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INFLUENCE OF DIFFERENT PREY DENSITIES AND APHID SPECIES ON THE DEVELOPMENT AND REPRODUCTION OF *COCCINELLA SEPTEMPUNCTATA* L. (COLEOPTERA : COCCINELLIDAE)

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Abstract : The influence of different prey densities and aphid species viz., *Brevicoryne brassicae* and *Lipaphis erysimi* (Kalt.) on the consumption, development and reproduction of *Coccinella septempunctata* L. were studied in the laboratory. The consumption of the larvae at varying prey densities increased from low to higher prey densities with upper asymptote at 65 aphids/day of *B. brassicae* and 50 aphids/day of *L. erysimi*. Similar responses were obtained in weight gained by the larva, relative growth rate of the larvae, reproductive responses of the adult female, longevity, fecundity and hatching success irrespective of the prey species. Developmental duration of the larvae was shortest at the optimum densities and longest at the 5 aphid density. The data on the consumption, duration, weight gained, pre-reproductive period, reproductive period, longevity, fecundity and hatching success revealed that *L. erysimi* aphid prey is more suitable for the development and reproduction of *C. septempunctata* than *B. brassicae* aphid.

Key words : *Coccinella septempunctata,* development, prey density, prey species, reproduction.

INTRODUCTION

Coccinella septempunctata is a predaceous ladybird beetle and is cosmopolitan in distribution. This beetle is of great economic importance due to its wide prey range which includes a number of potential pests of agricultural and horticultural crops (Singh and Singh, 1985; Omkar and Bind, 1993).

Larval development and adult reproduction of a predator are strongly affected by the availability of food. Variation in food availability and aphid species has the potential to affect the life attributes of the predator (Devi *et al.*, 2007). Moreover all aphid species are not equally suitable and ladybirds exhibit a choice for certain aphid species. Thus the present experiment was designed in order to assess the effect of

different prey densities of two aphid species viz., *Brevicoryne brassicae* and *Lipaphis erysimi* on the development and reproductive fitness of the adult beetle. The information so generated, will provide a way for the exploitation of *C. septempunctata* in the biological control of the above mentioned two aphid species.

MATERIALS AND METHODS

Adult males and females of *C. septempunctata* were collected from the field and mating pairs were kept in 9 cm Petri-dishes. They were supplied with excess supply of aphid species viz., *Brevicoryne brassicae* and *Lipaphis erysimi*. Eggs laid were kept in 5 cm Petri-dishes lined with dampened filter paper. Upon hatching, larvae were reared individually at one of the fixed prey densities of *B. brassicae* and *L. erysimi*. The prey densities fixed were 5, 20, 35, 50, 65 and 80 aphids/day for *B. brassicae* aphids while the densities for *L. erysimi* aphids were 5, 20, 35, 50 and 60 aphids/day. The total number of aphids consumed by the larvae at each density of both the prey species was recorded. Developmental duration of the

larvae in days and fresh weight of the larvae in mg were recorded after every moult. The relative growth rate (RGR) of the larvae was calculated from the recorded data using the formula, RGR= Final IV instar weight – Initial I instar weight/ developmental duration
The experiment was replicated 10 times (n=10) with each aphid species.

Larvae of this study that developed successfully into adult females were used for the study of effect of prey species and prey density on their reproduction. The emerged adults were continued to rear at their respective prey densities. Pre-reproductive, reproductive and post-reproductive period, lifetime fecundity, egg hatchability were recorded.

The data of the above experiments were subjected to analysis of variance followed by least significant difference test.

RESULTS AND DISCUSSION

The mean total and per day aphid consumed by *C. septempunctata* larvae when fed with varying prey densities of two aphid

Table 1. Total mean prey consumption and per day consumption of *C. septempunctata* larvae reared at varying prey densities of *B. brassicae* and *L. erysimi*

Prey density	*Brevicoryne brassicae*		*Lipaphis erysimi*	
	Total consumption	Per day consumption	Total consumption	Per day consumption
5	112.4 ± 4.6[a]	4.19±0.25	111.6 ± 3.96[a]	4.5±0.3
20	182.8 ± 5.63[ab]	11.43±0.38	268.8 ± 3.72[b]	15.63±0.52
35	233.0 ± 4.9[b]	15.33±0.53	324.0 ± 6.12[c]	21.89±0.75
50	266.6 ± 5.29[c]	19.75±1.02	394.8 ± 5.46[e*]	34.03±1.24
65	383.6 ± 6.58[d*]	30.44±1.95	381.2 ± 4.75[d]	29.32±0.86
80	363.8 ± 3.35[d]	26.75±0.88	-	-
cd	71.17		6.32	

Values are Mean±SE   Significant at P<0.05
Values followed by different letters are statistically different
* Values at optimum densities of the two aphid species are significant

species viz., *B. brassicae* and *L. erysimi* (Table 1) increased from low to higher densities. The consumption of *C. septempunctata* larvae when fed with *B. brassicae* was highest at 65 aphid density (383.6±6.58 aphids). The consumption above this density was found to be statistically similar with that of the consumption in 65 aphid density. Significant differences were also observed in the mean consumption of the larvae when fed with *L. erysimi* aphid. Aphid consumption was found to be maximum at the density of 50 aphids/individual/day (394.8±5.46 aphids). Thereafter the number of aphids consumed was significantly lower at 65 aphid density. Regression analysis revealed a curvilinear response. Further it was also observed that *C. septempunctata* larvae consumed more number of *L. erysimi* aphids than *B. brassicae* aphids (F= 16.16, P < 0.05).

Developmental duration of *C. septempunctata* larvae was inversely proportional with the number of aphid consumed (Table 2). Duration was longest at 5 aphid density irrespective of the prey species and shortest at the density where

consumption was maximum i.e. at 65 aphid density and 50 aphid density of *B. brassicae* and *L. eryimi* respectively. Developmental duration of the larvae fed with varying prey densities of *B. brassicae* were found to be significant and the values ranged from 12.6±0.89 days to 26.8±0.29 days whereas the developmental duration of the larvae fed with varying prey densities of *L. erysimi* ranged from 11.6±0.58 days to 24.8±1.05 days. Though the duration of development at optimum density of *L. erysimi* was comparatively shorter than the developmental duration at optimum density of *B. brassicae*, the difference was found to be statistically insignificant.

The weight gained by the larva and their relative growth rate was directly related to consumption and increased from low to higher prey densities irrespective of the prey species (Table 2). Maximum weight gain and relative growth rate of the larvae fed with the two aphid species were obtained at their respective optimum densities. Differences in values at different prey densities were found to be significant. Also, comparison of the results of weight gained at optimum densities

Table 2. Total developmental duration, weight gain and relative growth rate (RGR) of *C. septempunctata* larvae reared at varying prey densities of *B. brassicae* and *L. erysimi*

Prey density	B. brassicae			L. erysimi		
	Developmental duration	Weight gain	RGR	Developmental duration	Weight gain	RGR
5	26.8 ±0.29[c]	6.44±0.71[a]	0.24±0.03[a]	24.8±1.14[e]	7.55±0.99[a]	0.31±0.02[a]
20	15.6 ±0.52[b]	10.2 ±1.3[b]	0.64±0.04[b]	17.2±0.69[d]	16.80±1.46[b]	0.98±0.06[b]
35	13.0 ± 0.71[b]	21.35±0.58[c]	1.40±0.07[c]	14.8±0.75[c]	25.47±2.04[c]	1.72±0.11[c]
50	12.6 ± 0.4[a]	24.66±0.83[d]	1.83±0.13[d]	11.6±0.62[a]	31.48±1.57[e*]	2.72±0.23[e]
65	10.6 ± 0.89[a]	28.72±1.45[f*]	2.29±0.2[e]	13.0±0.90[b]	29.36±1.52[d]	2.27±0.17[d]
80	13.6 ± 1.14[a]	26.15±1.15[e]	1.92±0.17[d]	-	-	-
cd	1.5	1.17	0.20	1.17	1.10	0.089

Values are Mean±SE   Significant at P<0.05
Values followed by different letters are statistically different
* Values at optimum densities of the two aphid species are significant

Table 3. Duration of pre-reproductive, reproductive, post-reproductive period, fecundity and hatching success of *C. septempunctata* females at varying prey densities of *B. brassicae.*

Prey density	Pre-reproductive	Reproductive	Post-reproductive	Longevity	Fecundity	Hatching success
5	33.2±1.4[e]	-	-	33.2±1.4[a]	-	-
20	25.2±0.84[d]	20.6±0.6[a]	18.4±0.68[d]	64.2±0.73[b]	261.2±4.33[a]	49.21
35	22.4±1.12[c]	40.4±0.75[b]	15.8±0.58[c]	78.6±1.08[c]	606.8±5.28[b]	62.71
50	19.6±0.45[a]	61.6±0.93[c]	13.6±0.4[b]	91.8±2.58[d]	879.4±6.22[c]	73.59
65	17.4±0.54[a*]	74.4±0.68[d*]	10.8±0.49[a*]	102.3±1.85[e*]	1118±8.46[e*]	82.44
80	19.8±0.83[b]	63.2±1.55[c]	12.2±0.73[ab]	95.2±1.2[d]	908.8±3.45[d]	77.85
cd	2.2	3.4	2.0	4.76	13.0	

Values are Mean±SE   Significant at P<0.05
Values followed by different letters are statistically different
* Values at optimum densities of the two aphid species are significant

Table 4. Duration of pre-reproductive, reproductive, post-reproductive period, fecundity and hatching success of *C. septempunctata* females at varying prey densities of *L. erysimi*

Prey density	Pre-reproductive	Reproductive	Post-reproductive	Longevity	Fecundity	Hatching success
5	39.8±0.66[d]	-	-	39.8±0.66[a]	-	-
20	15.6±0.82[c]	26.4±2.23[a]	30.2±2.67[d]	72.2±3.77[b]	307±6.31[a]	65.69
35	13.4±0.81[b]	50.6±1.33[b]	27.6±1.12[c]	91.6±5.26[c]	697.4±3.97[b]	73.6
50	10.4±0.68[a*]	87.2±1.85[d*]	18.2±0.92[a*]	115.8±3.45[e*]	1312±5.53[d*]	88.32
65	13.8±0.58[ab]	72.8±0.86[c]	23.8±1.43[b]	110.4±4.87[d]	924±8.37[c]	83.85
cd	1.93	1.65	1.62	1.44	6.76	

Values are Mean±SE   Significant at P<0.05
Values followed by different letters are statistically different
* Values at optimum densities of the two aphid species are significant

of the two aphid species revealed that the weight gained by the larvae was significantly higher when fed with *L. erysimi* than *B. brassicae* (F= 65.66, P< 0.05).

