Biology and Productivity-linked Parameters of Lac Insect on Pigeonpea and its Natural Enemies

अरहर पर लाख कीट की जैविकी एवं उत्पादकता से जुड़े हुए मापदण्ड तथा प्राकृतिक शत्रु

Chetan Kalahal

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MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR (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

Chetan Kalahal

2017

Maharana Pratap University of Agriculture and Technology
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CERTIFICATE-I

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This is to certify that the thesis entitled **"Biology and Productivity-linked Parameters of Lac Insect on Pigeonpea and its Natural Enemies"** submitted for the degree of **Master of Science in Agriculture** in the subject of **Entomology**, embodies bonafide research work carried out by **Mr. Chetan Kalahal** 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 approved by the advisory committee on 17/05/2017.

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This is to certify that **Mr. Chetan Kalahal** student of **Master of Science in Agriculture, Department of Entomology**, Rajasthan College of Agriculture, Udaipur has made all corrections/ modifications in thesis entitled, **"Biology and Productivity-linked Parameters of Lac Insect on Pigeonpea and its Natural Enemies"** that were suggested by the External Examiner and the Advisory Committee in the oral examination held on / / 2017. The final copies of the thesis duly bound and corrected submitted on / / 2017 are enclosed herewith for approval.

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Place: Udaipur

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1. INTRODUCTION

Lac is one of the more valuable gifts of nature to man. It is the only resin of animal origin, being actually the secretion of a tiny scale insect, *Kerria lacca* Kerr belonging to the family Tachardiidae (=Kerriidae), super family Coccoidea of the order Hemiptera. The life cycle of lac insect starts with first instar larval stage, generally known as crawlers, which is the only mobile stage that settles and feeds on phloem sap by piercing its proboscis into phloem region of shoot and secrets the resin over the body. The crawlers after settlement undergo three successive moultings to become the adult.

The lac insect basically yields three useful materials *viz.*, resin, dye and wax. The major constituent of lac is the resin (68%) which is a polyester complex of straight chain hydroxy fatty acids of C_{14}-C_{18} carbon chain (such as aleuritic acid and butolic acids), mono and di–hydroxy acids along with hydroxy terpenic acids. Resin is commonly known as "lac" and is sold in the market as shellac or seedlac or button lac. Other constituents present are dye (1.2%), wax (6%), others (25%) like sugar, proteins, soluble salts, sand, woody matter, and insect body debris.

Lac has immense economic importance as its derived products are biodegradable, non toxic, environment friendly and have tremendous export potential. In addition to this, the lac insect-host association contributes to the conservation of biodiversity *viz*., soil flora, fauna and soil microorganisms (Sharma *et al*, 2006). It has versatile uses in the manufacture of paints, inks, micanite, pharmaceuticals, cosmetics, electrical industry, automobile industry, in defence, railways, marine and postal department, surface coating industry, confectionery industry for fruit and vegetable coating, soft drinks, chocolate, candy coating, lac dye for textile industry and in slow-release lac coated urea fertilizer for controlled release of nitrogen.

Commercial cultivation of lac is taken up in India, Myanmar, Thailand and parts of China, Taiwan, Indonesia, Philippines, Vietnam and Cambodia. India is the largest producer of lac, has a share of 62 per cent of the world production of 44,000 metric tons, and earned foreign exchange worth Rs. 15,262 lakhs (Ogle and Thomas, 2006). The national production of sticklac during 2012-2013 was 19,577 tons. Jharkhand state ranks first in lac production with 57.20 per cent contribution to total production followed by Chhattisgarh (17.87%), West Bengal (7.82%), Madhya

Pradesh (7.26%) and Maharashtra (5.30%). Regarding share of crops, *Jethwi* ranked first (34.39%) followed by *Baisakhi* (25.92%), *Aghani* (24.25%) and *Katki* (15.44%). Lac is exported to more than 70 different countries, but the major markets are Indonesia, Germany, U.S.A., Spain, Bangladesh, Italy, Switzerland, U.A.E and U.K. The total export of lac and its value added products in 2012-2013 was 4361.4 tons, which is valued at 480.3 crores (Anonymous, 2012-13).

In Rajasthan lac insect is naturally found in abundance on its natural host; peepal (*Ficus religiosa* Linn.), ber (*Ziziphus mauritiana* Lam), palas (*Butea monosperma* Lam.), bargad (*Ficus benghalensis* Linn.) and other trees, indicating that agro climatic condition of region is well suited for its survival and abundance in the region. In forest areas this natural resin is traditionally collected by the tribals and rurals for various uses but its commercial cultivation is not in practice due to lack of knowledge about the biology and host preference of lac insect.

Pigeonpea (*Cajanus cajan* Linn.) is a new host and strains of lac insect are being investigated to enhance the lac production. It is cultivated widely in different parts of the state and can be better exploited for commercial production of lac in the region, despite raising on ber, palas and kusum where gestation period is 5 to 10 years. Pigeonpea was identified as a favorite host for lac insect long back in 1950's, but on-farm lac production with pigeonpea has recently emerged as a result of increasing demand of lac from various parts of world (Zhenghong *et al*, 2001). Pigeonpea has been reported as promising host in North-Eastern parts of India (Roonwal, 1962).

Biotic and abiotic stresses are the two limiting factors responsible for reduction in yield of lac crop. Among biotic factors are predators and parasitoids; while certain weather factors cause abiotic stress, limiting the production of lac on different hosts, Among the predators *Eublemma amabilis* Moore (Lepidoptera; Noctuidae), *Pseudohypatopa pulverea* Meyr (Lepidoptera; Blastobasidae) and *Chrysopa lacciperda* Kimmins and *Chrysopa madestes* Banks (Chrysopidae; Neuroptera) are the major predators of regular occurrence causing severe losses to the lac production. (Sharma *et al*, 2006). Predators have been estimated to cause around 35 to 40 per cent loss to lac production (Glover, 1937; Jaiswal *et al*, 2008), while 5 to 10 per cent damage is caused by parasitoids (Varshney, 1976).

Under natural conditions, lac insect occur on common lac hosts but lack of knowledge about the biology of lac insect has hindered the development of lac production particularly in southern parts of Rajasthan. A complete knowledge of the life cycle of lac insect and production-limiting parameters in south west Rajasthan will bring about an impetus to the lac cultivation in the area. Hence, the present research work entitled, "Biology and Productivity-linked Parameters of Lac Insect *Kerria lacca* (Kerr) on Pigeonpea and its Natural Enemies" has been carried out with the following objectives:

i. To study the biology of lac insect on pigeonpea
ii. To evaluate the productivity-linked parameters of lac insect on pigeonpea.
iii. To record the natural enemies (major predators and parasitoids) of lac insect.

2. REVIEW OF LITERATURE

The studies carried out in the present investigation are new and not enough research has been done by researchers in this field hence very scanty information is available on the topics of present investigation. All the efforts have been made to review the available literature on aspects related to the present research.

2.1 Biology of lac insect

Sharma (1991) studied the various attributes of lac insect life cycle and recorded the normal behavior of lac on host plant and found that in *Kusmi* strain male emergence was 7-8 weeks after its settlement and it took about 142-160 days to mature, while in *Rangeeni* strain male emergence was 6-7 weeks after its settlement and it took about 120-137 days to mature.

Jaiswal and Sharma (2011) observed that the adult male in both the crops survived for 2 day and the first molting of lac insect takes place after 3 weeks in *Katki* and 7 weeks in case of *Baisakhi* crop after the settlement on shoot. Similar observations were also recorded from *Aghani* and *Jethwi* crop of *Kusmi* lac.

Mohanta *et al*. (2014) studied that bivoltine nature of *Kusmi* strains of lac insect, *Aghani* (winter) and *Jethwi* (summer) crops on kusum tree and noticed that it took 6 months 16 days and 5 months 5 days, respectively to complete its life. Similarly, *Katki* and *Baisakhi* crops of *Rangeeni* strain on palas tree took 3 months 16 days and 3 months 5 days respectively to complete their life cycle. Sharma and Jaiswal (2011) revealed that emergence of crawler normally completed within three weeks of inoculation and phunki should be removed as soon as possible after the complete emergence.

2.2 Productivity-linked parameters of lac insect

Kong *et al.* (1984) from Yunnan (China), reported that the reproductive potential of lac insect, *L. lacca* was relatively high and a female of the first generation laid 224-307 eggs while that of the second generation laid 160-240 eggs. Females were predominant in both generations. 75-80 per cent in first generation and 50-78 per cent in the second generation also duration of developmental stages of different generation is influenced by the local climate and the condition of host plant.

Subbarayudu and Ram (1997) surveyed the host plants of the Indian lac insect, *Kerria lacca* (Kerr) during 1995-96 mainly at the plantation of Indian Lac Research Institute, Namkum, Ranchi, Bihar and nearby premises, namely, Institute main campus, Kojatoli, Patratoli and Tetritoli and survey revealed 53 species of host plants belonging to 32 genera.

Mishra *et al.* (1999) evaluated the productivity of Indian lac insect, *K lacca* in terms of fecundity, live cell weight and dry cell weight of mature female lac on *F. semialata* and *F. macrophylla* live cell weight, a dry cell weight and fecundity varied from 13.16 to 38.33 mg, 8.00 to 19.00 mg and 253 to 565 eggs respectively on *F. semialata* whereas on *F. macrophylla* it varied from 16.83 to 31.67 mg, 9.33 to 18.83 mg and 297 to 477 respectively.

Mishra *et al.* (2000) studied the performance of lac insect stocks collected from different localities and host plant species in respect of five productivity linked female traits, *viz*., life period, fecundity, dry cell weight, diameter of the cell and rate of sticklac production during the rainy crop season on *F. macrophylla* by determining inter trait correlation for the former four traits as well as estimating genetic variance and heritability for all the five traits. A highly significant positive correlation between the cell weight and life period, cell weight and diameter of cell, fecundity and diameter of cell, as well as life period and diameter of cell was established. On the other hand, no significant correlation of fecundity with cell weight and life period was recorded.

Kumar *et al*. (2007) evaluated seven host plants of lac insect with reference to the quantity of lac produced and developmental parameters of which *Ziziphus mauritiana* (Lamk) was found to be the best host for lac production with maximum quantity of seedlac production (165.5 g/m.), highest fecundity (525.2 and 450.6 per female), female cell diameter (3.52 and 3.06 mm) and cell weight (14.21 and 10.12 mg); whereas, minimum quantity of seedlac production (134.83 g/m.), lowest fecundity (409.0 and 315.4), female cell diameter (3.27 and 2.60) and cell weight (13.60 and 9.40 mg) was recorded from pigeonpea *Baisakhi* crop. The impact of pigeonpea-lac insect interaction for the production of rawlac/scrapedlac as well as grain yield and protein quality in seeds was studied by Ghosh *et al.* (2014). They found that five genotypes of pigeonpea *viz.,* IPA 8-2, Bahar, Assam local, Accession no. 591139 and RCMP 5 were promising for lac production, however rearing of lac

insect on pigeonpea reduced the 100 seed weight (13.03%) and grain yield per plant (12.08%) significantly; but no significant reduction was observed in crude protein content in seeds (1.02%). The profit obtained from raw lac along with grain was higher than that from sole crop for grain.

Sharma *et al.* (2007) studied the resin producing efficiency of *Rangeeni* and *Kusmi* strain, of the Indian lac insect, *K. lacca and* showed that the *Kusmi* performed much better than *Rangeeni*. Resin production by individual female lac insects was highest on *Schleichera oleosa* (22.84 mg), followed by *Acacia auricaliformis* (18.9 mg), *Flemingia macrophylla* (9.43 mg) and *Cucurbita moschata* fruits (6.11 mg) for *Kusmi* and *A. auricaliformis* (9.09 mg), followed by *Butea monosperma* (8.76mg), *F. macrophylla* (7.49 mg) and *C. moschata* fruits (6.00 mg) for the *Rangeeni* strain.

Pal (2009) reported that the different host trees *viz., B. monosperma Z. mauritiana* and *Schleichera oleosa* contributed 52.88 per cent*,* 33.12 per cent and 9.79 per cent to lac production respectively while other minor hosts contributed for only 4.22 per cent in national lac production.

Ferdousee *et al*. (2010) reported that among the different host plants of lac insect cultivated in Rajshabi (Bangladesh), *Z mauritiana* (Kul) was found to be major and the most preferable host plant compared to *Samania saman* (Rain tree), *Acacia nilotica* (Babul), *Acacia catechu* (Khair) and *B. monosperma* (Palas). On the basis of lac production from a mature tree, *Albizia lebbeck* (Siris) was found the highest (80 kg.) producer followed by Kul, Khair, Palas and Babul.

Ramani (2010) reported that there are 12 lac producing states in India *viz.* Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Jharkhand, Madhya Pradesh, Maharashtra, Meghalaya, Orissa, Uttar Pradesh and West Bengal however Sharma and Jaiswal (2011) reported that lac insect ecosystem is a complex multi-tropic web of flora and fauna. It represents a rich biodiversity which includes 30 primary parasites, 45 secondary parasites and a variety of pests of lac-hosts and several microbes.

Srivastava (2011) reported approximately 4 kg broodlac is normally needed for inoculation of on average kusum tree, 1.5 kg broodlac is needed for inoculation of average ber tree and 0.75-1 kg broodlac needed for inoculation an average palas tree.

Kumar and Das (2012) reported that lac production during 2006-2007 was 14,020 metric tons and in the year 2010-11 it reduced to 6,949 metric tons.

More than 400 plant species were studied by Kaushik *et al*. (2012) as the likely hosts for the lac insect of which 113 host species were found to be successfully infested by the lac insect in India; among these, *Butea monosperma* (Lam), *Schleichera oleosa* (Lour), *Ziziphus mauritiana* (Lamk), *Cajanus cajan* (L), *Flemingia semialata* Roxband, *Flemingia macrophylla* Kuntze were found to be good hosts, while *Ficus semialata*, *Prosopis juliflora, Ficus elastic* Roxb, and *Dalbergia assamica* Benth found to be moderate host plants for lac insects; however, *Acacia catechu* (L), *Albizia saman* and *Ficus religiosa* were observed to be occasional host plants whereas *Azadirachta indica* A., *Ricinus communis* and *Citrus medica* L were recorded to be rare host plants.

Paul *et al*. (2013) reported that out of entire lac produced in the country, 80-85 Per cent is from *Rangeeni* strain which is contributed mainly by palas followed by ber, the most widely spread hosts in India. However, the best quality of resin is produced by *Kusmi* strain which is obtained from kusum in India followed by ber. In recent scenario, the *Kusmi* contribution in total production is about 15-20 per cent only due to its limited distribution. For *Rangeeni*, palas ranks first with 60-65 per cent and ber stands second only with 20-25 per cent contribution in total production.

Divakara (2013) conducted an experiment for two seasons in Mandar of Ranchi district and revealed that though there was significant reduction in the scrap lac yield but lac cultivation was feasible on *Flemingia macrophylla* as intercrop in under-storey of *Dalbergia sisso* (shade) and control condition (open). In general, at 75 days after inoculation, length of settlement was highest in understorey than control condition for winter (84.60%) and rainy (85.80%) crops. At 21 days after inoculation, winter crop recorded maximum density of insect settlement in understorey (77.80/cm^2) compare to control (70.08/cm^2). Whereas in rainy crop at 21 days after inoculation, the trend was reverse. After 75 days of inoculation, density of settlement was higher under control (45.71/cm^2, 16.20/cm^2) than in understorey (38.05/cm^2, 13.50/cm^2) for winter and rainy crop respectively. Average brood and stick lac yield per plant was higher under control than understorey condition in both winter (622.64 g, 342.74 g) and rainy (448.76g, 219.02 g) crop. The average 'scrappedlac' yield in control was 166.64 g/plant, which was 2.60 times to that in understorey (63.63

g/plant) for winter crop. In rainy crop, average scrap lac yield was 81.47 g/plant, which was 4.8 times more than in understorey (17.00 g/plant). In winter crop of *Rangeeni*, settlement density was highest on *C. calothyrsus* (51.27/cm^2) and *Malvaviscus penduliflorus* (51.13/cm^2) than other two hosts, whereas the lowest mortality was recorded in *C. calothyrsus* (12.48%) and *D. assamica* (22.36%), per cent male was more in *D. assamica* (34) than other hosts. Broodlac was inoculated for rising summer *Kusmi* (*Jethwi*) crop on Ber at the rate of 7 kg on 16 plants, kusum at the rate of 15 kg on 6 plants and *F. semialata* at the rate of 10 kg on 190 plants. Highest density of settlement of 130.10 per sq cm was recorded in kusum followed by ber (124.40) and *F. semialata* (110.10), whereas maximum mortality of 27.88 per cent was recorded in *F. semialata* followed by ber (24.91%) and kusum (18.75%). Male percentage was recorded to be highest in ber (26.86%) followed by *F. semialata* (24.84%) and kusum (17.82%)

Mohanta *et al.* (2014) reported that the initial density of settlement of larva ranged between 92.58-126.74 per sq cm and 93.12-109.62 per sq cm of *Kusmi* strain on kusum and ber trees respectively. The average density of living female cells at crop maturity varied between 3.38-12.67 no. /cm^2 on palas plant for *Rangeeni* strain of lac insect. The sex ratio (male: female) was 1:3 for all the crops, strains and host plants. The range of resin output per cell was 17.00-21.40 mg for winter crop and 19.00-25.60 mg for summer crop of *Kusmi* strain on kusum and ber plants.

