed by palas (*Butea monosperma*) and red gram (*Cajanus cajan*).

Meena and Sharma (2018) reported that lac associated fauna consists of predators viz., *P. pulverea* Meyrick, *E. amabilis* Moore, *C. zastrowi*; primary parasitoids viz., *T. tachardiae* Howard, *A. purpureus* Cameron, *T. clavicornis* Mashhood Alam and *E. dewitzii* Mahd. and the hyperparasitoids viz., *E. tachardiae* Howard, *A. fakhrulhajiae* Mahd., *B. tachardiae* Cameron and *B. greeni* Ashmed. He recorded the emergence of predators upto VIII week during October and in July upto VI weeks. Upto V and IV weeks emergence of parasitoids was recorded in the month of October and July, respectively. Emergence of hyperparasitoids was recorded upto V & IV-V week during October & July, respectively. Natural enemies took longer time to emerge in Oct/Nov than June/July.

Meena *et al.* (2020) carried out the study to record the lac insect occurrence and also to record new or potential host plants. The survey was carried out in Gujarat, Haryana and Rajasthan under one of the co-operating centers (MPUAT, Udaipur) of ICAR funded Network Project on Conservation of Lac Insect Genetic Resources (implemented and executed by ICAR-IINRG, Ranchi) during 2015 and 2016. During both the season *F. religiosa* was the most abundant host on which only *Rangeeni* strain of lac insect was found which had both crimson and yellow colour. A total of 21 host plants were reported under 14 genera from 6 families. Good encrustation of *Rangeeni* lac was recorded on *Acacia auriculiformis* Benth, *Annona reticulate* L., *Calliandra calothyrsus* Meissn, *Ficus religiosa*, *F. racemosa*, *F. tsiela* Roxb, *Peltophorum ferrugineum* Heyne, *Pithecellobium dulce* Benth, *Samanea saman* Merrill and *Z. mauritiana* Lam.

Monobrullah *et al.* (2020) conducted surveys in 28 districts of Bihar to record the presence of natural lac population and abundance of its different host plant species and natural population of lac insect was observed in 18 districts of Bihar in varied

proportion where it was mostly recorded on *F. religiosa*, *F. benghalensis* and rarely on *B. monosperma* and *Z. mauritiana*. The investigation also reveals the presence of 2 species each of predators and primary parasitoids namely *E. amabilis* & *P. pulvereus*, and *Tachardiaephagus tachardiae* & *Aprostocetus purpureus*. Parasitoids, *A. purpureus* was more in number as compared to *T. tachardiae*

Swami *et al.* (2021) conducted a location specific studies in arid western plains covering the states of Haryana, Rajasthan, Gujarat and Dadar and Nagar Haveli during lac crop season of 2019 -2020. A total 21 host plants were recorded in two year survey. The major hosts recorded for the natural occurrence of lac *viz.*, *Acacia lebbecks*, *A. auriculiformi*, *A. reticulate*, *Ficus benghalensis*, *F. palmate*, *F. racemosa*, *F. benjamina*, *F. tsiela*, *Peltophorum ferrugineum*, *Pithecellobium dulce*, *Polyalthia longifolia*, *Prosopis juliflora*, *P. cineraria*, *Samanea saman* and *Ziziphus mauritiana* under 14 genera from families *i.e.*, Fabaceae, Mimosaceae, Moraceae Annonaceae, Caesalpiniaceae, and Rhamnaceae. During both the years *Ficus religiosa* was recorded as the most abundant host. The studies on the lac insect associated fauna revealed that eleven species of predator, primary parasitoids and hyperparasitoids under eight families of three orders were recorded, of which eight species belonged to Hymenoptera, two to Lepidoptera and one species to Neuroptera were found to infest lac insect. The predators recorded were *Eublemma amabilis*, *Pseudohypatopa pulvereus* and *Chrysopa zastrowi*; primary parasitoids were *Tachardiephagus tachardiae*, *Aprostocetus purpureus*, *Tyndarichus clavicornis*, *Erencyrtus dewitzii* and hyperparasitoids were *Apanteles fakhrulhajiae*, *Eupelmus tachardiae*, *Bracon greeni* and *Brachymeria tachardiae*.

Bhatnagar *et al.* (2022) carried out a location specific survey under ICAR – Network Project on Conservation of Lac Insect Genetic Resources in Madhya Pradesh covering 319 blocks of 51 districts during 2015-2019 to reveal the presence of lac insect in the area. The major host plants bearing the population of cultivated lac insects in the area were Kusum (*Schleichera oleosa*), Ber (*Ziziphus mauritiana*), Palas (*Butea monosperma*) and Ghont (*Ziziphus xylopyra*) only. However, natural lac insect population was reported on Bargad (*Ficus benghalensis*), Peepal (*Ficus religiosa*), Babul (*Acacia nilotica*), Gular (*Ficus racemos*), Sitaphal (*Annona squamosa*), Rain tree (*Albizia lebbek*), Akashmoni (*Acacia auriculiformis*), Pakud (*Ficus rumphi*),

Khair (*Acacia catechu*), Jagli Jalebi (*Pithecolobium dulce*), Jangli Bargad (*Ficus citrifolia*), and Tendu (*Diospyros melanoxylon*).

2.2 Diversity and species richness of natural enemies of lac insect

Varshney (1976) recorded *E. amabilis*, *P. pulverea* Meyr, Moore, and *Chrysopa* sp., as 3 major predators of lac out of total 22 predators found associated with it whereas in Ranchi, *Bracon greeni* was recorded as dominant beneficial parasitoid however in Madhya Pradesh it was negligible in number.

Chiu *et al.* (1985) conducted a survey study at various locations in Taiwan and reported different lac associated natural enemies viz., *T. purpureus*, *E. tachardiae*, *T. tachardiae*, *Parechthrodryinus* sp., *Telsimia chujoi*, *Tachardiaephagus* sp., *Eublemma conspersa*, *Chrysopa* sp. and *Eublemma roseonivea* from different location in Taiwan. Sharma *et al.* (1997) revealed the presence of 14 different species of parasitoids belonging to 13 genera and presented by 10 families which were recorded to be associated with lac insect (*Kerria lacca*). *T. tachardiae* and *A. purpureus* were most abundant parasitoids associated with lac insect and accounted for 28.37 and 55.82 percent of the total natural enemies population, respectively. Among hyperparasitoids only *B. greeni* was recorded, with a contribution of 5.37 per cent which was lowest among the total population of natural enemies associated with lac. Jaiswal *et al.* (1998) documented the result of lac associated fauna under storage condition and reported that initially parasitoids *P. clavicornis*, *T. tachardiae* & *C. tschirchii* and predator *E. amabilis*, were present in freshly harvested lac whereas predator *P. pulverea* and parasitoids *E. tachardiae* and *A. purpureus* were recorded even 8 months after storage. Among beneficial fauna *E. claripennis* & *B. greeni* were recorded.

Sharma *et al.* (2008) conducted a survey in five different states of India namely Karnataka, Tamil Nadu, Jharkhand, Kerala & Assam to record the presence of lac insect and insect fauna associated with it. Emergence profile of lac associated fauna was presented from the different samples of lac collected from the five different states. The data revealed the presence of 2 predator species i.e., *E. amabilis* & *P. pulverea*; 5 species of primary parasitoids viz., *T. tachardiae*, *A. purpureus*, *T. somervilli*, *P. clavicornis* & *E. dewitzii*; 2 species of hyperparasitoids namely *P. sulci* & *B. greeni*. Of the emerged population reported during study 68, 29.6 & 2.4 per cent

was contributed by the predators, primary parasitoids & hyperparasitoids, respectively. *E. amabilis* was most dominant among predators and constituted 94.3 per cent of them while among the primary parasitoids *T. tacharidae* and *A. purpureus* formed the bulk and constituted 63.7 & 29.0 per cent of the population of primary parasitoids.

Rao *et al.* (2013) reported two Lepidopteran predators of which 8 individuals were of *E. amabilis* Moore and 3 individuals were of *P. pulverea* Meyrick belonging to family Noctuidae and Blastobasidae, respectively. Further, three hymenopteran parasitoids were recorded of which 29, 9 & 12 individuals were of *T. tachardiae* Howard (Encyrtidae), *A. purpureus* Cameron (Eulophidae) & *E. tachardiae* Howard (Euplemidae), respectively. One hypersitoid, *B. greeni* belonging to Braconidae family was also recorded in his study carried out at Entomology department of College of Agriculture, Rajendranagar, Hyderabad during 2012-13.

Virendra *et al.* (2017) recorded only two predators namely *E. amabilis* (Noctuidae; Lepidoptera) Moore & *P. pulverea* Meyrick (Blastobasidae; Lepidoptera) in stored samples of lac collected from storage structures and lac trader from Bargat block of Seoni district during 2015-16. Population of these predators was high in kuccha storage structure in comparison to pucca storage.

Meena and Sharma (2018) conducted a study to record different lac associated fauna and their species richness during 2015 to 2017 in western plains of India. Investigation revealed the presence eleven species and eight families of lac associated fauna. Of the associated fauna, predators were *P. pulverea*, *E. amabilis*, *C. zastrowi* and primary parasitoids were *E. dewitzii*, *T. clavicornis*, *T. tachardiae*, *A. purpureus*. Hyperparasitoid recorded in the study were *B. greeni*, *A. fakhrulhajiae*, *B. tacharidiae* & *E. tachardiae*. Among different natural enemies fauna two species belonged to Lepidoptera, eight to Hymenoptera and one to Neuroptera. It was further recorded that family Encyrtidae contributed maximum of 27.27 per cent to the total lac associated fauna and *E. dewitzii* was reported as most predominant parasitoid with 27.82, 39.91, 39.53 and 32.89 percent during 2015-2017. Family Braconidae contributed to 18.18 per cent to total fauna associated with lac insect and 9.09 per cent was contributed by each of the families namely Noctuidae, Eupelmidae, Blastobasidae, Chalcidae, Eulopidae & Chrysopidae.

Netam *et al.* (2019) conducted a study on the incidence of lac associated fauna in district Kanker of Chhattisgarh during 2015-2016 and 2016-2017. Various insects were recorded to be associated with lac insect in the *Rangeeni* strain of *katki* season of which *E. amabilis* and *P. pulverea* were recorded as major and *Chrysopa spp.* was recorded as minor predator with *E. amabilis* having peak density of 8.38 & 9.19 per 30 cm of stick lac on 2nd fortnight in month of August and *P. pulverea* was recorded with peak density of 6.61 & 6.77 per 30 cm of stick lac on 1st fortnight of the month of September. *T. tachardiae* with the peak density of 7.17 & 7.38 per 30 cm of stick lac was recorded to have potential to be major parasitoid whereas minor parasitoids recorded were *E. tachardiae*, *P. clavicornis* and *A. purpureus*. Hyperparasitoids (beneficial fauna) recorded were *B. greeni*, *P. sulci* and *B. tachardiae* in *Rangeeni* strain of *Katki* season.

Asaf and Seenuvasan (2019) reported the presence of seven parasitoids namely *Eurymyiocnema aphelinodius* (Ferriere), *Anicetus dodonia* (Ferriere), *T. tachardiae* (Howard), *B. greeni* (Ferriere), *E. tachardiae* (Howard), *A. purpureus* & *Marietta javensis* (Howard), and six predators viz., *E. amabilis* (Moorei), *P. pulverea*, *C. madestes* (Mishrasus), *Cryptoblabes ephestialis* (Hampson), *Ischnoptera fulvastrata*, *Phyllodromia humbertiana* (Kam) in his studies conducted on the busy host of lac. The samples for study were collected from open-field, crops in protected cultivation and wild flora.

Rajpoot *et al.* (2020) conducted a study in the state of Chattisgarh on *Rangeeni* lac, to record the seasonal incidence of lac associated natural enemies fauna during *Baisakhi* season of 2019-20. In the study, *E. amabilis* was recorded as major predator whereas *P. pulverea* as moderate and low intensity of occurrence was recorded for *Chrysopa spp.* Among parasitoids, *T. tachardiae* was dominant and *E. tachardiae* & *A. purpureus* were recorded as minor parasitoids.

Swami *et al.* (2021) reported highest numerical abundance for primary parasitoids among at the natural enemy fauna associated with lac of which *Eulophidae* & *Encyrtidae* contributed to 32.30 and 54.21 per cent, respectively. Predators were next in abundance with *E. amabilis* (8.44 per cent), *P. pulverea* (2.64 per cent) & *Chrysopa* (1.90 per cent). A small abundance of 0.59 per cent was recorded for hyperparasitoid of Braconidae family. Shannon Diversity Index recorded was 1.13, 1.11 & 1.09 for Haryana, Rajasthan and Gujarat, respectively.

Lodhi *et al.* (2021) carried out study in to record the abundance of lac associated fauna in Madhya Pradesh. Twelve species of different fauna represented by ten families were recorded of which there were three predators, four parasitoids and five hyperparasitoids. In both Seoni and Balghat districts parasitoids were dominant and followed by predators. Parasitoids, *T. tachardiae*, *P. clavicornis* were having abundance of 43.12 & 23.9 per cent in Seoni and 74.8 & 9.22 per cent in Balghat district, respectively whereas *E. amabilis* & *P. pulverea* were recorded as major predators with abundance of 18.70 & 8.31 in Seoni and 7.32 & 6.18 per cent in Balghat district, respectively. In both the districts, hyperparasitoids, *B. tachardiae* & *B. greeni* were recorded in least abundance.

Chahal *et al.* (2022) conducted a survey in various agro-climatic zones of Punjab to record the abundance of predators and parasitoids associated with lac during 2019-20. The abundance of 1.08- 44.09 per cent was recorded for the natural enemies in *Katki* crop. In the study, two predators were recorded *viz.* *E. amabilis* & *C. zastrowi sillemi* contributing to 44.09 & 5.38 per cent to the total natural enemy population, respectively. Further, three parasitoids namely *T. tachardiae*, *A. purpureus*, *P. clavicornis* and one hyperparasitoid, *B. greeni* were recorded with the abundance of 2.15, 26.88, 1.08 and 20.43 per cent, respectively. Here, the presence of *C. zastrowi sillemi* was recorded as one of the major predators while *P. pulverea* was lowest and high abundance was recorded for *B. greeni* which showed a very different trend from other similar studies. Evenness Index, Shannon- Weinner Diversity Index and Dominance Index recorded for natural enemy population was 0.80, 0.67 & 0.20, respectively in *Katki* crop. In *Baisakhi*, natural enemy abundance ranged from 6.56- 45.90 per cent with highest abundance of 45.90 per cent for *E. amabilis* (predator) and lowest abundance of 6.56 per cent for *T. tachardiae* (parasitoid). Evenness index, Shannon- Weinner Diversity Index, and Dominance Index recorded for natural enemy population in *Baisakhi* crop was 0.77, 0.65 & 0.23 per cent, respectively.

2.3 Morpho-taxonomic studies of major predators of *rangeeni* strain of lac

Miller (1977) reported that the wing measure, either wing length or wing span, is the most commonly used measure of body size in Lepidoptera. Ricklefs and Miles (1994) reported that morphological shape is most evidential aspect of an organism phenotype. It provides a strong linkage between species genotype and environment.

Roshkam and Brakefield (1996) reported that seasonal variation is an adaptive response to change in the environment, also known as seasonal polyphenism, is common among butterflies. The most prominent seasonal forms are dry and wet season. Each form is characterized by change in wing pattern and colouration.

Baylac *et al.* (2003), De la Riva *et al.* (2001) and Aytekin *et al.* (2007) reported that the wing span morphology of insect is extensively studied to clarify the relationship between closely related taxa and helps in identifying population within and between species of insect.

Mozaffarain *et al.* (2007) carried out geometric morphometric analysis to study the sexual dimorphism in the wing size and shape by locating ten landmarks in forewing and seven landmarks in hindwing of carob moth, *Ectomyelois ceratonia* (Lepidoptera: Pyralidae). They reported that wings in females are wider than those in males and forewings are longer in females and closer to each other than those in males.

Mutanen *et al.* (2007) reported that most of the morphological variations in moth and butterflies are due to the effects associated with the environment, whether phenotypic response or particularly those which act during ontogenic development. Rahman *et al.* (2009) reported the bionomics of *Eublemma amabilis* where he observed the morphological characters of the insect like body size, antennae, abdominal segment etc.

Digo *et al.* (2015) told that morphometric analyses are found useful for species identification and classification. It is the study of any quantitative measurement and analysis of morphological traits affecting on it. Bai *et al.* (2015) reported that butterflies possess attributes that are sensitive to gradual environmental change. Body size and shape variations in butterflies are correlated to environmental heterogeneity.

Barros (2015) reported that comparative studies on the size of adult Lepidoptera (moths and butterflies) frequently rely on single linear estimates of body size, namely of forewing length or wingspan. As the shape of the wings of these insects – in fact, of all body parts – differs from one taxon to another. He performed his measurements on dry set (pinned or spread), complete male specimens. When fresh adults were available, these were first dried in the position traditionally used for

these insects in entomological collections. They took following measurements in one of four ways: (a) under a stereomicroscope with an ocular micrometer, (b) on a digitized scale drawing made with an optical camera lucida adapted to a stereomicroscope ($\times 10$ to $\times 40$), (c) on a digital photograph of the specimen taken together with a standard scale bar, taken either with a macro lens (up to 1:1) or on a photo microscope at low magnification, or (d) with a Vernier caliper (exceptionally in the case of some of the largest moths). The program ImageJ (Rasband, 2012) was used to measure the digitized images.

Shi *et al.* (2015) reported that male and female of *L. dispar* were sexually dimorphic both in wing morphometric and colors. Males had smaller wings, weighed less, and had smaller wing loads than females. The total wing area of male gypsy moths was smaller than that of female moth across all eight geographical strain.

Zhong (2016) reported that butterflies and moths have a spectacular diversity of wing shape and size. They analyzed the hind wing shape and size of 76 *Saturniid* species representing 52 genera across five subfamilies using geometric morphometrics.

Goonesequera *et al.* (2018) reported that traditional morphometrics was used to measure and analyze 90 variables from wings, forelegs and genital of *M. perseus typhlus*, *M. mineus polydecta*, *M. subdita* and *M. rama* and set of 19 characters of wings, male genital and forelegs were identified to discriminate species.

Mahadi *et al.* (2021) conducted an analysis to study the morphometrics and length-length relationships (LLRs) of the Common Grass Yellow Butterfly, *Eurema hecabe* (L.) (Lepidoptera: Pieridae). Samples were collected randomly from the Rajshahi University Campus (RUC), Bangladesh, and the pictures were taken with a DSLR camera (Canon 750D) and measured using ImageJ software (1.48v). Here, a total of 14 different morphometric lengths *viz.* total body, antenna, wings (fore- and hindwing) and legs (fore-, mid- and hindleg) were evaluated.

Sousan *et al.* (2022) in his investigation carried out on sexual dimorphism and allometric relationship in the two underwing moths (Lep., Erebidae, Catocala) reported that wing size of the females was larger than males in *C. abacta*.

3. MATERIALS AND METHODS

The studies on, “Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect *Kerria lacca* (Kerr) in Arid Western Plains” were carried out at Department of Entomology, Udaipur, during 2022. An extensive survey was carried out during the month of June-July / Oct-Nov in three states of Arid Western Plains, namely, Rajasthan, Gujarat and Haryana to study the diversity and species richness of natural enemies of lac insect. The studies on morpho-taxonomy of major predators of the *Rangeeni* strain of lac insect was carried out at Lac laboratory cum Museum, with the Network Project on Conservation of Lac Insect Genetic Resources (NP-CLIGR) at Department of Entomology, Rajasthan College of Agriculture, Udaipur, during the year 2022. The materials used and methodology adopted to carry out the present investigation have been detailed as below:

3.1 Survey for the prevalence and abundance of natural enemies of lac insect, *Kerria lacca* (Kerr) in different states of Arid Western Plains on different hosts:

Extensive surveys were carried out during the month of June-July / Oct-Nov in three states of Arid Western Plains, namely, Rajasthan, Gujarat and Haryana, during 2022 under the Network Project on Conservation of Lac Insect Genetic Resources (NP-CLIGR) to study the prevalence and abundance of natural enemies of lac insect in the region.

Surveys were carried out in 10 districts each of Rajasthan, Gujarat and Haryana, during 2022. Different natural hosts of lac insect prevailing in the region were examined for the presence of population of lac insect and a detailed record of both lac host and lac insect genetic resources were maintained to generate a complete passport data of both host and lac insect resources of the region.

Samples of twigs from each host having the presence of lac (dead or live) was collected from as many possible locations of districts of three states of Arid Western Plains *viz.*, Rajasthan, Gujarat and Haryana, during 2022. The matured samples of brood lac collected were brought to laboratory and were kept in 60 mesh nylon cages for emergence of predators and parasitoids.

3.1.1 Observations:

The samples were observed regularly for the emergence of the predators and parasitoids. The emerged individuals of natural enemies were collected for the further studies. A record of all samples from three states was maintained and the following observations were recorded-

- 1) Total number of natural enemies emerged from each sample of three states
- 2) Total number of natural enemies emerged from host wise samples of three states
- 3) Passport data of host and lac insect

3.2 Diversity and species richness of natural enemies of lac insect

The studies on diversity and species richness of natural enemies of lac insect was carried out in Lac laboratory cum Museum (NP-CLIGR), Department of Entomology, Rajasthan College of Agriculture, Udaipur, during the year 2022. The emerged natural enemies were collected up to 4-6 weeks at weekly interval from the 60-mesh nylon net bags having the samples collected from various parts of Rajasthan, Gujarat and Haryana, during 2022 in June-July/ Oct-Nov and were identified with the help of methods described in “Lac insect and associated fauna-A practical Manual” by Mohanasundaram *et al.*, 2016. A proper record on natural enemies population was maintained. The number predators and parasitoids population were recorded, respectively for each sample of different locations of different districts of three states of Rajasthan, Gujarat and Haryana. The emerged natural enemies population was segregated based on their morphological characters and were identified up to their order and family.