The duration of pre-reproductive, reproductive, post-reproductive period, total longevity, fecundity and egg viability of females when reared at varying prey densities of *B. brassicae* and *L. erysimi* are presented in Table 3 & 4 respectively. The pre-reproductive, reproductive and post reproductive period decreased from low to higher prey densities irrespective of the prey

species and the variations observed were found to be significant. The pre-reproductive period was relatively prolonged when fed at low aphid density of 5 aphids/day/ individual. At the densities of 65 *B. brassicae* aphids and 50 *L. erysimi* aphids, pre-reproductive period was found to be shortest and the reproductive period longest. Adult longevity when fed with varying prey densities of *B. brassicae* and *L. erysimi* ranged from 33.2±1.4 to 102.6±1.85 days and 39.8±0.66 to 115.8±3.45 days respectively. Further pre-reproductive period of adult fed

with *L. erysimi* was significantly shorter than that of adults fed with *B. brassicae* (F = 17.50, P<0.05). Reproductive period and longevity of adult females fed on *L. erysimi* was found to be significantly longer than those fed with *B. brassicae* aphid ($F_{reproductive}$ = 55.35, P<0.05; $F_{longevity}$ = 9.78, P<0.05).

The fecundity and hatching success of adult females reared at varying prey densities of the two aphid species increased from low to higher densities with optimum response at the prey densities of 65 and 50 aphids/day of *B. brassicae* and *L. erysimi* respectively. Adult females reared at 5 aphid density of the two aphid species failed to oviposit. The number of eggs laid at 80 aphid density if *B. brassicae* and 60 aphid density were found to be significantly lower than at their respective optimum densities. Meanwhile if a comparison be made between the fecundity of adult females reared at optimum densities of the two aphid prey species it was found that the fecundity of adult *C. septempunctata* fed with *L. erysimi* was significantly higher than that of the adult fed with *B. brassicae* (F = 423.83, P<0.05).

Feeding and oviposition patterns of individual predator reflect the adaptiveness of their populations to foraging conditions in fields (Agarwala *et al.,* 2001). A number of studies have demonstrated the effects of prey quantity on the consumption, survival and reproduction of aphidophagous predators (Kawauchi, 1979; Ives *et al.* 1993, Yasuda and Ishikawa 1999). In the present study also the quantity of prey available for predation to the predator was found to significantly affect the consumption, survival and reproduction of the larva and adult of *C. septempunctata.* Their optimum responses in terms of consumption, development and reproduction were noticed at the prey densities of 65 aphid density and 50 aphid density of *B. brassicae* and *L. erysimi*

respectively thus exhibiting Holling's (1965) type II response. Such response is typical of predators foraging in unstable prey populations and this means rapid utilization of food by predators even at lower densities.

The duration of development, weight gained and relative growth rate was found to be directly related to the amount of aphid consumed. Developmental duration was prolonged for larvae reared at 5 aphid density irrespective of the prey species and shortest at the density where the consumption was highest. Present result is in conformity with that of Ives *et al.* 1993, Devi *et al.* 2007, Lokeshwari *et al.* 2010. Reduced consumption probably resulted in reduced nutritional levels thereby affecting the larval development.

Prey density also had a profound effect on the duration of pre-reproductive, reproductive, post-reproductive, longevity and fecundity of the adults irrespective of the prey species. At low prey density pre-reproductive period was considerably prolonged and reproductive duration was much shorter thereby affecting the fecundity and longevity of the beetles. While at the optimum densities pre-reproductive period was much shorten and reproductive period lengthened thereby facilitating oviposition. Similar reproductive responses with varying prey densities had also been reported by Agarwala *et al.* (2001), Sharmila *et al.* (2009) and Devi *et al.* (2007). The inability of the *C. septempunctata* adult females to oviposit at 5 aphid density may be the result of not getting enough nutrients required for ovariole maturation.

Further prey species was also found to significantly affect the consumption, development and reproduction of *C. septempunctata.* Prey are categorized as essential, alternative and rejected prey on the basis of quantitative data on

developmental parameters (Hodek and Honek, 1996). The results from the present study revealed that both *B. brassicae* and *L. erysimi* are essential prey of *C. septempunctata*. Essential foods ensure completion of larval development and oviposition and alternative food serves only as a source of energy and prolongs survival (Mills, 1990). It was observed that larvae of *C. septempunctata* consumed more of *L. erysimi* aphids than *B. brassicae* aphids and the performance of this beetle in terms of development and reproduction was much enhanced when fed with *L. erysimi*. The probable reason of this prey discrimination is directly linked to prey quality, requirement of high energy resources for metabolism and reproduction and to high lipids and proteins (Houck, 1991). Omkar and Srivastav (2003) also reported *L. erysimi* to be the most suitable prey of *C. septempunctata* compared to other 5 aphid species (viz., *Aphis craccivora, Aphis gossypii, Aphis nerii, Myzus persicae* and *Uroleucon compositae*).

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SYSTEMATICS AND BIOMETRICAL STUDIES OF *SCHOUTEDENIA EMBLICA* (PATEL & KULKARNI) (HOMOPTERA : GREENIDEINAE)

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Abstract : *Schoutedenia emblica* (Patel & Kulkarni, 1952) (Type species : *Cerciaphis emblica* Patel and Kulkarni, 1952; syn. *S. emblica andhraka* David and Hille Ris Lambers, 1956 is a one of the pest of aonla *Phyllanthus emblica* in eastern U.P. It can be distinguished by another species *S. ralumensis* Rübsaamen, 1905 by the characters such as length of p.t., proportion of p.t. to base of last antennal segment and to the ultimate rostral segments. Both morphs (apterous as well as alate) of *S. emblica* were re-described providing detailed morphometry of their different parts of the body.

In the present study, help of morphometry was taken to identify the instars of *S. emblica* reared on seedlings of food plants to a known instar and taken from non-clonal populations. Each instar was described and illustrated. The length of hindtibia and siphunculi are found to be useful characters for identifiying I and II instar of apterous and alatoid morphs while ratio of length of antennal segment III and IV are helpful in identifying apterous III, IV instars and adults. Size of wingpads and whether it overlaps each other or not separate the alate III and IV instars alates. A key was prepared to separate each instar of both morphs with high precision.

Key words : Amla aphid, *Schoutedenia emblica*, systematics biometry

INTRODUCTION

It is an established fact that the life cycle of the aphids is a complex sequence of events involving a series of different forms of individual (morphs) – the transition from one morph to another is triggered by changes in the environment (Hille Ris Lambers, 1966). The life cycle represented by parthenogenesis and sexual generation is designated *holocycly* whereas that involving continuous year-round parthenogenesis only is designated *anholocycly*. Some species exhibit either holocycly or anholocycly, and some a combination of both according to the environmental conditions they encounter in different regions (Blackman, 1976).

Biometrical studies are an important aspect of and a reliable criterion for age

grading aphids. Morphometrical data play a critical role in studying the population of the any species in the field. The aphid, *Schoutedenia emblica* (Patel and Kulkarni) is an indigenous pest of *Phyllanthus emblica* L. (Malpighiales : Phyllanthaceae) in India.

India shared about 65% of the Greenideinae fauna of the world (Ghosh and Agarwala, 1993) and endemism has been found to be more than 80% (Agarwala and Ghosh, M.R., 1985). Most of the species of this subfamily are distributed in north-east and northwest India and very few are reported from the plain of Uttar Pradesh (Singh *et al.*, 1999; Agrawal, R., 2006). On the basis of presence and absence of eminent body-projections in the apterae, Takahashi (1931) divided the subfamily Greenideinae into two tribes: Cervaphidini and Greenideini. In the same publication, he subdivided the tribe Cervaphidini into three subtribes Anomalaphidina, Cervaphidina and Setaphidina. For Anomalaphidina, comprising of only *Anomalaphis* Baker, he stated that the head is not fused with the pronotum in apterae, and for the other two he pointed out that in apterae the head is fused with the pronotum. Later, Eastop (1966) dealing with the Australian aphids, provided generic description of *Anomalaphis* and stated that the head and pronotum in apterae are fused. Thus, Eastop (1966) concluded that Takahashi's subtribe Anomalaphidina is not valid.

Earlier, Eastop (1961) considered the Takahashi's subtribe Setaphidina as the tribe Setaphidini under the subfamily Greenideinae. The only genus *Setaphis* van der Goot, 1917 comprising two species *luteus* van der Goot, 1917 and *viridis* van der Goot, 1917, later (Noordam, 1994) proved to be one and the same species has been transferred to the genus *Schoutedenia* Rübsaamen, 1905 (Remaudière, 1988).

Therefore, *Setaphis* becomes a synonym of *Schoutedenia.* Since the tribe 'Setaphidina' contained only one genus, *Setaphis,* which is a synonym of *Schoutedenia,* the name 'Setaphidina' cannot be used at the tribal or subtribal level and hence, the Eastop's tribe Setaphidini is considered as the tribe Schoutedeniini. Thus, Greenideini consists of three valid tribes: Cervaphidini, Geenideini, and Schoutedeniini.