2.3 Natural enemies (major predators and parasitoids) of lac insect

Witt (1901) was the first to study the general life history of *Eublemma amabilis* Moore and referred to its injurious nature with regarded to the lac insect while Mishra *et al.* (1930) from India, reported that *Eublemma amabilis* was widely distributed in India and was responsible for 30 per cent damage caused to lac insects. It completed six generation per year. The egg period ranged from 1-10 days, larval period ranged from 16- 128 days and pupal period ranged from 3-20 days while Glower (1937) recorded the two predators *E. amabilis* Moore (Lepidoptera: Noctuidae) and *Pseudohypatopa pulverea* Meyr (Lepidoptera: Blastobasidae) as the key pests of Lac crop causing a loss of around 30 to 40 per cent, while Narayanan (1962) too reported the *E. amabilis* as a monophagous predator of lac insects, causing damage to the tune of 20 to 25 per cent to lac crop, while Mehra (1965) reported the

ability of *C. madestes* to destroy the whole *Kusmi* crop and found that its first second and third instars larvae can destroy up to 20, 24 and 74 mature females of lac insect per day. Malhotra and Katiyar (1975) also reported *E amabilis* and *P pulverea* as major pest normally causing 30 -35 per cent damage to lac crop. Thomas (2004) reported squirrels (*Funambulus pennanti* Wroughton) damaging *Kusmi* lac. *F. pennanti* in the process of searching and eating the larvae of *E. amabilis* in *Kusmi* lac on *S. oleosa* plucked lac settlement that fell to the ground while Bhattacharya *et al*. (2007) recorded the *E. amabilis* the major pest of lac causing colossal losses to the magnitude of about 40 per cent. In a survey in the southern part of Rajasthan thirteen host plants of lac insect were recorded on which *Eublemma amabilis* Moore (Lepidoptera; Noctuidae) and *Pseudohypatopa pulverea* Meyr (Lepidoptera; Blastobasidae) were considered as the major pests of lac insect (Kumar *et al.* 2007)

Rahman *et al.* (2009) reported that *E. amabilis* causes more severe damage to the lac insect than any other natural enemies. At least 30-35per cent of the damage was caused by this predator alone. A single *E. amabilis* larva damaged about 46 mature cells prior to pupation.

Satapathy *et al*. (2011) reported the black moth, *Pseudohypatopa pulverea* (Meyr) was predominant followed by the white moth, *E. amabilis*, besides the larva of green lace wing feeding on the first instar crawlers. The adult moth of *E. amabilis* measured 8.72 mm in body length and 18.28 mm across the wing spread. Mohanta *et al.* (2014) reported that lac insect has some vertebrate predators like monkeys, squirrels, rats, lizards, woodpeckers, birds and insect predators are Lepidopteran (*E. amabilis, P. pulverea*) and Neuropterans (*Chrysopa madestes*, *Chrysopa lacciperda*).

Satapathy and Rout (2014) has documented three parasitoids *viz*., *Tachardiaephagus tachardiae* (Howard), *Parechtrodryinus clavicornis* (Cameron) and *Eupelmus tachardiae* (Howard) under agro-climatic conditions of Bhubaneswar (Odisha). These inimical parasitoids parasitizing the lac cells on host constituted about 53 per cent of the total natural enemies recorded in the lac ecosystem of coastal Odisha. The dominance status in terms of relative abundance of these natural enemies showed that *E. tachardiae* (Eupelmidae), *T. tachardiae* (Encyrtidae) were dominant in their abundance and constituted a major proportion (26.01-27.15%) of the total natural enemy population documented.

Varshney (1976) and Sharma *et al*. (2006) reported that there were 22 species of insect predators, 30 species of primary parasitoids and 45 species of hyper parasitoids responsible for biotic stresses associated with *Kerria lacca*. Shui-chen *et al*. (1985) from north Taiwan of China recorded five parasitoids *viz., Eupelmus tachardiae*, *Parechtrodryinus* sp., *Tachardiaephagus sp, T. tachardiae* and *Tetrastichus purpureus* and five predators *viz., Chrysopa sp. Eublemma conspera, E. roseonivea, Telsimia chujoi* and an oligotomid.

Sharma *et al.* (1997) reported that fourteen species of parasitoids belonging 13 genera representing ten families were found associated with *K. lacca*. Of these, *Aprostocetus purpureus* and *T. tachardiae* constituting 55.82 per cent and 28.37 per cent, respectively of the total population of parasitoids and were the most abundant species of natural enemies. Sharma *et al.* (2006) also reported large-scale pre-summer mortality of *Rangeeni* lac insects, especially in Jharkhand and West Bengal, in the recent years; affecting summer *Rangeeni* lac production. Samples of lac cultures collected from natural lac-hosts; *bhalia, palas* and *ber* collected from farmer fields in Jharkhand and West Bengal revealed that about 54 per cent of lac-insects of the samples were parasitized, showing unusual mortality in February, and nearly 25 per cent parasitization was recorded in the apparently normal cultures. Percent survival of lac-insects was only 20 per cent in the affected samples and 52 per cent in the apparently normal cultures.

Sharma *et al.* (2007) reported super parasitism in Indian lac insect*, K. lacca*; Parasitoids of *K. lacca* inflict severe damage to the crop affecting adversely the resin yield and the fecundity of the insects, particularly during the rainy season. There was 18.40 per cent in the *Kusmi* strain and 26.0 per cent parasitization in the *Rangeeni* strain. *A. purpureus* alone caused 7.80 and 11.80 per cent parasitization, respectively. Parasitoids upto 9 and 6 were found in a single cell. The average reduction in resin produced by a single female due to parasitism varied between 17.25 to 39.80 and 25.24 to 37.91 per cent in *Rangeeni* and *Kusmi* strain respectively, whereas reduction in fecundity of lac insects ranged between 22.44 to 96.82 and 25.29 to 90.39 per cent, respectively, for the 2 strains. As the number of parasitoids in each cell (22) increased, there was a corresponding decrease in resin production and fecundity; the latter being affected more severely.

Kumari *et al.* (2012) reported that quality of the broodlac is determined by the attributes of fecundity of the lac insects and it should be free from predators and parasites. Mean fecundity varied between 164 in rainy season (*Katki*) crop to 209 in summer season (*Baisakhi*) crop of *Rangeeni* strain and between 101 in winter season (*Aghani*) crop to 193 in summer season (*Jethwi*) crop of the *Kusmi* strain. Fecundity of lac insect is adversely affected by parasitization. The extent of parasitization varied between 15.50 per cent in summer season (*Baisakhi*) crop to 18.6 per cent in rainy season (*Katki*) crop of *Rangeeni* strain. While for *Kusmi* strain it was 19.04 per cent in winter season (*Aghani*) crop and 22.80 per cent in summer season (*Jethwi*) crop. Thus as the number of parasites in each cell increases, a correspondence decrease in fecundity count was noticed.

Koteswara *et al.* (2013) reported presence of insect parasitoids and predator species in naturally infested population of lac insect culture in Hyderabad (Andhra Pradesh). The rain trees, *Samania saman* Merr were severely infested by *Rangeeni* lac insect *K. lacca.* The same strain of lac insect was also found on trees of *Butea monosperma*, *Ficus religiosa*, *Schleichera oleosa* and *Ziziphus mauritiana* species in different parts of the state. On a lac stick of rain tree (Weight of 50 g and length of 60 cm), eight *E. amabilis*, (Lepidoptera: Noctuidae), three *P. pulverea* (Lepidoptera: Blastobasidae) insect predators; 29 numbers of *Tachardiaephagus tachardiae* Howard (Hymenoptera: Encyrtidae), nine *Aprostocetus purpureus* Cameron (Hymenoptera: Eulophidae), *12 Eupelmus tachardiae* Howard (Hymenoptera: Eupelmidae) parasitoids, and one *Bracon greeni* Ashmead (Hymenoptera: Braconidae) hyper-parasitoid were recorded. *Tachardiaephagus tachardiae* population was comparatively higher in kusum (38) and lower in *F. semialata* (6) and ber (4), whereas *A. purpureus* population was more in kusum (31) than *F. semialata* and ber. Only hyper-parasitoid observed was *Bracon greeni* and that too from *F. semialata* (4).

3. MATERIALS AND METHODS

The materials used and methodology adopted to study the biology and productivity-linked parameters of the lac insect on pigeonpea and its natural enemies have been described here in this chapter. The description has been arranged objective wise:

3.1 Experimental site

The experiment was conducted on *Rangeeni* strain of lac insect in *Katki* season at lac insect gene bank cum garden situated at Rajasthan College of Agriculture, MPUAT, Udaipur during 2016.

3.2 Raising of crop (pigeonpea)

The healthy host plants were raised by following the all the agronomic practices. The perennial variety of pigeonpea was sown to get healthy plants of proper age for lac inoculation with broodlac sticks. The crop was sown in the last week of April 2016 with row to row spacing of 100 cm and plant to plant spacing of 40 cm in plot size measuring 2.0 × 10 sq m. There were 30 plants in each set of experiment which replicated thrice. The brood lac of *Rangeeni* strain needed for the experiment were collected from the mature crop of *Rangeeni* strain prevailing in the region on its natural hosts bearing fully matured females. The brood lac were bundled and tied on host plants at 1-1.5ft above the ground level to provide succulent stem for crawlers to settle down. The brood lac bundles were tied in a 60 mesh nylon cage which allows only crawlers to move out retaining the parasitoids inside if any emerges simultaneously with the lac insect crawlers. The nymphs were allowed to emerge from mature females for about two weeks. After the emergence of newly hatched nymphs the phunki lac stick bundles were removed from host plants and kept in glass jars covered with muslin cloth and observed for emergence of parasitoids and predators.

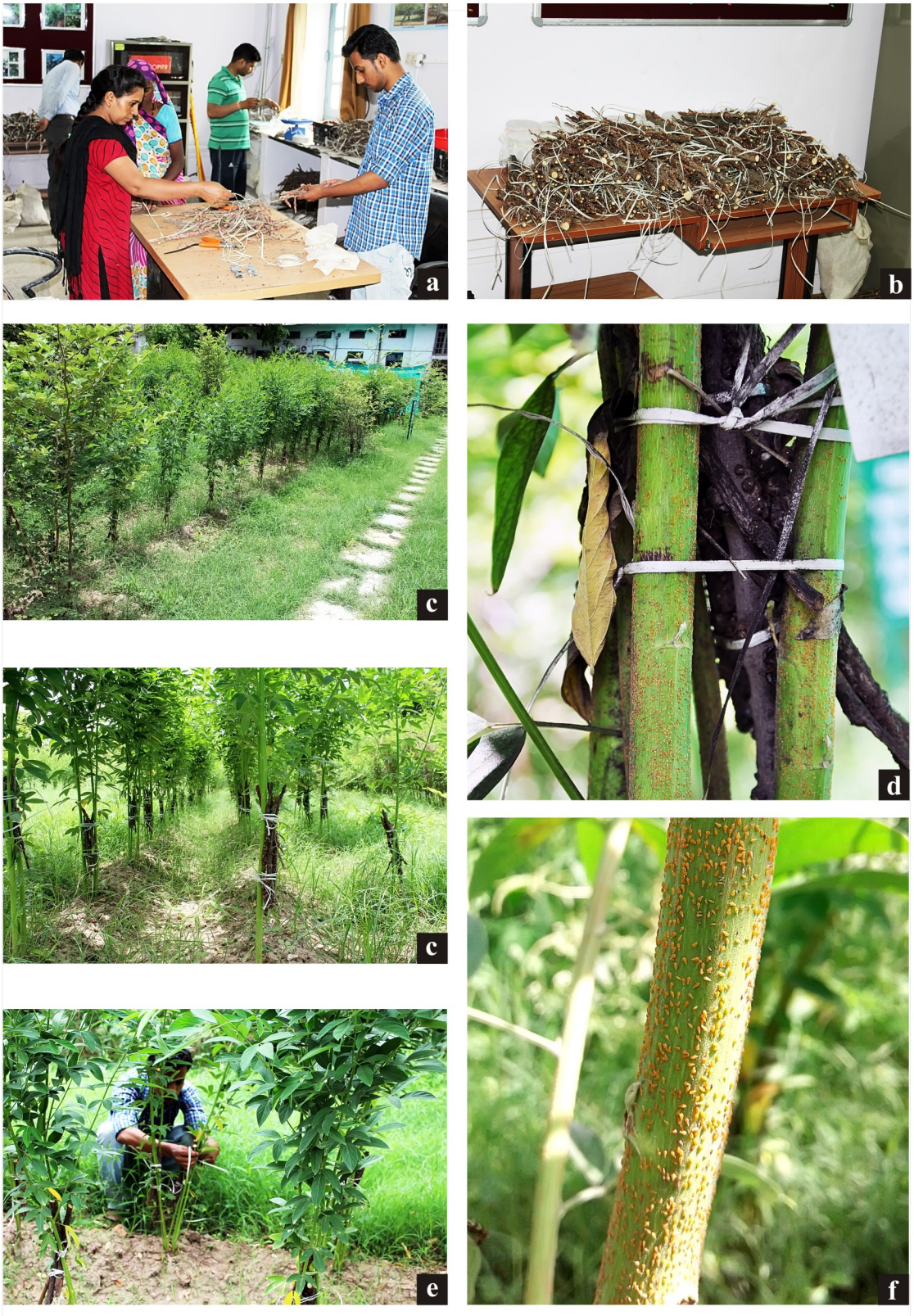

Plate 1: Photographs showing the experiment activities.
(a) Bundling of Broodlac sticks (b) Broodlac stock (c) General view of field experiment (d) Emergence of first instar crawlers of lac insect (e) Tieing of Broodlac on host (f) Settlement of crawlers on host stem

3.3 Biology of lac insect on pigeonpea

3.3.1 Observations

To study the biological parameters of *Rangeeni* strain of lac insect on pigeonpea the following parameters were recorded as per the standard procedure prescribed by Mohanasundaram *et al*., (2016) on ten plants in three sets of plots sown 45 days before the inoculation of brood lac.

i. Duration of pre sexual stages (Days)

Time elapsed between date of inoculation to male and female differentiation of lac insect was recorded as duration of pre sexual stages (days).

ii. Duration of male emergence (Days)

Time elapsed between date of initiation of male emergence to completion of male emergence was recorded as duration of male emergence (days).

iii. Sex ratio

At the time of emergence, larvae cannot be differentiated into males or females. After a certain period of growth, larvae can be differentiated into male and female lac insects based on their morphological differences (male cells are elongated while female cells are round shaped). The total number of the male and female cells per square cm was recorded on three sites of plant i.e. lower, middle, upper on ten plants in each plot.

iv. Life period (in days) of the female cell

Time elapsed between date of inoculation and maturity of females showing yellow spot at crop harvesting stage was recorded (in days) as life period (in days) of the female cell.

3.4 Productivity - linked parameters of lac insect on pigeonpea:

Initial density of settlement, initial mortality, final density of settlement, density at crop maturity, weight of female lac cell, fecundity and yield were recorded as productivity-linked parameters of lac insect.

3.4.1 Observations

To study the productivity-linked parameters of *Rangeeni* strain of lac insect on pigeonpea the following parameters were recorded on ten plants in three sets of plots sown 45 days before the inoculation of brood lac as per the standard procedure prescribed by Mohanasundaram *et al*. (2016).

i. Initial density of settlement (number per square cm)

The initial density of settlement was recorded at 7 days after the inoculation of broodlac on the 10 tagged plants in each set of plot where one square cm area was selected randomly and numbers of lac crawlers settled were counted visually by using magnifying glass and by placing a graph paper with one square cm area cut window on the stem of plant. Three such sites were selected at lower, middle and upper part of plant and average was taken as initial density of settlement (number per square cm).

ii. Initial mortality (%)

Observations on initial density were repeated at 21-days after inoculation of broodlac following the same procedure as described earlier. The process of crawlers emergence continues up to 2-3 weeks. The crawlers which were not able to find suitable sites for settlement die due to starvation. Observation at this stage is the true indication of the number of crawlers actually settled and that have started feeding. The initial mortality (%) was calculated by the following formula

$$\text{Initial mortality} = \frac{\text{Initial density} - \text{Density after 21 days of settlement}}{\text{Initial density}} \times 100$$

iii. Final density of settlement (number per square cm)

The final density of settlement of crawlers was calculated by the following formula i.e.

Final density of settlement = Initial density of settlement – Initial mortality

iv. Density at crop maturity (number per square cm)

To study the density of lac insect at crop maturity, the numbers of surviving female cells were counted at maturity when the lac crop matures with appearance of yellow spot on female cell. The numbers of mature females per square cm were counted by following the procedure of placing of graph paper with one square cm cut window.

v. Weight (in mg) of the female cell and resin output

Weight (mg) of individual female lac cell was recorded after completion of larval emergence using electronic balance and the resin produced by an individual female cell was recorded after removing the dead insect body from cells.

vi. Fecundity (number of young ones produced by the female insect)

To record the fecundity of lac insect, the mature female cells were placed individually into glass vials plugged with cotton for about a month and the total numbers of emerged larvae per female were counted and were recorded as fecundity of the female lac insect.

vii. Total yield (g)

Total yield (g) of sticklac and scrappedlac were recorded at harvest for tagged plants of each set of plots.

3.4.2 Statistical Analysis

The data recorded on different parameters were subjected to analysis as given below.

i. Mean density

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

Where,

Xi = No. of insects settled per sq cm

N = Total No. of plant sampled.