3.2.1 Observations:

The following mathematical analyses were used for estimating the species richness and abundance:

- i. Mean density:

$$\text{Mean density} = \frac{\sum X_i}{N}$$

Where,

X_i = No. of insects or natural enemies in i^{th} sample

N = Total No. of plants sampled

ii. Relative density:

$$\text{Relative density (RD \%)} = \frac{\text{Number of individual of one species}}{\text{Total number of individual of all species}} \times 100$$

iii. Simpson's Diversity Index:

$$D = \frac{1}{\sum s \frac{n_i(n_i-1)}{N(N-1)}}$$

Where,

n_i = It is the percentage cover of a species or number of organisms of species 'i'

N = It is the total percentage cover or total number of organisms

iv) Shannon-Weiner Diversity Index (H'):

$$\text{Shannon-Weiner Diversity Index (H')} = - \sum p_i \ln p_i;$$

Where,

p_i = the decimal fraction of individuals belonging to i^{th} species.

3.3 Morpho-taxonomic studies of major predators of the *Rangeeni* strain of lac insect

The studies on morpho-taxonomy of major predators of the *Rangeeni* strain of lac insect was carried out in the Lac laboratory cum Museum established under NP-CLIGR at Department of Entomology, Rajasthan College of Agriculture, Udaipur. The incidence of the two major predators viz., *Eublemma amabilis* (Moore) and *Pseudohypatopa* (= *Holcocera*) *pulverea* (Meyrick) thus obtained from the samples of brood lac sticks collected from three states of Rajasthan, Gujarat and Haryana were utilized to carry out morpho-taxonomic studies.

3.3.1 Observations:

The observation of various morphological variables for the two predators using Carl Zeiss Microscope was recorded as detailed below:

1) **Body length:** Body length (BdL) was measured from head to tip of the abdomen.

- 2) **Fore /Hind wing length:** Forewing's length (FWL) was measured from the base to apex of the fore wing. Hind wing length (HWL) was measured from the base to the middle of termen of hind wing.
- 3) **Antennal length:** Distance from base to tip of antennae was estimated as antennal length (AntL).
- 4) **Total wing span:** Measurement of distance between end of one wing to end of the other wing when the wings are fully stretched was estimated as total wing span (TWS).

4. RESULTS

The results of the investigations on “Diversity and Morpho-taxonomic Studies of Major Predators of lac insect, *Kerria lacca* (Kerr) in Arid Western Plains”, carried out at lac insect gene bank cum lac laboratory at Department of Entomology, Udaipur under Network Project on Conservation of Lac Insect Genetic Resources (NP-CLIGR) during 2022 have been described in this chapter under following subheads:

4.1 Survey for the prevalence and abundance of natural enemies of lac insect, *Kerria lacca* (Kerr) in different states of Arid Western Plains on different host:

Extensive surveys were carried out during the month of June-July / Oct-Nov in three states of Arid Western Plains, namely, Rajasthan, Gujarat and Haryana in year 2022 under the Network Project on Conservation of Lac Insect Genetic Resources (NP-CLIGR) to study the prevalence and abundance of natural enemies of lac insect.

The surveys were conducted in three states of Arid Western Plains at 77 locations in 8 districts of Rajasthan *viz.*, Jaipur, Alwar, Hanumangarh, Churu, Jhunjhunu, Sikar, Udaipur and Rajsamand; at 53 locations in 10 districts of Haryana *viz.*, Nuh, Mewat, Rewari, Jhajjar, Rohatak, Karnal, Kurukshetra, Kaithal, Jind and Hissar and at 48 locations in 9 districts of Gujarat *viz.*, Aravali, Mahisagar, Dahod, Kheda, Panchmahal, Gandhinagar, Vadodra, Anand and Sabarkantha to ascertain the prevalence of natural population of lac insect on the different prevailing natural host plants of the region (Appendix I).

During the survey six host plant species *viz.*, Peepal, *Ficus religiosa* Linn. (Moraceae), Bargad, *Ficus benghalensis* Linn. (Moraceae), Gular, *Ficus racemose* Linn. (Moraceae), Ber, *Ziziphus mauritiana* Lam. (Rhamnaceae), Babool/Kikar, *Vachellia nilotica* Linn. (Fabaceae) and Sitafal, *Annona squamosa* Linn. (Annonaceae) were recorded to harbor the natural population of lac insect in the varied intensities at all the three states of arid western plains and the results have been presented in Table 1.

In Rajasthan, during the survey of eight districts the presence of lac insect was recorded on Peepal, Bargad, Ber, Babool and Sitafal where the lac was recorded

maximum at 58 locations on Peepal followed by Ber, Bargad, Babool and Sitafal at 12, 10, 5 and 2 locations, respectively. Similarly, nine districts were surveyed in Gujarat and the presence of lac was recorded on Peepal, Ber, Bargad and Gular with maximum population of lac insect on Peepal at 41 locations followed by Ber, Bargad and Gular at eight, two and one location, respectively. The presence of lac was recorded on Peepal, Ber and Babool during the survey in ten districts of Haryana and the presence of maximum population of lac insect was recorded on Peepal at 43 locations followed by Ber and Babool at 10 and 2 locations, respectively, during 2022.

4.1.1 Host wise emergence of natural enemies and storage pests associated with lac insect, *Kerria lacca* (Kerr)

The data recorded on the emergence of different natural enemies and storage pests from the samples of various host collected during the survey from three states of Arid Western Plains have been tabulated in Table 2. A total of 180 samples of lac insect bearing twigs were bought and kept for the emergence of natural enemies and storage pests in the lac laboratory. The observations recorded on the emergence of natural enemies and storage pests depicts that total 521 individuals of natural enemies and storage pests emerged from 180 samples of five different hosts *viz.*, Peepal, Ber, Bargad, Babool and Gular (Appendix II). Total of 387 natural enemies and storage pests emerged from 140 samples of Peepal collected from Rajasthan, Gujarat and Haryana, of which 166, 89 and 132 natural enemies and storage pests emerged from the samples of three states, respectively. Similarly, a total of 96 natural enemies and storage pests emerged from 27 samples of Ber collected from Rajasthan, Gujarat and Haryana, of which 38, 26 and 32 natural enemies and storage pests emerged from the samples, respectively. Likewise total of 23 natural enemies and storage pests emerged from 8 samples of Bargad in which 12 emergence were from lac samples collected from Rajasthan and 11 from Gujarat whereas no lac samples on Bargad were collected from Haryana. It was also recorded that from 4 samples of Babool which were collected from the states of Rajasthan and Haryana, 12 natural enemies and storage pest emerged from the sample collected from Haryana whereas no natural enemy or storage pest emergence was observed from the samples collected from Rajasthan and three natural enemies emerged from one samples of Gular collected from Gujarat.

Among the samples of all the host plants collected from the three states of Arid Western Plains, maximum emergence of natural enemies was recorded from samples of Peepal which was followed by the samples of Ber and Bargad, respectively and the emergence from other host plants was minor and recorded emergence of only few natural enemies emergence.

4.1.2 Lac associated insect fauna emerged from different host plant samples of lac insect, *Kerria lacca* (Kerr)

The results of the studies conducted to ascertain the biotic fauna associated with the lac insect *Kerria lacca* (Kerr) in the three states of Arid Western Plains have been enumerated in Table 3. The observations recorded on the emergence of natural enemies from the lac samples collected from the three states reveal that a wide number of predators and parasitoids are associated with natural populations of lac insect of the region. It also reveals that the lac associated insect fauna recorded under present investigation belonged to four different order viz., Lepidoptera, Hymenoptera, Coleoptera and Psocoptera. Among all the natural enemies the two species of predators viz., *Eublemma amabilis* Moore and *Pseudohytopa pulvereana* Meyrick of families Noctuidae and Blastobasidae, respectively belongs to Lepidopteran order. The primary parasitoids of family Encyrtidae & Eulophidae and hyperparasitoid of family Braconidae belongs to order Hymenoptera. Apart from these a large population of storage pests were also observed which belongs to two different families Curculionidae & Liposelidae of order Coleoptera and Psocoptera, respectively.

The results reveal that a total of 73 Lepidopteran predators were recorded of which 58 were *Eublemma amabilis* Moore (Noctuidae) and 15 were *Pseudohytopa pulvereana* Meyrick (Blastobasidae). A total of 117 Hymenopterans were also recorded during investigation in which three species of primary parasitoids viz., 64 *Erencyrtus dewitzii* Madh. belonging to the family Encyrtidae, 20 *Tachardiaephagus tachardiae* Howard belonging to the family Encyrtidae, 24 *Aprostocetus (Tetrastichus) purpureus* Cameron belonging to the family Eulophidae and 9 individuals of hyperparasitoid, *Bracon greeni* of Braconidae family. A large number of storage pests were also observed to emerge from the collected samples viz., 51 *Sitophilus oryzae* Linn. belonging to the family Curculionidae and 4 *Oryzaephilus surinamensis* belonging to family Silvanidae, both of them belonged to the order Coleoptera and 276 *Liposcelis divinatorius* Muller belonging to the family Liposelidae and order Psocoptera.

Among all the insect fauna observed to be associated with lac insect Lepidopteran predators, *E. amabilis* and *P. pulverea* contributes to 30.52 and 7.89 per cent, respectively to the total population of natural enemies. Hymenopteran primary parasitoids, *E. dewitzii*, *T. tachardia*, *A. purpureus* and hyperparasitoid, *B. greeni* of Braconidae family contributed to 33.68, 10.52, 12.63 and 4.73 per cent, respectively to the total natural enemy population . In addition to these it was also recorded that the storage pests *S. oryzae*, *O. surinamensis* and *L. divinatorius* contributed 15.40, 1.20 and 83.38 per cent, respectively of the total storage pest population that emerged from lac samples.

Among the lac associated insect fauna primary parasitoid *E. dewitzii* (33.68 per cent) was in abundance followed by the predator *E. amabilis* (30.52 per cent) while other natural enemies viz., *T. tachardia*, *A. purpureus*, *P. pulverea* and hyperparasitoid, *B. greeni* contributed to the extent of 10.52 , 12.63 , 7.89 and 4.73 per cent, respectively.

4.1.3 Weekly emergence profile of insect fauna associated with lac insect, *Kerria lacca* (Kerr)

The data on the weekly emergence profile of parasitoids and predators associated with lac insect were weekly recorded from the lac samples collected from three states of arid western plains viz., Rajasthan, Gujarat and Haryana and are enumerated in table No. 4. The weekly emergence profile reveals that the emergence of natural enemies started after six weeks of lac storage and continued till next six weeks. The emergence of total 49, 70, 145, 109, 86 and 62 individuals of natural enemies was recorded in the Ist, IInd, IIIrd, IVth, Vth and VIth weeks, respectively. The maximum number of natural enemies emerged during the third week of lac storage. The predators *Eublemma spp* (Noctuidae) and *Pseudohypatopa spp* (Blastobasidae) emerged till the sixth week with the maximum emergence in fifth week and afterwards no emergence was recorded. Similarly, the primary parasitoids of family Encyrtidae and Eulophidae emerged from the samples till the fourth week of the storage with the highest emergence in third week whereas the emergence of hyperparasitoids, *B. greeni* started to emerge from the samples only in the third week and they continued to emerge till fifth week with maximum emergence in third week of storage. Emergence of storage pests started from first week after storage and continued till sixth week with highest emergence in the third week of lac storage.

Morphological Characters of the above mentioned insect fauna / Natural enemies

a) *Eretmocerus dewitzii* Madh. (Encyrtidae, Hymenoptera)

These insect samples were first identified by Dr. Mohammad Hayat.

Synonyms: *Eretmocerus dewitzii*, Mahdihassan (1924)

Host: *Kerria communis*, *K. fici*, *K. lacca*, *K. nagoliensis* and *Metatachardia conchiferata*

Distribution: Srilanka, India, Pakistan and Indonesia

Female: The body length of female varies between 0.8-1.4mm. Head is transverse and as broad as the thorax. Vertex is broad and the lateral ocelli is situated near the eyes. Eyes are green with purple reflection. Antennae is yellow, slightly brownish on the upper side of pedicel and funicle joins and it is inserted just above the clypeus. Scape is little broadened in the middle with pedicel twice as long as broad. The first funicle joint is small and 6th joint a little larger and club oval in shape. Thorax is orange yellow in colour with the pronotum in front and a green oval spot covering the posterior part of the pronotum and anterior third of the mesonotum. Propodeum and metanotum are brownish on the sides. Legs are yellow, with a small brown spots on the middle and hind tibiae near the base. Spurs of middle tibiae is almost as long as metatarsus. Wings are hyaline, large and reaching beyond the tip of the abdomen.

Abdomen: brown, more or less yellowish at the base. Ovipositor not protruding.

Male: Body length of the male varies between 0.9-1 mm similar to female. It differs from female only by the form of antennae which is formed of scape which is about thrice as long as broad in the middle, the short pedicel as long as broad with the two small funicle joints, transverse, not easily seen, and a club formed by one every elongate joint, 3 times or more as long as the scape, covered with short hairs.

b) *Tachardiaephagus tachardiae* Howard, (Encyrtidae; Hymenoptera)

These insect samples were identified by Dr. Mohammad Hayat for the first time.

Synonyms: *Encyrtus tachardiae*, Howard, *Tachardiaephagus thoracicus*, Ashmead, *Lissencyrtus troupe*, Cameron

Host: *Kerria albizzae*, *K. lacca*, *K. sindica*, *K. chinensis*, *K. lacca mysorensis*, *K. fici*, *K. communis*, *K. javana* and *Paratachardina lobata*

Distribution: Srilanka, India, Pakistan, Malaysia, Thailand, China and Taiwan

Grub is apodus, brown in colour, whitish body with yellow coloured eye of immature stage and yellow colour thorax with black colour eye before emergence.

Female: Head is black in colour with shining eyes, antennae is brown and 11 segmented, funicle with an apparent single (i.e. an enlarged club), thorax is black in colour, wings are large hyaline and membranous and very short marginal vein. Legs are yellow, tarsi is 4 segmented, tibial spur is present in both fore and middle legs. And abdomen is black in colour with protruding ovipositor and transverse axillae which meet medially and the positioning of the cerci anterior to the tip of the abdomen.

Male: Similar to female, antennae with small hair.

c) *Aprostocetus (Tetrastichus) purpureus* Cameron, (Eulophidae; Hymenoptera)

Synonyms: *Aprostocetus (Aprostocetus) purpureus* (Cameron, 1913), *Hardothrix purpurea* Cameron 1913, *Tetrastichus imsii* Mahdihassan 1923, *Tetrastichus purpureus* (Cameron).

Host: *Tachardia lacca*, *T. albizziae*, *Ceroplastes rubens*, *Pulvinaria psidii*, *Aonidiella aurantii*, *Aonidiella orientalis*, *Aspiotus sp.*, *Aspidiotus orientalis*, *Chinaspis sp.*, *Chrysomphalus aonidum*, *Melanaspsis glomerata*, *Pseudaulacaspis sp.*, *Pseudaulacaspis barberi*, *Pseudaulacaspis pentagona*, *Laccifer (=Kerria) chinensis*, *Laccifer (=Kerria) javanus*, *Laccifer (=Kerria) lacca*, *K. sindica*

Hyperparasitoid: *Coccophagus tschirchii*, *Leptomastix dactylopii* and *Tachardiaephagus tachardiae*

Grubs are apodus and pink in colour with outer white cover. Immature stage has yellowish body with pink colour eye and black colour body with pink colour eye before emergence.

Female: Body length varies between 1.5-1.8 mm. Head is black in colour and shining, very slightly punctulate and rounded, vertex is very short in size. Eyes pink in colour. Antennae brown, elongate, scape reaching a little beyond ocelli. The 8 funicle joints and the pedicellus nearly all are of equal length, the club are 3 in number and jointed, the last joint is short and pointed. Thorax, Mesonotum and

scutellum are slightly reticulate and the median groove of mesonotum and the two longitudinal grooves of the scutellum are well marked. Wings are large and hyaline, reaching beyond the end of the abdomen. Marginal nerve longer than submarginal nerve. Pterostigma is as long as a third of the marginal nerve and pubescence is not in rows. Legs are yellow, the base of the coxae stripes above and below the femur and end of tarsi is brownish with 4 segments. A shortened and straight fore tibial spur is present, marginal and stigma nerves are light yellow in colour, abdomen is a little longer than thorax and slightly broadened beyond the middle then is sharply pointed, ovipositor is slightly protruding. Adult female is black with purplish and greenish reflection, base of abdomen is more or less yellow.

Male: Body length is about 1.2 mm which is almost similar to female. Antennae has long bristles arranged in half-circles. Abdomen is shorter than the thorax with male genitalia, and the 1st abdominal segment is yellow, legs are clear yellow, coxae, part of femur, and of tarsi are brown in colour.

d) White moth; *Eublemma amabilis* Moore (Noctuidae; Lepidoptera)

It is a widely distributed predator in all the major lac growing regions of the country and is considered as the most destructive pest for lac insect. The eggs laid by moth are grayish-white in colour, flat, round, depressed in the centre and measures about 0.35 to 0.37 mm across the centre and consist of beautiful sculptured chorion. Eggs are generally laid singly on the lac encrustation and they turn white prior to the emergence of larvae. The larvae hatches out of the egg shell by making a hole at the side of the chorion. The length of first instar larva is about 0.51 to 0.54 mm. The newly hatched larva catches the lac insect either through one of the openings in the test or by tunnelling a hole through the encrustation. The attacked lac cell becomes hollow from inside and contains pink coloured discs of excreta and can be easily differentiated from the healthy lac cells. Colour of pupae is dark brick-brown and its object type. Adult female is white in colour with brown patches on margin of wings. Generally female are smaller and duller in colour and bulges out a little in the middle and then gradually tapers posteriorly and the male is bigger in size and brighter in colour and gradually tapers posteriorly.

e) **Black moth: *Pseudohypatopa* (=Holcocera) *pulverea* Meyrick, (Blastobasidae; Lepidoptera)**

This predator of lac insect is also widely distributed and found in all the lac growing areas of the country. The adult moths are blackish in colour and are smaller in size than *E. amabilis*. The eggs are oval in shape and are laid singly on the cell of the lac insect. Eggs measure about 0.5 mm X 0.3 mm. The freshly laid egg is colourless and it later on turns to deep pink colour with the growth of the embryo. Pupae is brown in colour and smaller in size than *E. amabilis*.

f) ***Sitophilus oryzae* Linn. (Curculionidae; Coleoptera)**

The body length of adults ranges between 3- 4.6 mm , with a long snout. The body colour appears to be brown/black, but on close examination, four orange/red spots are arranged in a cross on the wing covers. Longitudinally elliptical punctures on pronotal dorsum which are separated by a flat, median, longitudinal puncture-free zone. Male aedeagus is smooth and shiny. Epipharyngeal rods of larvae have virtually the same width throughout. Lateral lobes of Y- shaped sclerite of female genitalia not tapering and round at apex. Fewer than five sensory organs at the tip of the labial palps of larvae.

g) ***Oryzaephilus surinamensis* Linn. (Silvanidae; Coleoptera)**

It is dark brown beetle of 2.4-3 mm with cylindrical shape. Body is flattened and consists of saw-toothed like six projections on both the side of the prothorax. Towards the tip abdomen is tapered. Antennae are moniliform and long. Eyes are small and broad, head is triangular in shape, and these insects are not able to fly.

h) ***Liposcelis divinatorius* Muller (Psocoptera; Liposelidae)**

It is a minute insect, wingless, soft bodied, and have chewing mouthparts. They have long antennae, broad head and bulging eyes. The body of the insect appears pale and transparent in colour. Striations are visible on the body. As the insect matures the colour changes to dark brown.

4.2 Diversity and species richness of natural enemies of lac insect, *Kerria lacca* (Kerr)

Studies undertaken to record the diversity and species richness of natural enemies emerged from the lac samples collected from the three states of Arid Western

Plains have been tabulated in Table No. 5. The results of the investigation reveals that a total five species of natural enemies under three different categories *viz.*, predator, primary parasitoid & hyperparasitoid emerged from the lac samples collected from three states. A total of 190 individuals of natural enemies emerged from 180 lac samples collected from Rajasthan, Gujarat and Haryana. The maximum number of 88 individuals of natural enemies emerged from 90 lac samples of Rajasthan followed by 66 natural enemies which emerged from the 46 lac samples of Haryana and 36 natural enemies that emerged from 44 lac samples of Gujarat.

The data reveals that among natural enemies, a maximum of 108 individuals of primary parasitoids emerged from the samples followed by 73 individuals of predators and 9 individuals of hyperparasitoids, respectively.

The observations recorded on the emergence of natural enemies from the lac samples of three states *viz.*, Rajasthan, Gujarat and Haryana reveals that from lac samples collected from Rajasthan, total 88 individuals of natural enemies, under three categories *viz.*, predator, primary parasitoid, hyperparasitoid emerged of which the abundance of primary parasitoids was maximum with total 52 individuals, 38 of which belonging to Encritidae and 14 to Eulophidae family. Emergence of predators from the samples collected from Rajasthan was next in abundance with total 32 predators of which 25 individuals were *E. amabilis* and 7 were *P. pulverea* only 4 individuals of hyperparasitoids emerged from the samples of Rajasthan and were minimum in their abundance.

Similarly, the observations recorded from the samples of lac collected from Gujarat reveals that total 36 individuals of natural enemies emerged among which the emergence of primary parasitoids was maximum with 22 individuals of which 20 primary parasitoids were of Encyrtidae family and 2 were of Eulophidae family. Primary parasitoids were followed by 12 individuals of predators among which 9 individuals were *Eublemma amabilis* and 3 individuals were *Pseudohypatopa pulverea*. Lowest abundance was recorded for hyperparasitoids of Braconidae family with the emergence of 2 individuals from the total lac samples collected from Gujarat.

Likewise, the observations recorded from the lac samples collected from Haryana reveals that a total of 66 individuals of natural enemies emerged. The maximum emergence was recorded for primary parasitoids with 34 individuals of

which 26 individuals were of Encyrtidae and 8 individuals were of Eulophidae family. They were followed by 29 individuals of predators of which 24 were *Eublemma amabilis* and 5 were *Pseudohypatopa pulverea*. Minimum emergence was recorded for 3 individuals of hyperparasitoid of Braconidae family from the total lac samples of Haryana.