Rübsaamen (1905) described the genus *Schoutedenia* with *ralumensis* as the type species from New Guinea. Baker (1920) grouped the genus with a small group of closely related genera that were not placed under any Subfamily. Eastop and Hille Ris Lambers (1976) listed *Setaphis luteus* van der Goot, 1917, *Setaphis viridis* van der Goot, 1917 and *Cerciaphis emblica* Patel and Kulkarni, 1952 along with *ralumensis* under the genus *Schoutedenia* Rübsaamen, 1905. Ghosh, A.K. (1982) considered two species *ralumensis* and *luteus* under the genus *Schoutedenia* and *Cerciaphis bougainvilliae* Theobald, 1920 [= *Setaphis bougainvilleae* (Theobald, 1920) : George, 1927; = *Schoutedenia bougainvilleae* (Theobald, 1920) : Ghosh and Raychaudhuri, 1962; Ganguli and Ghosh, 1965; Ghosh A.K. *et al.*, 1970; Ghosh M.R. *et al.*, 1971; Singh *et al.*, 2005], *Cerciaphis emblica* Patel and Kulkarni, 1952, *Setaphis viridis* van der Goot, 1917, *Setaphis formosanus* Takahashi, 1929 and *Schoutedenia emblica andharaka* David and Hille Ris Lambers, 1956 were listed as synonymous with *luteus*. Remaudiere (1988) revised the genus *Schoutedenia* and recognised only one species, *ralumensis*, and rest of the aforesaid species as its synonymy. However, later on, Remaudiere (1990) in a note rectified his earlier decision and recognised *Schoutedenia emblica* (Patel and Kulkarni, 1952) as the second species under the genus. In doing so, he (*op. cit.*) considered

Schoutedenia emblica andhraka David and Hille Ris Lambers, 1956 as its only synonymy. Ghosh, A.K. and Agarwala (1993) studied the specimens of *Schoutedenia* collected from different parts of India, Nepal, Pakistan and Sri Lanka variably reported as *Schoutedenia luteus*, *Schoutedenia emblica*, *Schoutedenia emblica andhraka* and *Schoutedenia ralumensis* and concluded that both *ralumensis* and *emblica* are represented in the Indian region and can be distinguished by the length of p.t., proportion of p.t. to base of last antennal segment and to the ultimate rostral segments.

In India, Patel and Kulkarni (1952) reported the species for the first time on *Phyllanthus emblica* L. Later on, several workers reported *Schoutedenia emblica* from the same host plant (Raychaudhuri, D.N, 1980) from different places. Only *Flueggea leucopyrus* Willd. (= *Securinega leucopyrus* (Willd., bushweed) (Malpighiales : Phyllanthaceae) (Joshi and Poorani, 2007) was reported as other host plant. Literature dealing with its population biology is very scanty and sketchy.

MATERIALS AND METHODS

The aphids were collected either directly from the plants parts such as leaves, flowers, stem, buds, inflorescence bearing aphids by cutting that part of the plant. The infested part is then kept in plastic bags. Within 24 hours these plastic bags were brought to the laboratory. Among these collected aphids some of them were preserved in a preservative (a mixture of 70% ethyl alcohol and glycerin in the ratio of 5:1), for taxonomical studies. The remaining aphids were kept into a translucent plastic vials with wet cotton at the bottom. The open ends were covered with muslin cloth and tightened with rubber bands to get alate forms of the aphids. The extensive field notes on the colour of the specimen, food plants, intensity of infestation, locality and date of collection etc. were recorded.

a. Clearing of the collected material. The aphids were first gently boiled in 95% ethyl alcohol for 5 to 10 minutes in water bath. Thereafter, the alcohol is decanted off and the aphids were gently boiled again in 10% KOH solution until the specimen appeared somewhat transparent. KOH solution is decanted off after cooling and the specimens were again rinsed in 95% ethyl alcohol. The specimens were again put in saturated mixture of chloral hydrate and phenol and were heated for 10-15 minutes in water bath.

b. Mounting of the aphids. The cleared specimens were mounted in the mounting medium on micro-slides. Mounting medium was prepared by mixing chloral hydrate (200 g), powered gum acacia (120 g), glycerin (65 ml) and distilled water (200 ml). For this, firstly the gum was dissolved in distilled water. The chloral hydrate and glycerin were then poured in this solution. The solution was filtered twice through glass wool for removing impurities. After mounting the specimens, the slides were properly labeled and left in the trays in horizontal position, and then placed in an incubator at 50-60 °C for slow drying. The dried slides were stored in slide cabinets.

c. Measurement of the aphids. As suggested by Raychaudhuri, D.N. (1980), the following measurements were taken by ocular micrometer corroborated with stage micrometer and have expressed in mm.

Body length : Distance from middle of frons to tip to cauda.

Body width : Maximum width of body.

Antenna : Length of ultimate segment form its base of segment I to the tip of flagellum.

Base of ultimate segment of antenna: Length of the ultimate segment from basal articulation to distal end of primary rhinaria.

Processus terminalis (p.t.): Length of ultimate segment between apical end of primary rhinarium and tip of the segment.

Basal diameter of antennal segment (b.d.): Diameter of the segment just following basal articulation of the segment.

Ultimate rostral segment (u.r.s.): Length of the portion of rostrum between basal articulations of segment IV to the tip of rostrum.

Secondry segment of hind tarsus (h.t.2): Length of segment of hind tarsus from basal articulation to the tip.

Length of siphunculus: Length from its base to apex.

Length of cauda: Length from middle of its very base to apex.

RESULTS AND DISCUSSION

A. Characteristic features of *Schoutedenia* Rübsaamen, 1905

Body green to olive green or yellowish to lemon yellow in life. Head flat between the bases of antennae, without any tubercle, fused with pronotum in apterous morphs and separated in alate morphs; dorsal cephalic hairs few, short and with blunt apices. Eyes 3-faceted in apterous morphs and multi-faceted in alate morphs. Antennae 5-segmented, about 0.5-0.8x as long as the body, more distinctly imbricated apically; secondary rhinaria absent in apterous viviparae but usually present on a.s. III and IV in alate viviparae; flagellar hairs very short, sparse, with blunt apices, p.t. 0.4-0.9x as long as base of a.s. V. U.r.s. short, blunt, extend upto midcoxae or little beyond; 0.65-

0.90x as long as second segment of hind tarsus. Abdominal dorsum pale with reticular network of hexagones throughout, both in apterae and alatae; dorsal hairs short and blunt in apterae, short and with fine apices in alatae; 7th tergite bears a pair of long, hair-bearing dark processi with spinular imbrications. Siphunculi cone-shaped, brown, reticulated on basal half and 4-5 concentric rings on apical half, bearing 4-5 short hairs with blunt apices in apterae, and with acute apices in alatae. Cauda oval with 4 long hairs.

B. Description of *Schoutedenia emblica* (Patel and Kulkarni, 1952)

Type : *Cerciaphis emblica* Patel, G.S. and Kulkarni, H.L., 1952. *Current Science*, 21: 350.

a. Synonymy :

Schoutedenia emblica subsp. *andhraka* David and Hille Ris Lambers, 1956: *Indian J. Entomol.*, 18 : 41-44.

b. Citations

1952. *Cerciaphis emblica* Patel, G.S. and Kulkarni, H.L., *Curr. Sci.*, 21: 350.

1956. *Schoutedenia emblica* subsp. *andhraka* David and Hille Ris Lambers, 1956 : *Indian J. Entomol.*, 18 : 41-44.

1962. *Schoutedenia lutea* partim *emblica*, Ghosh, A.K. and Raychaudhuri, D.N., *J. Asiatic. Soc.*, 4: 104.

1963. *Schoutedenia emblica*, Behura, B.K., Recent *Adv. Zool. India*, 1961: 25-78.

1982. *Schoutedenia lutea* partim *emblica*, Ghosh, A.K., *Orient. Ins.*, 16 : 89.

1988. *Schoutedenia ralumensis* partim *emblica*, Remaudiere, G., *Bull. Soc. ent. Fr.*, 93 : 66.

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1990. *Schoutedenia lutea*, Lardner, R.M. and Hales, D., *Entomophaga*, 35(4) : 557-567.

1993. *Schoutedenia emblica*, Ghosh, A.K. and Agarwala, B.K. *Fauna of India (Homoptera: Aphididae), Part 6, Subfamily : Greenideinae. Zool. Surv. India*, 46-51.

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2009. *Cerciaphis emblica*, Bharpoda, T.M., Koshiya, D.J. and Korat, D.M., *Karnataka J. Agric. Sci.*, 22(2) :314-318.

2010. *Schoutedenia lutea*, Garg, V.K. and Patel, Y., *The Indian Forester*, 136(4): 14.

2011. *Schoutedenia emblica*, Sridhar, Y., *Indian J. Plant Prot.*, 39 : 35-37.

2013. *Schoutedenia emblica*, Qing-Hua Liu, A. B., Li-Yun Jiang, A. and Ge-Xia Qiao, A.C., *Invert. Syst.*, 27(4): 428-438.

c. Common names : Amla aphid, aonla aphid, emblica aphid, Indian gooseberry aphid.

d. Material examined : Several apterous viviparous and alate viviparous adults and nymphs; **host plants, location and date of collection:** Phyllanthaceae : *Phyllanthus emblica* L., Gorakhpur (20.v.2007), Mahrajganj (19.vii.2008), Kushinagar (10.ix.2008); Barda (Azamgarh) (17.vi.2007), Basti (10.viii.2007).

e. Morphological description

1. Parhtenogenetic viviparous morphs

i. Apterous parthenogenetic viviparous female (Fig. 1, Plate 1-2)

Body green to olive green to lemon yellow in life, 1.13-1.98 mm in length and 0.40-1.25 mm as the maximum width. Head flat between the bases of antennae, without any tubercle, fused with pronotum; dorsal cephalic hairs few, short and with blunt apices. Eyes 3-faceted. Antennae 5-
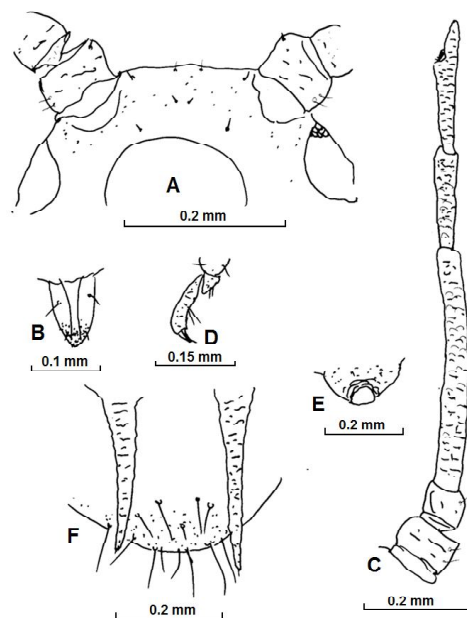

Fig. 1. *Schoutidenia emblica.* Apterous viviparous female: A. Head, B. u.r.s., C. Antenna, D. Hind tarsi, E. Siphunculus, F. Cauda with processi.

segmented, pale brown to brown, 0.65-1.08 mm long and 0.46-0.78x as long as the body; flagellum imbricated, secondary rhinaria absent; 2.12-2.68x as long as a.s. III; p.t. 0.06-0.10 mm long and 0.33-0.66x as long as base of the last antennal segment, 0.43-0.76x as long as h.t.2 and 0.52-1.10x as long as u.r.s. Rostrum short, reaching up to midcoxae; u.r.s. blunt, 0.08-0.13 mm long, 0.63-1.09x as long as h.t.2, segment 4 with 1 or 2 short pointed accessory hairs. Legs are pale brown, femora on distal half with spinular imbrications, such imbrications distributed all along the inner margin and distal one-third region of tibiae. First tarsal segment with 3 hairs.