Plate 2: View of different life stages of *Rangeeni* strain lac insect during experiment. (a) Initial density of settlement of crawlers per sq.cm (b) Final density of settlement of crawlers per sq.cm (c) Male/female cell differentiation per sq.cm (d) Emergence of adult male lac insect (wingless) (e) Wax secretion (f) Density of female cells per sq.cm at crop maturity (g) Matured lac stick (h) Emergence of crawlers from female cell

ii. Standard Deviation

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Where,

x_i = Number of insects settle per sq cm

N = Total number of plant sampled.

μ = Mean density of crawlers settled per sq.cm

iii. Range

Range = Lowest Value to Highest Value

iv. Standard Error

$$\text{Standard error} = \frac{\text{Standard deviation}}{\sqrt{\text{Number of samples}}}$$

3.5 Natural enemies of lac insect

The studies on natural enemies infesting *Rangeeni* strain of lac insect were conducted in lac insect museum cum laboratory at Department of Entomology, Rajasthan College of Agriculture Udaipur during 2016

The natural enemies of lac insect were collected, recorded and identified by Dr. Mohammad Hayat, Retired Principal Scientist and Head, Department of Zoology, Alighar Muslim University, Alighar, Uttar Pradesh and Dr. P. R. Shashank, Scientist (ARS), Division of Entomology, IARI, New Delhi and Sugan Chand Meena, Scientist (ARS), Indian institute of natural resins and gum (IINRG), Ranchi

3.5.1 Observations

To record the natural enemies of lac insect the phunki samples were collected randomly from 10 plants each containing with an average weight of 62.50 g after removal from the host plants. The samples were caged in wooden box (20×20×30 cm^3) with glass tubes and observed for the emergence of the parasitoid, predator for a period of one month and lac associated fauna (parasitoid and predators) were collected daily from emergence cage continuously up to one month, were counted and a record was maintained. The predatory and parasitic fauna were separated based upon morphological characters, got identified.

4. RESULTS

4.1 Biology of lac insect on pigeonpea

The biology of *Rangeeni* strain of lac insect was studied on pigeonpea during 2016 in *Katki* season. The different parameters of biology of lac insect were recorded on ten plants selected randomly in all the three sets of experiment and average was considered and analyzed with suitable statistical tools.

4.1.1 Duration of pre-sexual stages (Days)

The data recorded on the duration of pre-sexual stages (Days) of *Rangeeni* strain of lac insect in *Katki* season on pigeonpea during 2016 on ten randomly selected and tagged plants in all the three sets of experiment are presented in Table 1 and Appendix 1. The data reveal that male/female differentiation period varied from 47 to 51 days on 10 pigeonpea plants in three sets of experiment. The mean duration of pre-sexual stages recorded was 47.90, 48.50 and 48.70 days respectively for the three sets of experiments.

4.1.2 Duration of male emergence (Days)

The duration of male emergence (days) was calculated by taking the difference in the days of male emergence initiated and completed and are presented in Table 1 and Appendix 2. The mean duration of male emergence (days) were 11.30, 11.60 and 11.60 days three sets of experiments respectively on pigeonpea during *Katki* season, 2016. The minimum duration of male emergence observed was 10 days whereas maximum duration was 14 days. The observations reveal that the emergence of male started at 48.43 days (average in three sets of plots) after the inoculation of broodlac sticks and continued for two weeks on the plants observed in the three sets of experiment.

4.1.3 Sex ratio

The observations on sex ratio recorded as per cent male lac insect were calculated by counting the male and female cells per sq cm area in lower, middle, upper parts of ten pigeonpea plants in all the three sets of experiment and mean per cent male lac insect are presented in Table 2 and Appendix 3. The mean per cent male of *Rangeeni* strain of lac insect in *Katki* season on pigeonpea ranged from 4.02 per

cent in lower portion to 17.75 per cent in upper portion of pigeonpea during 2016. The mean per cent male insect at lower, middle, upper parts of host plant were 11.33, 17.75, 17.75; 7.33, 10.63, 11.73 and 4.02, 6.23, 11.56 per cent in the three sets of experiment respectively. The data on mean per cent male lac insect also revealed that a higher mean per cent male lac insect were recorded from upper portion (17.75, 11.73 and 11.56%) of plant stem compared to middle (17.75, 10.63 and 6.23%) and lower portion (11.33, 7.33 and 4.02%)

4.1.4 Life period (days) of the female cells.

A difference of days was observed in mean life period of female cells though were inoculated at the same time. The observations on mean life period of female cells recorded by calculating time elapsed between the date of inoculation and dates of harvesting are presented in Table 1 and Appendix 4. The results reveal that mean life period of female cells of *Rangeeni* strain of lac insect in *Katki* season on pigeonpea ranged from 116 to 118 days with mean of 117 days during 2016.

4.2 Productivity-linked parameters of lac insect on pigeonpea

The results of the investigations on various productivity-linked parameters *viz*., initial density of settlement, initial mortality, final density of settlement, density at crop maturity, weight of female lac cell, fecundity and total yield of *Rangeeni* strain of lac insect *Kerria lacca* (Kerr) in *Katki* season on pigeonpea (*Cajanus cajan*) during 2016 are presented in the following sub headings. The observations on different productivity-linked parameters were recorded and analyzed with suitable statistical tools.

4.2.1 Initial density of settlement (number per sq.cm)

The observations on mean initial density of settlement of crawlers on 10 randomly selected plants in three sets of experiment at lower, middle, upper parts of plants are presented in Table 3 and Appendix 5, 6 and 7.

The initial density of crawlers ranged from 68-117, 58-121 and 54-86 crawlers per sq.cm on lower, middle, upper parts of plant in set of experiment I respectively. The results show that mean initial density of settlement of 92.60, 84.10 and 60.00 crawlers per sq.cm were recorded in set of experiment I with a deviation of 14.86, 23.23 and 16.29 crawlers per sq.cm on lower, middle, upper portion respectively.

Table 1: Mean duration of pre sexual stages, male emergence and life period of female lac insect (Days) on pigeonpea during *Katki* season, 2016

S. No.	Parameters	Set of experiment I	Set of experiment II	Set of experiment III	Over all mean days
1.	Duration of pre sexual stages	47.90	48.50	48.70	48.36
2.	Duration of male emergence	11.30	11.60	11.60	11.50
3.	Life period of female cell	116	117	118	117

Table 2: Mean per cent male cells of *Rangeeni* strain lac insect on pigeonpea during *Katki* season, 2016

	Per cent male lac insect		
	Lower portion of plant	Middle portion of plant	Upper portion of plant
Set of experiment I	11.33	17.75	17.75
Set of experiment II	7.33	10.63	11.73
Set of experiment III	4.02	6.23	11.56

Similarly the mean initial density of settlement of crawlers observed in set of experiment II were 86.70, 91.60 and 71.00 crawlers per sq. cm with a deviation of 24.16, 15.02 and 16.08 crawlers per sq. cm and the initial density of crawlers ranged from 47-110, 47-110 and 54-107 crawlers per sq. cm on lower, middle, upper portion of plant respectively.

In set of experiment III the mean initial density of settlement of crawlers observed were 67.40, 64.70 and 61.00 crawlers per sq. cm with a deviation of 22.64, 16.52 and 28.38 crawlers per sq. cm and the initial density of crawlers ranged from 32-107, 35-92 and 20-103 crawlers per sq. cm on lower, middle, upper portion of plant respectively.

The data recorded on initial density of settlement of crawlers on pigeonpea in *Katki* season during 2016 were categorized into three different groups that are 20-50, 50-80 and 80 and above crawlers for 10 plants in three sets of experiment. The category wise mean initial density of settlement of crawlers is presented in Table 4.

The category wise of mean of initial density of crawlers reveals that in lower portion of plant no plant was in the category group of 20-50 crawlers, 2 plants were in the category of 50-80 crawlers with an average density of 73.50 crawlers per sq. cm whereas 8 plants were found in the category of 80 and above crawlers with an average density of 97.37 crawlers per sq. cm in set of experiment I. Similarly the data tabulated for middle parts of plant show that no plant was in category group of 20-50 crawlers, 6 plants were in the category of 50-80 crawlers with an average density of 67.00 per sq. cm whereas 4 plants were observed in the category of 80 and above crawlers with an average density of 109.75 crawlers per sq. cm. The observations on upper parts of plant reveal that 3 plants were in the category of 20-50 crawlers with an average density of 45.66 crawlers per sq. cm, 5 plants were in the category of 50-80 crawlers with an average density of 58.40 crawlers per sq. cm and 2 plants were observed in the category of 80 and above crawlers with an average density of 85.00 crawlers per sq. cm.

The observations of the category wise mean initial density of crawlers in the set of experiment II revealed that, at lower portion of plant one plant was observed in category of 20-50 crawlers with an average density of 47.00 crawlers per sq. cm, 3 plants were in the category of 50-80 crawlers with an average density of 65.33 crawlers per sq. cm and 6 plants were observed in the category of 80 and above

crawlers with an average density of 104.00 crawlers per sq. cm. Similarly at middle portion of plant no plant had density in category of 20-50 crawlers, 2 plants were in the category of 50-80 crawlers with an average density of 71.00 crawlers per sq. cm and 8 plants were found in the category of 80 and above crawlers with an average density of 96.75 per sq. cm and at upper portion of plant 3 plants were in the category of 20-50 with an average density of 45.66 crawlers per sq. cm, 5 plants were in the category of 50-80 crawlers with an average density of 58.40 crawlers per sq. cm whereas 2 plants were observed in the category of 80 and above crawlers with an average density of 85.00 crawlers per sq. cm.

The results of the category wise mean initial density of crawlers in the sets of experiment III reveal that at lower portion one plant was recorded with density in category of 20-50 crawlers with an average density of 32.00 crawlers per sq. cm, 7 plants were in the category of 50-80 crawlers with an average density of 61.85 crawlers per sq. cm whereas 2 plants were observed in the category of 80 and above crawlers with an average density of 104.50 crawlers per sq. cm and at the middle portion of plant one plant was having density in category of 20-50 crawlers with an average density of 35.00, 7 plants were in the category of 50-80 crawlers with an average density of 62.14 crawlers per sq. cm whereas 2 plants were observed in the category of 80 and above crawlers with an average density of 88.50 crawlers per sq. cm. The mean initial density of crawlers at the upper portion of plant 4 plants were in the category of 20-50 crawlers with an average density of 34.25 crawlers per sq. cm, 2 plants were in the category of 50-80 crawlers with an average density of 56.00 per sq. cm whereas 4 plants were observed in the category of 80 and above crawlers with an average density of 90.00 crawlers per sq. cm.

4.2.2 Initial Mortality (%)

The observations on mean per cent initial mortality recorded at 21-days after inoculation of broodlac of *Rangeeni* strain of lac insect in *Katki* season on pigeonpea during 2016 are presented in Table 5 and Appendix 5, 6 and 7. The data reveal that the first instar crawlers of lac insect which were not able to find suitable sites for settlement, died due to starvation and remaining population at this stage were the true number of crawlers actually settled. The results reveal 7.55, 8.12, 10.40 ; 7.70, 6.46, 7.49 and 9.09, 12.27 and 12.58 per cent mean mortality of first instar crawlers at lower, middle and upper portion of plant in three sets of experiment respectively.

Table 3: Mean initial density of settlement (per sq.cm) of first instar crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Initial density of settlement per sq. cm				
		Lower portion	**Middle portion**	**Upper portion**
Set of experiment I	Mean ($\bar{x}$)	92.60	84.10	60.00
	SD (σ)	14.86	23.23	16.29
	SE	4.70	7.35	5.15
	Range (R)	68-117	58-121	54-86
Set of experiment II	Mean ($\bar{x}$)	86.70	91.60	71.00
	SD (σ)	24.16	15.02	16.08
	SE	7.64	4.75	5.08
	Range (R)	47-110	47-110	54-107
Set of experiment III	Mean ($\bar{x}$)	67.40	64.70	61.00
	SD (σ)	22.64	16.52	28.38
	SE	7.16	5.22	8.97
	Range	32-107	35-92	20-103

Table 4: Category wise mean initial density of settlement (per sq.cm) of first instar crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Initial density of settlement per sq. cm									
	Set of experiment I			Set of experiment II			Set of experiment III		
Category	**Lower portion of plant**	**Middle portion of plant**	**Upper portion of plant**	**Lower portion of plant**	**Middle portion of plant**	**Upper portion of plant**	**Lower portion of plant**	**Middle portion of plant**	**Upper portion of plant**
20-50	0 (0.00)	0 (0.00)	3 (45.66)	1 (47.00)	0 (0)	3 (45.66)	1 (32.00)	1 (35.00)	4 (34.25)
50-80	2 (73.50)	6 (67.00)	5 (58.40)	3 (65.33)	2 (71.00)	5 (58.40)	7 (61.85)	7 (62.14)	2 (56.00)
80 & above	8 (97.37)	4 (109.75)	2 (85.00)	6 (104.00)	8 (96.75)	2 (85.00)	2 (104.50)	2 (88.50)	4 (90.00)

*Figures in parenthesis are average initial density of settlement of crawlers (No/cm^2)

4.2.3 Final density of settlement (number per sq.cm)

The observations on mean final density of settlement of first instar crawlers recorded on lower, middle, upper portion of 10 randomly selected plants in three sets of experiment are presented in Table 6 and Appendix 8.

The final density of settlement of crawlers ranged from 62-106, 50-114 and 40-83 crawlers per sq.cm on lower, middle, upper portion of plant in sets of experiment I respectively. The results show that mean final density of settlement of crawlers in set of experiment I were 85.50, 78.20 and 53.10 crawlers per sq.cm with a deviation of 14.74, 22.70 and 17.10 crawlers per sq.cm on lower, middle, upper portion of plant respectively.

Similarly the mean final density of crawlers ranged from 40-104, 62-102 and 42-102 crawlers per sq.cm on lower, middle, upper portion of plant in set of experiment II respectively. The result also show that mean final density of settlement of crawlers in set of experiment II were 80.20, 85.90 and 65.00 crawlers per sq.cm with a deviation of 22.91, 15.66 and 18.26 crawlers per sq.cm on lower, middle, upper portion of plant respectively.

The final density of crawlers ranged from 30-101, 28-83 and 17-96 crawlers per sq.cm on lower, middle, upper portion of plant in set of experiment III respectively and the mean final density of settlement of crawlers in set of experiment III were 61.90, 57.30 and 54.60 crawlers per sq.cm with a deviation of 22.26, 17.10 and 28.60 crawlers per sq.cm on lower, middle, upper portion of plant respectively.

The data recorded on final density of settlement of first instar crawlers on pigeonpea in *Katki* season during 2016 were categorized into three different groups that are 20-50, 50-80, 80 and above crawlers for 10 plants in each sets of experiment. The category wise on mean final density of settlement of crawlers are presented in Table 7.

The results of category wise mean final density of settlement of crawlers in set of experiment I reveals that in lower portion of plant no plant was in the category group of 20-50 crawlers, 3 plants were in the category of 50-80 crawlers with an average density of 68.66 crawlers per sq.cm whereas 7 plants were observed in the category of 80 and above crawlers with an average density of 92.71 crawlers per sq.cm. Similarly the data tabulated for middle portion of plant show that no plant was in category group of 20-50 crawlers, 6 plants were in the category of 50-80 crawlers with an average density of 61.83 crawlers per sq.cm whereas 4 plants were observed in the category of 80 and above crawlers with an average density of 102.75 crawlers

per sq.cm. The observations on upper portion of plant reveal that 6 plants were in the category of 20-50 crawlers with an average density of 41.16 crawlers per sq.cm, 2 plants were in the category of 50-80 crawlers with an average density of 60.50 crawlers per sq.cm and 2 plants were observed in the category of 80 and above crawlers with an average density of 81.50 crawlers per sq.cm.