Apart from different natural enemies a large number of storage pests also emerged from the lac samples of three states. A total of 331 storage pests emerged of which maximum emergence was of 276 individuals belonging to Liposelidae family and it was followed by 51 & 4 individuals of Curculionidae and Silvanidae family, respectively. The data recorded for storage pests from the samples of three states reveals that a total of 128, 93 & 110 individuals emerged from the lac samples of Rajasthan, Gujarat and Haryana, respectively of which 103, 79 & 94 individuals were of Liposelidae family and 23, 13 & 15 and 2,1 & 1 individuals were of Curculionidae and Silvanidae family, respectively, during 2022.

4.2.1 Relative density, mean density and diversity indices of insect fauna associated with lac insect, *Kerria lacca* (Kerr)

i) Relative density of insect fauna associated with lac insect, *Kerria lacca* (Kerr)

The data on the relative density and mean density of insect fauna associated with lac insect (*Kerria lacca*) is tabulated in Table No. 6 shows that the population of primary parasitoids was maximum, contributing to 56.84 per cent to total lac associated insect fauna from the lac samples which was followed by the population of predators and hyperparasitoids which contributed to 38.42 & 4.73 per cent, respectively to the total lac associated insect fauna, during 2022.

The results also demonstrated that the relative density of the natural enemies emerged from the collected lac samples was maximum with 46.31 per cent in Rajasthan followed by 34.73 per cent in Haryana and 18.94 per cent in Gujarat.

The data recorded on the relative density of the lac associated insect fauna emerged from the samples of Rajasthan shows that the relative density of primary parasitoids was highest with 59.08 per cent of which individuals of family Encyrtidae and Eulophidae individually contributed to the relative density of 43.18 & 15.90 per cent, respectively. Predators were next in abundance with relative density of 36.35 per

cent out of which contribution of *E. amabilis* was 28.40 per cent and contribution of *P. pulverea* was 7.95 per cent. The lowest relative density of 4.54 per cent was recorded for hyperparasitoids of Braconidae family among the natural enemy fauna associated with lac insect in Rajasthan.

Similarly, the observations recorded on the relative density of the natural enemies emerged from the lac samples collected from Gujarat demonstrates that the relative density of primary parasitoids was maximum with 61.10 per cent of which the contribution of individuals of Encritidae and Eulophidae family was 55.55 and 5.55 per cent, respectively. High relative density after primary parasitoids was recorded for predators with 33.33 per cent out of which 25.00 & 8.33 per cent was contributed by *E. amabilis* & *P. pulverea*, respectively. The least contribution to relative density was recorded for the hyperparasitoids of Braconidae family with 5.55 per cent in Gujarat.

Likewise, the relative density recorded for the emerged natural enemies from the samples of lac collected from Haryana reveals that the primary parasitoids have maximum relative density of 52.05 per cent of which 39.39 & 12.12 per cent was contributed by the individuals of Encrytidae and Eulophidae family. Predators with the relative density of 43.92 percent were next in abundance of which 36.36 per cent was contributed by the individuals of *E. amabilis* and 7.57 per cent was contributed by the individuals of *P. pulverea*. Lowest relative density was recorded for individuals of hyperparasitoids of family Braconidae with 4.54 per cent.

The observations also reveals that among the three states the relative density of primary parasitoids was maximum in Gujarat with 61.10 per cent followed by 59.08 and 52.05 per cent in Rajasthan and Haryana whereas the relative density of predators was highest in Haryana with 43.92 per cent followed by 36.35 and 33.33 per cent in Rajasthan and Gujarat. The relative density recorded for hyperparasitoid was highest in Gujarat with 5.55 per cent and was followed by Rajasthan and Haryana with equal relative density of 4.54 per cent in both the states.

Apart from natural enemies a large number of storage pests were also recorded from the three states of Arid Western Plains. The maximum relative density of 84.40 per cent was recorded for the storage pests belonging to Liposelidae family which was followed by the relative density of 15.59 and 1.20 per cent for the storage pest of Curculionidae and Silvanidae family, respectively. The relative density of storage

pests belonging to Liposelidae family was maximum with 85.45 per cent in Haryana followed by 84.94 & 80.46 per cent in Gujarat and Rajasthan, respectively whereas the relative density of storage pests of Curculionidae family was maximum with 17.96 per cent in Rajasthan followed by 13.97 & 13.63 per cent in Gujarat and Haryana, respectively. Storage pest of Silvanidae family was having highest relative density in Rajasthan with 1.56 per cent followed by 1.07 & 0.90 per cent in Gujarat and Haryana, respectively.

ii) Mean Density of insect fauna associated with lac insect, *Kerria lacca* (Kerr)

The maximum mean density of 1.43 was recorded for the natural enemy population of Haryana followed by the mean density of 1.38 & 0.97 for Gujarat and Rajasthan, respectively. The data also reveals that among natural enemies, a maximum mean density of 0.60 was recorded for individuals of primary parasitoids followed by mean density of 0.40 & 0.05 for the individuals of predators and hyperparasitoids, respectively.

The mean density of natural enemies recorded from the lac samples of three states *viz.*, Rajasthan, Gujarat and Haryana reveals that the mean density of natural enemies emerged from the lac samples collected from Rajasthan was 0.97 for primary parasitoids which was maximum and of which individuals of Encritidae and Eulophidae family had mean density of 0.42 & 0.15, respectively. Mean density of predators from the samples collected from Rajasthan was next in abundance with 0.27 for *E. amabilis* and 0.07 for *P. pulverea*. Lowest mean density of 0.04 was recorded for hyperparasitoids that emerged from the samples of Rajasthan.

Similarly, the observations recorded from the samples of lac collected from Gujarat reveals that maximum mean density of 0.50 was recorded for primary parasitoids of which mean density of 0.45 & 0.04 was recorded for the individuals of Encrytidae and Eulophidae family, respectively. Mean density of 0.27 for predators was next to primary parasitoids with 0.20 for *Eublema amabilis* and 0.06 for *Pseudohypatopa pulverea*. Lowest mean density was recorded for hyperparasitoids, *B. greeni* of Braconidae family with 0.04.

Likewise, the mean density of natural enemies recorded from the lac samples collected from Haryana reveals that primary parasitoids have maximum mean density

of 0.73 and among primary parasitoids, 0.56 & 0.17 was the mean density recorded for individuals of Encyrtidae and Eulophidae family, respectively. It was followed by mean density of 0.63 for predators of which mean density of 0.52 & 0.10 was recorded for *Eublema amabilis* and *Pseudohypatopa pulverea*, respectively. Minimum mean density of 0.06 was recorded for individuals of hyperparasitoid, *B. greeni* of Braconidae family.

Apart from different natural enemies a large number of storage pests also emerged from the lac samples of three states. A mean density of 1.53 was maximum for individuals belonging to Liposelidae family and it was followed by mean density of 0.28 & 0.02 for storage pests of Curculionidae and Silvanidae family, respectively. The mean density recorded for storage pests from the samples of three states shows that the mean density was maximum of 2.39 for storage pests emerged from samples of Haryana followed by mean density of 2.11 & 1.42 for the individuals of storage pests in Gujarat and Rajasthan, respectively. Mean density of Liposelidae and Curculionidae was maximum in Haryana with the value of 2.04 & 0.32, respectively and was followed by Gujarat and Rajasthan with mean density of 1.79 & 0.29 and 1.14 & 0.25, respectively. Whereas, mean density of Silvanidae was recorded almost equal in all the three states with the value of 0.02.

iii) Diversity indices of three states of Arid Western Plains

The Shannon-Weiner and Simpson Diversity Indices are popular metrics used in ecology to calculate diversity of a particular area. Shannon-Weiner diversity index is based on Claude Shannon's formula for entropy and estimates species diversity. The index takes into account the number of species living in a habitat (richness) and their relative abundance (evenness). Simpson's Diversity Index is a measure of diversity which takes into account the number of species present as well as the relative abundance of each species. As the species richness and evenness increases, so the diversity increases. High score (close to 1) indicates high diversity whereas low score (close to 0) indicates low diversity. Higher value for Simpson's Diversity Index indicates the greater diversity of species. The Shannon-Weiner Diversity Index and Simpson's Diversity Index was calculated for the different species of insect fauna emerged from the lac samples of three different states of Arid Western Plains and the values have been recorded in Table No. 7. The data reveals that the value of both Shannon-Weiner and Simpson's Diversity indices were highest for Rajasthan with

the value of 1.54 & 0.712 followed by Haryana with the value of 1.46 & 0.672 and lowest diversity indices were calculated for the state of Gujarat with the value of 1.26 & 0.592, respectively. The results demonstrate that samples of Rajasthan has highest and Gujarat has the lowest diversity of natural enemy fauna associated with natural lac insect, *Kerria lacca*. Therefore Rajasthan has highest species abundance followed by Haryana and Gujarat.

4.3 Morpho-taxonomic study of major predators of lac insect, *Kerria lacca* (Kerr)

The studies on morpho-taxonomic studies of major predators of lac insect was carried out in the Lac laboratory cum Museum established under NP-CLIGR at Department of Entomology, Rajasthan College of Agriculture, Udaipur during 2022. The major predators viz., *Eublemma amabilis* (Moore) and *Pseudohypatopa* (= *Holcocera*) *pulverea* (Meyrick) emerged from the samples of brood lac sticks collected from three states of Rajasthan, Gujarat and Haryana were utilized to carry out morpho-taxonomic studies.

The predators emerging from the samples were collected carefully from nylon cage, killed and preserved properly to record the observations on various morphological variables of the two predators using Carl Zeiss Microscope. The observations were recorded for 10 specimens of both male and female separately. The parameters viz., body length, wing span, length of right and left antennae, length and breadth of forewing and hindwing were recorded for both male and female separately (Appendix III).

4.3.1 *Eublemma amabilis*

The observations recorded on different morphological parameters of the male & female of predator *Eublemma amabilis* have been presented in Table No. 8.

A. Male, *Eublemma amabilis*

The mean of the different morphological parameters of male are detailed below:

i) Body Length & Wingspan

The body length and wingspan for the male ranged from 1.00 to 1.95 mm and 2.32 to 3.09 mm with the mean of 1.08 and 2.60 mm, respectively.

ii) Antennae

The mean length of both right and left antennae was recorded to be equal with 0.39 mm which ranged from 0.25 to 0.58 mm for right antennae and 0.24 to 0.58 mm for left antennae.

iii) Forewing and Hindwing

The length and breadth of right forewing of male ranged from 0.86 to 1.32 mm and 0.41 to 0.59 mm with a mean length and breadth of 1.15 and 0.50 mm, respectively. Similarly, the length and breadth of left forewing of male ranged from 0.81 to 1.38 mm and 0.40 to 0.58 mm with the mean length and breadth of 1.13 and 0.49 mm, respectively.

The data on the length and breadth of right hindwing of male ranged from 0.68 to 1.07 mm and 0.31 to 0.64 mm with a mean length and breadth of 0.85 and 0.47 mm, respectively. Similarly, the length and breadth of left hindwing of male ranged from 0.65 to 1.02 mm and 0.30 to 0.68 mm with the mean length and breadth of 0.85 and 0.47 mm, respectively.

B) Female, *Eublemma amabilis*

The mean of the different morphological parameters of female are detailed below:

i) Body Length and Wingspan

The body length and wingspan for female ranged from 1.00 to 1.24 mm and 2.32 to 2.85 mm with the mean of 1.11 and 2.60 mm, respectively.

ii) Antennae

The length of right and left antennae of female ranged between 0.33 to 0.48 mm and 0.32 to 0.49 mm with the mean of 0.39 and 0.40 mm, respectively.

iii) Forewing and Hindwing

The length and breadth of right forewing of female ranged from 0.97 to 1.24 mm and 0.44 to 0.59 mm with a mean length and breadth of 1.03 and 0.57 mm, respectively. Similarly, the length and breadth of left forewing of female ranged from 1.00 to 1.23 mm and 0.44 to 0.64 mm with the mean length and breadth of 1.13 & 0.49 mm, respectively.

The data on the length and breadth of right hindwing of female ranged from 0.77 to 0.97 mm and 0.34 to 0.54 mm with a mean length and breadth of 0.78 and 0.49 mm, respectively. Similarly, the length and breadth of left hindwing of female ranged from 0.73 to 0.92 mm and 0.34 to 0.60 mm with the mean length and breadth of 0.85 and 0.49 mm, respectively.

4.3.2 *Pseudohypatopa pulverea*

The observations recorded on different morphological parameters of the male & female of predator *Pseudohypatopa pulverea* have been presented in Table No. 8.

A) Male, *Pseudohypatopa pulverea*

The mean of the different morphological parameters of male of are detailed below:

i) Body Length & Wingspan

The body length and wingspan of male ranged from 0.62 to 0.69 mm and 1.50 to 1.80 mm with the mean of 0.66 and 1.50 mm, respectively.

ii) Antennae

The mean length of both right and left antennae was recorded to be equal with 0.47 mm that lies in the same range of 0.46 to 0.49 mm for both the antennae.

iii) Forewing and Hindwing

The length and breadth of right forewing of male ranged from 0.67 to 0.71 mm and 0.17 to 0.19 mm with a mean length and breadth of 0.68 and 0.18 mm, respectively. Similarly, the length and breadth of left forewing of male ranged from 0.66 to 0.69 mm and 0.17 to 0.19 mm with the mean length and breadth of 0.68 and 0.18 mm, respectively.

The data on the length and breadth of right hindwing of male ranged from 0.62 to 0.65 mm and 0.22 to 0.26 mm with a mean length and breadth of 0.63 and 0.25 mm, respectively. Similarly, the length and breadth of left hindwing of male ranged from 0.61 to 0.66 mm and 0.23 mm to 0.26 mm with the mean length and breadth of 0.63 and 0.25 mm, respectively.

A) Female, *Pseudohypatopa pulverea*

The mean of the different morphological parameters of female of are detailed below:

i) Body Length & Wingspan

The body length and wingspan for female ranged between 0.73 to 0.75 mm and 1.70 to 1.90 mm with the mean of 0.74 and 1.70 mm, respectively.

ii) Antennae

The mean length of both right and left antennae was put down to be equal with 0.47 mm that lies in the same range from 0.46 mm to 0.48 mm, respectively.

iii) Forewing & Hindwing

The length and breadth of right forewing of female ranged from 0.74 to 0.78 mm and 0.19 to 0.22 mm with a mean length and breadth of 0.76 and 0.20 mm, respectively. Similarly, the length and breadth of left forewing of female ranged from 0.76 to 0.78 mm and 0.19 to 0.21 mm with the mean length and breadth of 0.77 and 0.20 mm, respectively.

The data on the length and breadth of right hindwing of female ranged from 0.60 to 0.65 mm and 0.30 to 0.35 mm with a mean length and breadth of 0.61 and 0.32 mm, respectively. Similarly, the length and breadth of left hindwing of female ranged from 0.61 to 0.64 mm and 0.31 to 0.35 mm with the mean length and breadth of 0.61 and 0.32 mm, respectively.

From the results of the present study, it is apparent that in the surveys, six host plants were recorded to harbour natural lac population, among which Peepal was the major host followed by Ber, Bargad, Babool, Sitafal & Gular in the three states of Arid Western Plains, respectively. Among the samples of six host plants, emergence of natural enemies was recorded only from the samples of five host plants. The maximum emergence of lac associated insect fauna was observed from Peepal followed by Ber, Bargad, Babool & Gular, respectively. There was no emergence recorded from the samples of Sitafal. Among the emerged natural enemies of lac insect maximum emergence was recorded for primary parasitoids followed by predators and minimum emergence was recorded for hyperparasitoids from the samples of three states viz., Rajasthan, Gujarat and Haryana, respectively. The

morpho-taxonomic study of the male and female of major predators viz., *Eublema amabilis* & *Pseudohypatopa pulverea* suggests that morphological parameters viz., body length, wingspan, length of right and left antennae, length and breadth of both forewings & hindwings are greater for female *Eublema amabilis* than male which suggests that female predator of *Eublema amabilis* is larger in size than male. The morpho-taxonomic study for *Pseudohypatopa pulverea* also shows that all the morphological parameters are greater for female than male and hence female is larger in size than male.

Table 1: Location wise collection of host plant samples along with natural population of lac insect in Arid Western Plains, during 2022.

S.No.	States	No. of locations with presence of host plant containing lac encrustation	Host plant name		Family
			Common Name	Scientific Name	
1	Rajasthan	58	Peepal	<i>Ficus religiosa</i> L.	Moraceae
		12	Ber	<i>Ziziphus mauritiana</i> Lam.	Rhamnaceae
		10	Bargad	<i>Ficus benghalensis</i> L.	Moraceae
		05	Babool	<i>Vachellia nilotica</i> L.	Fabaceae
		02	Sitafal	<i>Annona squamosa</i> L.	Annonaceae
2	Gujarat	41	Peepal	<i>Ficus religiosa</i> L.	Moraceae
		08	Ber	<i>Ziziphus mauritiana</i> Lam.	Rhamnaceae
		02	Bargad	<i>Ficus benghalensis</i> L.	Moraceae
		01	Gular	<i>Ficus racemose</i> L.	Moraceae
3	Haryana	43	Peepal	<i>Ficus religiosa</i> L.	Moraceae
		10	Ber	<i>Ziziphus mauritiana</i> Lam.	Rhamnaceae
		02	Babool	<i>Vachellia nilotica</i> L.	Fabaceae

Table 2: Lac insect associated fauna emerged from different host plant samples collected from Arid Western Plains, during 2022.

S.No	No. of host plant samples collected	Total number of natural enemies emerged from different states of Arid Western Plains			Total
		RAJASTHAN	GUJARAT	HARYANA	
1	PEEPAL (140)	166	89	132	387
2	BER (27)	38	26	32	96
3	BARGAD (08)	12	11	-	23
4	BABOOL (04)	-	-	12	12
5	GULAR (1)	-	03	-	03

Table 3: Different natural enemies and storage pests emerged from the lac samples collected from Arid Western Plains, during 2022.

S.No.	Trophic level states	Fauna	Order	Individuals per order	Individuals per Family	Family	Percentage contribution
1	Predators	<i>Eublemma amabilis</i> Moore	Lepidoptera	73	58	Noctuidae	30.52%
		<i>Pseudohypatopa pulverea</i> Meyrick			15	Blastobasidae	7.89%
2	Primary parasitoid	<i>Erencyrtus dewitzii</i> Mahd.	Hymenoptera	117	64	Encyrtidae	33.68%
		<i>Tachardiaephagus tachardiae</i> Howard			20	Encyrtidae	10.52%
		<i>Aprostocetus (Tetrastichus) purpureus</i> Cameron			24	Eulophidae	12.63%
3	Hyperparasitoid	<i>Bracon greeni</i> Ashmead			9	Braconidae	4.73%
STORAGE PESTS							
S.No.	Fauna		Order	Individuals per order	Individuals per family	Family	Percentage contribution
1	<i>Sitophilus oryzae</i> Linn.		Coleoptera	55	51	Curculionidae	15.40%
2	<i>Oryzaephilus surinamensis</i> Linn.				4	Silvanidae	1.20%
3	<i>Liposcelis divinatorius</i> Muller		Psocoptera	276	276	Liposelidae	83.38%

Table 4: Weekly emergence profile of insect fauna associated with lac insect, *Kerria lacca* (Kerr), during 2022.

Weeks after storage	Trophic Level Status								Total
	Predators		Primary parasite		Hyperparasite	Storage pests			
	<i>Noctuidae</i>	<i>Blastobasidae</i>	Encyrtidae	Eulophidae	Braconidae	Curculionidae	Silvanidae	Liposelidae	
I	9	2	16	5	0	7	0	10	49
II	8	1	22	4	0	9	1	25	70
III	13	3	32	9	4	15	1	68	145
IV	13	3	14	6	2	8	1	62	109
V	14	4	0	0	3	6	0	59	86
VI	1	2	0	0	0	6	1	52	62

Table 5: Numerical abundance of species of different natural enemies and storage pests emerged from the lac samples collected from Arid Western Plains, during 2022.

S. No.	State/ No. of samples	Natural enemies							Total Emergence	Storage pests			Total Emergence
		Predator			Primary parasitoid			Hyper parasitoid		Curculionidae (so)	Silvanidae (os)	Liposelidae (ld)	
		Noctuidae (ea)	Blastobasidae (pp)	Total	Encyrtidae (ed & tt)	Eulophidae (ap)	Total						
1	Rajasthan (90)	25	7	32	38	14	52	4	88	23	2	103	128
2	Gujarat (44)	9	3	12	20	2	22	2	36	13	1	79	93
3	Haryana (46)	24	5	29	26	8	34	3	66	15	1	94	110
TOTAL		58	15	73	84	24	108	9	190	51	4	276	331

[ea=*Eublemma amabilis*; pp=*Pseudohypatopa pulvereae*; ed=*Erencyrtus dewitzii*; tt=*Tachardiaephagus tachardiae*; ap= *Aprostocetus purpureus*; bg= *Bracon greeni*; so= *Sitophilus oryzae*; os= *Oryzaephilus surinamensis*; ld= *Liposcelis divinatorius*]

Table 6: Relative density and mean density of insect fauna associated with lac insect, *Kerria lacca* (Kerr), during 2022.

S. No.	STATE	Lac Associated Insect Fauna											
		Predator (%)			Primary parasitoid (%)			Hyper parasitoid (%)	Total Relative Density	Storage Pest (%)			Total Relative Density
		Noctuidae (ea)	Blastobasidae (pp)	Total	Encyrtidae (ed & tt)	Eulophidae (ap)	Total	Braconidae (bg)		Curculionidae (so)	Silvanidae (os)	Liposelidae (ld)	
1	Rajasthan (90)	28.40 (0.27)	7.95 (0.07)	36.35 (0.35)	43.18 (0.42)	15.90 (0.15)	59.08 (0.57)	4.54 (0.04)	46.31 (0.97)	17.96 (0.25)	1.56 (0.02)	80.46 (1.14)	38.67 (1.42)
2	Gujarat (44)	25.00 (0.20)	8.33 (0.06)	33.33 (0.27)	55.55 (0.45)	5.55 (0.04)	61.10 (0.50)	5.55 (0.04)	18.94 (1.38)	13.97 (0.29)	1.07 (0.02)	84.94 (1.79)	28.09 (2.11)
3	Haryana (46)	36.36 (0.52)	7.57 (0.10)	43.92 (0.63)	39.39 (0.56)	12.12 (0.17)	52.05 (0.73)	4.54 (0.06)	34.73 (1.43)	13.63 (0.32)	0.90 (0.02)	85.45 (2.04)	33.53 (2.39)
Total (180)		30.52 (0.32)	7.89 (0.08)	38.42 (0.40)	44.21 (0.46)	12.63 (0.13)	56.84 (0.60)	4.73 (0.05)		15.5 (0.28)	1.20 (0.02)	84.40 (1.53)	

[ea=*Eublemma amabilis*; pp=*Pseudohypatopa pulvereae*; ed=*Erencyrtus dewitzi*; tt=*Tachardiaephagus tachardiae*; ap= *Aprostocetus purpureus*; bg= *Bracon greeni*; so= *Sitophilus oryzae*; os= *Oryzaeophilus surinamensis*; ld= *Liposcelis divinatorius*]

[value inside the parenthesis () represents mean density {no. of individuals per sample}]

[values outside the parenthesis () represents relative density]

Table 7: Diversity indices of the lac associated fauna of three states of Arid Western Pains, during 2022.