Abdominal dorsum pale, with non-spinular polygons all over, each polygon filled with reticulations; dorsal hairs sparse, short and with blunt apices, the longest one on anterior tergites 0.04-0.06 mm long; venter with spinular imbrications all over; 7th tergite with a pair of pleurally placed finger-like processi, brown, 0.11-0.33 mm long and with spinular imbrications. Siphunculi cone-shaped, brown, reticulated on basal half and 4-5 concentric rings on apical half, bearing 4-5 short hairs with blunt apices, 0.05-0.10 mm long and 0.03-0.07x as long as body, with 3-4 short spinular interconnecting striae. Cauda broadly oval with 4 long and fine hairs.

Measurements (in mm) of apterous viviparous female : Length of body 1.60; width 1.00; antenna 0.93; a.s. III 0.41, IV 0.14. V (0.17+0.08); u.r.s. 0.11; h.t.2 0.14; siphunculus 0.06.

ii. Alate parthenogenetic viviparous female (Fig. 2, Plate 3-4)

Body green to olive green in life, 1.40-1.95 mm in length and 0.58-0.83 mm as the maximum width. Head flat between the bases of antennae, without any tubercle,
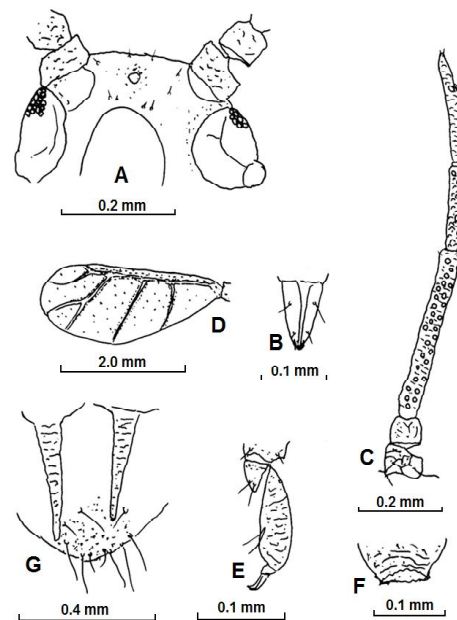
Fig. 2. *Schoutidenia emblica* Alate viviparous female: A. Head, B. u.r.s., C. Antenna, D. Forewing, E. Hind tarsi, F. Siphunculus, G. Cauda with processi.

separated from pronotum (unlike apterae); dorsal cephalic hairs few, short and with blunt apices. Eyes multi-faceted. Antennae 5-segmented, pale brown to brown, 0.70-1.40 mm long and 0.50-0.92x as long as the body; segment I and II scabrous; flagellum imbricated throughout, round secondary rhinaria present on segment III (22-31) and IV (1-5), asymmetry in number of right and left antennae common; 1.87-3.54x as long as a.s. III; p.t. 0.06-0.09 mm long and 0.36-0.66x as long as base of the last antennal segment, 0.58-0.79x as long as h.t.2 and 0.63-0.90x as long as u.r.s. Rostrum short, reaching up to midcoxae; u.r.s. blunt, 0.08-0.13 mm long, 0.63-1.09x as long as h.t.2, bearing 1 or 2 short pointed accessory hairs. Abdominal dorsum pale, with non-spinular polygons all over, each polygon filled with reticulations; dorsal hairs sparse, short and with blunt apices; venter with spinular

imbrications all over; 7th tergite with a pair of pleurally placed finger-like processi, brown, 0.16-0.23 mm long and with spinular imbrications. Siphunculi cone-shaped, brown, reticulated on basal half and 4-5 concentric rings on apical half, 0.06-0.10 mm long and 0.03-0.07x as long as body. Cauda broadly oval with 4 long and fine hairs.

Wings with veins bordered deep brown; forewings with media usually once-branched but in few specimens media of one side was twice branched; hindwings small and without oblique vein.

Measurements (in mm) of an ovipara : Length of body 1.65; width 0.83; antenna 0.90; a.s. III 0.37, IV 0.16. V (0.15+0.10); u.r.s. 0.11; h.t.2 0.12; siphunculus 0.06.

2. Sexual morphs

No sexual morph was observed in this area throughout the year. However, Ghosh, A.K. and Agarwala (1993) described the oviparous females and apterous males collected from Andhra Pradesh on *Phyllanthus emblica*. This indicates that the *Schoutedenia emblica* may enjoy monoecious holocyclic life at least at some places in its distribution range.

Following description is after Ghosh, A.K. and Agarwala (1993).

i. Apterous oviparous female : Body 1.4-1.6 mm long and 0.7-0.9 mm as maximum width. Head scabrous anteriorly, with polygons laterally and medially. Antennae 5-segmented, about half as long as body; flagellum pale, imbricated, segments III, IV, and V pale on basal half rest dusky brown; p.t. half as long as base of a.s. V. Rostrum reaching hind coxae; u.r.s. 0.80 times as long as h.t.2. Abdominal dorsum pale, covered with polygons enclosing non-spinular reticulations; processi on 7th tergite 0.20-0.28 mm long. Siphunculi with apical striae,

bearing 3-4 hairs and about 0.03 times as long as body. Hind femora with 16-21 round accessory rhinaria. Genital disc with short and long hairs; claspers well-developed.

Measurements (in mm) of an ovipara : Length of body 1.60; width 0.90; antenna 0.95; a.s. III 0.36, IV 0.19. V (0.18+0.09); u.r.s. 0.10; h.t.2 0.12; siphunculus 0.05.

ii. Apterous male : Body rather dusky, 1.06-1.21 mm long and 0.60-0.61 mm as maximum width. Antennae 5-segmented, 0.72-0.88 times as long as body; flagellum imbricated, segments III with 21-23 and V with 8-10 small round secondary rhinaria; p.t. 0.4 times as long as base of a.s. V and about as long as u.r.s. Rostrum reaching hind coxae; u.r.s. 0.75 times as long as h.t.2; processi on 7th tergite 0.18-0.21 mm long. Siphunculi 0.04 times as long as body; femora and tibiae densely imbricated. Male genitalia well-developed. Genital disc with a few hairs.

Measurements (in mm) of an apterous male : Length of body 1.18; width 0.55; antenna 0.84; a.s. III 0.30, IV 0.20, V (0.18+0.08); u.r.s. 0.09; h.t.2 0.12; siphunculus 0.05.

C. Instar characteristics and their identification

Aphid populations are characterised by facultative polymorphism and the existence of overlapping generations features which complicate the study of their population dynamics (Hughes, 1972). Hughes (1962, 1963, 1972) developed a method for time-specific analysis of populations which overcame these problems. This technique has since been used in the study of the population dynamics of *Myzus persicae* in the International Biological Programme (van Emden, 1972). Since of *Schoutedenia emblica* is not well known, their identification

along with diagnostic characters for separation of its various nymphal instars are prepared.

The biological control of the aphids also needs a full understanding of the population dynamics of the target pest(s) so that biocontrol agents (parasitoids) can be used against them at appropriate time. Timing is an important consideration since the parasitoids are only able to attack and successfully develop in aphids of a certain stage of development (Messenger, 1970). The approach adopted here to identify nymphal instars of *Schoutedenia emblica* is similar to that of Behura *et al.* (1976a, b), Gilbert *et al.* (1976), Hutchison and Hogg (1983, 1985) and Singh and Srivastava (1989a, b) adopted for other aphids. It also helps in estimating the stage structures of various instars in the field population.

Singh *et al.* (2005) has given the morphometry of some characters of nymphal stages of *Schoutedenia ralumensis* but have not prepared key for instar identification.

In the present study, help of morphometry of nymphal stages was taken to identify the instars of *Schoutedenia emblica* reared on leaves to a known instar and taken from non-clonal populations.

a. Characteristics of apterous morph (Fig. 3-6)

i. First instar apterous nymphs (Fig. 3): First instar nymphs of *Schoutedenia emblica* are very small and are about half millimetre long (0.550 ± 0.025 SD mm). Head smooth and bears 4 segmented antennae. Antennae 0.50-0.57 x as long as body; a.s. I and II smooth, III distally imbricated with 1 primary rhinarium, IV (base + p.t.) entirely imbricated with 1 primary rhinarium, p.t. 0.58-0.66x as long as last a.s. U.R.S. measures 0.083 ± 0.004 mm and bears 2 primary and 2 small

secondary hairs and 3.30–3.56x as long as siphunculi. Femur and tibia smooth. Tibial spinules (13-18) on all legs are small and distributed more distally. H.t.1 with 3 hairs; h.t.2 imbricated with 3 pairs of long hairs (subequal to its maximum diameter) distributed 1 pair apically, 1 pair in middle and 1 pair distally near the empodium. Siphunculus small and about 0ne-third to cauda. The cauda is broadly oval and bears 2 hairs.

Measurements (in mm) of first instar nymph : Length of body 0.55; width 0.29; antenna 0.29; a.s. III 0.12, IV (0.08+0.05); u.r.s. 0.08; h.t.2 0.09; siphunculus 0.02.