The results of the category wise mean final density of settlement of crawlers in the set of experiment II revealed that at lower portion of plant two plant were having density in category of 20-50 crawlers with an average density of 44.00 crawlers per sq.cm, 2 plants were in the category of 50-80 crawlers with an average density of 68.50 crawlers per sq.cm and 6 plants were observed in the category of 80 and above crawlers with an average density of 96.66 crawlers per sq.cm and at middle portion of plant no plant had density in category of 20-50 crawlers, 4 plants were in the category of 50-80 crawlers with an average density of 69.25 crawlers per sq.cm and 6 plants were observed in the category of 80 and above crawlers with an average density of 97.00 crawlers per sq.cm. The mean final density of settlement at upper portion of plant 2 plants were in the category of 20-50 crawlers with an average density of 44.50 crawlers per sq.cm, 6 plants were in the category of 50-80 crawlers with an average density of 62.83 crawlers per sq.cm whereas 2 plants were observed in the category of 80 crawlers and above with an average density of 92.00 crawlers per sq.cm

Similarly the results of the category wise mean final density of settlement of crawlers in the set of experiment III reveal that at lower portion of plant 3 plants were in category of 20-50 crawlers with an average density of 41.00 crawlers per sq.cm, 5 plants were in the category of 50-80 crawlers with an average density of 60.00 crawlers per sq.cm whereas 2 plants were observed in the category of 80 and above crawlers with an average density of 98.00 crawlers per sq.cm and at the middle portion of plant 3 plants were in category of 20-50 crawlers with an average density of 57.50 crawlers per sq.cm, 6 plants were in the category of 50-80 crawlers with an average density of 62.50 crawlers per sq.cm whereas 1 plant was having density in the category of 80 and above crawlers with an average density of 83.00 crawlers per sq.cm. The observation on the upper portion of plant 5 plants were in the category of 20-50 crawlers with an average density of 30.20 crawlers per sq.cm, 2 plants were in the category of 50-80 crawlers with an average density of 66.00 crawlers per sq.cm whereas 3 plants were observed in the category of 80 and above crawlers with an average density of 87.66 crawlers per sq.cm

Table 5: Mean per cent mortality of crawlers of *Rangeeni* strain lac insect on pigeonpea during *Katki* season, 2016

	Mean per cent mortality per sq.cm		
	Lower portion of plant	**Middle portion of plant**	**Upper portion of plant**
Set of experiment I	7.55	8.12	10.40
Set of experiment II	7.70	6.46	7.49
Set of experiment III	9.09	12.27	12.58

Table 6: Mean final density of settlement (per sq.cm) of crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Final density of settlement per sq. cm				
		Lower portion of plant	**Middle portion of plant**	**Upper portion of plant**
Set of experiment I	Mean ($\bar{x}$)	85.50	78.20	53.10
	SD (σ)	14.74	22.70	17.10
	SE	4.66	7.17	5.40
	Range (R)	62-106	50-114	40-83
Set of experiment II	Mean ($\bar{x}$)	80.20	85.90	65.00
	SD (σ)	22.91	15.66	18.26
	SE	7.27	4.95	5.77
	Range (R)	40-104	62-102	42-102
Set of experiment III	Mean ($\bar{x}$)	61.90	57.30	54.60
	SD (σ)	22.26	17.10	28.60
	SE	7.04	5.40	9.04
	Range (R)	30-101	28-83	17-96

Table 7: Category wise mean final density of settlement (per sq.cm) of crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Final density of settlement									
	Set of experiment I			Set of experiment II			Set of experiment III		
Category	**Lower portion of plant**	**Middle portion of plant**	**Upper portion of plant**	**Lower portion of plant**	**Middle portion of plant**	**Upper portion of plant**	**Lower portion of plant**	**Middle portion of plant**	**Upper portion of plant**
20-50	0 (0.00)	0 (0.00)	6 (41.16)	2 (44.00)	0 (0.00)	2 (44.50)	3 (41.00)	3 (57.50)	5 (30.20)
50-80	3 (68.66)	6 (61.83)	2 (60.50)	2 (68.50)	4 (69.25)	6 (62.83)	5 (60.00)	6 (62.50)	2 (66.00)
80 & above	7 (92.71)	4 (102.75)	2 (81.50)	6 (96.66)	6 (97.00)	2 (92.00)	2 (98.00)	1 (83.00)	3 (87.66)

*Figures in parenthesis are average final density of settlement of crawlers (No/cm^2)

4.2.4 Density at crop maturity (Number of female cells per sq.cm)

The data on mean density of mature female cells per sq.cm of *Rangeeni* strain of lac insect in *Katki* season during 2016 recorded on lower, middle, upper sites on ten plants in three set of experiment are presented in Table 8 and Appendix 9.

The results reveal that in the set of experiment I, the mean density of female cells were 5.00, 3.80 and 4.90 female cells per sq.cm with a deviation of 1.63, 1.81 and 1.44 cells per sq.cm on lower, middle, upper portion of ten plants respectively and the density of female cells ranged from 3-7, 1-6 and 3-7 per sq.cm on lower, middle, upper portion of plant respectively. In the set of experiment II, the mean density of female cells per sq.cm were recorded as 4.00, 4.20 and 4.40 female cells per sq.cm with a deviation of 1.63, 1.39 and 1.83 female cells per sq.cm on lower, middle, upper portion of plant respectively and the density of female cells ranged from 2-7, 2-6 and 2-8 per sq.cm on lower, middle, upper portion of plant respectively. Likewise, the data recorded from the plants in set of experiment III reveal that the mean density of female cells were 6.40, 5.70 and 6.00 female cells per sq.cm with a deviation of 1.34, 1.25 and 1.88 female cells per sq.cm on lower, middle, upper portion of plant respectively and the density of female cells ranged from 4-11, 3-11 and 4-11 per sq.cm on lower, middle, upper portion of plant respectively.

4.2.5 Weight of female cell and resin weight (mg)

The weight of female cells were recorded for ten samples in each plot and kept in glass vial individually after the emergence of crawlers. The weight of female cells was recorded by using electronic balance and resin weight was also recorded by removing the dead insect body from mature cells. The average of ten cells was considered as mean weight of cells as well as mean resin weight in mg. The observations recorded on mean weight of female cells and mean resin weight (mg) are presented in Table 9 and Appendix 10.

The results reveal that the mean weight of female cells recorded in three set of experiment were 12.20, 12.30 and 14.70 mg respectively with an overall mean of 13.06 mg. The minimum weight of female cell recorded was 6.00 mg in set of experiment II and maximum weight of female cell recorded was 24.00 mg in set of experiment III. The mean resin weight recorded in three set of experiment 9.60, 10.10 and 12.40 mg with an overall mean of 10.70. The minimum resin weight of female cell recorded was 4.00 mg in set of experiment I and maximum resin weight of female cell recorded as 19.00 mg in set of experiment III respectively.

4.2.6 Fecundity per female cell

The mature 10 female cells from each plot were kept in separate glass vials plugged with cotton individually up to 1 month duration and emerged crawlers were counted. The observations recorded on fecundity of female cells are presented in Table 10 and Appendix 11.

The results reveal that the average number of crawlers emerged from single female cells of *Rangeeni* strain of lac insect were 327.50, 258.30 and 162.90 crawlers respectively with an overall mean of 249.56 crawlers in three set of experiment respectively. The maximum fecundity recorded per female cell was observed as 430.00 crawlers in set of experiment I whereas minimum fecundity recorded per female cell was 95.00 crawlers in plot set of experiment.

4.2.7 Yield of sticklac and scrappedlac in gm

The data on mean yield of sticklac and scrappedlac of *Rangeeni* strain of lac insect on pigeonpea in *Katki* season during 2016 were recorded from 10 plants in three set of experiment and are presented in Table 9 and Appendix 12, 13.

The mean yield of sticklac recorded from 10 plants in three set of experiment was 242.50, 210.00 and 252.20 g respectively with an overall mean of 235.00 g sticklac per plant. The maximum yield of sticklac was recorded 400.00 g per plant in set of experiment III whereas minimum yield of sticklac was recorded 125.00 g per plant in all the three set of experiment.

The mean scrappedlac yield recorded from 10 plants in three set of experiment was 11.43, 12.79 and 22.67 g respectively with an overall mean of 15.63 g scrappedlac per plant. The maximum yield of scrappedlac was recorded 29.45 g per plant in set of experiment III whereas minimum yield was recorded 3.74 g per plant in set of experiment I.

Table 8: Mean density of mature female cells (per sq.cm) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Density at maturity (No of female cells per sq.cm)				
		Lower portion of plant	**Middle portion of plant**	**Upper portion of plant**
Set of experiment I	Mean ($\bar{x}$)	5.00	3.80	4.90
	SD (σ)	1.63	1.81	1.44
	SE	0.52	0.57	0.45
	Range (R)	3-7	1-6	3-7
Set of experiment II	Mean ($\bar{x}$)	4.00	4.20	4.40
	SD (σ)	1.63	1.39	1.83
	SE	0.51	0.44	0.58
	Range (R)	2-7	2-6	2-8
Set of experiment III	Mean ($\bar{x}$)	6.40	5.70	6.00
	SD (σ)	1.34	1.25	1.88
	SE	0.42	0.39	0.59
	Range (R)	4-11	3-11	4-11

Table 9: Mean weight of female cell (mg), resin weight per cell (mg), sticklac yield per plant (g) and scrappedlac yield per plant (g) on pigeonpea during *Katki* season, 2016

S. No.	Parameters	Set of experiment I	Set of experiment II	Set of experiment III	Over all mean
1.	Female cell weight (mg)	12.20	12.30	14.70	13.06
2.	Resin weight (mg)	9.60	10.10	12.40	10.70
3.	Sticklac yield per plant (g)	242.50	210.00	252.50	235.00
4.	Scrappedlac yield per plant (g)	11.43	12.79	22.67	15.63

Table 10: Mean fecundity (per female cell) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Set of experiment	Mean fecundity per female cell
I	327.50
II	258.30
III	162.90
Over all mean	249.56

4.3 Natural enemies (major predator and parasitoids) of lac insect

The observations were recorded on the number of different natural enemies (predator and parasitoids) emerged from *Rangeeni* strain of lac insect on pigeonpea in *Katki* season during 2016. The observations were recorded by collecting and identifying different species separately and are given in Table 11.

The results reveal that a total 716 natural enemies emerged were collected from 10 bags each containing phunki lac sticks of *Rangeeni* strain of lac insect in *Katki* crop during 2016. The natural enemies recorded were identified to belonging to three orders *viz.*, Hymenoptera (700), Coleoptera (9) and Lepidoptera (7).

The highest number i.e. 700 natural enemies belonging to order Hymenoptera were recorded from the samples during investigation. Among Hymenopterans 670 individuals were observed belonging to family Encyrtidae and 30 belonging to Eulophidae. The species wise distribution of the natural enemies recorded during investigation reveal that 3 species namely *Erencyrtus dewitzi* Mahd, *Tachardiaephagus tachardiae* Howard and *Aprostocetus* (*Tetrastichus*) *purpureus* Cameron belonging to Encyrtidae, Encyrtidae and Eulophidae family contributes 88.41, 5.17, 4.19 per cent respectively to the total natural enemies population.

The observation on natural enemies also reveal that among 7 Lepidopteron predators 5 were identified as *Eublemma amabilis* Moore belonging to family Noctuidae and 2 as *Pseudohypatopa* (*Holcocera*) *pulverea* Meyr belonging to family Blastobasidae which contributes 0.70 and 0.28 per cent respectively to the total natural enemies population.

Similarly the 9 Coleopteran predator i.e. *Oryzaephilus spp*, belonging to family Silvanidae were also recorded with 1.23% contribution to the total population of natural enemies.

Table 11: Population of natural enemies recorded on *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016.

S. No.	Order	Total Number	Family	Scientific name of species	Number of each species	Per cent contribution of orders	Per cent contribution of family	Per cent contribution of each species
1.	Hymenoptera	700	Encyrtidae	*Erencyrtus dewitzi*	633	97.77%	93.58%	88.41%
				Tahardiaephagus tachardiae	37			5.17%
			Eulophidae	*Aprostocetus (Tetrastichus) purpureus*	30		4.19%	4.19%
2.	Lepidoptera	7	Noctuidae	*Eublemma amabilis*	5	0.98%	0.7%	0.7%
			Blastobasidae	*Pseudohypatopa pulverea*	2		0.28%	0.28%
3.	Coleoptera	9	Silvanidae	*Oryzaephilus spp*	9	1.26%	1.26%	1.26%
	Total natural enemies collected	716						

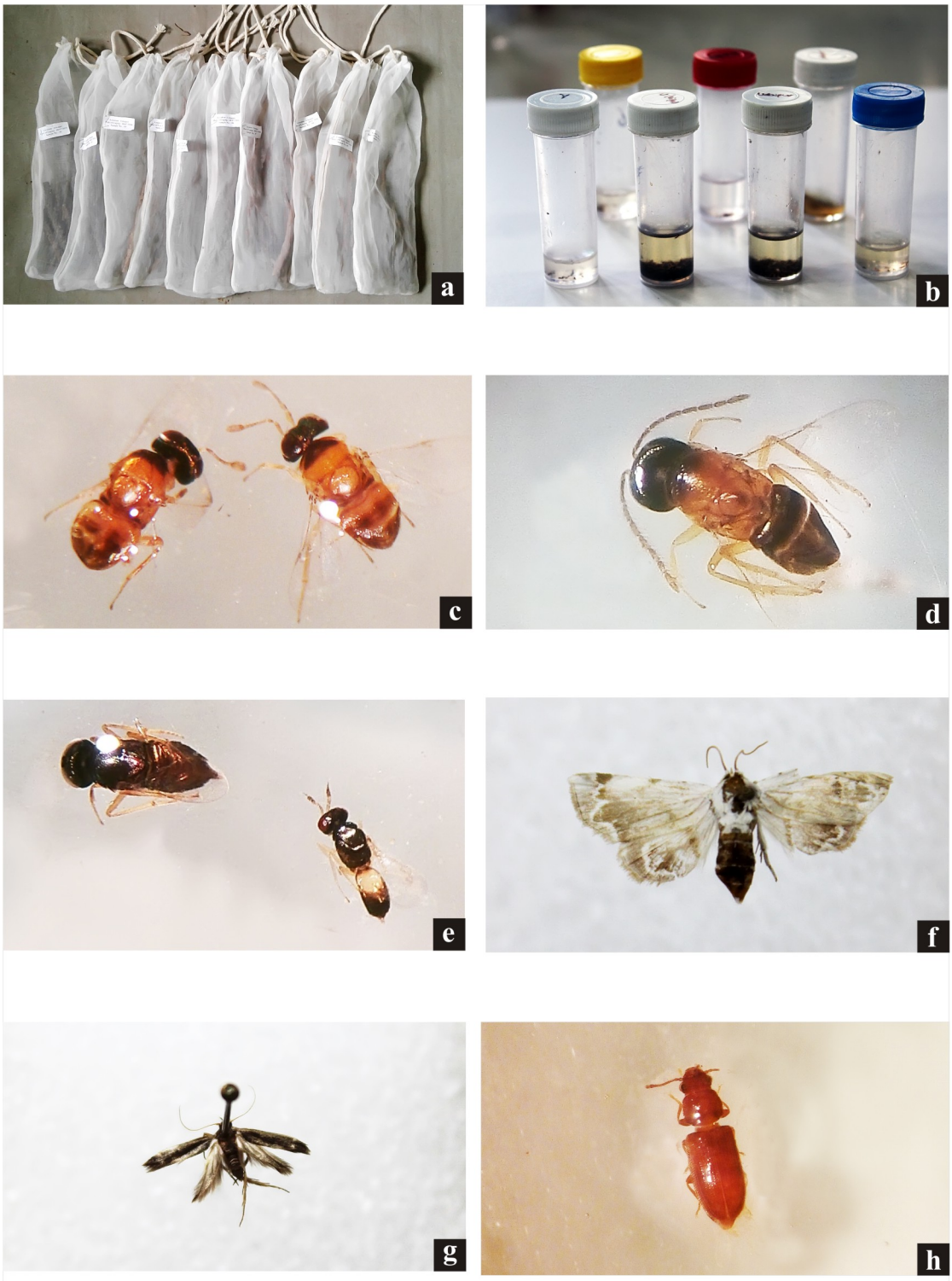

Plate 3: Natural enemies of lac insect recorded during the study.
(a) Caging of Broodlac Sticks (b) Preservation of hymenopteran parasitoids in 70% alcohol (c) *Erencyrtus dewitzi* Mahd (Encyrtidae ; Hymenoptera) (d) *Tachardiaephagus tachardiae* Howard (Encyrtidae ; Hymenoptera) (e) *Aprostocetus* (*Tetrastichus*) *purpureus* Cameron (Eulophidae ; Hymenoptera) (f) *Eublemma amabilis* Moore (Noctuidae ; Lepidoptera) (g) *Pseudohypatopa (Holcocera) pulverea* Meyr (Blastobasidae; Lepidoptera) (h) *Oryzaephilus spp* Linn (Silvanidae ; Coleoptera)

5. DISCUSSION

Lac is the only resin of animal origin, being actually the secretion of a tiny scale insect, *Kerria lacca* Kerr belonging to the family Tachardiidae (=Kerriidae), super family Coccoidea of the order Hemiptera. It is major source of livelihood of millions of backward population especially tribles in many states of country. Indian lac insect *Kerria lacca* Kerr alone contributes more than 80% of total lac production (Mohansundram *et al,* 2017). Lac insect is naturally found in abundance on its natural hosts in urban as well as in forest areas and is cultivated commercially on preferred hosts; Ber (*Ziziphus mauritiana),* Palas (*Butea monosperma*) and Kusum (*Schleichera oleosa*) etc. The pigeonpea (*Cajanus cajan*) has also been identified as a favorite host for lac insect long back in 1950's and has emerged as a promising host for cultivation of *Rangeeni* strain of lac insect (Zhenghong *et al*. 2001). It is cultivated widely in different states of country and it could be better exploited for commercial production of lac in the region particularly southern Rajasthan provided a complete knowledge about bioecology and life cycle of lac insect is made available.

The objectives of present investigation were to study the biology and productivity-linked parameters of lac insect *Kerria lacca* Kerr on pigeonpea (*Cajanus cajan*) along with its natural enemies for *Rangeeni* strain best suited to agro-ecological conditions of southern parts of Rajasthan. A complete knowledge of lac insect and its life cycle on pigeonpea will overcome the hindrance in development of lac production and will bring about impetus to the lac cultivation in the area particularly in southern Rajasthan.

The results obtained after investigation under the different objectives have been discussed in the light of available literature in following subheading:

5.1 Biology of lac insect on pigeonpea

Pigeonpea (*Cajanus cajan*) was used as host to study the biology of *Rangeeni* strain of lac insect in *Katki* crop season during 2016 to establish the biology of lac insect.