S.no	State	Shannon- Weiner Diversity Index	Simpson's Diversity Index
1	Rajasthan	1.54	0.712
2	Gujarat	1.26	0.592
3	Haryana	1.46	0.672

(*Diversity of species of associated fauna is found highest in Rajastha followed by Haryana and lowest in Gujarat)

Table 8: Morpho-taxonomic measures of major predators of Lac insect (*Kerria lacca*)- *Eublemma amabilis* & *Pseudohypatoppa pulverea*, during 20222.

S. No.	Parameters (mm)		<i>Eublemma amabilis</i>				<i>Pseudohypatoppa pulverea</i>			
			Male		Female		Male		Female	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	Body length		1.00-1.95	1.08	1.00-1.24	1.11	0.62-0.69	0.66	0.73-0.75	0.74
2	Total Wingspan		2.32-3.09	2.60	2.32-2.85	2.60	1.50-1.80	1.50	1.70-1.90	1.70
3	Antennae	R	0.25-0.58	0.39	0.33-0.48	0.39	0.46-0.49	0.47	0.46-0.48	0.47
		L	0.24-0.58	0.39	0.32-0.49	0.40	0.46-0.49	0.47	0.46-0.48	0.47
4	Forewing (Length)	R	0.86-1.32	1.15	0.97-1.24	1.03	0.67-0.71	0.68	0.74-0.78	0.76
		L	0.81-1.38	1.13	1.00-1.23	1.05	0.66-0.69	0.68	0.76-0.78	0.77
5	Forewing (Breadth)	R	0.41-0.59	0.50	0.44-0.59	0.57	0.17-0.19	0.18	0.19-0.22	0.20
		L	0.40-0.58	0.49	0.44-0.64	0.58	0.17-0.19	0.18	0.19-0.21	0.20
6	Hindwing (length)	R	0.68-1.07	0.86	0.77-0.97	0.78	0.62-0.65	0.63	0.60-0.65	0.61
		L	0.65-1.02	0.85	0.73-0.92	0.77	0.61-0.66	0.63	0.61-0.64	0.61
7	Hindwing (Breadth)	R	0.31-0.64	0.47	0.34-0.54	0.49	0.22-0.26	0.25	0.30-0.35	0.32
		L	0.30-0.68	0.47	0.34-0.60	0.49	0.23-0.26	0.25	0.31-0.35	0.32

[R= Right ; L= Left]

Fig 1 : Location wise collection of host plant samples along with natural population of lac insect in Arid Western Plains, during 2022.

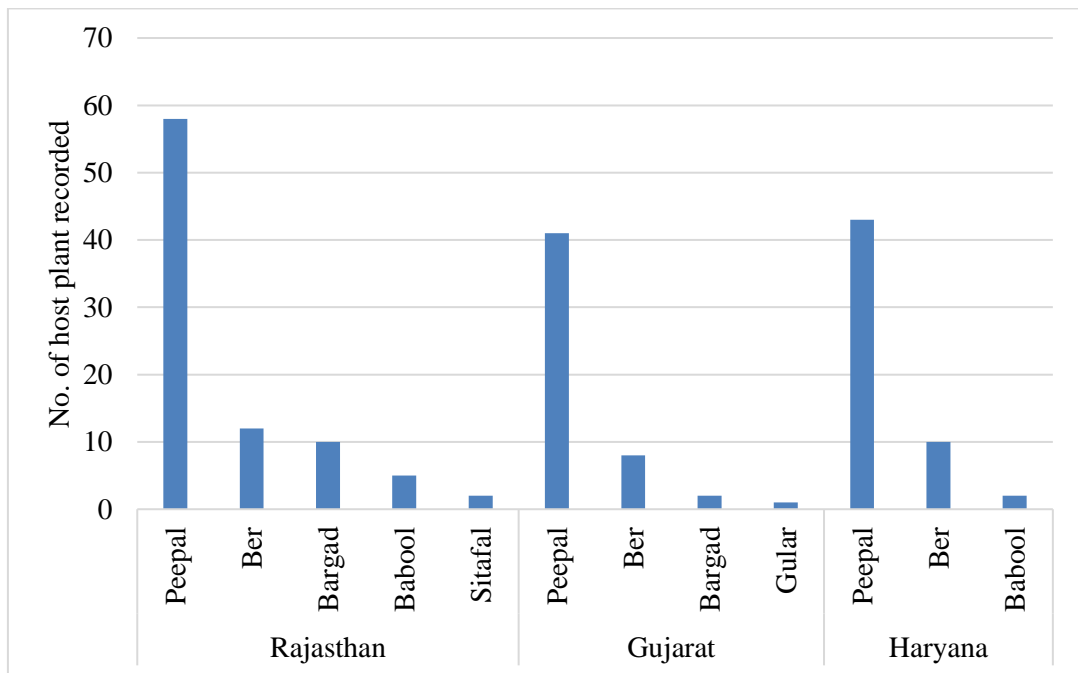


Fig 2: Lac insect associated fauna emerged from different host plant samples collected from Arid Western Plains, during 2022.

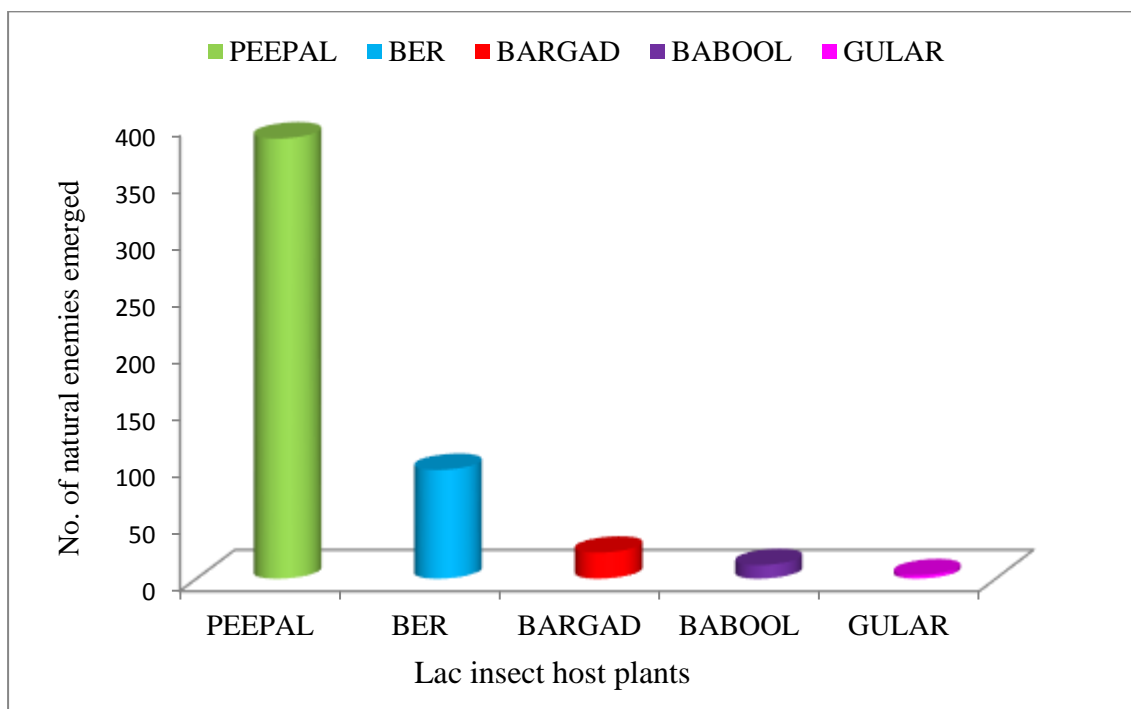


Fig 3: Different natural enemies and storage pests emerged from the lac samples collected from Arid Western Plains, during 2022.

Fig 3.1: Natural Enemies

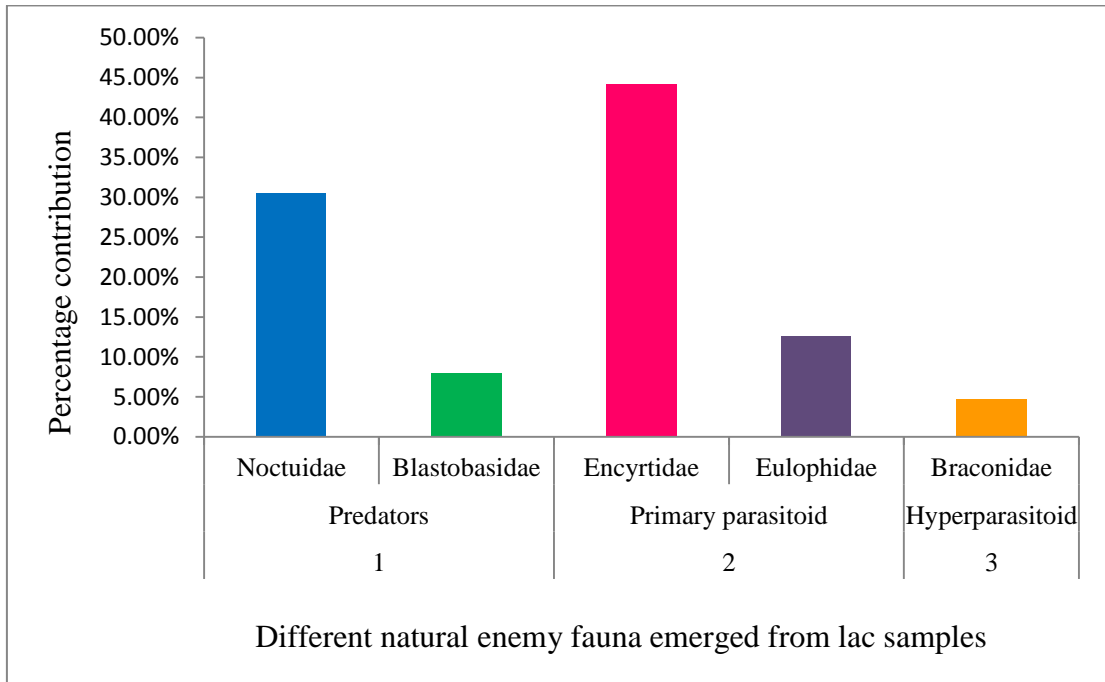


Fig 3.2: Storage pests

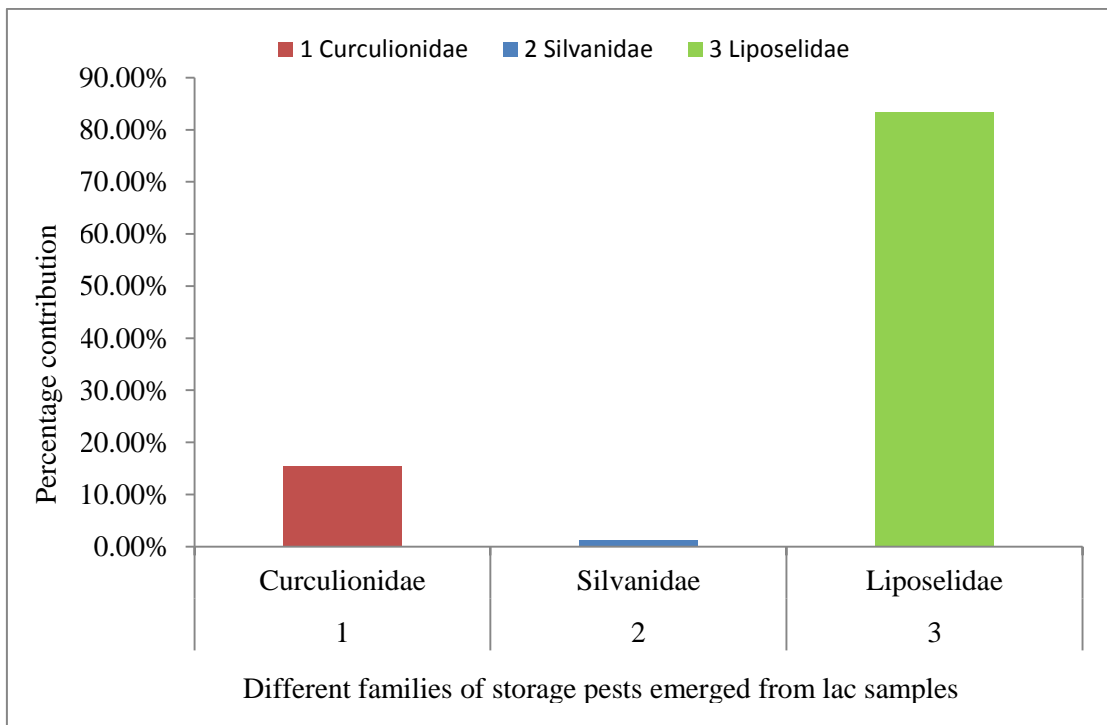


Fig 4: Weekly emergence profile of insect fauna associated with lac insect, *Kerria lacca* (Kerr), during 2022.

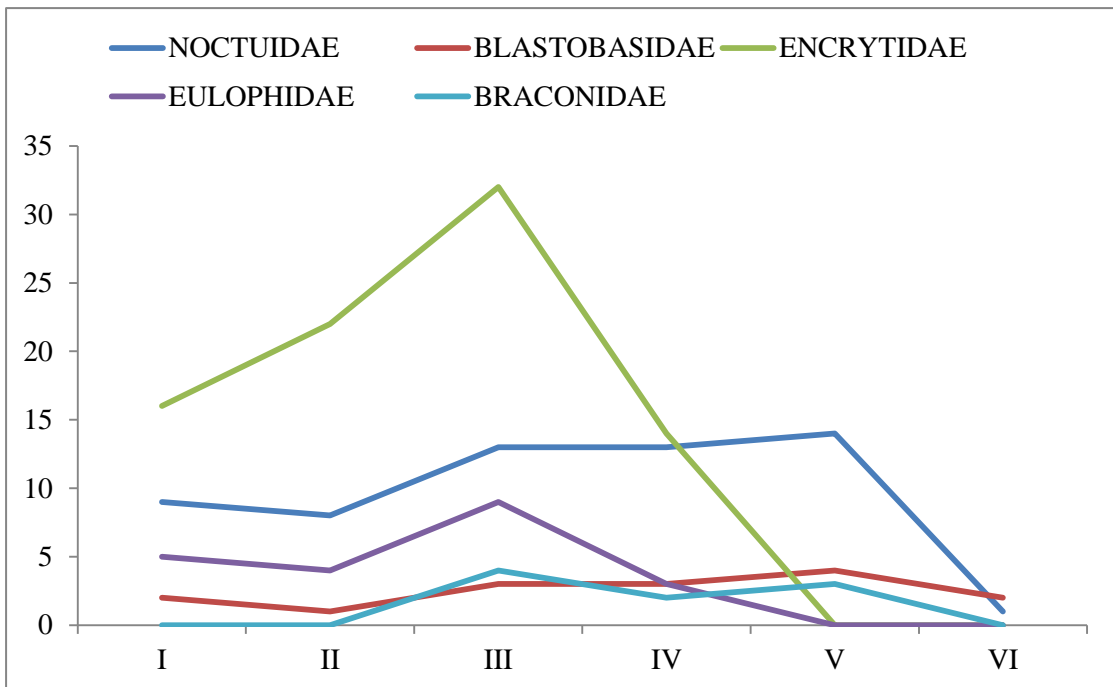


Fig 5: Numerical abundance of species of different natural enemies and storage pests emerged from the lac samples collected from Arid Western Plains, during 2022.

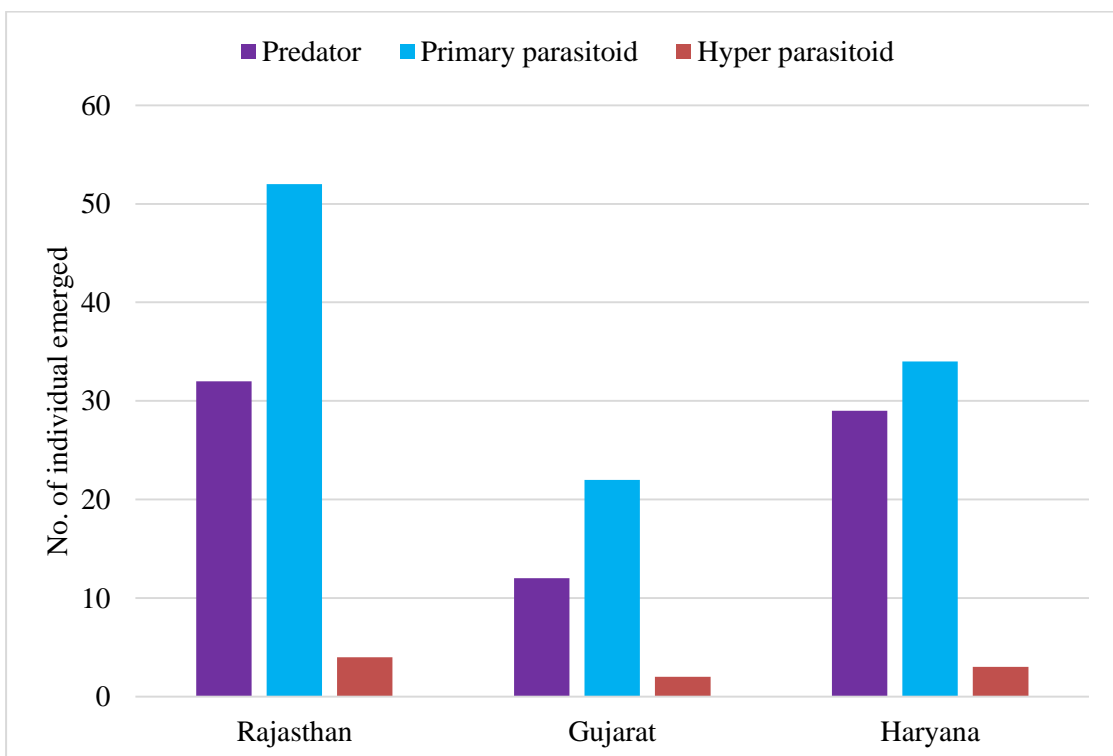


Fig 6: Relative density and mean density of insect fauna associated with lac insect, *Kerria lacca* (Kerr), during 2022.

Fig. 6.1: Relative density

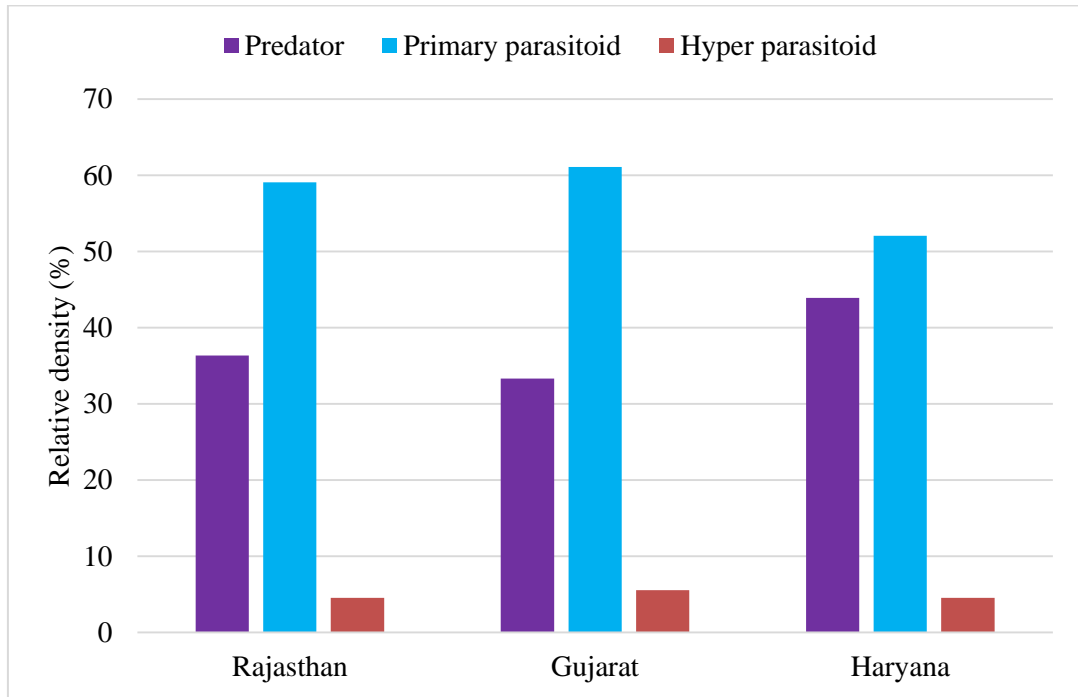


Fig 6.2: Mean density

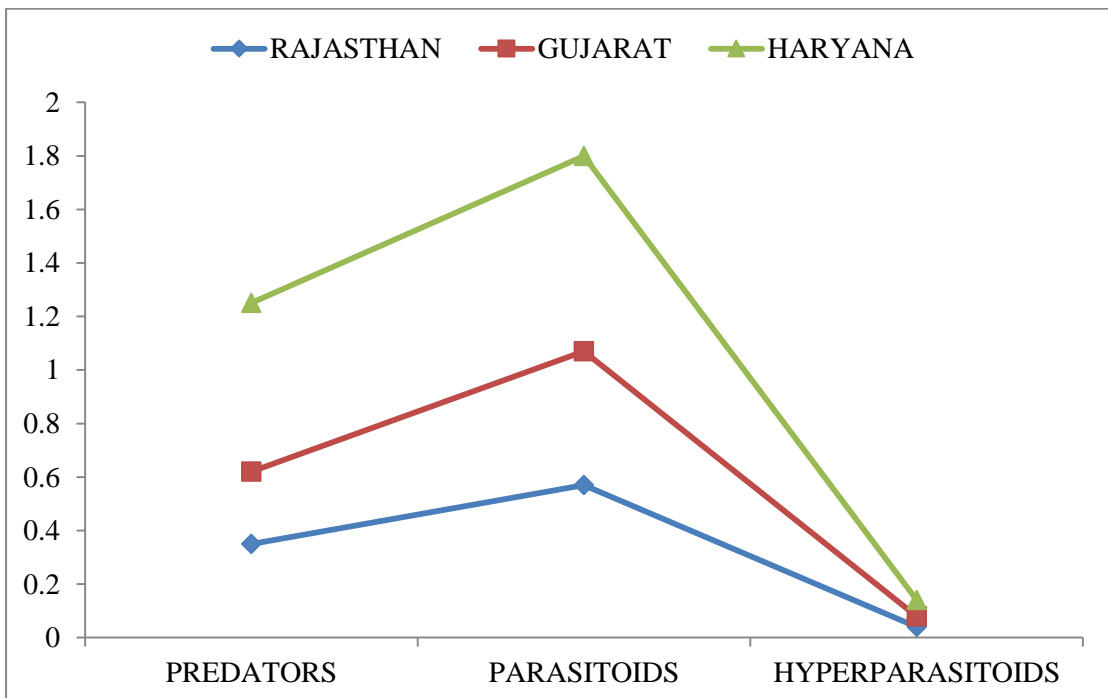


Fig 7: Diversity indices of the lac associated fauna of three states of Arid Western Pains, during 2022.