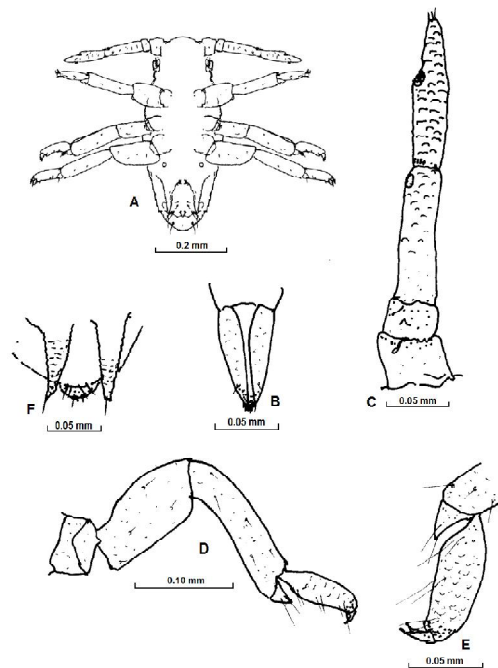*ii. Second instar apterous nymphs* (Fig. 4). Second instar nymphs of *Schoutedenia emblica* are small and measures

Fig. 3. First instar nymph of *Schoutedenia emblica* : A. Body, B. U.r.s, C. Antenna, D. Hindleg, E. H.t.2, F. Posterior part of abdomen showing cauda and supracaudal processi.
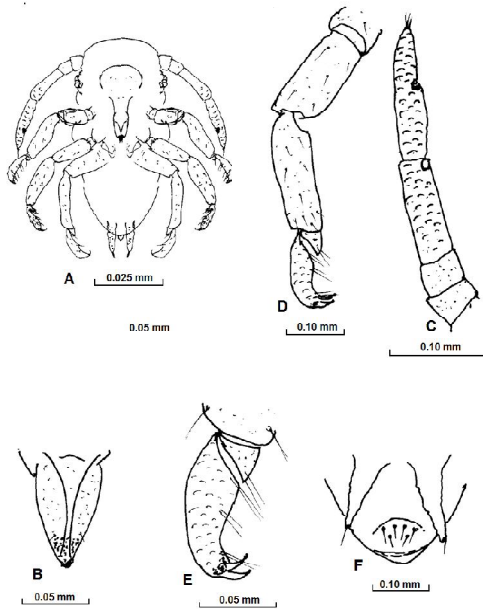
Fig. 4. Second instar nymph of *Schoutedenia emblica* : A. Body, B. U.r.s, C. Antenna, D. Hindleg, E. H.t.2, F. Posterior part of abdomen showing cauda and supracaudal processi.

0.694±0.043 SD mm. Head smooth and bears 4 segmented antennae. Antennae 0.43-0.50x as long as body; a.s. I and II smooth, III distally imbricated with 1 primary rhinarium, IV (base + p.t.) entirely imbricated with 1 primary rhinarium, p.t. 0.55-0.67x as long as last a.s. U.r.s. measures 0.083 ± 0.004 mm and bears 2 primary and 2 small secondary hairs and 2.13–2.92x as long as siphunculi. Femur smooth, tibia distally faintly imbricated. Tibial spinules (13-22) on all legs are small and distributed more distally. H.t.1 with 3 hairs; h.t.2 imbricated with 3 pairs of long hairs (subequal to its maximum diameter) distributed 1 pair apically, 1 pair in middle and 1 pair distally near the empodium. Siphunculus small and 0.32-0.56x as long as cauda. The cauda is broadly oval and bears 2 hairs.

Measurements (in mm) of second instar nymph : Length of body 0.69; width 0.36; antenna 0.32; a.s. III 0.12, IV (0.09+0.06); u.r.s. 0.08; h.t.2 0.10; siphunculus 0.03.

iii. Third instar apterous nymphs (Fig. 5). Third instar nymphs of *Schoutedenia emblica* are larger than second instar and measures 0.819 ± 0.150 SD mm. Head smooth and bears 5-segmented antennae. Antennae 0.36-0.60x as long as body; a.s. I smooth and a.s. II slightly wrinkled, a.s. III faintly imbricated basally while distinctly imbricated distally and 0.32-0.44x as long as antennae, a.s. VI slightly darker than a.s. I-III and imbricated entirely with 1 primary rhinarium, V (base + p.t.) entirely imbricated with 1 primary rhinarium, p.t. 0.49-0.70x as long as base of last a.s. U.r.s. measures 0.085 ± 0.005 SD mm and bears 2 primary and 2 small secondary hairs and 1.75-2.06x as
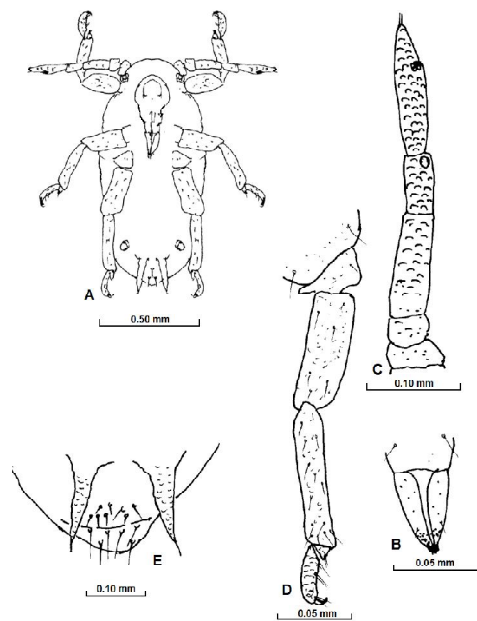

Fig. 5. Third instar nymph of apterous *Schoutedenia emblica* A. Body, B. U.r.s, C. Antenna, D. Hindleg, E. H.t.2, F. Posterior part of abdomen showing cauda and supracaudal processi.
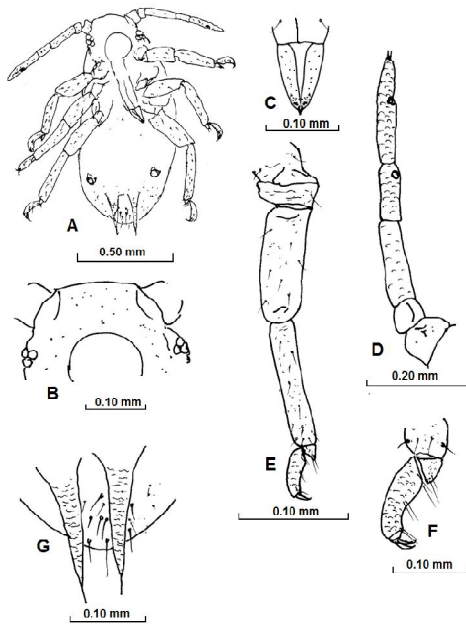
Fig. 6. Fourth instar nymph of apterous *Schoutedenia emblica* : A. Body, B. Head, C U.r.s, D. Antenna, E. Hindleg, F. H.t.2, G. Posterior part of abdomen showing cauda and supracaudal processi.

long as siphunculi. Femur smooth, tibia distally faintly imbricated. Tibial spinules (10-14) on all legs are small and distributed more distally. H.t.1 with 3 hairs; h.t.2 imbricated with 2 pairs of long hairs (subequal to its maximum diameter) distributed 1 pair apically, 1 pair in middle and 1 pair distally near the empodium. Siphunculus small and 0.80-1.17x as long as cauda. The cauda is broadly oval and bears 2 hairs.

Measurements (in mm) of third instar nymph : Length of body 0.82; width 0.39; antenna 0.37; a.s. III 0.10, IV 0.07, V (0.10+0.06); u.r.s. 0.09; h.t.2 0.10; siphunculus 0.05.

iv. Fourth instar apterous nymphs (Fig. 6). Fourth instar nymphs of *Schoutedenia emblica* are larger than third instar and

measures 0.969 ± 0.135 SD mm. Head smooth and bears 5-segmented antennae. Antennae 0.47-0.82x as long as body; a.s. I and II scrabrous while rest of the antennae are imbricated; a.s. III 0.24-0.37x as long as antennae, a.s. VI slightly darker than a.s. I-III with 1 primary rhinarium, V (base + p.t.) entirely imbricated with 1 primary rhinarium, p.t. 0.33-0.62x as long as last a.s. U.r.s. measures 0.097 ± 0.006 mm and bears 2 primary and 2 small secondary hairs and 1.70-2.53x as long as siphunculi. Femur and tibia imbricated. Tibial spinules (10-14) on all legs are small and distributed more distally. H.t.1 with 2 hairs; h.t.2 imbricated with 3 pairs of long hairs (subequal to its maximum diameter) distributed 1 pair apically, 1 pair in middle and 1 pair distally near the empodium. Siphunculus small and subequal to cauda. The cauda is broadly oval and bears 2 hairs.

Measurements (in mm) of fourth instar nymph : Length of body 0.97; width 0.50; antenna 0.51; a.s. III 0.16, IV 0.10, V (0.12+0.06); u.r.s. 0.10; h.t.2 0.11; siphunculus 0.05.

Interestingly, the length of antennae (al), base of last a.s. (bs), and siphunculus (siph) increased linearly with increase of body size (i.e., from first instar to adult stage). The correlation coefficients of all regressions are significant at $P < 0.001$ as follows: $Y_{al} = -0.0157 + 0.5122 X$, $r = 0.942$; $Y_{bs} = 0.0304 + 0.0872 X$, $r = 0.977$; $Y_{siph} = 0.0235 + 0.0280 X$, $r = 0.861$.

b. Characteristics of alate morph (Fig. 7-8)

First and II instar nymphs of apterous and alate morphs cannot be segregated either taken from the field collected samples or from clones of the aphids reared in the laboratory that develop into alate morphs. The sample
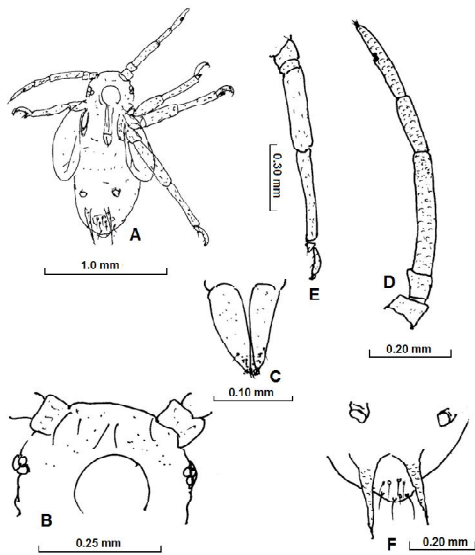
Fig. 7. Third instar nymph of alate *Schoutedenia emblica* : A. Body, B. Head, C U.r.s, D. Antenna, E. Hindleg, F. Posterior part of abdomen showing cauda and supracaudal processi.

taken from the clones containing I and II instar insignificantly differ from those of apterous morphs, in the body size, antennal size and a.s. III which are of taxonomic use.