5.1.1 Duration of pre sexual stages (Days)

Lac insect after settlement on host undergoes pre-sexual stages before attaining male and female stages which in turn decides the fecundity and quantity of lac produced. The results presented in Table 1, Appendix 1 and depicted in fig.1 reveal that the minimum period which lac insect takes for male/female cell differentiation was 47 days whereas the maximum period of cell differentiation was upto 51days. The results clearly indicate that in normal behavior lac insect takes about 7 weeks for male/female differentiation. The present findings are in agreement with the findings of Sharma (1991) who also recorded 6 to 7 week duration for the cell differentiation in *Rangeeni* strain of lac insect after its settlement.

5.1.2 Duration of male emergence (Days)

The male lac insect generally emerges 6-7 weeks after the settlement. They may be winged or wingless and the relative number of two forms varies considerably in different seasons of the lac crops. The lifespan of males is very short as it fertilizes the females and dies. The longevity of male lac insects determines the fertilization of females for producing next generation. The results of presented in Table 2, Appendix 2 and depicted in fig.1 reveal that male emergence on pigeonpea in *Katki* season during 2016 lasts from 10-14 days. The mean duration for initiation of male emergence was recorded 48.36 days after the inoculation and emergence continues upto 14days during 2016. The similar results have been observed by Sharma (1991) who recorded the male emergence in *Rangeeni* strain of lac insect at 6-7 weeks after its inoculation while Jaiswal and Sharma (2011) observed longevity of males as only 2 days in *Rangeeni* strain during *Katki* crop.

5.1.3 Sex ratio (% male insect)

The lac cell can not be differentiated into male/female at the time of emergence but after a period of certain growth cells can easily differentiated into male/female based on their shape (males are elongated while females are round) and

other morphological differences. At this stage the females are sexually mature and fertilized by the males after the emergence of male lac insect from the cell. The observations on sex ratio recorded as mean per cent male lac insect of *Rangeeni* strain in *Katki* season during 2016 presented in Table 2, Appendix 3 and depicted in fig.2 reveal that there was a difference in mean per cent male lac insect of *Rangeeni* strain on lower, middle and upper portion of plant which were observed as 11.33, 7.33, 4.02; 17.75, 10.63, 6.23 and 17.75, 11.73, 11.56 per cent in three set of experiment respectively. The mean per cent male insects were recorded higher on upper portion as compared to middle and lower portion of plants with range from 4.02-17.75 per cent males. The results of present investigation are almost similar to observations by Divakara (2013) who recorded highest per cent of male insect on Ber (26.86%) followed by *F. semialata* (24.84%) and Kusum (17.82%). According to Kong *et al*, (1984) females were predominant in both the seasons of *Kerria lacca* with 75-80 per cent in first generation and 50-78 per cent in second generation.

5.1.4 Life period (Days) of the female cells

The state of female cell activity lasts for varying number of weeks depending upon temperature, host plant and strains of lac insect. The female lac insect lives for relatively longer period and are the chief sources of lac secretion. The duration of longevity or life period of female cells of lac insect depends on various factors such as species, strain, season of development and climatic conditions of area. The results of presented in Table 1, Appendix 4 and depicted in fig.1 reveal that there was no difference in life period of female cells of *Rangeeni* strain of lac insect in *Katki* crop during 2016. The life period of female cell during present investigation ranged from 116-118 days from the date of inoculation to date of harvesting which is in conformity with the findings of Mohanta *et al* (2014) who reported that *Rangeeni* strain on palas (*Butea monosperma*) took 3 months 16 days to complete their life cycle however according to Sharma (1991) *Rangeeni* strain of lac insect took 120-137 days to mature.

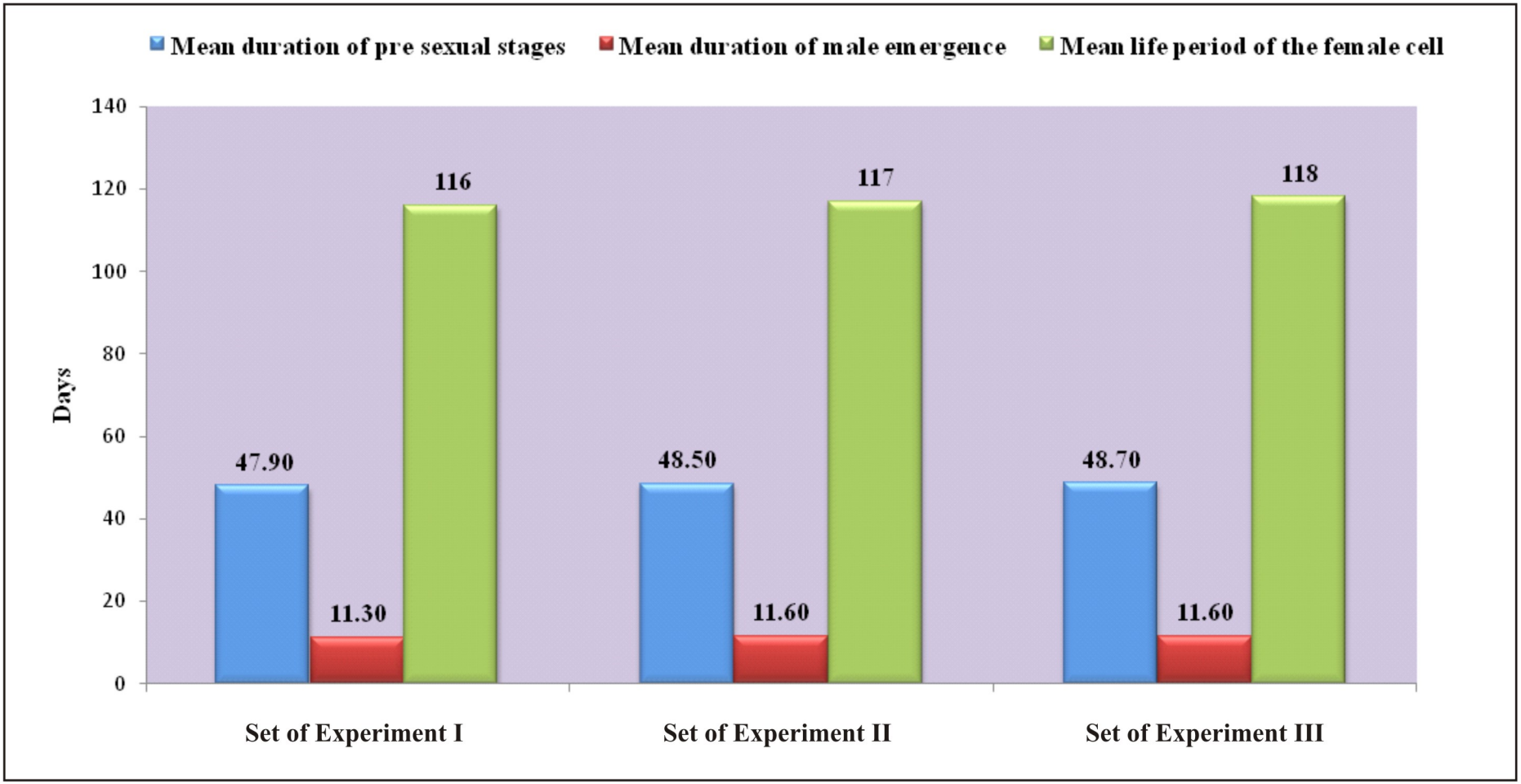

Fig. 1: Mean duration of pre-sexual stages, male emergence and life period of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016.

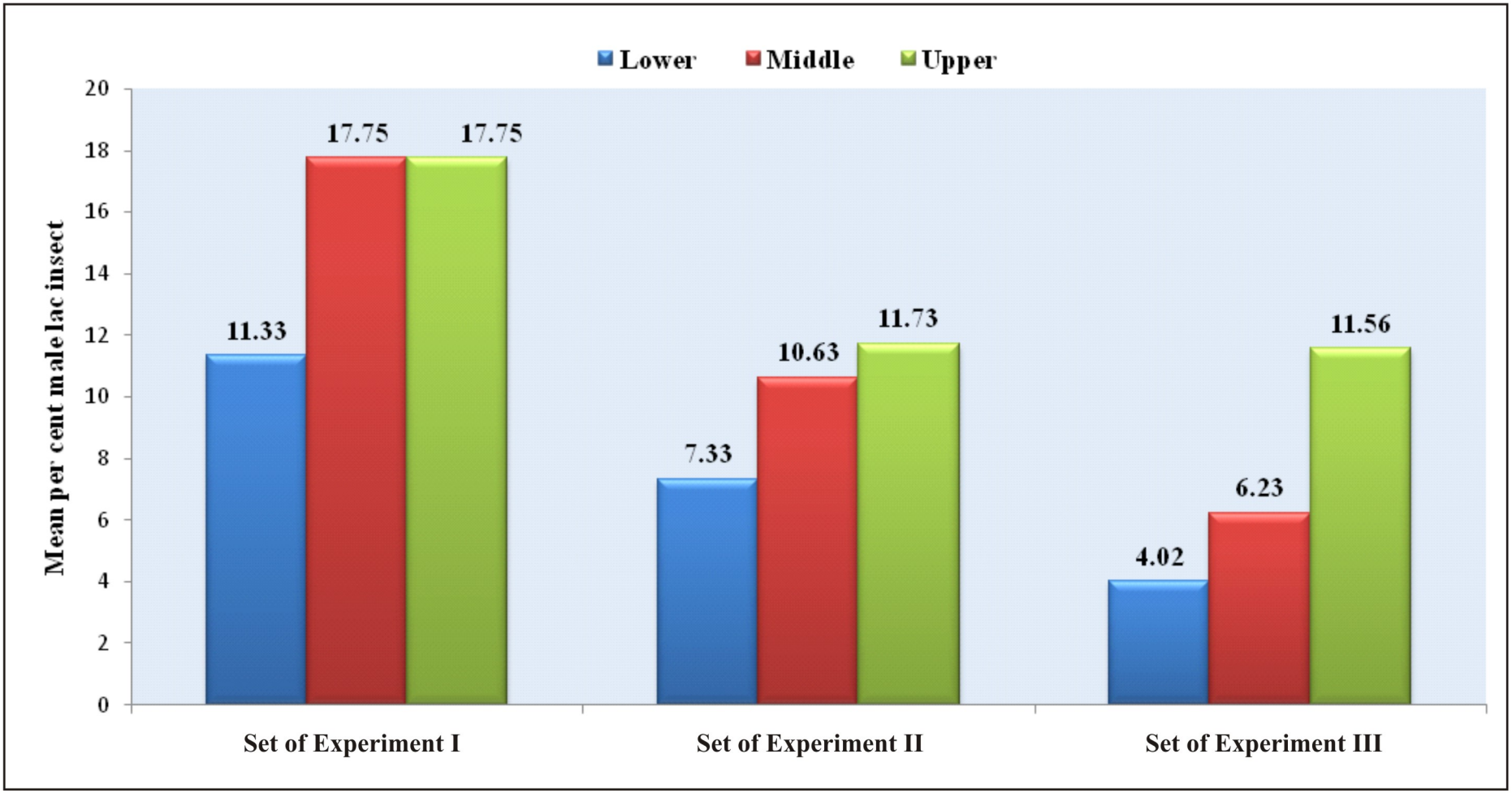

Fig. 2: Mean per cent male of *Rangeeni* strain lac insect on pigeonpea during *Katki* season, 2016.

5.2 Productivity-linked parameters of lac insect on pigeonpea

The productivity of lac insect on different host depends upon the various factors governing the development of lac insect, host and lac insect. The lac being the secretion of the insect is directly affected by the biotic and abiotic stresses. Besides the several developmental parameters (Mishra *et al*, 2000) which contribute in growth, feeding, secretion and oviposition of lac insect influence the relative production of resin by lac insect.

The role of developmental parameters has been discussed earlier by various workers (Kaushik *et al*. 2012, Divakara 2013, Kumar *et al*. 2007, Mohanta *et al*. 2014 etc) but in India the systematic work on productivity linked parameters of lac insect has started recently few years back in 2014, with the initiation of ICAR Network project on "Conservation of Lac Insect Genetic Resources" as a result of which definite guidelines for studies on this aspect were developed.

In the present investigation seven different productivity-linked parameters of lac insect contributing to the productivity of *Rangeeni* strain of lac on pigeonpea in *katki* crop were studied during 2016 to establish the resin producing efficiency and quantity of lac produce by Indian lac insect (*Kerria lacca* Kerr) on pigeonpea (*Cajanus cajan*). The different parameters linked with productivity of lac insect have been discussed in the light of the research work done by various workers as detailed below under the following subheads:

5.2.1 Initial density of settlement (Number per sq.cm)

The gravid female lays eggs inside encrustation and first instars larvae hatch out which crawls and settle at suitable sites on succulent stem of host plant. The settlement of the first instar crawlers takes place within a period of a week or two of the hatching.

The observations of mean initial density of settlement of crawlers recorded 7 days after the inoculation of broodlac and presented in Table 3 and depicted in fig.3 reveal that there was a difference in a mean initial density of settlement of first instar crawlers on lower, middle and upper portion of plant. The observed range of initial density of settlement of first instar crawlers of *Rangeeni* strain of lac insect on pigeonpea in *Katki* season during 2016 was 68-117, 58-121, 54-86; 47-110, 17-110, 54-107 and 32-107, 35-92, 20-103 crawlers per sq.cm respectively on lower, middle

and upper portion of host plant in three set of experiment. Some researchers have studied the initial density of settlement of larvae in *Kusmi* strain, but no studies on this aspect of *Rangeeni* strain have been revealed by the researchers however the results of present investigations are in alignment with the findings of Mohanta *et al*. (2014) who reported that initial density of settlement of larvae ranged between 92.58-126.74 crawlers per sq.cm and 93.12-109.62 crawlers per sq.cm of *Kusmi* strain on Kusum and Ber trees respectively.

5.2.2 Initial mortality (%)

The first instar crawlers which could not find suitable sites for settlement on host plant could not survive and dies due to starvation within a week or two of its emergence. The observations on per cent initial mortality of first instar crawlers recorded at 21 days after inoculation of broodlac of *Rangeeni* strain of lac insect in *Katki* season on pigeonpea during 2016 and presented in Table 5 and depicted in fig.3 and data shows that mean per cent initial mortality of first instar crawlers varied from 6.46 per cent in middle portion to 12.57 per cent in upper portion of plants under experimental condition. The results of present investigations reveal that 7.55, 8.12, 10.40; 7.7, 6.46, 7.49 and 9.09, 12.27, 12.58 per cent mean mortality were recorded from lower, middle and upper portion of the plants in three set of experiment respectively. The results of the present investigation confer the findings of Divakara (2013) who recorded minimum per cent mortality of *Rangeeni* strain of lac insect in *C. calothyrsus* (12.48%) and *D. assamica* (22.36%) and maximum per cent mortality of *Kusmi* strain in *Jethwi* season in *F. semialata* (27.88%) followed by ber (24.91%) and kusum (18.75%).

5.2.3 Final density of settlement (Number per sq.cm)

The mean final density of settlement of first instar crawlers were recorded by subtracting the density of crawlers in initial and initial mortality (number). The data presented in Table 6 and depicted in fig.3 reveal that maximum final density of settlement of crawlers observed was 114 crawlers per sq.cm while minimum final density of settlement of crawlers of *Rangeeni* strain of lac insect was 17 crawlers per sq.cm on pigeonpea in *Katki* season during 2016. The observations made by Divakara (2013) supports the results of present investigation who recorded maximum density (77.8 crawlers/cm^2) of insect settlement in *F. macrophylla* as intercrop in understorey of *Dalbergia sisso* 21 days after of inoculation of broodlac.

5.2.4 Density at crop maturity (number of cells per sq.cm)

The lac cells are exposed to several biotic and abiotic stresses during life period on the host hence also affect the density of female cells at crop maturity and vary widely from initial density of settlement. The female cell during their growth period increases in size and density at maturity determines the yield of lac insect at harvest and the potential of broodlac for next generation therefore can be considered as an important parameter linked with productivity of lac insect.

The data on mean of female cells per sq.cm of *Rangeeni* strain of lac insect in *Katki* crop season during 2016 presented in Table 8 and depicted in fig.3 reveal that mean density of female cell recorded at crop maturity were 5.00, 3.80, 4.90; 4.00, 4.20, 4.40 and 6.40, 5.70, 6.00 female cells per sq.cm respectively on lower, middle and upper portion of plant in three set of experiment, The maximum density of female cells of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season recorded during investigation was 11.00 female cells per sq.cm and minimum density recorded was 1.00 female cell per sq.cm. The results of present investigation are in full alignment with the findings of Mohanta *et al*. (2014) who also recorded average density of living female cells at crop maturity were 3.38-12.67 cells per sq.cm on palas plant for *Rangeeni* strain of lac insect. The drastic reduction in settlement density of females when compared to initial density of settlement may be attributed to mortality due to non feeding at initial stage, existing biotic/abiotic factors and death of male insects which die soon after fertilizing the females.