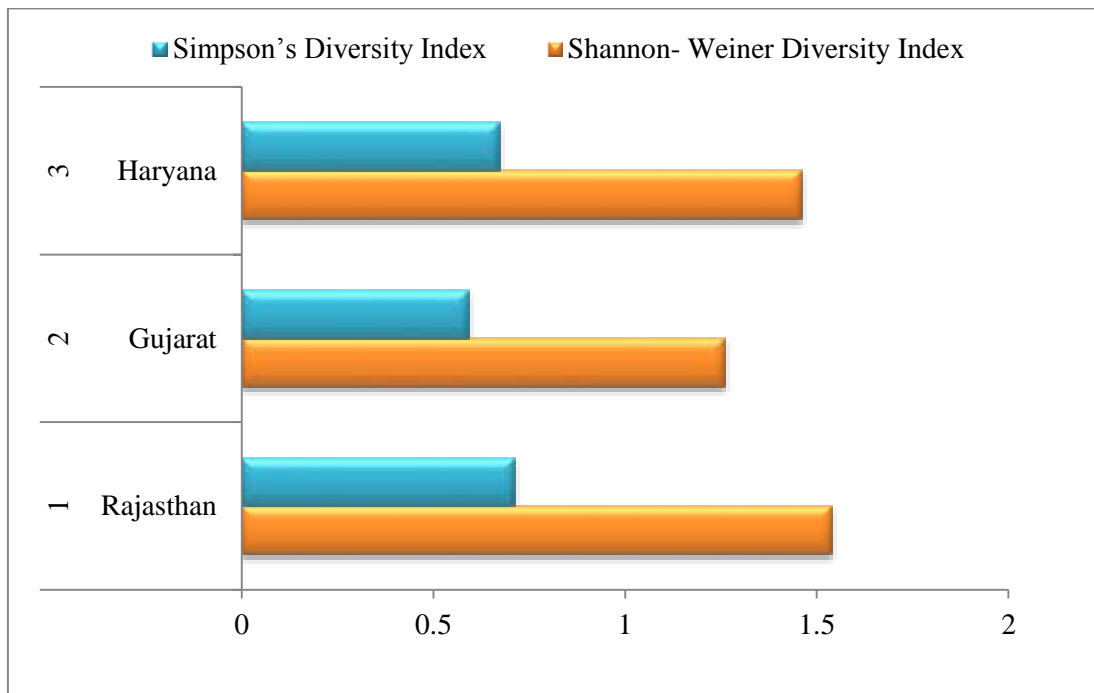
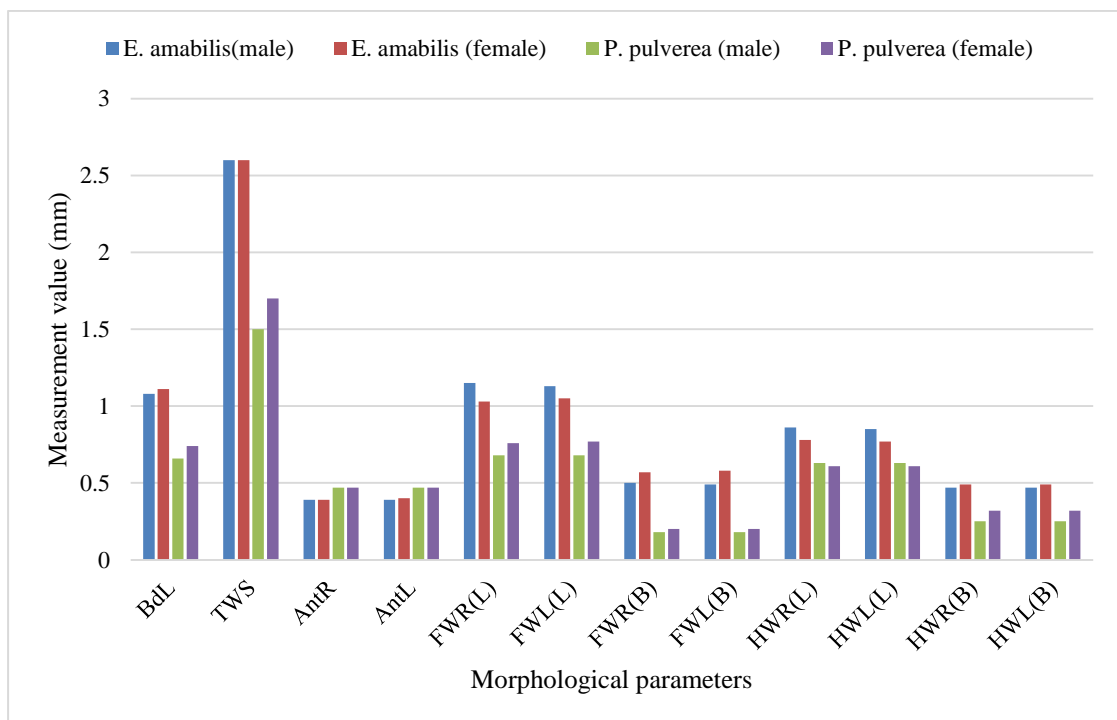


Fig 8: Morpho-taxonomic measures of major predators of Lac insect (*Kerria lacca*) *Eublemma amabilis* & *Pseudohyattoppa pulverea*, during 2022.



[BdL= Body Length; TWS= Total Wingspan; AntR= Right Antennae length; AntL= Left Antennae length; FWR(L)= Right Forewing Length; FWL(L)= Left Forewing Length; FWR(B)= Right Forewing Breadth; FWL(B)=Left Forewing Breadth; HWR(L)=Right Hind Wing Length; HWL(L)=Left Hindwing Length; HWR(B)=Right Hindwing Breadth; HWL(B)=Left Hindwing Breadth]



A) Host plant bearing natural lac encrustation



B) Collection of lac sample



C) Sorting and storage of lac bearing twigs



D) State wise tagging of lac sample



E) Samples of lac collected from different states of Arid Western Plains

Plate 1: Survey and collection of lac host plant samples harbouring natural population of lac insect from Arid Western Plains under NP-CLIGR, during 2022



A) Observing natural enemies emerged from lac samples



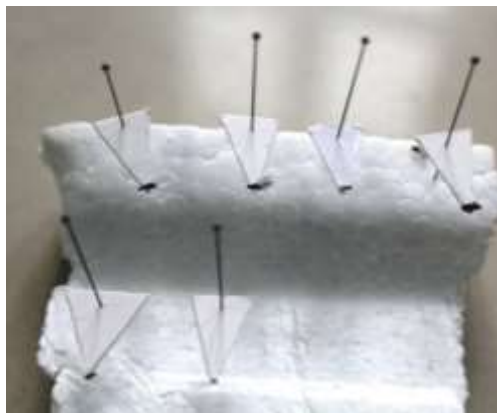
B) Emergence of predators



C) Emerged larvae and adult of *Eublemma ammabilis*



D) Collection of predator



E) Collection of parasitoids



F) Pinning of predators

Plate 2: Emergence of lac insect associated fauna from the samples collected from the Arid Western Plains, during 2022



C) Encyrtid *spp.*



D) Eulophid *spp.*



E) Braconid *spp.*



F) Psocopteran *spp.*



G) Coleopteran *spp.*

Plate 3: Different natural enemies and storage pests emerged from the lac samples collected from Arid Western Plains, during 2022



B) Host wise emergence from Rajasthan



C) Host wise emergence from Haryana



D) Host wise emergence from

Plate 4: Host wise emergence of natural enemies from the sample of three different states of Arid Western Plains, during 2022



A) Body length



B) Total Wing Span



C) Left Forewing Breadth



D) Left Hindwing Breadth



E) Right Forewing Length



F) Left Hindwing Length

Plate 5: Description of morpho-taxonomic parameters of female *Eublemma amabilis*



A) Body length



B) Total Wing Span



C) Left Forewing Breadth



D) Left Hindwing Breadth



E) Right Forewing Length



E) Right Anttenal Length

Plate 6: Description of morpho-taxonomic parameters of male *Eublemma amabilis*



A) Body length



B) Total Wing Span



C) Right Forewing Breadth



D) Right Hindwing Breadth



E) Right Forewing Length



E) Right Hindwing Length

Plate 7: Description of morpho-taxonomic parameters of female *Pseudohypatopa pulverea*



A) Body length



B) Total Wing Span



C) Left Forewing Breadth



D) Right Hindwing Breadth



E) Left Forewing Length



E) Right Hindwing Length

Plate 8: Description of morpho-taxonomic parameters of male *Pseudohyatopa pulvereae*

5. DISCUSSION

The results of the investigation carried out on “Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect, *Kerria lacca* (Kerr) in Arid Western Plains” have been discussed below in the light of all the available literature and the major conclusions drawn have been mentioned as under:

5.1 Survey for the prevalence and abundance of natural enemies of lac insect, *Kerria lacca* (Kerr) in different states of Arid Western Plains on different host:

Extensive surveys were carried out in the three states of Arid Western Plains viz., Rajasthan, Gujarat and Haryana to record the presence of lac insect on prevailing hosts. The presence of lac insect was observed on six host plants species viz., Peepal *F. religiosa*, Ber, *Ziziphus mauritiana*, Bargad, *Ficus benghalensis*, Babool /Kikar, *Vachellia nilotica*, Sitafal, *Annona squamosa* and Gular, *Ficus racemose* (Fig 1). The observations recorded at 178 locations of 27 districts of three states of Arid Western Plains in June-July/ Oct-Nov, during 2022 depicted that among six host plant species, Peepal, *Ficus religiosa* recorded at 142 locations was the most dominant host of lac insect in all the three states. Apart from Peepal *F. religiosa* other host plants viz., Ber, *Ziziphus mauritiana*, Bargad, *Ficus benghalensis*, Babool /Kikar, *Vachellia nilotica*, Sitafal, *Annona squamosa* and Gular, *Ficus racemose* were also recorded to harbor natural population of lac insect at 30, 12, 7, 2 and 1 location, respectively.

The prevalence of lac insect on Peepal at maximum locations in the survey of three states is in line with the findings of Meena *et al.* (2020) and Swami *et al.* (2021) who during their surveys have also observed *F. religiosa* most frequently occurring host for *Rangeeni* lac during 2015- 2016 and 2019-2020, respectively. In their studies they have also shown the presence of good lac encrustation on *F. benghalensis*, *F. racemosa*, *Z. mauritiana*, *Acacia auriculiformis*, *A. lebeck*, *A. reticulata*, *F. palmate*, *F. benjamina*, *F. tsiela*, *Peltophorum ferrugineum*, *Pithecellobium dulce*, *Calliandra calothyrsus*, *Polyalthia longifolia*, *Prosopis cineraria*, *P. juliflora* and *Samanea saman* which also supports the results of the present study carried out during 2022.

Similarly, Bhatnagar *et al.* (2022) who have carried out survey covering 319 blocks of 51 districts in Madhya Pradesh during 2015-2019 recorded the presence of natural lac population on Peepal (*F. religiosa*), Bargad (*F. benghalensis*), Ber (*Z. mauritiana*), Babool (*A. nilotica*), Gular (*F. racemose*), Sitaphal (*A. squamosa*) etc. which confirms the result of the present study.

5.1.1 Host wise emergence of natural enemies and storage pests associated with lac insect, *Kerria lacca* (Kerr)

The results of the investigation on the emergence of different natural enemies and storage pests from the samples of various host plants collected during the survey from three states of Arid Western Plain reveals that the emergence of natural enemies and storage pests was maximum (387) from the collected samples of Peepal in all the three states *viz.*, Rajasthan, Gujarat and Haryana and was followed by Ber with 96 number of storage pests and natural enemies whereas minimum (3) natural enemies and pests of storage were recorded from stored samples of Gular and samples of Bargad and Babool showed emergence of 23 and 12 number of natural enemies and storage pests, respectively (Fig. 2). Not much studies have been done so far on the host wise emergence of natural enemies of lac insect, however the result of the present studies confers the results of the study carried out by Mohanasundram *et al.* (2018) who have attempted to find out the variation in the lac associated fauna in relation to different host plants *viz.*, ber, palas and red gram for both *Kusumi* and *Rangeeni* strain of lac and have found that the emerged population of lac associated fauna was significantly more on ber followed by palas and red gram.

5.1.2 Lac associated insect fauna emerged from different host plant samples of lac insect, *Kerria lacca* (Kerr)

The lac insects being sedentary in nature are more vulnerable to be attacked by various natural enemies, also secretion of resin and honey dew attracts many pests both during their life period and storage. The occurrence of natural enemies have been reported to infect the lac insect throughout the life period. As many as 35 species of primary and 45 species of secondary parasitoids have been reported in lac insect ecosystem (Varsney, 1970 and Sharma *et al.*, 2006)

The observations on lac associated insect fauna emerged from different host samples reveals that both natural enemies and storage pests emerged from lac

samples. Natural enemies recorded in the investigation belong to two major insect orders viz., Lepidoptera and Hymenoptera. In the studies two predators viz., *E. amabilis* (Noctuidae; Lepidoptera), *P. pulverea* (Blastobasidae; Lepidoptera), three primary parasitoids represented by *A. purpureus* (Eulophidae; Hymenoptera), *T. tachardiae*, and *E. dewitzii* (Encyrtidae; Hymenoptera) and one hyperparasitoid, *B. greeni*, (Braconidae; Hymenoptera) were recorded (Fig. 3.1). Among total 190 natural enemies, 64 individual belonged to *Erencyrtus dewitzii* Madh.(Encyrtidae; Hymenoptera), 58 individuals to *Eublemma amabilis* Moore (Noctuidae; Lepidoptera), 24 individuals to *Aprostocetus (=Tetrastichus) purpureus* Cameron (Eulophidae; Hymenoptera), 20 individuals to *Tachardiaephagus tachardiae* Howard (Encyrtidae; Hymenoptera), 15 individuals to *Pseudohypatopa pulverea* Meyric (Blastobasidae; Lepidoptera) and 9 individuals of *Bracon greeni* (Braconidae; Hymenoptera) with contribution of 33.68, 30.52, 12.63, 10.52, 7.89 & 4.73 per cent, respectively. It was recorded in the present investigation that primary parasitoids were most dominant and among them Encyrtidae and Eulophidae dominates together with the contribution of 56.83 per cent and are followed by predators *E. amabilis* and *P. pulverea* which together contribute to 38.41 per cent and a small population of hyperparasitoids was also recorded to contribute 4.73 per cent to the total natural enemy population. Apart from natural enemies large number of storage pests were also recorded. Storage pests recorded mainly belonged to order Psocoptera and Coleoptera. Out of total 331 storage pests, 276 belongs to Liposelidae family 51 to Curculionidae and 4 to Silvanidae family with the contribution of 83.38, 15.40 and 1.20 per cent, respectively (Fig. 3.2). The results of the present study is in line with the findings of Kalahal (2017), Meena and Sharma (2018), Monobrullah *et al.* (2020) and Swami *et al.* (2021).

The results of present study are in full agreement with the findings of Meena and Sharma (2018) & Swami *et al.* (2021) who have also recorded Lepidoptera and Hymenoptera as the two major insect order of natural enemies. In their survey study in the Arid Western Plains they have also reported predators viz., *E. amabilis* (Noctuidae; Lepidoptera), *P. pulverea* (Blastobasidae; Lepidoptera) primary parasitoids viz., *A. purpureus* (Eulophidae; Hymenoptera), *T. tachardiae*, and *E. dewitzii* (Encyrtidae; Hymenoptera) and hyperparasitoids, *B. greeni* (Braconidae; Hymenoptera) which is similar to the results of present investigation. Similar to our

study in their study they have also depicted that primary parasitoids were dominant and are dominated by Encyrtidae (54.21%) and Eulophidae (32.30%) they are followed by predators *E. amabilis* (8.44%), *P. pulverea* (2.64%) and they also recorded small population of hyperparasitoid of Braconidae family with 0.59% contribution. They have also reported highest mean relative density for *E. amabilis* among predators and *E. dewitzii* among parasitoids and least number of hyperparasitoids in their study therefore all these findings are exactly in line with the present study and thus confirms the result of the present investigation.

Furthermore, the results of the investigation are supported by the findings of Monobrullah *et al.* (2020) and Kalahal (2017) who have reported two species of predators viz., *E. amabilis*, *P. pulverea*, and three species of primary parasitoids namely *E. dewitzii*, *T. tachardiae* and *A. purpureus* during their investigation. Monobrullah *et al.* (2020) recorded that among the parasitoids, *A. purpureus* was found more in number (42 per 10 cm lac encrustation) as compared to *T. tachardiae* (14 per 10 cm lac encrustation) whereas Kalahal (2017) have shown that among primary parasitoids *E. dewitzii* is most dominant and is followed by *T. tachardiae* and *A. purpureus*, respectively both the results are in line with the results of the present investigation. Results of the present study are also in full agreement with the findings of Kalahal (2017) who have also recorded the presence of that storage pest *Oryzaphilus spp.* of Silvanidae family and Coleopteran order in the stored lac samples with contribution of 1.3% .

5.1.3 Weekly emergence profile of insect fauna associated with lac insect, *Kerria lacca* (Kerr)

The data on the weekly emergence profile of parasitoids and predators associated with lac insect was recorded for the period of six weeks from the initiation of emergence and has been depicted in Fig 4. The emergence of natural enemies started after six weeks of lac storage and continued till next six weeks. The result shows that the emergence of natural enemies was 45 individuals in the first week which increased to maximum of 145 individuals during the third week and thereafter it declined to 62 individuals. The emergence of the major predators viz., *Eublemma amabilis*. and *Pseudohypatopa pulverea* was recorded during all the six weeks with maximum emergence during the fifth week with 14 individuals of *E. amabilis* and 4 individuals of *P. pulverea* of Noctuidae and Blastobasidae family, respectively.

Similarly, primary parasitoids emerged till fourth week of lac storage with maximum emergence during third week with 32 and 9 individuals of Encyrtidae and Eulophidae, respectively. Likewise, hyperparasitoids of Braconidae family emerged till fifth week after lac storage with maximum emergence of 4 individuals during third week (Fig 4). Storage pests showed emergence upto sixth week with maximum emergence during third week with 15, 1 and 68 individuals of Curculionidae, Silvanidae and Liposelidae family, respectively. The findings of the present study are in line with the findings of Meena and Sharma (2018) who have also recorded the emergence of predators viz. *E. amabilis* & *P. pulveria* upto upto six weeks, primary parasitoids viz., *T. tachardiae*, *A. purpureus* and *E.dewitzii* upto four weeks and hyperparasitoids *B. greeni* within five weeks during the month of June –July/ Oct- Nov from the stored lac samples.

5.2 Diversity and species richness of natural enemies of lac insect, *Kerria lacca* (Kerr)

Lac insect is attacked by number of natural enemies both predators and parasitoids, many of which are non-specific to lac insect but have become threat to it. Prevalence of these natural enemies are governed by various factors including change in the environment and host ecosystem. The studies on diversity and species richness of natural enemies causing economic losses of the lac insect have been done to get the precise estimation of the total number of insect species within specific order.

The results of the present studies reveals that the lac associated insect fauna comprises of both natural enemies and storage pests. As many as six species of natural enemies belonging to two order were recorded during the investigation. Among natural enemies two species of predators were recorded viz., *Eublemma amabilis* and *Pseudohypatopa pulvereana* belonging to family Noctuidae & Blastobasidae and order Lepidoptera, respectively. Similarly, three species of primary parasitoids belonging to two different families were recorded viz., *Erencyrtus dewitzii*, *Tachardiaephagus tachardiae* of Encyrtidae family and *Aprostocetus purpureus* of Eulophidae family and order Hymenoptera. Likewise, one species of hyperparasitoid, *Bracon greeni* of family Braconidae and order Hymenoptera was also recorded (Fig. 5). Apart from natural enemies three species of storage pests belonging to three different families and two different orders were also recorded namely *Sitophilus oryzae* and *Oryzophilus surinamensis* belonging to family Curculionidae and Silvanidae and order Coleoptera, respectively. *Liposcelis divinatorius* of family

Liposelidae and order Psocoptera is another storage pest recorded from the three states viz., Rajasthan, Gujarat and Haryana. The result of this investigation are supported by Bhattacharya *et al.* (2007) , Sharma *et al.* (2008) and Swami *et al.* (2021) who have also recorded two species of predator viz., *E. amabilis* and *P. pulverea* as a key or major predator of lac. Three species of primary parasitoids viz., *Erencyrtus dewitzi*, *Tachardiaephagus tachardiae* of Encyrtidae family and *Aprostocetus purpureus* of Eulophidae family and hyperparasitoid, *Bracon greeni* of family Braconidae and order Hymenoptera. The population of primary parasitoid belonging to family Encyrtidae (54.21%) and Eulophidae (32.30%) to be dominant and followed by predators *E. amabilis* (8.44%), *P. pulverea* (2.64%) and *Chrysopa* (1.90%). In the study a small population of hyperparasitoid of Braconidae family was recorded with 0.59%.