Third and IV instar alate nymphs of *Schoutedenia emblica* can easily be identified from apterous morphs by having wing pads. The wing pads of III instar nymph are much smaller (Fig. 7) and do not overlap each other while in IV instar (Fig. 8) the wing pads are comparatively larger than III instar and overlap each other. Head of the both instars bears 5-segmented antennae. The III and IV instar of alate morph are larger than that of apterous morph. Measurements of body parts of III and IV instars are displayed in Table 1. Cauda bears 2 hairs in III instar while 2-4 in IV instar nymphs like apterous morphs.

i. Third instar alate nymphs (Fig. 7). Third instar nymphs of alate morph of *Schoutedenia emblica* are larger (more than

1.5x) than third instar of apterous morph and measures 1.325 ± 0.050 SD mm. Head smooth with little reticulation and bears 5-segmented antennae. Antennae longer than the apterous morph and 0.57x as long as body; a.s. I smooth while and a.s. II slightly wrinkled, a.s. III distinctly imbricated and 0.39-0.40x as long as antennae, a.s. VI imbricated entirely with 1 primary rhinarium, V (base + p.t.) entirely imbricated with 1 primary rhinarium, p.t. 0.55x as long as last a.s. U.r.s. measures 0.108±0.005 mm and bears 2 primary and 2 small secondary hairs like apterous morph. Femur and tibia imbricated. Tibial spinules on all legs are small and distributed more distally. H.t.1 with 2 hairs; h.t.2 imbricated with 3 pairs of long hairs (subequal to its maximum diameter) distributed 1 pair apically, 1 pair in middle and 1 pair distally near the empodium. Siphunculus small and 0.50x as long as
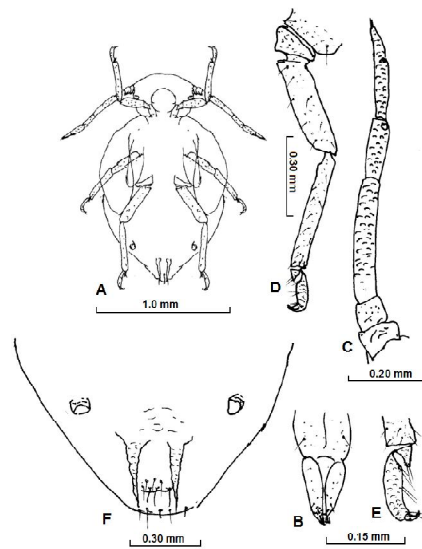

Fig. 8. Fourth instar nymph of alate *Schoutedenia emblica* : A. Body, B. U.r.s, C. Antenna, D. Hindleg, E. H.t.2, F. Posterior part of abdomen showing siphunculi, cauda and supracaudal processi.

cauda. The cauda is broadly oval and bears 2 hairs.

Measurements (in mm) of third instar alate nymph : Length of body 1.32; width 0.63; antenna 0.75; a.s. III 0.30, IV 0.15, V (0.15 + 0.08); u.r.s. 0.11; h.t.2 0.12; siphunculus 0.05.

ii. Fourth instar alate nymphs (Fig. 8). Fourth instar nymphs of alate morph of *Schoutedenia emblica* are larger than fourth instar and measures 1.50-1.85 mm. Head smooth and bears 5-segmented antennae. Antennae 0.47-0.57x as long as body; a.s. I and II scrabrous while rest of the antennae are imbricated and more darker; a.s. III 0.34-0.41x as long as antennae, a.s. VI with 1 primary rhinarium, V (base + p.t.) entirely imbricated with 1 primary rhinarium, p.t. 0.41-0.54x as long as last a.s. U.r.s. measures 0.10-0.12 mm and bears 2 primary and 2 small secondary hairs and 1.29-1.61x as long as siphunculi. Femur and tibia imbricated. Tibial spinules on all legs are small and distributed more distally. H.t.1 with 2 hairs; h.t.2 imbricated with 3 pairs of long hairs (subequal to its maximum diameter) distributed 1 pair apically, 1 pair in middle and 1 pair distally near the empodium. Siphunculus small and subequal to cauda. The cauda is broadly oval and bears 2 hairs.

Measurements (in mm) of fourth instar alate nymph : Length of body 1.64; width 0.77; antenna 0.84; a.s. III 0.31, IV 0.15, V (0.16 + 0.08); u.r.s. 0.11; h.t.2 0.14; siphunculus 0.07.

Interestingly, the length of antennae (al), h.t.2, and siphunculus (siph) increased linearly with increase of body size (i.e., from first instar to adult stage).

D. Key for identification of instars of *Schoutedenia emblica*

1. Antennae 4 segmented.................**2**
-   Antennae 5 segmented...............**3**

2. Hindtibia less than 1.75 mm in length, siphunculus small and less than 0.025 mm in length...**Apterous/Alate I instar**
-   Hindtibia more than 1.80 mm in length, siphunculus more than 0.030 mm in length.......**Apterous/Alate II instar**

3. Wing pad absent.....................**4**
-   Wing pad present **6**

4. Length of a.s. III less than 1.40 times to that of a.s. IV and less than 2.00 times larger than p.t. .... **Apterous III instar**
-   Length of a.s. III more than 1.40 times to that of a.s. IV and more than 2.00 times to that of p.t. **5**

5. Length of a.s. III less than 1.60 times to that of a.s. IV and less than 2.60 times larger than p.t.. **Apterous IV instar**
-   Length of a.s. III more than 1.70 times to that of a.s. IV and more than 3.50 times larger than p.t. .... **Apterous adult**

6. Wing pads small and do not completely overlap; length of siphonculi 0.5x to that of cauda ....**Alate III instar**
-   Wing pads large and partially overlap or fully developed; length of siphunculi more than 0.5x to that of cauda **7**

7. Wing pads large, siphunculi subequal to that of cauda ....**Alate IV instar**
-   Wings fully developed......**Alate adult**

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SURVEY OF BIOCONTROL AGENTS OF WOOLLY APHID, *CERATOVACUNA LANIGERA* ZEHNTNER (HOMOPTERA-APHIDIDAE) ON SUGARCANE OF SATARA DISTRICT, MAHARASHTRA.

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Abstract : Sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner was first reported in West Bengal in 1958, then spread in other part of Northeastern region. Woolly aphid was first noticed in Sangli District in July 2002 and then spread subsequently other districts of western Maharashtra and then spread in Marathwada and Vidarbha region. As far as western Maharashtra is concerned woolly aphid infestation was seen since 2002 in various proportions and causes serious damage to sugarcane ultimately yield and sugar recovery were decreased so far. We have surveyed predators on the woolly aphid, viz. *Dipha aphidivora* (Meyrick), *Micromus igorotus* (Banks), *Eupeodes confrater* (Wiedmann), *Chrysoperla carnea* (Stephens). Of which larvae *Eupeodes confrater* and *Dipha aphidivora* were consumed large number of aphids in their life span and also effective during dry condition. Keeping in view, the attempt has been made on record of biocontrol agents of woolly aphids.

Key words : Sugarcane, woolly aphid, *Ceratovacuna lanigera*, biocontrol agents, Satara District

INTRODUCTION

Sugarcane and sugar beet are the two main sources of white crystal sugar in the world and sugarcane contributes about 70 per cent. Worldwide sugarcane occupies an area of 20.1 m. ha with a total production of 1318.1 m. t. at a productivity rate of 65.5 tonnes per ha. India contribute 20.4 per cent area (4.32 m. ha) and 18.6 per cent of production (2.70 m. t.) and ranks second among the sugarcane growing countries of the world in both area and production. In the country, it is an important cash crop which shares 7 per cent of the total value of agricultural output occupying only 2.8 per cent of the gross cropped area. The sugar industry with more than 450 sugar factories in operation is the second largest agro based industry in India next to cotton textile industry

(Anon., 2005).

As many as 125 species of insects are known to infest sugarcane as major pests in various parts of the world which are causing economic loss to the extent of 20 per cent in yield and 15 per cent in sugar recovery. In India, the crop withstands more than 289 different pests, out of which 213 are insects. Of these, 20 species have been considered as major pests on sugarcane including moth borers, termites, white grubs, scale insects, pyrilla, white flies, mealy bugs, armyworm etc. (Likhil, 2006). The severe outbreak of *Ceratovacuna lanigera* Zehntner is a new addition to the major pest category causing severe losses in cane yield and sugar recovery during last three years (Patil *et al.,* 2004a).

According to Raychaudhuri (1984), more than 15 species of aphids associated with the sugarcane in India of which seven species belongs to subfamily Aphididae, five from Pemphiginae, three from Hormaphidinae and one from Drepanosiphinae. Subfamily Hormaphidinae, *Ceratovacuna lanigera* is serious pest of sugarcane noticed in India and oriental region.

Infestation of woolly aphid was present either side of midrib under surface of sugarcane leaves and then spread over entire leaves. Woolly aphid is economically important groups of insects (Blackman and Eastop, 2000) since they cause the damage to sugarcane by sucking the cell sap from leaves. As a result, white yellowish spots develop on the leaves, which become brittle and gradually dry completely. Aphids continuously excreting copious honeydew, which create sooty moulds on the leaves. Continuous infestation leads to reduction in the length and weight of the cane as well as sugar content of the sap (Joshi and Viraktamath, 2004; Jadhav and Sathe, 2010).