5.2.5 Weight of cell (mg) and resin weight (mg)

The weight of female cells of *Rangeeni* strain of lac insect on pigeonpea in *Katki* season during 2016 were recorded by electronic balance and resin weight were also recorded by removing dead insect body from the female cells. The results presented in Table 9 and depicted in fig.4 reveal that the mean weight of single female cell was 13.06 mg and ranged from 6-24 mg. The present results are in conformity with the findings Kumar *et al*. (2007) who evaluated 7 host plants of lac insect with reference to the cell weight found that it ranged from 10.12-14.21 mg in ber and 9.40-13.60 mg in pigeonpea (*Baisakhi*). The results of present study are also in full alignment with the findings of Mishra *et al*. (1999) who also evaluated the productivity of Indian lac insect (*Kerria lacca* Kerr) on *F. semialata* and *F. macrophylla* in terms of dry cell weight and recorded 8-19 mg and 9-18.83 mg cell weight on two hosts respectively.

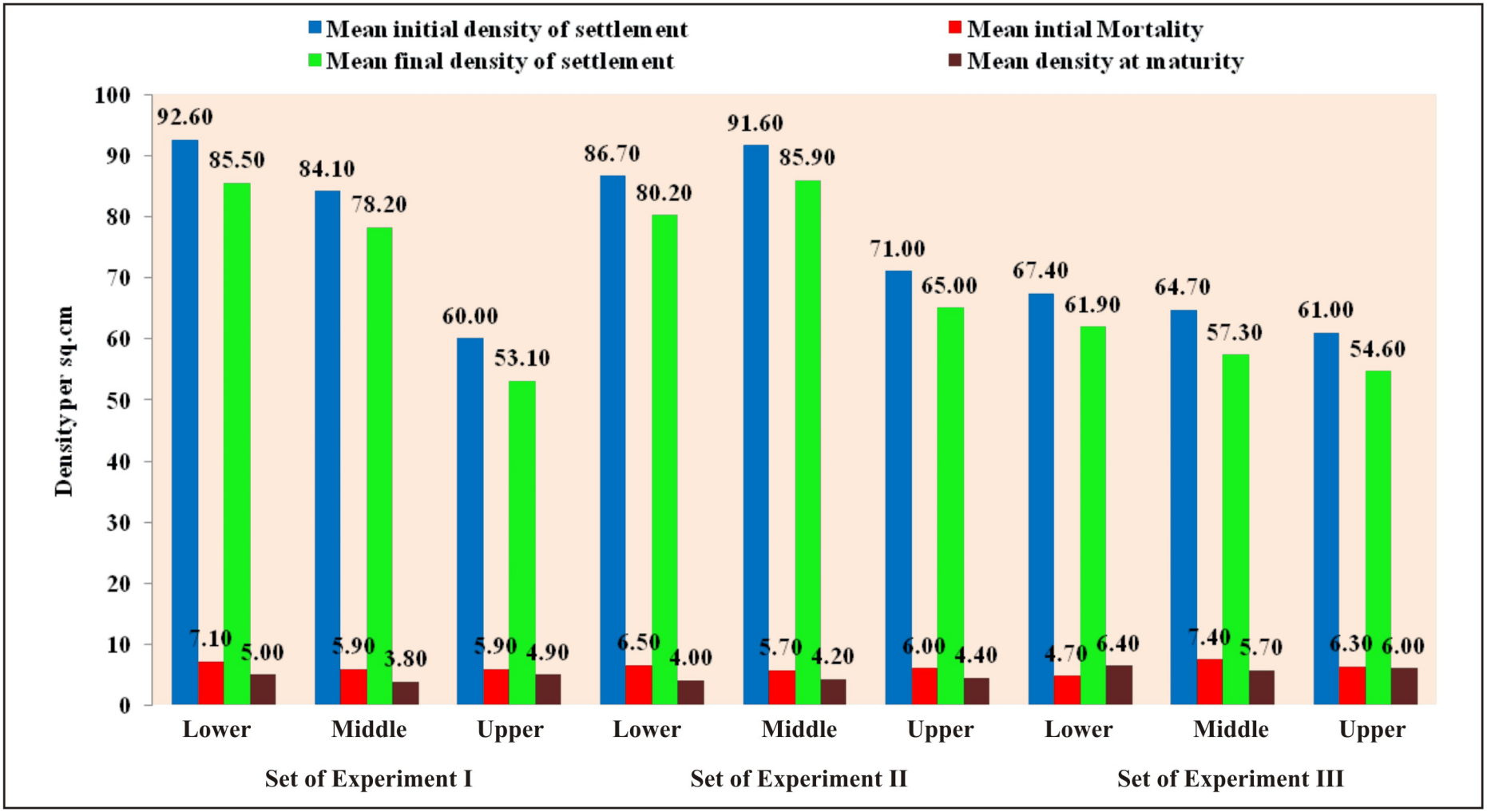

Fig. 3: **Mean initial density of settlement, initial mortality, final density of settlement, density at maturity of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016.**

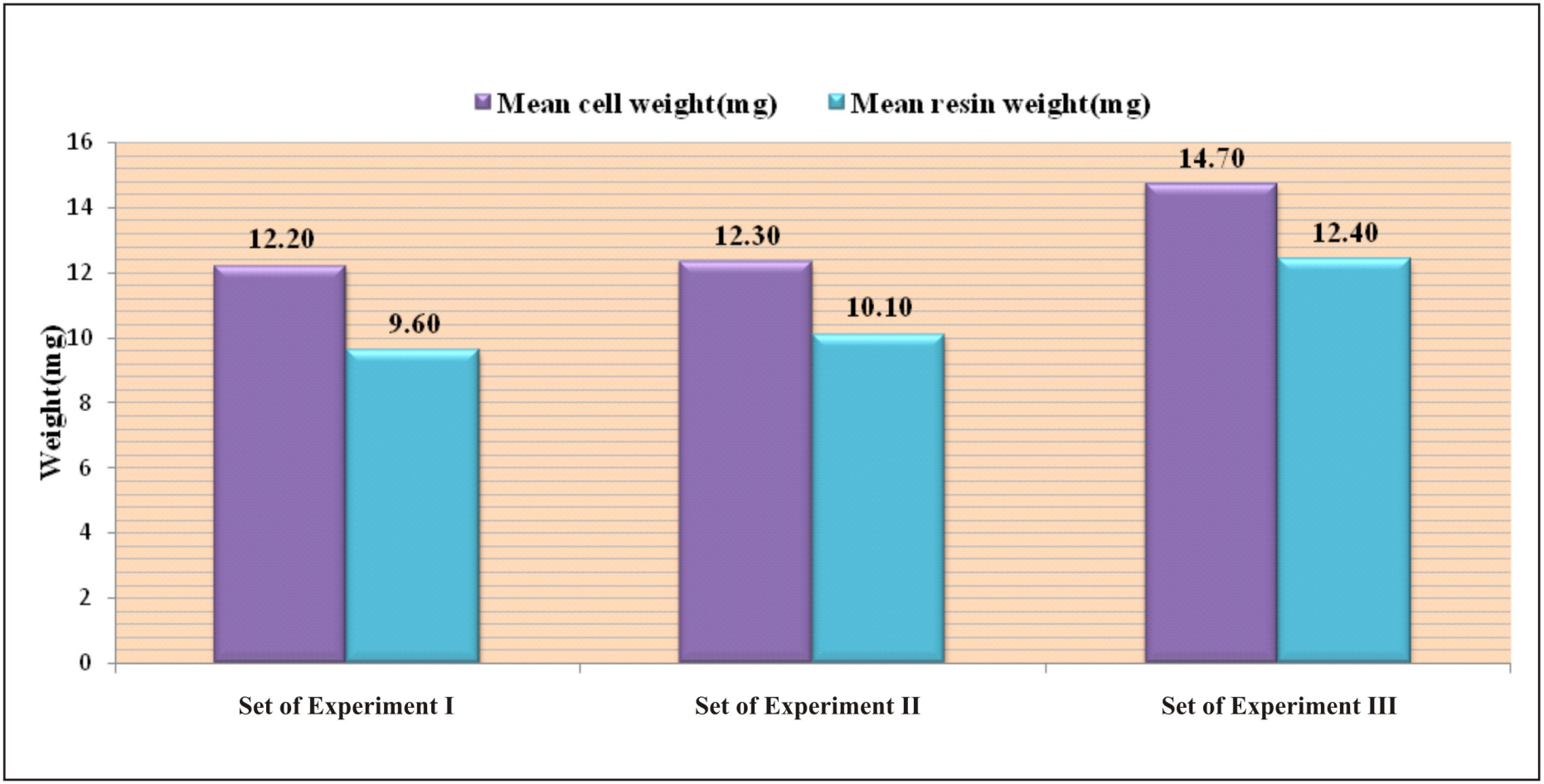

Fig. 4: Mean female cell and resin weight of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016.

The mean resin weight recorded in *Rangeeni* strain of lac insect on pigeonpea in *katki* season during 2016 was 10.70 mg per cell and ranged from 4-19 mg per cell. The results are in conformity to the findings of Sharma *et al*. (2007) who studied the resin producing efficiency of *Rangeeni* strain of *Kerria lacca* on different hosts and recorded highest resin weight on *A*. *auricaliformis* (9.09 mg), followed by *B*. *monosperma* (8.76 mg), *F*. *macrophylla* (7.49 mg) and *C*. *moschata* fruits (6.00 mg)

5.2.6 Fecundity (per female cell)

The eggs are laid by the female within the lac cell. Generally it lays about 200-500 eggs per female cell which may be fertilized or unfertilized. The female generally lays well developed eggs which hatch within few hours. The results presented in Table 10 and depicted in fig.5 reveal that the maximum larvae emerged per female cell were 430 while minimum 95 larvae emerged per female cell. The mean larvae emerged from single female cells of *Rangeeni* strain of lac insect on pigeonpea were 249.56 during *Katki* season 2016. The results of present investigation gets full support from the findings of Kong *et al*. (1984) who also reported that the reproductive potential of *Kerria lacca* ranged from 224-307 eggs in 1st generation and 160-240 eggs in 2nd generation. Similarly the findings of Mishra *et al*. (1999) who evaluated the productivity of Indian lac insect (*Kerria lacca* Kerr) on *F*. *semialata* and *F*. *macrophylla* in terms of fecundity and found that the fecundity varied from 253-565 and 297-477 larvae per female cell on the two hosts under study, respectively also strengthens the results of present investigation. The findings of Kumar *et al*. (2007) are also in support of the present investigation who evaluated 7 host plants of lac insect with reference to the fecundity and found highest fecundity in Ber (525.20 & 450.60) and lowest in pigeonpea (*Baisakhi*) (409.00 & 315.40)

5.2.7 Yield (g)

The data recorded on mean yield of sticklac and scrappedlac of *Rangeeni* strain of lac insect on pigeonpea in *Katki* crop season during 2016 presented in Table 9 and depicted in fig.6 reveal that mean yield of sticklac was 235.00 g per plant and ranged from 125-400g which confer the findings of Divakara (2013) who recorded 342.74 g and 219.02 g sticklac yield in *Flemengia*. *spp* in winter and rainy season respectively per plant. The results also reveal that mean scrappedlac yield per plant were 15.63 g and ranged from 3.74-29.45 g. The similar study to record the

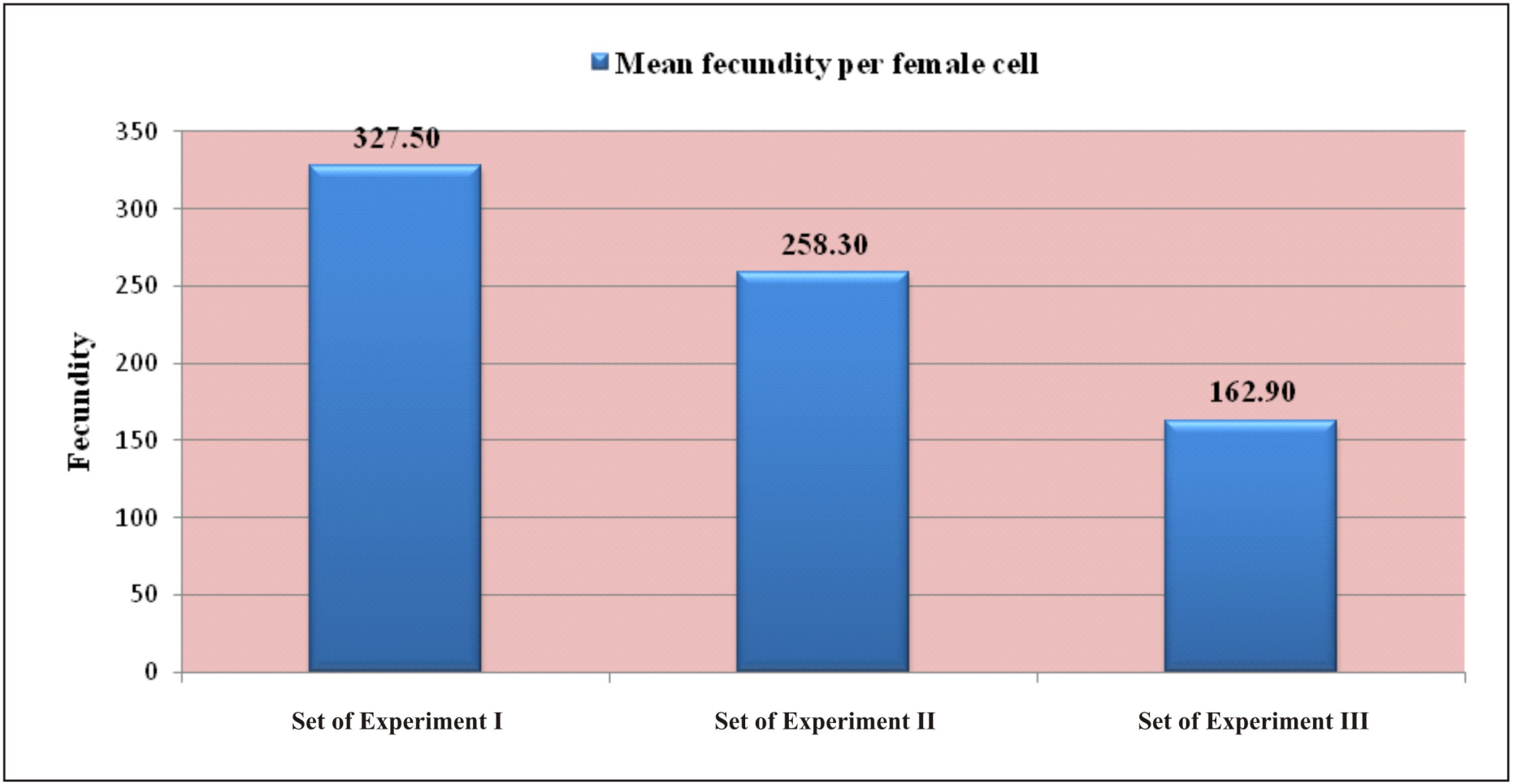

Fig. 5: Mean fecundity of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016.

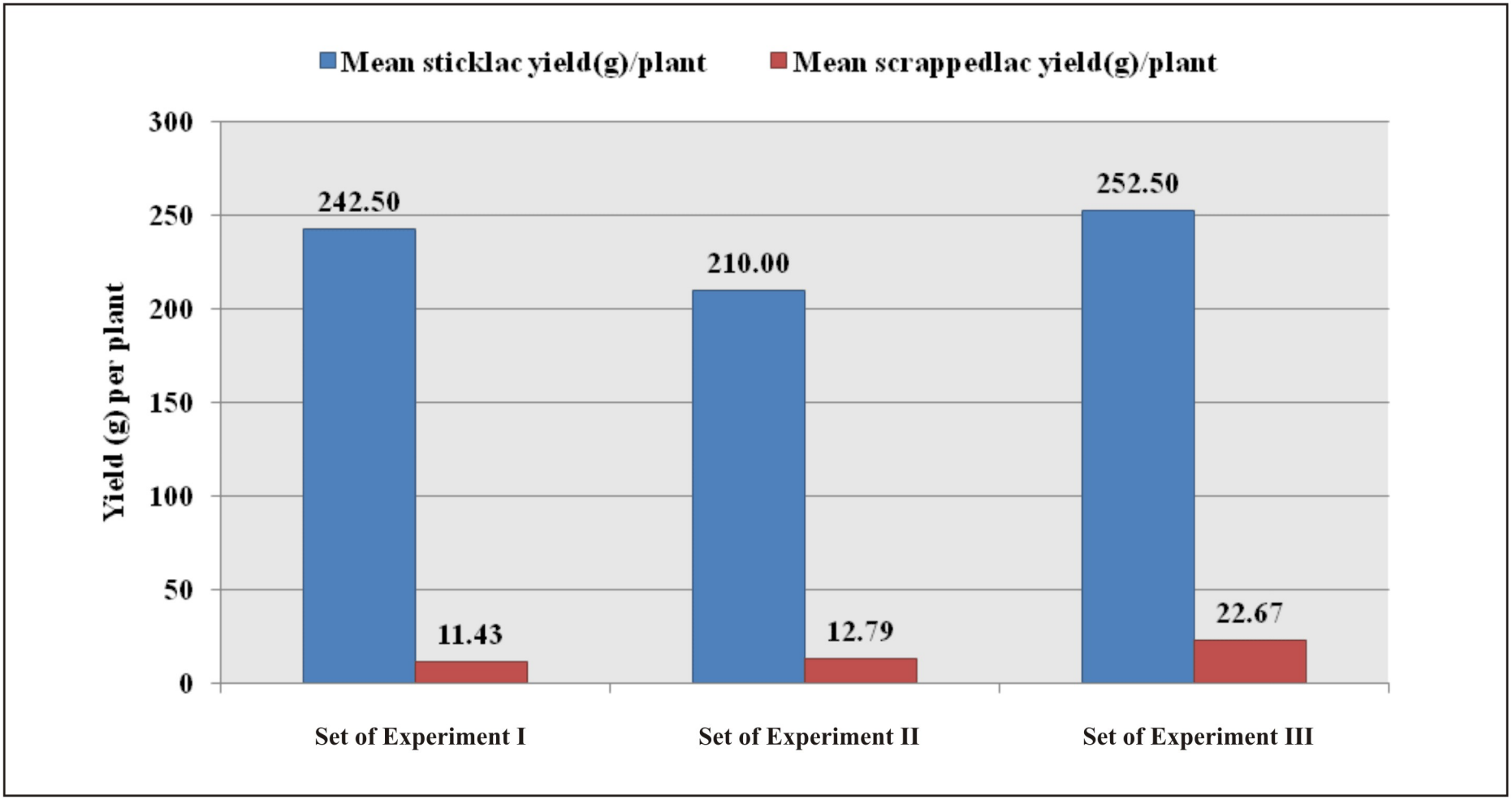

Fig. 6: Mean yield of sticklac and scrappedlac of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016.

scrapedlac yield was conducted by Divakara (2013) who recorded scrappedlac yield per plant 166.64 g in winter and 81.47 g in rainy season. The variation of results with the findings of the present investigation in the yield may be attributed to the size, growth, length of the plants, strain of lac insect and climatic condition etc which may cause difference in the yield of scrapedlac.