5.2.1 Relative density, mean density and diversity indices of insect fauna associated with lac insect, *Kerria lacca* (Kerr)

Among the insect fauna associated with lac insect (*Kerria lacca*) the maximum relative and mean density of 56.84 per cent and 0.60 was recorded for primary parasitoids (Encyrtidae & Eulophidae) which was followed by the predators (Noctuidae & Blastobasidae) and hyperparasitoids (Braconidae) with relative density of 38.42 & 4.73 per cent and mean density of 0.40 & 0.05, respectively. The results also demonstrated that the relative density of the natural enemies which emerged from the collected lac samples was maximum with 46.31 per cent in Rajasthan followed by 34.73 per cent in Haryana and 18.94 per cent in Gujarat whereas mean density of natural enemies was maximum of 1.43 in Haryana and was followed by 1.38 & 0.97 in Gujarat & Rajasthan, respectively (Fig. 6.1 & Fig. 6.2). Among storage pests a high relative density was recorded for storage pests belonging to family Liposelidae followed by storage pests of family Cuculionidae and Silvanidae with 84.40, 15.50 & 1.20 percent, respectively. The present study gets support from the findings of Meena and Sharma (2018) who reported that 27.27 per cent of the genera as well as species belonged to family Encyrtidae; 18.18 per cent to Braconidae and 9.09 per cent each to Eupelmidae, Chalcididae, Noctuidae, Blastobasidae, Chrysopidae, and Eulophidae. *E. dewitzi* recorded the most abundant parasitoid among all the associated fauna with average relative densities of 27.82, 39.91, 39.53, 32.89 per cent during different seasons (Oct 2015, July and Oct 2016 and July 2017, respectively).

The findings of this investigation also gets support from the study of Kalhal *et al.* (2018) who reported that the 3 species parasitoids belonging to order Hymenoptera viz., *T. tachardiae* Howard (5.2%) and *E. dewitzii* Mahd (88.4%) of family Encyrtidae and *A. purpureus* Cameron (4.2%) belonging to family Eulophidae which contributed 97.8 percent to the total population of natural enemies. The two species of predators of Lepidoptera viz., *E. amabilis* Moore (0.70%) of family Noctuidae and *P. pulverea* Meyr (0.3%) of Blastobasidae family contributed 1 percent to the total natural enemy population.

Diversity indices calculated for the three states of Arid Western Plains shows that both Shannon-Weinner and Simpson Diversity Indices were maximum with 1.54 & 0.712 for Rajasthan followed by 1.46 & 0.672 for Haryana and both the diversity indices were recorded lowest for Gujarat with 1.26 & 0.592, respectively (Fig. 7). The result of this investigation is in partial agreement with the findings of Swami *et al.* (2021) who recorded Shannon-Weinner Diversity Index highest (1.13) for Haryana followed by 1.11 for Rajasthan and 1.09 for Gujarat this could be due to the mean of the diversity index they have considered for two years 2019 & 2020 whereas in the present study the diversity indices have been calculated only for one year 2022.

5.3 Morpho-taxonomic study of major predators of lac insect, *Kerria lacca* (Kerr)

Morpho- taxonomic study is the study of classification of organisms according to their morphology. Morphological characters are traditionally useful as evidence at all taxonomic levels, but particularly at specific and generic rank. Ther morpho-taxonomic studies will help in characterization, identification, classification and relationship among related species. Therefore, the results of the present study will help in identification and characterization of new species of *Eublemma amabilis* (Moore) and *Pseudohypatopa* (= *Holcocera*) *pulverea* (Meyrick) if discovered in future.

Morpho-taxonomic studies were carried out for the major predators of lac insect (*Kerria lacca*) viz. *Eublemma amabilis* (Moore) and *Pseudohypatopa* (= *Holcocera*) *pulverea* (Meyrick) in the Lac laboratory cum Museum established under NP-CLIGR at Department of Entomology, Rajasthan College of Agriculture, Udaipur. The results of the investigation demonstrated that the mean of body length, total

wingspan, length of right & left antenna, length of right & left forewing and hindwing, breadth of right & left forewing and hind wing were 1.08, 2.60, 0.39 & 0.39, 1.15 & 1.13, 0.50 & 0.49, 0.86 & 0.85. 0.47 & 0.47 mm, respectively for *E. amabilis* male and 1.11, 2.60, 0.39 & 0.40, 1.03 & 1.05, 0.57 & 0.58, 0.78 & 0.77, 0.49 & 0.49 mm for *E. amabilis* female, respectively. Similarly, for male *P. pulverea* the mean of the parameters were recorded as 0.66mm for body length, 1.50mm for wingspan, 0.47mm length for both antennae, 0.68 mm length & 0.18mm breadth for both right and left forewings, 0.63mm length & 0.25 mm breadth for both right and left hindwings. Likewise the mean parameters recorded for female *P. pulverea* were 0.74 mm for body length, 1.70 mm for wingspan, 0.47 mm length for antennae, 0.76 mm & 0.77 mm length for both right and left forewings, 0.20 mm breadth for both forewings, 0.61 mm length & 0.32 mm breadth for both right and left hindwings. The overall result of the investigation also shows that all the parameters of females were larger in both *E. amabilis* & *P. pulverea*. Thus, females of both the predators were larger in size.

Research work on the morpho-taxonomic studies of major predators *viz.*, *Eublemma amabilis* (Moore) and *Pseudohypatopa* (= *Holcocera*) *pulverea* (Meyrick) is very scanty however the information has been gathered from the related morphometric work which has been undertaken on the other Lepidopteran species and their results have been presented and discussed here and depicted in Fig. 8.

Shi *et al.* (2015) has worked on gypsy moths and reported that male and female of *L. dispar* were sexually dimorphic in wing morphometric. Males had smaller wings, weighed less, and had smaller wing loads than females. The total wing area of male gypsy moths was smaller than that of female moth across all eight geographical strain. Similarly, the results of the present investigation gets support from the work of Mozaffarain *et al.* (2007) who worked on carob moth, *Ectomyelois ceratoniae* who reported that wings in females are wider than those in males and forewings are longer in females than those in males. Likewise, Sousan *et al.* (2022) also reported that wing size of the females was larger than males in *C. abacta* which elaborates the findings of the present investigation.

6. SUMMARY

The results of the investigations carried out under Network Project on Conservation of Lac Insect Genetic Resources (NP-CLIGR) on “Diversity and Morpho-taxonomic Studies of Major Predators of lac insect, *Kerria lacca* (Kerr) in Arid Western Plains”, at lac insect gene bank cum lac laboratory at Department of Entomology, Udaipur during 2022 can be summarised as:

Surveys were carried out at 178 locations in the three states of Arid Western Plains viz., Rajasthan, Gujarat and Haryana. During the surveys conducted, lac insects were recorded on 6 host plants viz., Peepal, *Ficus religiosa* Linn. (Moraceae), Bargad, *Ficus benghalensis* Linn. (Moraceae), Gular, *Ficus racemose* Linn. (Moraceae), Ber, *Ziziphus mauritiana* Lam. (Rhamnaceae), Babool /Kikar, *Vachellia nilotica* Linn. (Fabaceae) and Sitafal, *Annona squamosa* Linn. (Annonaceae). Among all these host plants lac insect was recorded maximum at 142 locations on Peepal and minimum at one location on Gular. Among three states maximum host plants with the presence of lac insect were recorded in Rajasthan followed by Gujarat and Haryana, respectively.

The emergence of maximum 387 natural enemies and storage pests was recorded from Peepal which was followed by Ber, Bargad, Babool & Gular with 96, 23, 12 & 3 natural enemies and storage pests, respectively. Emerged natural enemies and storage pests belonged to total four orders and seven families and were classified as predators, primary parasitoids and hyperparasitoids. Major predators recorded were *E. amabilis* Moore and *P. pulverea* Meyric with contributed 30.52 and 7.89 per cent to the total lac associated fauna and belonged to Noctuidae and Blastobasidae family and Lepidopteran order. Primary parasitoids and hyperparasitoids belonged to Hymenopteran order of which primary parasitoids belonged to Encyrtidae and Eulophidae family and hyperparasitoids belonged to Braconidae family. Among all the natural enemies the primary parasitoid of Encyrtidae family were recorded to be maximum with total contribution of 44.20 per cent and followed by primary parasitoids of Eulophidae family with the contribution of 12.63 per cent and hyperparasitoids were recorded to be minimum with the contribution of 1.74 per cent to the total population of lac associated fauna. Apart from these a large population of storage pests was also recorded that belonged to Curculionidae and Liposelidae

family and Coleoptera and Psocoptera order, respectively. Among the three storage pests *Liposcelis divinatorius* Muller belonging to Liposelidae family were maximum with the contribution of 83.38 per cent and were followed by storage pests viz. *Sitophilus oryzae* Linn. and *Oryzaephilus surinamensis* Linn. belonging to the family Curculionidae & Silvanidae which contributed 15.40 and 1.20 per cent, respectively to the total storage pest population emerged from stored lac samples.

The weekly emergence profile shows that the natural enemies and storage pests emerged from Ist to VIth week with the maximum emergence in IIIrd week. The emergence of predators was till VIth week with maximum emergence in Vth week. Emergence of storage pests could be observed till VIth week with maximum emergence in IIIrd week. Primary parasitoids emerged only till IVth week with maximum emergence in IIIrd week whereas hyperparasitoids emerged in very less number and only for three weeks starting from IIIrd to Vth week with maximum emergence in IIIrd week.

Among the three states maximum 88 number of natural enemies emerged from lac samples collected from Rajasthan followed by Haryana & Gujarat with 66 & 36 natural enemies, respectively. In all the three states primary parasitoids were maximum and were followed by predators and the minimum emergence was recorded for hyperparasitoids. The same trend was followed by storage pests as they were recorded maximum 125 from the stored lac samples collected from Rajasthan and were followed by the lac samples of Haryana and Gujarat with 111 & 95 storage pests, respectively. Among the three storage pests the storage pests belonging to Liposelidae family were maximum with 276 individuals and were followed by 51 & 4 individuals of Curculionidae and Silvanidae family, respectively.

Among the three states the maximum relative density of natural enemies and storage pests was 46.31 & 38.67 per cent in Rajasthan while it was 18.94 & 28.09 per cent in Gujarat which was minimum. Among the natural enemies the relative density was highest 44.21 & 12.63 per cent for primary parasitoids of family Encritidae and Eulophidae, respectively and was followed by predators viz., *Eublemma amabilis* and *Pseudohytopa pulverea* with 30.52 and 7.89 per cent, respectively. Hyperparasitoids belonging to Braconidae family had lowest relative density in all the three states with 4.73 per cent. Among the storage pests the individuals belonging to Liposelidae

family have highest relative density of 84.40 per cent and was followed by the relative density of individuals of Curculionidae and Silvanidae family with 15.50 & 1.20 per cent, respectively.

Mean density of natural enemies was maximum in the lac samples collected from Haryana (1.43) followed by Gujarat (1.38) and Rajasthan (0.97), respectively. Among natural enemies primary parasitoids have maximum mean density (0.60) followed by predators (0.40) and hyperparasitoids (0.05), respectively. Maximum mean density of storage pests was recorded in Haryana (2.39) followed by Gujarat (2.11) and Rajasthan (1.42), respectively. Among storage pests highest mean density was recorded for individuals of Liposelidae family (1.53) followed by storage pests of Curculionidae (0.28) and Silvanidae family (0.02), respectively.

The value of Shannon- Weinner Index and Simpson Diversity Index were highest for Rajasthan (1.54 & 0.712) followed by Haryana (1.46 & 0.672) and Gujarat (1.26 & 0.592), respectively.

The observations for various morphological parameters *viz.*, body length, wingspan, length of right and left antennae, length and breadth of both forewings & hindwings of both male and female of major predators *viz.*, *Eublema ammabilis* & *Pseudohypatopa pulverea* shows that females is larger in size than males for both the predators.

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Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect, *Kerria lacca* (Kerr) in Arid Western Plains

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ABSTRACT

The present study entitled as “Diversity and Morpho-taxonomic Studies of Major Predators of Lac Insect, *Kerria lacca* (Kerr) in Arid Western Plains” was carried out in the Department of Entomology, Rajasthan College of Agriculture, MPUAT, Udaipur, during 2022. Survey for the presence of natural population of lac insect on various host plants were carried out at 178 locations of 27 districts of Arid Western Plains viz., Rajasthan, Gujarat and Haryana and the presence of lac was recorded on hosts viz., Peepal, Bargad, Ber, Babool, Gular and Sitafal, of which Peepal was the most predominant host of natural lac recorded at total 142 locations. Among all the host plant samples, highest natural enemy emergence was recorded from the samples of Peepal (387) followed by Ber (96), Bargad (23), Babool (12) and Gular (3). Lac associated fauna emerged from different host samples comprises of both natural enemies and storage pests belonging to four orders viz., Lepidoptera, Hymenoptera, Coleoptera and Pcoptera and eight families viz., Noctuidae (*E. amabilis*), Blastobasidae (*P. pulverea*), Encyrtidae (*E. dewitzii* & *T. tachardiae*), Eulophidae (*A. purpureus*), Braconidae (*B. greeni*), Curculionidae (*S. oryzae*), Silvanidae (*O. surinamensis*) & Liposelidae (*L. divinatorius*). Of emerged natural enemies primary parasitoids were maximum, followed by predators and hyperparasitoids with contribution of 44.20, 38.41 and 4.73 per cent to the total natural enemy population. Individuals emerged from the lac host samples collected from Rajasthan were maximum (88), followed by Haryana (66) and Gujarat (36) with relative density of 46.31, 34.73 & 18.94 per cent, respectively. Mean density calculated for emerged natural enemies was maximum in Haryana (1.43) followed by Gujarat (1.38) and Rajasthan (0.97), respectively. Lac associated fauna emerged after six weeks of storage till next VI weeks with maximum emergence in IIIrd week. In morpho-taxonomic studies carried out for male & female of *E. amabilis* and *P. pulverea*, size of female was recorded larger than male.

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पश्चिमी शुष्क मैदानी क्षेत्र में लाख कीट, *Kerria Lacca* (Kerr) के प्रमुख परभक्षियों की विविधता एवं बाह्य-वर्गिकी का अध्ययन

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अनुक्षेपण

पश्चिमी शुष्क मैदानी क्षेत्र में लाख कीट, *Kerria Lacca* (Kerr) के प्रमुख परभक्षियों की विविधता एवं बाह्य-वर्गिकी का अध्ययन वर्ष 2022 के दौरान राजस्थान कृषि महाविद्यालय, एम. पी.यू.ए.टी., उदयपुर के कीट विज्ञान विभाग में किया गया। विभिन्न पोषक पौधों पर लाख कीट की प्राकृतिक आबादी की उपस्थिति के लिए शुष्क पश्चिमी, मैदानी इलाकों जैसे – राजस्थान, गुजरात एवं हरियाणा के 27 जिलों के 178 स्थानों पर सर्वेक्षण किया गया। जिसमें प्राकृतिक लाख की उपस्थिति पीपल, बरगद, बेर, बबूल, गुलर एवं सीताफल पर दर्ज की गई।

सभी पोषक पौधों में पीपल को प्राकृतिक लाख का प्रमुख पोषक पौधा माना गया जिसकी उपस्थिति 142 स्थानों पर दर्ज की गई। सभी पोषक पौधों के नमूनों में से सबसे अधिक पीपल (387), फिर बेर (96), बरगद (23), बबूल (12) और गुलर (3) से प्राकृतिक परभक्षियों का उद्भव देखा गया। विभिन्न पोषक नमूनों में से उद्भव लाख से सम्बन्धित प्रमुख कीटों में प्राकृतिक परभक्षियों के साथ भण्डारण कीट भी शामिल है, जो चार वर्गों अर्थात् Lepidoptera, Hymenoptera, Coleoptera or Pscoptera, और आठ परिवार जैसे :- Noctuidae (*E. amabilis*), Blastobasidae (*P. Pulverea*), Encyrtidae (*E. dewitzii* & *T. tachardiae*), Eulophidae (*A. purpureus*), Braconidae (*B. greeni*), Curculionidae (*S. oryzae*), Silvanidae (*O. surinamensis*) & Liposelidae (*L. divinatorius*) में बांटे जा सकते हैं। उत्पन्न हुए प्राकृतिक परभक्षियों में प्राथमिक परजीवियों की संख्या सबसे अधिक दर्ज की गई, जो की 44.20 प्रतिशत थी। इसके बाद परभक्षियों और हाइपरजीवियों का स्थान था जिनका योगदान कुल लाख सम्बन्धित कीटों की आबादी में 38.41 और 04.73 प्रतिशत रहा। राजस्थान से एकत्रित किए गये लाख पोषक नमूनों से उत्पन्न हुए परजीवियों की संख्या अधिकतम (88) थी। इसके बाद उत्पन्न हुये परजीवियों की संख्या क्रमशः हरियाणा (66) एवं गुजरात (36) थी, जिनका सापेक्ष घनत्व क्रमशः 46.31, 34.73 और 18.94 प्रतिशत था। उत्पन्न हुए प्राकृतिक परभक्षियों के लिए गणना की गई, जिनका औसत घनत्व क्रमशः हरियाणा (1.43) अधिकतम, गुजरात (138) और राजस्थान (0.97) रहा। लाख नमूनों को छः सप्ताह भण्डारित करने के बाद छठवें सप्ताह में लाख-परभक्षियों का उद्भव प्रारम्भ हुआ, जो की अगले छः हफ्ते तक चला और तीसरे हफ्ते में लाख परभक्षियों का उद्भव अधिकतम रहा। लाख कीट के प्रमुख परभक्षियों— *E. amabilis* और *P. pulverea* की बाह्य-वर्गिकी का अध्ययन मादा व नर के लिए अलग-अलग किया गया, जिसमें मादा का आकार नर के आकार की तुलना में बड़ा दर्ज किया गया।

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APPENDIX- I**Passport data of host plant and lac insect (June-July/Oct-Nov, during 2022)****RAJASTHAN**

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
1	298	N 24° 34.884` E 073° 42.144`	1882 ft	05.06.2022	Shahpura Post office	Shahpura, Jaipur, Rajasthan	Peepal	Collected sample(Live)
2	299	N 27° 25.388` E 076° 03.324`	1879 ft	05.06.2022	Primary School Chatarpura, Viratnagar	Viratnagar, Jaipur, Rajasthan	Peepal	Collected sample(Live)
3	300	N 27° 25.010` E 076° 06.195`	1892 ft	05.06.2022	Bilwadi bus stand, Viratnagar	Viratnagar, Jaipur, Rajasthan	Peepal	Not collected sample (Dead)
4	301	N 27° 47.516` E 076° 44.808`	1460 ft	06.06.2022	Bambora, Kisangarhbas	Kisangarhbas, Alwar, Rajasthan	Peepal	Collected (Dead sample)
5	302	N 27° 47.519` E 076° 44.802`	1437 ft	06.06.2022	Khairthal	Kisangarhbas, Alwar, Rajasthan	Peepal	Collected (Dead sample)
6	303	N 27° 49.055` E 076° 43.646`	1443 ft	06.06.2022	PHC, Kisangarhbas	Kisangarhbas, Alwar, Rajasthan	Peepal	Not collected sample (Dead)
7	304	N 27° 54.532` E 076° 48.559`	980 ft	06.06.2022	Yadav Farm House, Tijara	Tijara, Alwar, Rajasthan	Ber	Collected sample(Live)
8	305	N 27° 56.528` E 076° 50.460`	978 ft	06.06.2022	Near Jain Mandir, Tijara	Tijara, Alwar, Rajasthan	Ber	Collected (Dead sample)
9	306	N 27° 56.017` E 076° 51.062`	1036 ft	06.06.2022	Saini Kirana Store, Tijara	Tijara, Alwar, Rajasthan	Peepal	Collected sample (Live)
10	307	N 27° 56.833` E 076° 50.793`	932 ft	06.06.2022	Infront of Shyam tent house, Tijara	Tijara, Alwar, Rajasthan	Ber	Collected (Dead sample)
11	308	N 27° 57.606` E 076° 49.736`	913 ft	06.06.2022	Birmapur, Kotkasim	Kotkasim, Alwar, Rajasthan	Peepal	Not collected sample (Dead)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
12	309	N 27° 56.959` E 076° 50.644`	933 ft	06.06.2022	Roadways bus stand Tijara	Tijara, Alwar, Rajasthan	Ber	Collected sample (Live)
13	310	N 28° 06.654` E 076° 50.044`	911 ft	06.06.2022	Gram Panchayat, Tapukara	Tapukara, Alwar, Rajasthan	Peepal	Collected sample (Live)
14	314	N 28° 12.670` E 076° 51.879`	861 ft	06.06.2022	CGST Office, Bhiwadi	Bhiwadi, Alwar, Rajasthan	Peepal	Dead Sample Not Collected
15	315	N 28° 12.756` E 076° 51.736`	865 ft	06.06.2022	Near Jodhpur Sweets, Phool bhag, Bhiwadi	Bhiwadi, Alwar, Rajasthan	Peepal	Dead Sample Not Collected
16	316	N 28° 12.736` E 076° 50.927`	854 ft	06.06.2022	Neelam Chowk, Bhiwadi	Bhiwadi, Alwar, Rajasthan	Peepal	Collected sample (Both Live/Dead)
17	317	N 28° 12.691` E 076° 50.462`	842 ft	06.06.2022	Samtalpur, Rewadi road, Bhiwadi	Bhiwadi, Alwar, Rajasthan	Peepal	Collected sample (Live)
18	442	N 24° 45.467` E 073° 43.320`	2030 ft	06.07.2022	Bus stand, Ekling ji	Udaipur, Rajasthan	Peepal	Collected sample (Live)
19	443	N 24° 46.636` E 073° 44.680`	1960 ft	06.07.2022	Texi stand, Delwara	Udaipur, Rajasthan	Bargad	Collected sample(Live)
20	444	N 24° 46.693` E 073° 44.952`	1925 ft	06.07.2022	Khatik Mohalla, Delwara	Udaipur, Rajasthan	Peepal	Collected sample (Live)
21	445	N 24° 56.612` E 073° 49.467`	1878 ft	06.07.2022	Gokul dham Hotel, Nathdwara	Rajsamand	Peepal	Not collected sample (Dead)
22	446	N 25° 02.228` E 073° 51.618`	1882 ft	06.07.2022	Chandi Marble, NH- 8, Rajsamand	Rajsamand	Peepal	Collected sample(Live)
23	447	N 25° 10.535` E 073° 50.369`	2013 ft	06.07.2022	Opposite oppolo Tyres, Rajsamand	Rajsamand	Peepal & Bargad	Collected sample (Live)
24	448	N 25° 10.742` E 073° 50.244`	2022 ft	06.07.2022	Opposite gurukripa Restro., Rajsamand	Rajsamand	Bargad	Live sample Collected