Due infestation of woolly aphids severe losses in cane yield and sugar recovery. The losses to the tune of 26 per cent in yield and 24 per cent in sugar content have been reported (Shankar and Shitole, 2004). In Maharashtra, 7 to 39 per cent reduction in cane yield and 1.2 to 3.43 unit reduction in sugar recovery has been reported. A total loss of about Rs. 874 crores has been estimated in India due to damage caused by SWA (Patil *et al.,* 2004b).

Woolly aphids are less mobile and found on ventral surface of leaves where chemicals couldn't reach to control the pest in usual manner. Under such condition application of biocontrol agents play an important role in the control of woolly aphid up to certain level. Without any harm to the crop and environment, maximum degree of success have been achieved by biological control agents such as *Dipha aphidivora* (Meyrick), *Micromus igorotus* (Banks), *Eupeodes confrater* (Wiedmann), *Chrysoperla carnea* (Stephens), Lady bird beetles, Spider etc. of which larvae *Eupeodes confrater* and *Dipha aphidivora* were consumed large number of aphids in their life span and also effective during dry condition while *Micromus* only active in rainy season during cool and cloudy climate. Apart from that we noted larvae of lady bird beetle, spiders etc. on the woolly aphids.

MATERIAL AND METHODS

Survey was carried out in the selected spots of study area of Satara district in Maharashtra during rainy season up to month January in 2009 and 2010 for study the biocontrol agents of woolly aphids on sugarcane. The observations were made at morning and evening time at 15 days intervals and adopted one man one hour search technique. During survey observed the variety of biocontrol agents, photograph

it's and samples of biocontrol agents were carried out in laboratory. In laboratory study we had used glass tubs, glass beakers and rearing jars for the rearing the larvae of *Dipha aphidivora, Micromus igorotus, Eupeodes confrater and Chrysoperla carnea.* We had provided fresh leaves of sugarcane with woolly aphids to the larvae three times in day for feeding. We cut the leaves of sugarcane into pieces and count the how many aphids on same. At evening we calculated how many wooly aphids remains in the jar and how many consumed by the larvae. This method continued till formation of pupa. We studied the average feeding potential of larvae of Dipha *aphidivora, Micromus igorotus, Eupeodes confrater and Chrysoperla carnea* and found that *Dipha aphidivora* (> 150), *E. confrater* (120-135), *Micromus igorotus* (42-55) and *Chrysoperla carnea* (65-110) per days. We also studied the biology of the biocontrol agents.

RESULTS AND DISCUSSION

The infestation of white woolly aphid on sugarcane was first recorded in West Bengal on (Basu and Banerjee, 1958) and then noticed in different part of North East India. As far as Maharashtra is concerned white woolly aphid was first time recorded in July 2002 in Sangli district (Mote and Puri, 2003)**.** Subsequently, it spreads in Kolhapur, Satara, Pune, Solapur and Ahmadnagar. Lingappa *et al.* (2003) noticed woolly aphid spreads at borderline of Karnataka in Athani, Balgaon district in

September, 2002 then into other districts. Woolly aphid then spreads in Uttar Pradesh, Andra Pradesh, Bihar and Uttaranchal states (Joshi and Viraktamath, 2004).

In Maharashtra, woolly aphids on sugarcane were first time noticed in July 2002 in Sangli district. Immediately it spreads throughout western Maharashtra viz. Kolhapur, Satara, Pune, Solapur and Ahmadnagar districts. Out of total sugarcane area 20% area was infested by woolly aphid with highest infestation at Sangli district subsequently then Kolhapur, Satara, Pune districts. As far as Western Maharashtra is concerned the rate of infestation by woolly aphid was 15-17%. The highest infestation was noticed at western part of Sangli, Satara, Kolhapur and Pune district due to heavy rain fall, high humidity, comparatively low temperature and long period cloudy atmosphere than the eastern parts western Maharashtra due to low rain fall, less humidity, comparatively high temperature and clear atmosphere.

In last ten years we observed drastic changes were taken place in the weather parameters hence, changes took place in plantings and harvestings of the crops. It causes pest outbreak and affects the yield of the crops. Heavy and discontinuous rain fall, comparatively low temperature, high humidity, cool wind and long period of cloudy atmosphere were highly favourable for woolly aphid infestation on sugarcane plant. These conditions were highly favourable in western part of western

Fig. 1. *Dipha aphidivora* Larva, Cocoon, Pupa and Adult

Maharashtra since last six to seven years. Hence, infestation of woolly aphid was found every year in the western parts such as Ajara, Gaganbawada, Radhanagari, Chandoli, Patan,   Medha, and Mulasi Tahsil of the western Maharashtra in rainy season. Here, the attempt has been made on western part of Satara district for study of biocontrol agents of woolly aphids.

During survey biocontrol agent's *viz.* *Dipha aphidivora*, *Micromus igorotus*, *Eupeodes confrater, Chrysoperla carnea* were found on sugarcane woolly aphids of western Maharashtra. We collected larvae and cocoons of *Dipha aphidivora*, *Micromus igorotus*, *Eupeodes confrater* and *Chrysoperla carnea* form infested sugarcane field and carried in laboratory. They provided with fresh infested leaves with woolly aphids every day at morning and evening time and observed the feeding rate and biology in captivity.

Puttannavar *et al.* (2006) reported that *Conobathra aphidivora* (Fig. 1) was potential predators of woolly aphid and it has been found to occur in nearly all the areas from which the aphid has been reported and occasionally has a very substantial effect on the aphid populations. A single larva can consume more than 150 aphids/ day and about 6000 aphids in its life span and can clear a heavily infested sugarcane leaf with 4000-6000 aphids. During survey we found that the larva of *Conobathra aphidivora* was very active and voracious feeder on the woolly aphids. Female laid whitish/ yellowish 70-110 eggs on ventral surface of leaf in and around the infestation of woolly aphids. Incubation period was 5-6 days. The larvae had four molts and five instars; entire larval period was 24 to 35 days. The first instar and second instar was greenish yellow coloured with fine, rare whitish hairs on the body. The duration of first and second instar

was 2-3 days and 3-5 days respectively. The third, fourth and fifth instar was dark greenish coloured with transverse white strips on the body. The duration of third, fourth and fifth instar was 6-8 days, 8-12 days and 5-8 days respectively. Larva secretes whitish silk thread on leaves for protection. In fourth and fifth instar larva become voracious feeder and active. Average single larva consumed 100-150 woolly aphids/ day. Pupa was dark brown coloured situated in silk thread secreted by larva. Pupal period was noticed 7-9 days. Adult male moths survived 1-2 days and female 1-3 days. The entire life cycle completed in one and half month. During survey adult moths of Dipha were seen afternoon in sugarcane field at 4 pm and mating took place at night. They were able maintain in dry season. Hence, more important for control of sugarcane woolly aphid.

According to Patil *et al.* (2004b), a female syrphid fly *E. confrater* (Fig. 2) laid
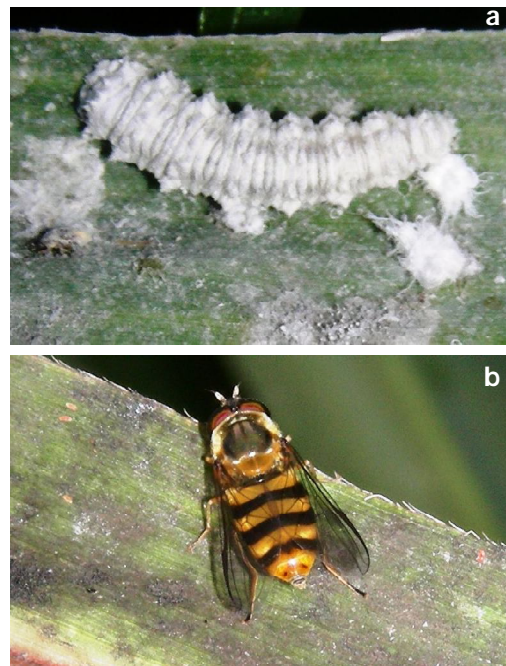

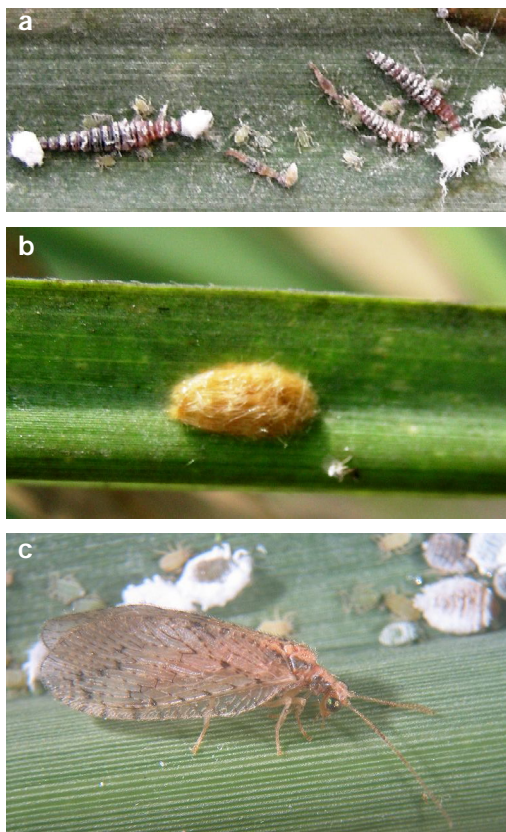Fig. 2. *Eupeodes confrater :* a. larva and b. adult

Fig. 3. *Micromus igorotus :* a. larvae, b. cocoon and c. adult

200-553 eggs. The eggs were laid individually on the ventral surface of the leaves around the colonies of woolly aphids. The eggs were grayish white, elongate or oval with sub-spherical shape tapering towards blunt end. Before hatching, the egg turned grayish brown in colour and became white after hatching. Incubation period lasted for 4 to 6 days while. Syrphid fly had three larval instars. The first instar larva was creamy white and slight tapered at the anterior end. The duration of the first instar ranged between 3 to 4 days and consumed average 20- 25 aphids/day. The second instar larva was whitish, uniformly broad and narrowing towards anterior end with wrinkled cuticle. The duration of second instar was 4-5 days and consumed average 70- 85 aphids/day.