5.3 Natural enemies associated with the lac insect

Lac insect sucks the sap from specific plants known as lac hosts and being sedentary in nature is more vulnerable to be attacked by numbers of pests. A number of natural enemies (predators and parasitoids) have been found to infest lac insect during their sedentary life stages and also storage. The occurrence of natural enemies has been recorded to infest the lac insect throughout the year. Almost 35 species of primary and 45 species of secondary parasitoids have been reported in lac insect ecosystem. (Varshney, 1970 and Sharma *et al*, 2006)

The observations on the number of different natural enemies (predator and parasitoids) recorded from *Rangeeni* strain of lac insect on pigeonpea in *Katki* crop during 2016 has been presented in Table 11 and depicted in fig.7. The results recorded by collecting and identifying different species separately reveal that among total 716 natural enemies, 700 belong to Hymenoptera, 7 belong to order Lepidoptera and 9 belong to order Coleoptera. Among Hymenopterans 633 individuals were identified as *Erencyrtus dewitzi* Mahd belonging to family Encyrtidae, 37 individuals were identified as *Tachardiaephagus tachardiae* Howard belonging to family Encyrtidae and 30 individuals were identified as *Aprostocetus* (*Tetrastichus*) *purpureus* Cameron belonging to family Eulophidae. Among Lepidopteran two species *viz., Eublemma amabilis* Moore (5), *Pseudohypatopa* (*Holcocera*) *pulverea* Meyr (2) belonging to family Noctuidae and Blastobasidae were recorded to infest lac insect. Similarly one species was identified as *Oryzaephilus*. *Sp* (9), belonging to family Silvanidae of the order Coleoptera. The orders Hymenoptera, Lepidoptera and Coleoptera contributed 97.77, 0.98 and 1.26 per cent to the total natural enemies' population respectively. The results also reveal that the population of different species *viz., Erencyrtus dewitzi* Mahd, *Tahardiaephagus tachardiae* Howard, *Aprostocetus* (*Tetrastichus*) *purpureus* Cameron, *Eublemma amabilis* Moore, *Pseudohypatopa (Holcocera*) *pulverea* Meyr and *Oryzaephilus*. *spp* contributed 88.41, 5.17, 4.19, 0.70, 0.28 and 1.26 per cent respectively to the total population of natural enemies.

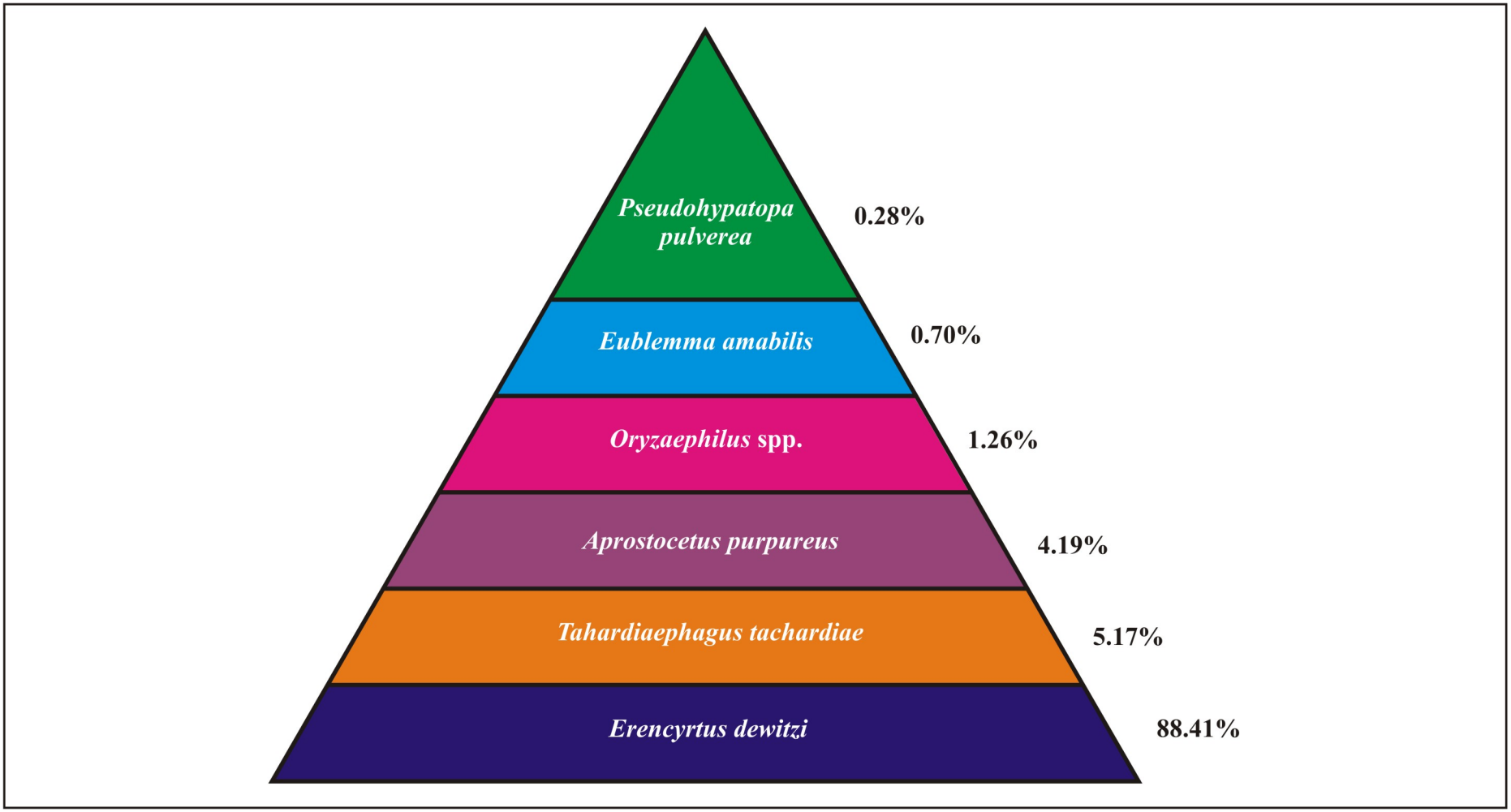

Fig. 7: Different species of natural enemies of lac insect recorded during experiment 2016.

Various research workers (Witt 1901, Glower 1937, Narayanan 1962, Varshney 1970 and Sharma *et al* 2006) studied the distribution and damage caused by the natural enemies (parasitoids and predators) to the lac insect and reported 22 species of insect predators, 30 species of primary parasitoids and 45 species of hyper parasitoid responsible for biotic stress associated with *Kerria lacca* Kerr. The results of the present investigations gets full support from the findings of Satapathy and Rout (2014) who had documented three parasitoids *viz*., *T. tachardiae* (Howard), *Parechtrodryinus clavicornis* Cameron and *E. tachardiae* Howard contributing about 53 per cent of the total natural enemies recorded in the lac ecosystem. They also reported that *E. tachardiae* (Eupelmidae), *T. tachardiae* (Encyrtidae) were dominant in their abundance and constituted a major proportion (26.01-27.15 %) of the total natural enemies population.

The findings of Sharma *et al.* (1997) who reported fourteen species of parasitoids belonging 13 genera representing ten families associated with *K. lacca* of these, *Aprostocetus purpureus* and *T. tachardiae* constituting 55.82 per cent and 28.37 per cent respectively to the total population of parasitoids are in alignment with the results of present study. Similarly Koteswara *et al.* (2013) also reported parasitoids of *Rangeeni* strain of lac insect *K. lacca* on a lac stick of rain tree (Weight of 50 g and length of 60 cm). They recorded 8 individuals *E. amabilis*, (Lepidoptera: Noctuidae), 3 individuals *P. pulverea* (Lepidoptera: Blastobasidae) insect predators; 29 individuals *Tachardiaephagus tachardiae* Howard (Hymenoptera: Encyrtidae), 9 individuals *Aprostocetus purpureus* Cameron (Hymenoptera: Eulophidae) among the population of natural enemies recorded during that investigation.

On the basis of results recorded in the present investigation and the discussions in the light of the work carried out by various scientist, it could be inferred that the *Rangeeni* strain of lac insect completes all the life stages of life cycle on the pigeonpea host and thrives well till maturity. The different productivity-linked parameters studies also showed positive results; hence in order to promote the cultivation of lac insect in tribal belt of southern Rajasthan, apart from ber and palas, the traditionally growing perennial pigeonpea crop could also be better utilized as the preferred host for its cultivation however there is a need to carry out further

investigations on the different related aspects such as effects of lac insect populations on the yield of pigeonpea, its varietal suitability, host preference, insect host interactions and its correlation with different biotic and abiotic factors. Thus the result of the present findings will not only help in understanding the life stages of lac insect during lac cultivation but will also provide an opportunity for further research in the subject.

6. SUMMARY

The results of the present investigation on **"**Biology and productivity-linked parameters of lac insect *Kerria lacca* Kerr on pigeonpea (*Cajanus cajan*) and its natural enemies" carried out at lac insect gene bank cum garden situated at Department of Entomology, Rajasthan College of Agriculture, MPUAT, Udaipur during 2016 have been summarized and detailed as under.

The biology of *Rangeeni* strain of lac insect was studied on pigeonpea during 2016 in *Katki* season. The mean duration of pre-sexual stages recorded were 47.90, 48.50 and 48.70 days in three plots respectively, and ranged from 47-51 days. The male emergence started 48.43 days after the inoculation of broodlac and mean duration of male emergence recorded were 11.30, 11.60 and 11.60 days respectively in three set of experiment with range of 10-14 days. The sex ratio observed as mean per cent male insect varied from lower portion of plant to upper portion of plant. The higher mean per cent male insect were recorded from upper portion of plant (17.75, 11.73, 11.56%) compared to middle (17.75, 10.63, 6.23%) and lower (11.33, 7.33, 4.02%) portion of plant in three set of experiment respectively during *Katki* season, 2016. The total life period of *Rangeeni* strain of lac insect on pigeonpea in *Katki* season during 2016 was recorded as 117 days from the date of inoculation to date of harvesting.

The various productivity-linked parameters were studied on *Rangeeni* strain of lac insect on pigeonpea in *Katki* season during 2016. The mean initial density of settlement of crawlers varied from lower portion to upper portion of plant and ranged from 20-121 crawlers per sq.cm with mean initial density of settlement of crawlers were 92.60, 84.10, 60.00 ; 86.70, 91.60, 71.00 and 67.40, 64.70, 61.00 crawlers per sq.cm at lower, middle and upper parts of plant in three set of experiment respectively. The mean per cent initial mortality recorded during settlement at lower, middle and upper portion of plants were 7.55, 8.12, 10.39 ; 7.70, 6.46, 7.49 and 9.08, 12.27, 12.57 per cent in three set of experiment respectively during 2016. The final density of settlement of crawlers varied from 17-117 crawlers per sq.cm with a mean final density of 85.50, 78.20, 53.10; 80.20, 85.90, 65.00 and 61.90, 57.30, 54.60 crawlers per sq.cm of settlement at lower, middle and upper portion of plant in three set of experiment respectively. The mean density of female cells at maturity recorded

at lower, middle and upper portion of plant were 5.00, 3.80, 4.90 ; 4.00, 4.20, 4.40 and 6.40, 5.70, 6.00 female cells per sq.cm in three set of experiment respectively and ranged from 1-11 cells per sq.cm. The fecundity of female cell recorded during investigation varied from 95-430 larvae per cell, with a mean fecundity of 249.56 larvae per female cell. The weight of female cell varied from 6-24 mg per cell with a mean weight of 13.06 mg per cell and the resin weight ranged from 4-19 mg per cell with a mean weigh of resin 10.70 mg per cell. The mean sticklac yield recorded was 235.00 g per plant and ranged from 125-400 g. Similarly the mean scrapped yield was recorded as 15.63 g per plant and ranged from 3.74-29.45 g per plant.

The natural enemies (parasitoids and predator) of *Rangeeni* strain of lac insect were recorded in *Katki* season during 2016. The results reveal that the three species of hymenopteran parasitoids *viz., Erencyrtus dewitzi* Mahd (88.41%) and *Tachardiaephagus tachardiae* Howard (5.17%) belonging to family Encyrtidae and *Aprostocetus* (*Tetrastichus*) *purpureus* Cameron (4.19%) belonging to family Eulophidae contributed (97.77%) to the total natural enemies population and two species of Lepidopteran predators *viz., Eublemma amabilis* (0.70%) belonging to family Noctuidae and *Pseudohypatopa* (*Holcocera*) *pulverea* Meyr (0.28%) belonging to family Blastobasidae contributed 0.98 per cent to the total natural enemies population and one species of Coleopteran predator *i.e. Oryzaephilus spp* belonging to family Silvanidae contributed 1.26 per cent to the total natural enemies population.

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Biology and Productivity-Linked Parameters of Lac Insect on Pigeonpea and Its Natural Enemies

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ABSTRACT

The investigations on biology and productivity-linked parameters of lac insect on pigeonpea and its natural enemies were carried out in the lac insect gene bank cum garden situated at Department of Entomology, Rajasthan College of Agriculture, MPUAT, Udaipur during 2016 with an aim to study the biological parameters *viz.,* duration of pre-sexual stages (days), duration of male emergence (days), sex ratio (per cent male insect) and life period of female lac insect (days) on pigeonpea, to evaluate the productivity-linked parameters *viz.,* initial and final density of settlement (crawlers per sq.cm), initial mortality (%), density at crop maturity (number of female cells per sq.cm), fecundity (larvae per female cell), weight of female cell and resin (mg) and yield (g) of lac insect and to record the natural enemies (parasitoids and predators) of lac insect.

The mean duration of pre-sexual stages lasts 48.36 days from the inoculation of broodlac with 11.50 days mean duration of male emergence and 11.33, 7.33, 4.02; 17.75, 10.63, 6.23 and 17.75, 11.73, 11.56 per cent male in lower, middle and upper portion of plant in three set of experiment respectively. The total life period of *Rangeeni* strain of lac insect in *Katki* crop season on pigeonpea recorded 117 days.

The initial density of settlement of first instar crawlers on a plant varied in different parts of plant which ranged from 20-121 crawlers per sq.cm and with a mean initial density of settlement of 92.60, 84.10, 60.00; 86.70, 91.60, 71.00 and 67.40, 64.70, 61.00 crawlers per sq.cm at lower, middle and upper parts of plants in three set of experiment respectively and the per cent mortality ranged from 6.46-12.58 per cent. The mean final density of settlement first instar crawlers ranged from 17-114 crawlers per sq.cm with mean of 85.50, 78.20, 53.10; 80.20, 85.90, 65.00 and 61.90, 57.30, 54.60 crawlers sq.cm on lower, middle and upper portion of plant in three set of experiment respectively. The density of female cells during maturity ranged from 01-11 cells per sq.cm and the fecundity recorded for single female cell was 95-430 larvae per cell. The cell and resin weight ranged from 6-24 mg per cell, 4-19 mg per cell, respectively while mean sticklac and scrappedlac yield recorded were 235g per plant, 15.63 g per plant respectively.

The three species of hymenopteran parasitoids *viz., Erencyrtus dewitzi* Mahd, *Tachardiaephagus tachardiae* Howard and *Aprostocetus* (*Tetrastichus*) *purpureus* Cameron contributed 97.77 per cent to the total natural enemies population whereas two species of lepidopteran and one species of coleopteran predators *viz*., *Eublemma amabilis*, *Pseudohypatopa* (*Holcocera*) *pulverea* Meyr and *Oryzaephilus spp* contributed 0.70, 0.28 and 1.26 per cent to the total natural enemies population respectively.