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
25	449	N 25° 16.705` E 073° 46.912`	2203 ft	06.07.2022	Goamti road, Rajsamand	Rajsamand	Peepal	Collected (Dead sample)
26	450	N 25° 16.705` E 073° 46.912`	2202 ft	06.07.2022	Vinayak motors, Goamti	Rajsamand	Sitafal & Bargad	Collected (Live sample)
27	451	N 25° 21.081` E 073° 46.725`	2458 ft	06.07.2022	Goamti bypass	Rajsamand	Peepal & Ber	Collected (Dead sample)
28	452	N 25° 21.080` E 073° 46.724`	2460 ft	06.07.2022	Near Goamti bypass	Rajsamand	Peepal	Collected sample (Live)
29	453	N 25° 21.081` E 073° 46.724`	2460 ft	06.07.2022	Diver road, Goamti	Rajsamand	Sitafal & Bargad	Collected (Live sample)
30	454	N 24° 37.926` E 073° 44.617`	2132 ft	07.07.2022	Mehro ka Guda, Udaipur	Udaipur	Peepal	Collected (Dead sample)
31	455	N 24° 38.693` E 073° 44.252`	2112 ft	07.07.2022	Amberi, Udaipur	Udaipur	Bargad	Collected (Dead sample)
32	456	N 24° 38.911` E 073° 43.113`	2024 ft	07.07.2022	Anita marble, Sukher, Udaipur	Udaipur	Peepal	Collected sample (Live)
33	457	N 24° 38.157` E 073° 43.550`	2037 ft	07.07.2022	Bhairavgarh, Khelgaon, Udaipur	Udaipur	Kikar	Collected sample (Live)
34	458	N 24° 36.979` E 073° 44.057`	2025 ft	07.07.2022	Near Khelgaon, Udaipur	Udaipur	Kikar & Peepal	Collected (Live sample)
35	368	N 29° 11.179` E 075° 19.789`	666 ft	12.10.2022	Chhani badi, Bhadra	Bhadra, Hanumangarh, Rajasthan	Peepal	Collected sample (Dead)
36	369	N 29° 06.548` E 075° 10.569`	637 ft	12.10.2022	Shiwan moters, Bhadra	Bhadra, Hanumangarh, Rajasthan	Peepal	Collected sample (Dead)
37	370	N 29° 06.459` E 075° 10.400`	639 ft	12.10.2022	Bus Stand, Bhadra	Bhadra, Hanumangarh,	Peepal	Not Collected sample (Live)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
						Rajasthan		
38	371	N 29° 00.748` E 075° 14.600`	663 ft	12.10.2022	Utrada bas, Bhadra	Bhadra, Hanumangarh, Rajasthan	Peepal	Collected sample (Dead)
39	372	N 28° 58.015` E 075° 14.736`	665 ft	12.10.2022	SS School, Bhanai, Bhadra	Bhadra, Hanumangarh, Rajasthan	Bargad	Not Collected sample (Dead)
40	373	N 28° 53.409` E 075° 17.008`	654 ft	12.10.2022	Siddhmukh, Rajgarh	Rajgarh, Churu, Rajasthan	Peepal	Collected sample (Dead)
41	374	N 28° 44.076` E 075° 20.629`	734 ft	12.10.2022	Kishanpura, Rajgarh	Rajgarh, Churu, Rajasthan	Peepal	Collected sample (Dead)
42	375	N 28° 37.793` E 075° 23.017`	786 ft	12.10.2022	Rajgarh Bus Stand	Rajgarh, Churu, Rajasthan	Peepal	Collected sample (Dead)
43	376	N 28° 19.100` E 075° 26.094`	955 ft	12.10.2022	Muktidham, Mandrella, Chirawa	Chirawa, Jhunjhunu, Rajasthan	Peepal	Not Collected sample (Dead)
44	377	N 28° 09.600` E 075° 24.406`	1036 ft	12.10.2022	Isarpur, Alsisar	Jhunjhunu, Rajasthan	Peepal	Collected sample (Dead)
45	378	N 28° 07.113` E 075° 23.050`	1160 ft	12.10.2022	Mandawa mod	Jhunjhunu, Rajasthan	Babool	Collected sample (Live & Dead)
46	379	N 28° 06.160` E 075° 20.894`	1111 ft	13.10.2022	Vaidpura village, Durgapura	Jhunjhunu, Rajasthan	Peepal	Not Collected sample (Dead)
47	380	N 28° 03.600` E 075° 10.500`	1064 ft	13.10.2022	Tetra villege, Mandawa	Jhunjhunu, Rajasthan	Peepal	Collected sample (Dead)
48	381	N 28° 03.452` E 075° 09.627`	1067 ft	13.10.2022	Bisau mod police station	Jhunjhunu, Rajasthan	Peepal	Collected sample (Live)
49	382	N 28° 00.370` E 074° 58.751`	1069 ft	13.10.2022	Salasar bartan bhandar, Fatahpur	Fatahpur, Sikar, Rajasthan	Peepal	Collected sample (Dead)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
50	383	N 27° 42.010` E 074° 44.147`	1125 ft	13.10.2022	Sikar road, Salasar	Churu, Rajasthan	Peepal	Collected sample (Dead)
51	384	N 27° 37.159` E 075° 07.380`	1398 ft	13.10.2022	Nehru Park	Sikar, Rajasthan	Peepal	Collected sample (Live)
52	385	N 27° 36.690` E 075° 08.140`	1424 ft	13.10.2022	Salasar bus stand, Sikar City	Sikar, Rajasthan	Peepal	Collected sample (Dead)
53	386	N 27° 36.412` E 075° 08.471`	1441 ft	13.10.2022	Kureshi Mohalla, Sikar	Sikar, Rajasthan	Peepal	Collected sample (Live)
54	387	N 27° 22.105` E 075° 34.081`	1615 ft	13.10.2022	Dayal Hospital, Ringus, Sri madhopur	Sri madhopur, Sikar, Rajasthan	Peepal	Collected sample (Live)
55	388	N 27° 22.067` E 075° 34.140`	1612 ft	13.10.2022	Ringus gav bus stand, Sri madhopur	Sri madhopur, Sikar, Rajasthan	Peepal	Collected sample (Live)
56	389	N 27° 11.191` E 075° 43.050`	1663 ft	13.10.2022	Balaji Dharmkata, Chomu	Chomu, Jaipur, Rajasthan	Peepal	Collected sample (Live)
57	390	N 27° 22.066` E 075° 34.142`	1668 ft	13.10.2022	Hanuman ji Ka rasta, Chomu	Chomu, Jaipur, Rajasthan	Bargad	Collected sample (Live)
58	391	N 26° 50.607` E 075° 47.482`	1404 ft	13.10.2022	Mahveer Nagar, Jaipur City	Jaipur, Rajasthan	Peepal	Not Collected sample (Dead)
59	392	N 26° 52.568` E 075° 46.466`	1334 ft	13.11.2022	Utkarsh Classes, Jaipur	Jaipur, Rajasthan	Peepal	Collected sample (Live/Dead)
60	393	N 26° 52.523` E 075° 42.648`	1346 ft	13.11.2022	Taruchaya Residency	Jaipur, Rajasthan	Peepal	Not Collected sample (Dead)
61	459	N 24° 36.973` E 073° 44.068`	2023 ft	04.11.2022	Khelgaon, Udaipur	Udaipur	Bargad	Collected sample (Live)
62	460	N 24° 36.470` E 073° 43.963`	1960 ft	04.11.2022	RTO Office, Pratapnagar, Udaipur	Udaipur	Peepal	Collected sample (Live)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
63	461	N 24° 35.857` E 073° 43.809`	1912 ft	04.11.2022	JRNVU, Pratapnagar, Udaipur	Udaipur	Kikar & Ber	Collected (Live sample)
64	462	N 24° 35.856` E 073° 43.803`	1913 ft	04.11.2022	FoE, MLSU, Udaipur	Udaipur	Bargad & Ber	Not Collected (Dead sample)
65	463	N 24° 35.687` E 073° 44.010`	1910 ft	04.11.2022	CTAE Campus, MPUAT, Udaipur	Udaipur	Peepal	Collected sample (Live)
66	464	N 24° 35.075` E 073° 43.906`	1898 ft	04.11.2022	Sundarvas, Udaipur	Udaipur	Ber & Peepal	Collected (Live sample)
67	465	N 24° 34.994` E 073° 43.687`	1897 ft	04.11.2022	Ranapratap nagar, Railway station, Udaipur	Udaipur	Peepal& Kikar	Not Collected sample (Live)
68	466	N 24° 34.988` E 073° 43.494`	1900 ft	04.11.2022	Sevaashram Chouraha, Udaipur	Udaipur	Peepal	Collected sample (Live)
69	467	N 24° 33.388` E 073° 42.915`	1940 ft	04.11.2022	VIP Colony, Sec-09, Udaipur	Udaipur	Peepal	Not Collected sample (Live)
70	468	N 24° 32.201` E 073° 42.696`	1992 ft	05.11.2022	Titardi, Udaipur	Udaipur	Peepal & Ber	Not Collected sample (Live)
71	469	N 24° 30.793` E 073° 43.840`	1962 ft	05.11.2022	Sri ji Marble, Titardi, Udaipur	Udaipur	Peepal	Collected sample (Live)
72	470	N 24° 33.330` E 073° 42.373`	1934 ft	05.11.2022	Savina mandi, Udaipur	Udaipur	Peepal&Ber	Collected sample (Live)
73	471	N 24° 33.365` E 073° 42.307`	1931 ft	05.11.2022	Revti bus stand, Udaipur	Udaipur	Kikar & Ber	Collected sample (Live)
74	472	N 24° 39.879` E 073° 40.035`	2023 ft	05.11.2022	Limkheda mod, Udaipur	Udaipur	Peepal	Collected sample (Live)
75	473	N 24° 39.514` E 073° 41.216`	1995 ft	05.11.2022	Lakhawli, Udaipur	Udaipur	Ber	Collected sample (Live)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
76	474	N 24° 40.347` E 073° 41.143`	2042 ft	05.11.2022	Rajkiya public school, Lakhawali, Udaipur	Udaipur	Bargad	Collected sample (Live)
77	475	N 24° 35.877` E 073° 43.608`	1948 ft	05.11.2022	Kalka Mata road, Udaipur	Udaipur	Peepal	Collected sample (Live)

GUJARAT

S. No.	Location No.	Location	Elevation	Date	Place	Block/District/State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
1	394	N 24° 34.877` E 073° 42.121`	1188 ft	26.06.2022	Samalaji gram panchayat, Aravli	Samalaji, Aravli, Gujrat	Peepal	Collected sample (Live)
2	395	N 23° 41.335` E 073° 22.925`	1038 ft	26.06.2022	Coperative bank, Modasa, Aravli	Modasa, Aravli, Gujrat	Peepal	Collected sample (Live)
3	396	N 23° 27.948` E 073° 17.873`	492 ft	26.06.2022	Mahila Police Station, Modasa, Aravli	Modasa, Aravli, Gujrat	Peepal	Collected sample (Live)
4	397	N 23° 21.713` E 073° 27.938`	490 ft	26.06.2022	Malpur Bus Stand	Malpur, Aravli, Gujrat	Peepal	Not Collected (Dead sample)
5	398	N 23° 21.512` E 073° 27.845`	504 ft	26.06.2022	Near Bank of Baroda, Malpur, Aravli	Malpur, Aravli, Gujrat	Peepal	Collected sample (Live)
6	399	N 23° 21.657` E 073° 27.918`	503 ft	26.06.2022	Shiv Mandir, Malpur, Aravli	Malpur, Aravli, Gujrat	Peepal & Bargad	Collected sample (Live)
7	400	N 23° 21.790` E 073° 28.109`	501 ft	26.06.2022	Malpur police stand, Malpur, Aravali	Malpur, Aravli, Gujrat	Ber	Collected (Dead sample)
8	401	N 23° 11.815` E 073° 52.753`	469 ft	26.06.2022	Sant dev mandir, Santrampur	Santrampur, Mahisagar, Gujrat	Peepal	Not Collected (Dead sample)
9	402	N 23° 11.386` E 073° 53.781`	468 ft	26.06.2022	Bus stand, Santrampur	Santrampur, Mahisagar, Gujrat	Peepal	Not Collected (Dead sample)
10	403	N 23° 09.388` E 073° 57.876`	624 ft	26.06.2022	Santrampur Jalod highway, Santrampur	Santrampur, Mahisagar, Gujrat	Peepal & Ber	Collected (Dead sample)
	404	N 23° 09.351` E 074° 00.233`	631 ft	26.06.2022	Padaliya, Fatehpur, Dahod	Fatehpur, Dahod, Gujrat	Peepal	Collected sample (Live)

S. No.	Location No.	Location	Elevation	Date	Place	Block/District/State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
12	405	N 23° 05.693` E 074° 09.300`	817 ft	26.06.2022	Vishwakarma mandir, Jalod	Jalod, Dahod, Gujrat	Peepal	Collected (Dead sample)
13	406	N 23° 06.273` E 074° 09.481`	853 ft	26.06.2022	Police station, Jalod	Jalod, Dahod, Gujrat	Peepal	Collected (Dead sample)
14	407	N 22° 59.637` E 074° 10.000`	926 ft	26.06.2022	Kheda, Dahod	Kheda, Gujrat	Peepal	Not Collected (Dead sample)
15	408	N 22° 49.469` E 074° 14.120`	893 ft	27.06.2022	KVK, Dahod	Dahod, Gujrat	Peepal	Collected sample (Live)
16	409	N 22° 49.889` E 074° 14.296`	1011ft	27.06.2022	Central school ,Godra road, Dahod City	Dahod, Gujrat	Peepal	Collected sample (Live)
17	410	N 22° 49.927` E 074° 15.048`	987 ft	27.06.2022	Shree Ram medical store, Godra road, Dahod	Dahod, Gujrat	Ber	Collected Sample(Live)
18	411	N 22° 50.132` E 073° 59.469`	689 ft	27.06.2022	Near railway bridge, Limkheda, Dahod	Limkheda, Dahod, Gujrat	Peepal	Collected sample (Live)
19	412	N 22° 49.990` E 073° 59.188`	698 ft	27.06.2022	Limkheda bus stand, Limkheda, Dahod	Limkheda, Dahod, Gujrat	Peepal	Collected sample (Live)
20	413	N 22° 43.131` E 073° 54.888`	723 ft	27.06.2022	Tehsildar office, Devgarh baria, Dahod	Devgarh baria, Dahod, Gujrat	Ber	Collected (live)
21	414	N 22° 42.358` E 073° 54.758`	686 ft	27.06.2022	Adhar super market, Devgarh baria, Dahod	Devgarh baria, Dahod, Gujrat	Bargad	Collected (Dead sample)
22	415	N 22° 42.307` E 073° 54.740`	682 ft	27.06.2022	Murlidhar ranchor rai mandir, Devgarh baria, Dahod	Devgarh baria, Dahod, Gujrat	Peepal	Collected sample (Live)
23	416	N 22° 42.173` E 073° 54.680`	662 ft	27.06.2022	Panchayat samiti office, Devgarh baria	Devgarh baria, Dahod, Gujrat	Peepal	Not Collected (Dead sample)
24	417	N 22° 46.437` E 073° 37.525`	431 ft	27.06.2022	ST stand, Godhra Panch mahal	Godhra, Panch mahal, Gujrat	Peepal & Ber	Collected sample (Live)

S. No.	Location No.	Location	Elevation	Date	Place	Block/District/State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
25	418	N 22° 46.376` E 073° 37.299`	449 ft	27.06.2022	Near Mahalaxmi clinic, Godra	Godhra, Panch mahal, Gujrat	Peepal	Collected sample (Live)
26	419	N 22° 44.659` E 073° 35.842`	453 ft	22.10.2022	Ahmad truck parking, Godra-Halol road, Godra	Godhra, Panch mahal, Gujrat	Ber	Collected sample (Live)
27	420	N 22° 36.412` E 073° 27.599`	327 ft	22.10.2022	Near bus stand, Kalol	Kalol, Gandhinagar, Gujrat	Peepal	Collected sample (Live)
28	421	N 22° 36.332` E 073° 27.565`	314 ft	22.10.2022	Police station, Kalol	Kalol, Gandhinagar, Gujrat	Peepal	Collected sample (Live)
29	422	N 22° 32.272` E 073° 27.798`	338 ft	22.10.2022	Trio square, Halol	Halol, Panch mahal, Gujrat	Peepal	Collected sample (Live)
30	423	N 22° 30.552` E 073° 28.265`	374 ft	22.10.2022	Bus stand, Halol	Halol, Panch mahal, Gujrat	Peepal	Not Collected (Dead sample)
31	424	N 22° 33.423` E 073° 13.591`	186 ft	22.10.2022	Bramha kumari vidhalya , Savli	Savli, Vadodara, Gujrat	Peepal	Not Collected (Dead sample)
32	425	N 22° 33.509` E 073° 13.347`	195 ft	22.10.2022	Kabristan, Savli	Savli, Vadodara, Gujrat	Peepal	Collected sample (Live)
33	426	N 22° 33.769` E 072° 56.795`	144 ft	22.10.2022	Crescent restaurant , Anand	Anand, Gujrat	Peepal & Gular	Collected (Live sample)
34	427	N 22° 34.068` E 072° 56.696`	130 ft	23.10.2022	Piplag, Nadiad	Nadiad, Kheda, Gujrat	Peepal	Collected sample (Live)
35	428	N 22° 40.842` E 072° 51.619`	126 ft	23.10.2022	Indra nagar Nadiad, Kheda	Nadiad, Kheda, Gujrat	Ber	Collected sample (Live)
36	429	N 22° 41.083` E 072° 52.442`	130 ft	23.10.2022	Narobi colony, Madhusudhan Bhawan, Nadiad	Nadiad, Kheda, Gujrat	Peepal	Not Collected (Dead sample)

S. No.	Location No.	Location	Elevation	Date	Place	Block/District/State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
37	430	N 22° 40.938` E 072° 52.704`	139 ft	23.10.2022	Infront of J.S Medical College, Nadiad	Nadiad, Kheda, Gujrat	Peepal	Collected sample (Live)
38	431	N 22° 40.938` E 072° 52.705`	161 ft	23.10.2022	Sarkari mandi, Mahudha	Mahudha, Kheda, Gujrat	Peepal	Collected sample (Live)
39	432	N 22° 49.570` E 072° 56.395`	160 ft	23.10.2022	Bharat patrol pump, Mahudha	Mahudha, Kheda, Gujrat	Ber	Collected sample (Live)
40	433	N 22° 53.847` E 072° 59.363`	210 ft	23.10.2022	Durga motor garaz, Kathlal, Kheda	Kathlal, Kheda, Gujrat	Peepal	Not Collected (Dead sample)
41	434	N 22° 54.645` E 072° 59.539`	214 ft	23.10.2022	Essar patrol pump, Kathlal	Kathlal, Kheda, Gujrat	Peepal	Not Collected (Dead sample)
42	435	N 23° 01.192` E 073° 03.837`	250 ft	23.10.2022	TVS showroom, Kapadvanj	Kapadvanj, Kheda, Gujrat	Peepal	Collected sample (Live)
43	436	N 23° 01.179` E 073° 03.823`	308 ft	23.10.2022	Vardhman vidhalya , Dahegam	Dahegam, Gandhinagar, Gujrat	Peepal	Collected sample (Live)
44	437	N 23° 01.179` E 073° 03.823`	311 ft	23.10.2022	Sabji mandi, modas road, Dahegam	Dahegam, Gandhinagar, Gujrat	Peepal	Collected sample (Live)
45	438	N 23° 01.179` E 073° 03.823`	442 ft	23.10.2022	Jodidar motor repairing, Talod	Talod, Sabarkantha, Gujrat	Peepal	Not Collected (Dead sample)
46	439	N 23° 21.077` E 072° 56.945`	403 ft	23.10.2022	Mataji chowk, Talod	Talod, Sabarkantha, Gujrat	Peepal	Collected sample (Live)
47	440	N 23° 21.075` E 072° 56.945`	433 ft	23.10.2022	Payal auto garaz , Prantij, Sarbarkantha	Prantij, Sabarkantha, Gujrat	Peepal	Not Collected (Dead sample)
48	441	N 23° 21.075` E 072° 56.945`	433 ft	23.10.2022	Prantij approach road, Prantij	Prantij, Sabarkantha, Gujrat	Peepal	Collected sample (Live)

HARYANA

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
1	311	N 28° 06.328` E 077° 00.519`	635 ft	06.06.2022	Near Islam Hotel, Nuh, Mewat	Nuh, Haryana	Peepal	Collected sample (Live)
2	312	N 28° 12.124` E 076° 57.239`	869ft	06.06.2022	Taoru, Mewat	Taoru, Mewat, Haryana	Ber	Collected sample (Both Live/Dead)
3	313	N 28° 12.486` E 076° 55.421`	842 ft	06.06.2022	Atal Seva Kendra, Nizampur, Taoru, Nuh	Taoru, Mewat, Haryana	Peepal	Dead Sample Not Collected
4	318	N 28° 12.474` E 076° 48.291`	804 ft	06.06.2022	Daruheda, Rewari	Rewari, Haryana	Babool	Collected sample (Live)
5	319	N 28° 12.324` E 076° 47.377`	801 ft	06.06.2022	Govt. Animal Hospital, Daruheda	Rewari, Haryana	Peepal	Collected sample (Live)
6	320	N 28° 12.323` E 076° 47.377`	802 ft	07.06.2022	Rewari Main	Rewari, Haryana	Peepal	Dead Sample Not Collected
7	321	N 28° 11.993` E 076° 38.609`	786 ft	07.06.2022	Azad Chowk, Shiv Mandir, Rewari	Rewari, Haryana	Peepal	Collected sample (Live)
8	322	N 28° 12.190` E 076° 37.289`	780 ft	07.06.2022	Delhi gate, Saini Public School, Rewari	Rewari, Haryana	Peepal	Collected sample (Live)
9	323	N 28° 12.165` E 076° 37.266`	791 ft	07.06.2022	In front Saini Public School, Rewari	Rewari, Haryana	Peepal	Dead Sample Not Collected
10	324	N 28° 14.981` E 076° 29.920`	787 ft	07.06.2022	Nagal mudi, Jatusana, Rewari	Jatusana, Rewari, Haryana	Peepal or Ber	Collected sample (Both Live/Dead)
11	325	N 28° 15.056` E 076° 29.644`	750 ft	07.06.2022	Gramin Bank Jatusana, Rewari	Jatusana, Rewari, Haryana	Peepal	Not Collected sample (Dead)
12	326	N 28° 15.056` E 076° 29.644`	723 ft	07.06.2022	Kosli, Nahar, Rewari	Nahar, Rewari, Haryana	Peepal	Dead Sample Not Collected

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
13	327	N 28° 23.836` E 076° 29.380`	738 ft	07.06.2022	Nahar Bus Stand	Nahar, Rewari, Haryana	Peepal	Collected sample (Live)
14	328	N 28° 31.651` E 076° 36.206`	716 ft	07.06.2022	M.R. college, Jhajjar	Jhajjar, Haryana	Peepal	Collected sample (Live)
15	329	N 28° 32.474` E 076° 36.709`	705 ft	07.06.2022	Hasanpura dham, Jhajjar	Jhajjar, Haryana	Peepal	Not Collected sample Dead
16	330	N 28° 36.563` E 076° 38.696`	695 ft	07.06.2022	Nagar Palika, Jhajjar	Jhajjar, Haryana	Ber	Dead Sample Not Collected
17	331	N 28° 36.637` E 076° 38.709`	698 ft	07.06.2022	Bhagat singh Chowk, Jhajjar	Jhajjar, Haryana	Peepal	Collected sample (Live)
18	332	N 28° 39.158` E 076° 36.959`	715 ft	07.06.2022	Jai durga traders, Beri, Rohtak	Beri, Rohtak	Peepal	Dead Sample Collected
19	333	N 28° 55.171` E 076° 35.717`	742 ft	07.06.2022	Seman Station, Rohtak	Beri, Rohtak	Peepal	Dead Sample Collected
20	334	N 29° 29.543` E 076° 76.973`	748 ft	07.06.2022	Gharonda, Karnal	Gharonda, Karnal, Haryana	Ber	Collected sample (Live)
21	335	N 29° 41.496` E 076° 59.255`	736 ft	08.06.2022	Old bus stand, Karnal	Karnal, Haryana	Peepal	Collected sample (Dead)
22	336	N 29° 41.344` E 076° 59.113`	766 ft	08.06.2022	Lakkad mandi, Karnal	Karnal, Haryana	Peepal	Collected sample (Live)
23	337	N 29° 53.062` E 077° 03.063`	815 ft	08.06.2022	Tehsil office, Indri, Karnal	Indri, Karnal, Haryana	Peepal	Collected sample (Dead)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
24	338	N 29° 59.378` E 077° 02.701`	823 ft	08.06.2022	Near Gurudwara, Ladwa, Kurushetra	Haryana	Peepal	Collected sample (Dead)
25	339	N 29° 59.664` E 077° 02.315`	832 ft	08.06.2022	Ladwa Police, Station, Ladwa, Kurushetra	Ladwa, Kurushetra, Haryana	Peepal	Collected sample (Live)
26	340	N 29° 58.588` E 076° 53.625`	821 ft	08.06.2022	Sadar Police Station, Pipli, Kurushetra	Kurushetra, Haryana	Peepal	Collected sample (Live)
27	341	N 29° 57.583` E 076° 49.267`	801 ft	08.06.2022	Brahm Kund Sarovar, Kurushetra	Kurushetra, Haryana	Peepal	Sample Not Collected (Dead)
28	342	N 29° 57.445` E 076° 50.105`	794 ft	08.06.2022	KDB, Road Kurushetra	Kurushetra, Haryana	Peepal	Sample Not Collected (Dead)
29	343	N 29° 58.837` E 076° 35.131`	751 ft	08.06.2022	Pehowa, Kurushetra	Pehowa, Kurushetra	Peepal	Collected sample (Live)
30	344	N 29° 57.661` E 076° 34.927`	756 ft	08.06.2022	Near Haryana dairy, Pehowa, Kurushetra	Pehowa, Kurushetra	Peepal	Dead Sample Not Collected
31	345	N 29° 48.228` E 076° 24.229`	744 ft	14.10.2022	Nagar Parishad, Kaithal	Kaithal, Haryana	Peepal	Collected sample (Both Live/Dead)
32	346	N 29° 46.340` E 076° 33.151`	777 ft	14.10.2022	Pundri main road, Pundri, Kaithal	Pundri, Haryana	Ber or Peepal	Collected sample (Both Live/Dead)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
33	347	N 29° 34.152` E 076° 28.936`	740 ft	14.10.2022	Jind road, Rajowd, Jind	Jind, Haryana	Peepal	Collected sample (Dead)
34	348	N 29° 28.995` E 076° 27.055`	726 ft	14.10.2022	Near Water Pond, Alewa, Jind	Alewa, Jind, Haryana	Peepal	Collected sample (Dead)
35	349	N 29° 22.873` E 076° 20.473`	731 ft	14.10.2022	Kandela bus stand, Jind	Jind, Haryana	Peepal	Collected sample (Live)
36	350	N 29° 20.732` E 076° 18.870`	720 ft	14.10.2022	Traffic Police Station, Ring road, Jind	Jind, Haryana	Peepal	Not Collected sample (Dead)
37	351	N 29° 19.460` E 076° 18.200`	725 ft	14.10.2022	Infront of power house, Jind	Jind, Haryana	Peepal	Collected sample (Live)
38	352	N 29° 13.423` E 076° 08.345`	702 ft	14.10.2022	Old bus stand, Naoraund, Hisar	Naoraund, Hisar, Haryana	Peepal	Collected sample (Live)
39	353	N 29° 10.075` E 076° 03.172`	706 ft	14.10.2022	Dhani Brahamnan, Naoraund, Hisar	Naoraund, Hisar, Haryana	Peepal	Not Collected sample (Dead)
40	354	N 29° 06.676` E 075° 59.046`	691 ft	14.10.2022	Sarvoday Homeopathic, Hansi, Hisar	Hansi, Hisar, Haryana	Peepal	Collected sample (Live)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
41	355	N 29° 06.372` E 075° 58.759`	691 ft	14.10.2022	Anaj police chowki, Hansi, Hisar	Hansi, Hisar, Haryana	Peepal	Not Collected sample (Dead)
42	356	N 29° 05.897` E 075° 58.650`	693 ft	14.10.2022	Sector-6, Hansi, Hisar	Hansi, Hisar, Haryana	Peepal	Collected sample (Live)
43	357	N 29° 08.867` E 075° 42.493`	714 ft	15.10.2022	DR. Office, HAU, Hisar	Hisar, Haryana	Babool	Collected sample (Live)
44	358	N 29° 08.911` E 075° 42.736`	714 ft	15.10.2022	Infront of NCC Office, HAU, Hisar	Hisar, Haryana	Peepal	Collected sample (Dead)
45	359	N 29° 09.116` E 075° 43.044`	665 ft	15.10.2022	Gate no. 1 HAU, Hisar	Hisar, Haryana	Ber	Collected sample (Live)
46	360	N 29° 10.180` E 075° 43.060`	667 ft	15.10.2022	Namdev Chowk, Hisar City	Hisar, Haryana	Peepal	Collected sample (Dead)
47	361	N 29° 10.875` E 075° 42.446`	674 ft	15.10.2022	Housing Board Colony, Sirsa road, Hisar	Hisar, Haryana	Ber	Collected sample (Live)
48	362	N 29° 19.823` E 075° 38.023`	671 ft	15.10.2022	Agroha, Sirsa road, Hisar	Hisar, Haryana	Peepal	Collected sample (Live)
49	363	N 29° 19.144` E 075° 37.960`	682 ft	15.10.2022	Agroha mod, Agroha, Hisar	Agroha, Haryana	Ber	Collected sample (Live/Dead)

S. No	Location No.	Location	Elevation	Date	Place	Block/District or State	Host	Lac Sample Collected/ Not Collected (Live /Dead)
50	364	N 29° 17.195` E 075° 30.033`	659 ft	15.10.2022	Sawariya oil mill, Adampur, Hisar	Adampur, Hisar	Peepal	Collected sample (Live)
51	365	N 29° 15.024` E 075° 27.151`	684 ft	15.10.2022	Adampur, Siswal Road, Hisar	Adampur, Hisar	Ber	Collected sample (Live)
52	366	N 29° 13.396` E 075° 26.617`	671 ft	15.10.2022	Bhagwati settring store, Adampur, Hisar	Adampur, Hisar	Ber	Collected sample (Live)
53	367	N 29° 12.994` E 075° 25.401`	667 ft	15.10.2022	Moda khera, bus stand, Adampur, Hisar	Adampur, Hisar	Peepal	Collected sample (Live)

APPENDIX- II

No. of natural enemies emerged from each sample of three states of Arid Western Plains, during 2022

S. No.	RAJASTHAN		GUJARAT		HARYANA	
1.	Sample 1	1	Sample 1	3	Sample 1	4
2.	Sample 2	3	Sample 2	4	Sample 2	3
3.	Sample 3	2	Sample 3	2	Sample 3	-
4.	Sample 4	12	Sample 4	1	Sample 4	6
5.	Sample 5	1	Sample 5	1	Sample 5	15
6.	Sample 6	2	Sample 6	-	Sample 6	-
7.	Sample 7	5	Sample 7	-	Sample 7	-
8.	Sample 8	-	Sample 8	-	Sample 8	12
9.	Sample 9	4	Sample 9	-	Sample 9	2
10.	Sample 10	3	Sample 10	2	Sample 10	6
11.	Sample 11	5	Sample 11	15	Sample 11	-
12.	Sample 12	2	Sample 12	-	Sample 12	5
13.	Sample 13	-	Sample 13	-	Sample 13	9
14.	Sample 14	5	Sample 14	4	Sample 14	-
15.	Sample 15	5	Sample 15	-	Sample 15	24
16.	Sample 16	1	Sample 16	1	Sample 16	-
17.	Sample 17	1	Sample 17	1	Sample 17	2
18.	Sample 18	2	Sample 18	-	Sample 18	-
19.	Sample 19	3	Sample 19	3	Sample 19	6
20.	Sample 20	1	Sample 20	-	Sample 20	-
21.	Sample 21	2	Sample 21	2	Sample 21	3
22.	Sample 22	3	Sample 22	3	Sample 22	8
23.	Sample 23	1	Sample 23	-	Sample 23	3
24.	Sample 24	1	Sample 24	-	Sample 24	2

S. No.	RAJASTHAN		GUJARAT		HARYANA	
25.	Sample 25	-	Sample 25	5	Sample 25	-
26.	Sample 26	-	Sample 26	5	Sample 26	4
27.	Sample 27	-	Sample 27	2	Sample 27	3
28.	Sample 28	2	Sample 28	8	Sample 28	5
29.	Sample 29	2	Sample 30	3	Sample 30	6
30.	Sample 30	3	Sample 31	-	Sample 31	3
31.	Sample 31	1	Sample 32	7	Sample 32	-
32.	Sample 32	-	Sample 33	3	Sample 33	5
33.	Sample 33	1	Sample 34	9	Sample 34	4
34.	Sample 34	2	Sample 35	2	Sample 35	-
35.	Sample 35	3	Sample 36	4	Sample 36	3
36.	Sample 36	4	Sample 37	3	Sample 37	-
37.	Sample 37	2	Sample 38	5	Sample 38	5
38.	Sample 38	6	Sample 39	1	Sample 39	6
39.	Sample 39	3	Sample 40	6	Sample 40	2
40.	Sample 40	-	Sample 41	3	Sample 41	1
41.	Sample 41	3	Sample 42	3	Sample 42	-
42.	Sample 42	5	Sample 43	8	Sample 43	9
43.	Sample 43	5	Sample 44	10	Sample 44	2
44.	Sample 44	4			Sample 45	-
45.	Sample 45	7			Sample 46	8
46.	Sample 46	3				
47.	Sample 47	8				
48.	Sample 48	3				
49.	Sample 49	2				
50.	Sample 50	3				
51.	Sample 51	4				
52.	Sample 52	-				

S. No.	RAJASTHAN		GUJARAT		HARYANA	
53.	Sample 53	-				
54.	Sample 54	2				
55.	Sample 55	4				
56.	Sample 56	-				
57.	Sample 57	3				
58.	Sample 58	5				
59.	Sample 59	6				
60.	Sample 60	-				
61.	Sample 61	6				
62.	Sample 62	7				
63.	Sample 63	2				
64.	Sample 64	3				
65.	Sample 65	5				
66.	Sample 66	1				
67.	Sample 67	3				
68.	Sample 68	2				
69.	Sample 69	1				
70.	Sample 70	2				
71.	Sample 71	2				
72.	Sample 72	-				
73.	Sample 73	-				
74.	Sample 74	1				
75.	Sample 75	-				
76.	Sample 76	2				
77.	Sample 77	-				
78.	Sample 78	1				
79.	Sample 79	-				
80.	Sample 80	2				

S. No.	RAJASTHAN		GUJARAT		HARYANA	
81.	Sample 81	1				
82.	Sample 82	-				
83.	Sample 83	2				
84.	Sample 84	-				
85.	Sample 85	2				
86.	Sample 86	1				
87.	Sample 87	2				
88.	Sample 88	1				
89.	Sample 89	4				
90.	Sample 90	2				

APPENDIX-III

Measurement values of various morphological parameters of male and female of *Eublemma amabilis* and *Pseudohypatopa pulverea*

A) MALE *Eublemma amabilis* (mm)

Parameters	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	AVERAGE
BL	1.00	1.20	1.08	0.95	1.10	1.20	1.13	1.09	1.01	1.10	1.08
FWLL	1.04	1.38	1.05	0.96	1.00	1.21	1.29	1.25	0.81	1.20	1.13
FWBL	0.48	0.58	0.51	0.40	0.42	0.53	0.47	0.58	0.42	0.57	0.49
FWLR	1.04	1.32	1.11	1.09	1.01	1.26	1.23	1.27	0.86	1.31	1.15
FWBR	0.47	0.59	0.51	0.42	0.43	0.56	0.46	0.57	0.41	0.58	0.50
HWLL	0.80	0.93	0.79	0.65	0.79	0.92	0.92	0.99	0.73	1.02	0.85
HWBL	0.46	0.57	0.42	0.47	0.30	0.51	0.48	0.41	0.46	0.68	0.47
HWLR	0.78	0.92	0.84	0.68	0.80	0.93	0.92	0.97	0.77	1.07	0.86
HWBR	0.48	0.59	0.43	0.47	0.31	0.50	0.47	0.41	0.46	0.64	0.47
TWS	2.38	3.09	2.32	2.44	2.43	2.96	2.89	2.97	2.08	2.83	2.60
LA	0.26	0.39	0.44	0.24	0.36	0.45	0.49	0.58	0.48	0.28	0.39
RA	0.25	0.39	0.45	0.24	0.35	0.45	0.49	0.58	0.48	0.29	0.39

[M= Male; BL= Body Length; FWLL= Fore Wing Length Left; FWLR=Fore Wing Length Right; FWBL= Fore Wing Breadth Left; FWBR= Fore Wing Breadth Right; HWLL= Hind Wing Length Left; HWLR= Hind Wing Length Right; HWBL= Hind Wing Breadth Left; HWBR= Hind Wing Breadth Right; LA= Left Antennae; RA= Right Antennae, TWS= Total Wingspan]

B) FEMALE *Eublemma amabilis* (mm)

Parameters	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	AVERAGE
BL	1.24	1.18	1.01	1.19	1.01	1.08	1.00	1.11	1.12	1.19	1.11
FWLL	1.20	1.19	1.03	1.13	1.00	1.10	1.23	1.15	1.03	1.23	1.12
FWBL	0.59	0.64	0.45	0.44	0.52	0.49	0.53	0.49	0.49	0.52	0.55
FWLR	1.05	1.21	1.02	1.14	0.97	1.12	1.16	1.19	1.01	1.24	1.11
FWBR	0.56	0.59	0.46	0.44	0.54	0.49	0.52	0.45	0.48	0.52	0.50
HWLL	0.92	0.73	0.77	0.81	0.73	0.83	0.85	0.84	0.75	0.90	0.81
HWBL	0.60	0.51	0.34	0.49	0.45	0.40	0.54	0.39	0.36	0.47	0.42
HWLR	0.97	0.77	0.77	0.86	0.78	0.83	0.84	0.84	0.76	0.91	0.83
HWBR	0.50	0.48	0.34	0.49	0.47	0.40	0.54	0.39	0.38	0.47	0.44
TWS	2.72	2.85	2.44	2.65	2.32	2.49	2.80	2.66	2.39	2.78	2.60
LA	0.38	0.35	0.40	0.42	0.47	0.44	0.39	0.49	0.35	0.32	0.40
RA	0.37	0.35	0.40	0.42	0.46	0.43	0.38	0.48	0.34	0.33	0.39

[F= Female; BL= Body Length; FWLL= Fore Wing Length Left; FWLR=Fore Wing Length Right; FWBL= Fore Wing Breadth Left; FWBR= Fore Wing Breadth Right; HWLL= Hind Wing Length Left; HWLR= Hind Wing Length Right; HWBL= Hind Wing Breadth Left; HWBR= Hind Wing Breadth Right; LA= Left Antennae; RA= Right Antennae, TWS= Total Wingspan]

C) MALE *Pseudohypatopa pulverea* (mm)

Parameters	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	AVERAGE
BL	0.65	0.68	0.66	0.67	0.62	0.64	0.66	0.69	0.68	0.65	0.66
FWLL	0.69	0.68	0.69	0.68	0.67	0.69	0.68	0.66	0.67	0.68	0.68
FWBL	0.19	0.18	0.18	0.18	0.17	0.18	0.17	0.18	0.18	0.19	0.18
FWLR	0.70	0.71	0.69	0.68	0.67	0.68	0.67	0.67	0.67	0.68	0.68
FWBR	0.18	0.18	0.19	0.19	0.18	0.18	0.17	0.18	0.18	0.19	0.18
HWLL	0.63	0.62	0.63	0.62	0.65	0.66	0.64	0.63	0.65	0.64	0.63
HWBL	0.26	0.25	0.26	0.25	0.24	0.23	0.24	0.26	0.25	0.26	0.25
HWLR	0.64	0.63	0.63	0.62	0.64	0.65	0.64	0.63	0.64	0.65	0.63
HWBR	0.25	0.25	0.26	0.26	0.25	0.22	0.24	0.26	0.25	0.26	0.25
TWS	1.60	1.50	1.60	1.70	1.80	1.70	1.50	1.60	1.50	1.60	1.05
LA	0.49	0.47	0.48	0.49	0.48	0.47	0.46	0.48	0.49	0.47	0.47
RA	0.48	0.46	0.47	0.49	0.48	0.47	0.46	0.47	0.48	0.48	0.47

[M= Male; BL= Body Length; FWLL= Fore Wing Length Left; FWLR=Fore Wing Length Right; FWBL= Fore Wing Breadth Left; FWBR= Fore Wing Breadth Right; HWLL= Hind Wing Length Left; HWLR= Hind Wing Length Right; HWBL= Hind Wing Breadth Left; HWBR= Hind Wing Breadth Right; LA= Left Antennae; RA= Right Antennae, TWS= Total Wingspan]

D) FEMALE *Pseudohypatopa pulverea* (mm)

Parameters	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	AVERAGE
BL	0.74	0.75	0.73	0.74	0.75	0.74	0.73	0.75	0.74	0.75	0.74
FWLL	0.78	0.77	0.78	0.76	0.78	0.77	0.77	0.76	0.78	0.78	0.77
FWBL	0.20	0.19	0.21	0.20	0.20	0.19	0.20	0.20	0.21	0.20	0.20
FWLR	0.74	0.76	0.77	0.77	0.78	0.77	0.77	0.75	0.77	0.78	0.76
FWBR	0.21	0.20	0.21	0.22	0.20	0.21	0.21	0.19	0.20	0.21	0.20
HWLL	0.61	0.62	0.61	0.63	0.62	0.64	0.61	0.61	0.62	0.61	0.61
HWBL	0.33	0.32	0.33	0.32	0.31	0.33	0.34	0.35	0.32	0.33	0.32
HWLR	0.61	0.62	0.60	0.62	0.61	0.65	0.62	0.60	0.62	0.61	0.61
HWBR	0.30	0.31	0.32	0.31	0.32	0.34	0.33	0.35	0.32	0.33	0.32
TWS	1.80	1.70	1.80	1.80	1.90	1.80	1.70	1.80	1.80	1.80	1.70
LA	0.48	0.48	0.47	0.46	0.47	0.48	0.48	0.47	0.48	0.48	0.47
RA	0.48	0.48	0.47	0.47	0.47	0.47	0.47	0.46	0.48	0.48	0.47

[F= Female; BL= Body Length; FWLL= Fore Wing Length Left; FWLR=Fore Wing Length Right; FWBL= Fore Wing Breadth Left; FWBR= Fore Wing Breadth Right; HWLL= Hind Wing Length Left; HWLR= Hind Wing Length Right; HWBL= Hind Wing Breadth Left; HWBR= Hind Wing Breadth Right; LA= Left Antennae; RA= Right Antennae, TWS= Total Wingspan]

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