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अरहर पर लाख कीट की जैविकी एवं उत्पादकता से जुड़े हुए मापदण्ड तथा प्राकृतिक शत्रु

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(मुख्य सलाहकार)

अनुक्षेपण

अरहर पर लाख कीट की जैविकी एवं उत्पादकता से जुड़े हुए मापदण्ड तथा प्राकृतिक शत्रु पर राजस्थान कृषि महाविद्यालय, उदयपुर के कीट विज्ञान विभाग में लाख आनुवांशिकी संग्रह केन्द्र एवं लाख संग्रहालय में प्रयोगशाला में सन् 2016 में लाख कीट की जैविकी व उत्पादक मापदण्डों के अध्ययन के उद्देश्यों से अनुसंधान किया गया। इस अध्ययन में लाख कीट की जैविकी मापदण्ड जैसे – पूर्वयौन अवस्था की अवधि, नर निर्गमन अवधि, लिंगानुपात, मादा लाख कीट की जीवन अवधि एवं उत्पादकता सम्बन्धित पैमानों जैसे – प्रारम्भिक बसाव घनत्व (संख्या/वर्ग से.मी.), प्रारम्भिक मृत्यु दर (%), फसल परिपक्वता पर अन्तिम बसाव घनत्व (प्रति वर्ग से.मी. कोशिकाओं की संख्या), प्रजनन क्षमता (शिशु/मादा कोशिका), राल (मि.ग्रा.) व मादा कीट कोशिका का वजन व लाख की उपज (ग्राम) एवं लाख के प्राकृतिक शत्रुओं (परजीव्याब व परभक्षी) को दर्ज किया गया। पूर्व यौन अवस्था की औसत अवधि संचारण से 48.36 दिनों बाद, नर निर्गमन की औसत अवधि 11.5 दिन, पौधों के ऊपरी भाग से निचले भाग पर औसत नर प्रतिशत उपस्थिति 17.50, 11.73, 11.56 प्रतिशत से 11.33, 7.33, 4.02 प्रतिशत दर्ज की गई। कतकी फसल ऋतु में लाख कीट की रंगीनी प्रजाति की कुल जीवन अवधि अरहर पर 117 दिन दर्ज की गई।

शिशु लाख कीट की संख्या पौधे के अलग–अलग हिस्सों में भिन्न–भिन्न पाई गई जिसकी सीमा 20–121 शिशु प्रति वर्ग से.मी. थी। पौधों के निचले, मध्यम एवं ऊपरी भागों में औसत प्रारम्भिक आबादी घनत्व तीन अध्ययन में क्रमशः 92.6, 84.1, 60; 86.7, 91.6, 71 एवं 67.4, 64.7, 61 शिशु/वर्ग से.मी. व औसत मृत्यु दर प्रतिशत की सीमा 6.46-12.57 प्रतिशत दर्ज की गई। आबादी के औसत अन्तिम बसाव घनत्व संख्या की सीमा 17–114 प्रति वर्ग से.मी. 85.5, 76.2, 53.1; 80.2, 85.9, 65 एवं 61.9, 57.3, 54.6 प्रति वर्ग से.मी. का औसत पौधों के निचले, मध्यम एवं ऊपरी भाग पर दर्ज किया गया। परिपक्वता के दौरान मादा कोशिकाओं का घनत्व 1–11 कोशिका प्रति वर्ग से.मी. दर्ज किया गया। मादा कोशिका की प्रजनन क्षमता 95-430 शिशु

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[*] स्नातकोत्तर शोधार्थी, कीट विज्ञान विभाग, राजस्थान कृषि महाविद्यालय, उदयपुर (राज.)
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प्रति कोशिका, कोशिका एवं राल का वजन क्रमशः 6-24 मि.ग्रा. प्रति कोशिका व 4-19 मि.ग्रा. प्रति कोशिका, स्टिक लाख (छड़ी लाख) एवं छिली लाख की औसत उपज क्रमशः 235 ग्राम प्रति पौधा एवं 15.63 ग्राम प्रति पौधा दर्ज की गई।

हायमेनोप्टेरन परजीव्याभ की तीन प्रजातियों *इरेनसारटस डेविडजी* मोहद, *टाकार्डिएफैगस टेकार्डिए* हॉवर्ड और *अप्रोस्टोसिटस* (*ट्रेटास्टिकस*) *परपुरियस* कैमरन ने कुल प्राकृतिक शत्रुओं की आबादी में 97.77% योगदान दिया जबकि लेपिडोप्टेरन की दो प्रजातियाँ एवं कोलियोप्टेरन की एक प्रजाति क्रमशः *युब्लेमा अमाबिलिस, स्युडोहाइपटोप* (*होलकोसिरा*) *पलवेरिया* मेयर एवं *ओराइजीफिलस स्पीशीस* का कुल प्राकृतिक शत्रुओं की आबादी में 0.7%, 0.28%, 1.26% का योगदान दिया।

Appendix 1: Duration (days) of pre-sexual stages (male/female) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Duration of pre sexual stages (Days)									
	Set of experiment I			Set of experiment II			Set of experiment III		
Plant No.	**DOI**	**Date of Male/Female differentiation**	**No. days**	**DOI**	**Date of Male/Female differentiation**	**No. days**	**DOI**	**Date of Male/Female differentiation**	**No. days**
P_1	8/7/2016	25/8/2016	49	8/7/2016	24/8/2016	48	8/7/2016	26/8/2016	50
P_2	8/7/2016	25/8/2016	49	8/7/2016	24/8/2016	48	8/7/2016	25/8/2016	49
P_3	8/7/2016	24/8/2016	48	8/7/2016	23/8/2016	47	8/7/2016	23/8/2016	47
P_4	8/7/2016	23/8/2016	47	8/7/2016	24/8/2016	48	8/7/2016	26/8/2016	50
P_5	8/7/2016	23/8/2016	47	8/7/2016	25/8/2016	49	8/7/2016	27/8/2016	51
P_6	8/7/2016	23/8/2016	47	8/7/2016	26/8/2016	50	8/7/2016	26/8/2016	50
P_7	8/7/2016	23/8/2016	47	8/7/2016	26/8/2016	50	8/7/2016	24/8/2016	48
P_8	8/7/2016	25/8/2016	49	8/7/2016	26/8/2016	50	8/7/2016	22/8/2016	46
P_9	8/7/2016	24/8/2016	48	8/7/2016	24/8/2016	48	8/7/2016	23/8/2016	47
P_{10}	8/7/2016	24/8/2016	48	8/7/2016	23/8/2016	47	8/7/2016	25/8/2016	49

*DOI – Date of inoculation of broodlac

Appendix 2: Duration of male emergence (Days) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Duration of male emergence (Days)									
	Set of experiment I			Set of experiment II			Set of experiment III		
Plant No	Date of initiation	Date of completion	No. days	Date of initiation	Date of completion	No. days	Date of initiation	Date of completion	No. days
P_1	25/8/2016	5/9/2016	12	24/8/2016	3/9/2016	11	26/8/2016	5/9/2016	11
P_2	25/8/2016	3/9/2016	10	24/8/2016	3/9/2016	11	25/8/2016	6/9/2016	13
P_3	24/8/2016	3/9/2016	11	23/8/2016	3/9/2016	12	23/8/2016	3/9/2016	12
P_4	23/8/2016	3/9/2016	12	24/8/2016	4/9/2016	12	26/8/2016	6/9/2016	12
P_5	23/8/2016	2/9/2016	11	25/8/2016	4/9/2016	11	27/8/2016	6/9/2016	11
P_6	23/8/2016	5/9/2016	14	26/8/2016	5/9/2016	11	26/8/2016	6/9/2016	11
P_7	23/8/2016	2/9/2016	11	26/8/2016	6/9/2016	12	24/8/2016	3/9/2016	11
P_8	25/8/2016	3/9/2016	10	26/8/2016	6/9/2016	12	22/8/2016	3/9/2016	13
P_9	24/8/2016	4/9/2016	12	24/8/2016	4/9/2016	12	23/8/2016	2/9/2016	11
P_{10}	24/8/2016	2/9/2016	10	23/8/2016	3/9/2016	12	25/8/2016	4/9/2016	11

Appendix 3: Sex ratio as per cent male of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

		Lower			Middle			Upper		
Set of experiment	**Plant No**	**No of male cells/sq.cm**	**No of female cells/sq.cm**	**% male insect**	**No of male cells/sq.cm**	**No of female cells/sq.cm**	**% male insect**	**No of male cells/sq.cm**	**No of female cells/sq.cm**	**% male insect**
I	1	3	21	12.5	2	12	14.28	1	10	9.09
	2	0	5	0	1	16	5.88	3	10	23.07
	3	0	6	0	1	12	7.69	3	11	21.42
	4	6	10	37.5	7	6	53.84	4	12	25
	5	3	14	17.64	2	10	16.66	4	16	20
	6	0	9	0	3	15	16.66	4	12	25
	7	1	10	9.09	2	14	12.5	4	21	16
	8	2	8	20	2	6	25	1	16	5.88
	9	2	10	16.66	0	14	0	2	10	16.66
	10	0	10	0	2	6	25	3	6	33.33
II	1	0	8	0	3	3	50	2	10	16.66
	2	1	6	14.28	1	6	14.28	0	8	0
	3	0	5	0	0	6	0	2	14	12.5
	4	0	4	0	2	12	14.28	0	3	0
	5	4	20	16.66	0	8	0	2	20	9.09
	6	3	15	16.66	4	20	16.66	2	8	20
	7	2	10	16.66	0	10	0	3	15	16.66
	8	0	6	0	2	16	11.11	3	6	33.33
	9	0	9	0	0	5	0	1	10	9.09
	10	1	10	9.09	0	4	0	0	6	0
III	1	0	3	0	0	8	0	1	2	33.33
	2	0	6	0	2	20	9.09	2	10	16.66
	3	0	3	0	1	6	14.28	0	4	0
	4	0	5	0	2	16	11.11	2	12	14.2
	5	2	16	11.11	0	4	0	2	12	14.28
	6	0	6	0	0	4	0	1	10	9.09
	7	0	4	0	0	4	0	0	3	0
	8	0	5	0	1	10	9.09	1	10	9.09
	9	3	15	16.66	2	14	12.5	2	22	8.33
	10	2	14	12.5	1	15	6.25	3	25	10.71

Appendix 4: Life period (Days) of the female cells of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

	Set of experiment I			Set of experiment II			Set of experiment III		
Plant No	**DOI**	**DOH**	**Life period (days)**	**DOI**	**DOH**	**Life period (days)**	**DOI**	**DOH**	**Life period (days)**
P_1	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_2	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_3	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_4	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_5	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_6	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_7	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_8	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_9	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118
P_{10}	8/7/2016	4/11/2016	116	8/7/2016	5/11/2016	117	8/7/2016	6/11/2016	118

*DOI – Date of inoculation of broodlac & DOH – Date of harvesting

Appendix 5: Initial density of settlement (per sq.cm) of first instar crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Set of experiment I												
Lower					Middle				Upper			
Plant No	Total	Live	Dead	Mortality (%)	Total	Live	Dead	Mortality (%)	Total	Live	Dead	Mortality (%)
1	68	62	6	8.82	76	70	6	7.89	48	40	8	16.66
2	92	71	21	21.73	107	94	13	12.14	76	65	11	14.47
3	79	73	6	7.59	105	100	5	4.76	63	56	7	11.11
4	110	106	4	3.63	70	67	3	4.28	52	49	3	5.76
5	106	100	6	5.66	75	72	3	4	44	40	4	9.09
6	94	87	7	7.44	58	56	2	3.44	45	41	4	9.09
7	117	105	12	10.25	121	114	7	5.78	86	80	6	6.97
8	87	84	3	3.44	63	56	7	19.44	50	43	7	14
9	89	86	3	3.37	106	103	3	2.83	84	83	1	1.19
10	84	81	3	3.57	60	50	10	16.66	51	43	8	15.6

Appendix 6: Initial density of settlement (per sq.cm) of first instar crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Set of experiment II												
Lower					Middle				Upper			
Plant No	Total	Live	Dead	Mortality (%)	Total	Live	Dead	Mortality (%)	Total	Live	Dead	Mortality (%)
1	100	87	13	13	67	62	5	7.46	58	42	16	10.3
2	110	104	6	5.45	90	82	8	8.88	60	47	13	21.66
3	95	88	7	7.36	110	102	8	7.27	63	62	1	1.58
4	101	96	5	4.95	80	73	7	8.75	71	65	6	8.45
5	75	70	5	6.66	102	98	4	3.92	85	82	3	3.52
6	110	99	11	10	75	69	6	8	76	71	5	6.57
7	70	67	3	4.28	81	73	8	9.87	54	50	4	7.4
8	47	40	7	14.89	107	101	6	5.6	78	75	3	3.84
9	51	48	3	5.88	102	100	2	1.96	58	54	4	6.89
10	108	103	5	4.62	102	99	3	2.94	107	102	5	4.67

*Initial density of settlement in No/cm^2 and Initial mortality (%)

Appendix 7: Initial density of settlement (per sq.cm) of first instar crawlers of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Set of experiment III												
	Lower				Middle				Upper			
Plant No	Total	Live	Dead	Mortality (%)	Total	Live	Dead	Mortality (%)	Total	Live	Dead	Mortality (%)
1	102	95	7	6.86	85	83	2	2.35	103	96	7	6.79
2	68	65	3	4.41	60	56	4	6.66	94	87	7	7.44
3	32	30	2	6.25	60	53	7	11.66	47	39	8	17.02
4	58	50	8	13.79	56	54	2	3.57	83	80	3	3.61
5	75	71	4	5.33	92	79	13	14.13	80	77	3	3.75
6	53	49	4	7.54	73	67	6	8.21	62	55	7	11.29
7	107	101	6	5.6	73	66	7	9.58	50	42	8	16
8	65	62	3	9.23	53	38	15	28.3	45	32	13	28.88
9	54	44	10	18.51	60	49	11	18.33	20	17	3	15
10	60	52	8	13.33	35	28	7	20	25	21	4	16

*Initial density of settlement in No/cm^2 and Initial mortality (%)

Appendix 8: Final density of settlement (per sq.cm) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

	Set of experiment I			Set of experiment II			Set of experiment III		
Plant No	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
1	62	70	40	87	62	42	95	83	96
2	71	94	65	104	82	47	65	56	87
3	73	100	56	88	102	62	30	53	39
4	106	67	40	96	73	65	50	54	80
5	100	72	40	70	98	82	71	79	77
6	87	56	41	99	69	71	49	67	55
7	105	114	80	67	73	50	101	66	42
8	84	56	43	40	101	75	62	38	32
9	86	103	83	48	100	54	44	49	17
10	81	0	43	103	99	102	52	28	21

*Final density of settlement in No/cm^2

Appendix 9: Density at maturity of female cells (per sq.cm) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Set of experiment I				Set of experiment II			Set of experiment III		
Plant No	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
1	7	6	4	2	2	2	6	5	4
2	3	3	6	4	5	2	5	5	4
3	6	5	3	2	5	5	8	6	5
4	6	3	6	3	2	3	6	7	6
5	5	6	4	4	3	4	7	7	7
6	3	3	6	3	5	4	8	3	9
7	3	3	6	6	5	6	4	5	8
8	6	1	4	5	5	5	6	7	4
9	7	6	7	4	4	5	8	6	8
10	4	2	3	7	6	8	6	6	5

*Density at maturity (Number of female cells per sq.cm)

Appendix 10: Female cell weight (mg) and resin weight (mg) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Cell Weight (mg)				Resin Weight (mg)		
Sample No	**Set of experiment I**	**Set of experiment II**	**Set of experiment III**	**Set of experiment I**	**Set of experiment II**	**Set of experiment III**
1	7.00	6.00	8.00	6.00	5.00	7.00
2	12.00	13.00	24.00	11.00	11.00	19.00
3	8.00	20.00	10.00	5.00	15.00	9.00
4	9.00	15.00	8.00	8.00	13.00	6.00
5	9.00	13.00	12.00	4.00	12.00	11.00
6	19.00	9.00	16.00	14.00	6.00	15.00
7	14.00	10.00	24.00	13.00	9.00	17.00
8	10.00	11.00	15.00	8.00	9.00	13.00
9	14.00	18.00	20.00	10.00	15.00	18.00
10	20.00	8.00	10.00	17.00	6.00	9.00

Appendix 11: Fecundity (per female cell) of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Sample No	Set of experiment I	Set of experiment II	Set of experiment III
1	412	160	208
2	310	224	186
3	430	314	107
4	240	321	215
5	343	330	98
6	362	354	109
7	408	286	346
8	210	312	142
9	250	162	123
10	310	120	95

Appendix 12: Yield (g) of sticklac of *Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Plant No	Set of experiment I	Set of experiment II	Set of experiment III
P_1	225.00	150.00	225.00
P_2	250.00	175.00	250.00
P_3	220.00	250.00	125.00
P_4	340.00	200.00	400.00
P_5	240.00	200.00	275.00
P_6	250.00	250.00	325.00
P_7	125.00	225.00	250.00
P_8	300.00	350.00	200.00
P_9	275.00	175.00	300.00
P_{10}	200.00	125.00	175.00

Appendix 13: Yield (g) of scrappedlac *of Rangeeni* strain of lac insect on pigeonpea during *Katki* season, 2016

Plant No	Set of experiment I	Set of experiment II	Set of experiment III
P_1	21.95	8.21	28.34
P_2	4.62	19.28	19.12
P_3	15.65	14.77	15.66
P_4	6.64	12.65	29.45
P_5	17.62	5.45	29.45
P_6	3.74	24.23	25.26
P_7	11.64	7.23	34.52
P_8	14.52	13.25	15.77
P_9	8.64	14.62	17.18
P_{10}	9.32	8.23	11.95