The third instar was whitish due to associate with wool of aphids and body transversely elevated with crest seen from lateral side. The duration was 3 to 5 days and consumed average 120-135 aphids/day. The total larval period of *E. confrater* varied from 10-14 days. Pupae were whitish brown coloured with cylindrical shape. Pupation observed either in leaf sheath or trash or in soil, with a pupal duration of 6-7 days. Adult survived 10 to 20 days and the life cycle was 25-47 days. During survey Syrphid fly was observed in sugarcane field at after 4 pm and night. Mating took place at night. They were seen during adverse condition i.e. dry period also. Hence, more important for control of sugarcane woolly aphid.

Lingappa *et al.* (2004) has been reported that larvae of *Micromus igorotus* (Banks) (Fig. 3) was quite abundant and had great potential in control of woolly aphids on sugarcane. He reported predators complete its life cycle in 25 days. The larvae have three instars spanning about 5-7 days. Larvae and adults have a feeding potential of 20-25 aphids/day. Fecundity ranged from 110 to 170 over a period of 16-18 days. During the survey we found that a larva of Micromus was active during rainy season. The female moth laid 100- 135 cream white eggs on ventral surface of sugarcane leaves around the colonies of woolly aphids. The incubation period of eggs was 3-4 days. A larva undergoes two molts and three instars. The larval period was 7-9 days. The larvae were slight flat, broad at middle and tapered both ends like mugger. Average single larva consumed 42-55 woolly aphids/ day. During larval period single larva consumed average 325-410 woolly aphids. Pupa was found in crevices of leaf, cream coloured and oval. Pupal period lasts for 3-6 days. Adult of *Micromus* was brown coloured, Male survived 3-5 days and female 6-8 days. The total life of *Micromus* moth was 18- 30 days.

Chrysoperla carnea moth and its larvae

were observed on infested leaves of sugarcane in rainy season. Moth was greenish coloured. Female of Crysoparla was laid 600-750 eggs on ventral side of leaf. Eggs were stalked and incubation period was 3-4 days. Larval period was noted 10-12 days with three instars. Mature larvae were white coloured and broad at middle. We noted average 300-350 woolly aphids were consumed by single larva during larval period. Pupa was whitish coloured and pupal period was 6-15 days. Adults survived 40-60 days and total life span was noted average about 65-110 days. *Chrysoperla* had slow growth compared to *Conobathra*, Syrphid fly and *Micromus* but could survived in dry conditions like Syrphid fly.

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DIVERSITY OF THE APHID PARASITOIDS IN EASTERN UTTAR PRADESH

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Abstract: Aphid parasitoids belong to two families of Hymenoptera : Aphelinidae and Braconidae (subfamily Aphidiinae). Aphelinidae comprises only one species, *Aphelinus gossypii* Timberlake which more common on several species of aphids on many plant species and needs future investigation considering its biology and population dynamics. The Braconidae comprises ten species, *Aphidius colemani* Viereck, *Aphidius matricariae* Haliday, *Aphidius smithi* Sharma & Subba Rao, *Aphidius uzbekistanicus* Luzhetzki, *Binodoxys indicus* (Subba Rao & Sharma), *Diaeretiella rapae* (McIntosh), *Ephedrus plagiator* (Nees), *Lipolexis orygmae* Gahan, *Lysiphlebia mirzai* Shuja-uddin, and *Lysiphlebus delhiensis* (Subba Rao & Sharma).

Key words : Aphelinidae, aphids, Braconidae, parasitoids.

INTRODUCTION

Faunal composition, distribution, biological peculiarities, etc. of the parasitoids of aphids in the particular areas are the basic sources from which many principal features of the parasitoids may be derived. Imortant results, however, may be obtained even for the applied research. The knowledge of the host range of a target parasitoid species allows us to determine the agro-ecosystem relations and possibly even to join several biological programmes (crop–pest aphid species–parasitoid species) together. In India, several aphid parasitoids have been studied but only few of them have really been utilised in the biological control of aphids (Singh, 2001). Thus, other parasitoids must be extensively studied to use as potent agents.

Therefore, in the present contribution as the first step of biological control of aphids, their parasitoids were observed and identified. The study of biology of natural enemies in future will be useful in testing their potency against several aphids in biological control programme. Herewith, detail of the parasitoids of the identified aphid species of the terai area of northeast Uttar Pradesh are given.

MATERIALS AND METHODS

Seven districts of eastern U.P. viz.,

Kushinagar, Deoria, Gorakhpur, Meharaj-ganj, Sant Kabirnagar, Basti and Siddharthanagar were extensively surveyed for the diversity of aphid species and their natural enemies on various food plants from 2003 to 2010.

The aphidiines (Hymenoptera: Braconidae) are the major parasitoids of aphids. The sample of alive aphids were put into the plastic vials (2.5 x 10 cm or more) and covered with rubber band to get the parasitoids. These vials were kept in BOD incubator at 22 °C and 70-80% RH. If they are parasitised, after a week, the aphids get mummified. These mummies were kept gently in incubators for adult emergence. The larvae and certain parts of the adults such as metanotum, tergite_1, wings, and genitalia were mounted for taxonomic purposes. Adults were also dried and mounted on paper card.

RESULTS

In the course of present studies 11 species of parasitoids of aphids were identified (Table 1) on several species of aphids (Table 2).

Aphid parasitoids belong to two families of Hymenoptera:Aphelinidae and Braconidae (subfamily Aphidiinae). Aphelinidae comprises only one species, *Aphelinus gossypii* Timberlake which more common on several species of aphids on many plant species and needs future investigation considering its biology and population dynamics. The Braconidae comprises ten species, *Aphidius colemani* Viereck, *Aphidius matricariae* Haliday, *Aphidius smithi* Sharma & Subba Rao, *Aphidius uzbekistanicus* Luzhetzki, *Binodoxys indicus* (Subba Rao & Sharma), *Diaeretiella rapae* (McIntosh), *Ephedrus plagiator* (Nees), *Lipolexis orygmae* Gahan, *Lysiphlebia mirzai* Shuja-uddin, and *Lysiphlebus delhiensis* (Subba Rao & Sharma).

Stary and Ghosh (1983) compiled the fauna of aphid parasitoids of India belonging to Hymenoptera. Later, Singh and Tripathi (1991) updated it. The up-dated research must everywhere be taken from a broader viewpoint, hence each specialist working on a partial problem should know and always keep in his mind the whole biological control building, its floor and corridors, and his own position there.

Aphid parasitoids mainly belong to two families of Hymenoptera: Aphelinidae and Braconidae (subfamily Aphidiinae). In the present survey work following parasitic wasps of aphids were encountered.

(a) Aphelindae : Hymenoptera

1. *Aphelinus gossypii* **Timberlake :** The parasitoid is a generalist parasitoid of aphids and is distributed worldwide. In the present collection following hosts of the parasitoid were observed : *Aphis fabae solanella* Theobald, *Aphis gossypii* Glover, *Brachycaudus helichrysi* (Kaltenbach), *Melanaphis sacchari* (Zehntner), *Myzus persicae* (Sulzer), *Rhopalosiphum maidis* (Fitch), *Sitobion miscanthi* (Takahashi). Earlier, Ahmad and Singh (1992a) and Tripathi and Singh (1997) have studied its incidence on aphids in eastern U.P.

(b) Braconidae : Hymenoptera

Braconid parasitoids of aphids are the major parasitoid guild of aphids everywhere in the world and some of them had shown their utility in the biological control of aphids, e.g., *Aphidius matricariae* Haliday., *Aphidius colemani* Viereck, *Aphidius smithi* Sharma & Subba Rao, *Aphidius uzbekistanicus* Luzhetzki, *Diaeretiella rapae* (McIntosh), *Binodoxys indicus* (Subba Rao & Sharma)

etc. In the present survey, following parasitoids of the group were observed on different aphid species on several crops.

2. *Aphidius colemani* Viereck : It is a polyphagous parasitoid species distributed throughout the world parasitizing a number of aphid species, viz., cotton aphid, faba aphid, cabbage aphid, green peach aphid, corn aphid, grain aphid etc. (Stary and Ghosh, 1983). In the target area, it was observed to parasitise *Aphis fabae solanella* Theobald, *Aphis gossypii* Glover, and *Myzus persicae* (Sulzer) only on solanaceous crops and cucurbits.

3. *Aphidius matricariae* Haliday : Similar to *Aphidius colemani* Viereck, *Aphidius matricariae* Haliday is worldwide in distribution and highly used species in biological control of several aphid speies worldwide. However, in the target area, it was observed only on *Toxoptera aurantii* (B.d. Fonsc.).

4. *Aphidius smithi* Sharma & Subba Rao : Indian in origin, this species is widely used against pea aphid in most of the European countries and USA (Singh, 2001). In the target area also the parasitoid was found parasitizing *Acyrthosiphon pisum* (Harris) on pea.

5. *Aphidius uzbekistanicus* Luzhetzki : It is an Eurasian species mostly parasitizing grain aphids but locally it was found also on *Aphis gossypii* Glover on brinjal in addition to *Melanaphis sacchari* (Zehntner), *Rhopalosiphum maidis* (Fitch), *Sitobion miscanthi* (Takahashi) on sorghum and corn.

6. *Binodoxys indicus* (Subba Rao & Sharma) : It is one of the well known species and is well documented in India (Singh and Agarwala, 1992). The parasitoid was used against *Aphis craccivora* Koch and *Aphis gossypii* Glover in India (Singh, 2001). In the recent survey, it was observed on *Aphis craccivora* Koch, *Aphis fabae solanella* Theobald, *Aphis gossypii* Glover, *Aphis nerii* (B.d. Fonsc.), *Brachycaudus helichrysi* (Kaltenbach), *Hysteroneura setariae* (Thomas), *Myzus persicae* (Sulzer), *Toxoptera aurantii* (B.d. Fonsc.). All these aphid speies are already in the list of host in India (Stary and Ghosh, 1983).

7. *Diaeretiella rapae* (McIntosh) : Though, the species was earlier known as a parasitoid of brassica aphid (Raj and Sharma, 1993) but recent survey revealed that it is a polyphagous (Stary and Ghosh, 1983; Pike *et al.*, 1999). Locally, the species was well documented (Shukla *et al.*, 1997; Singh, S., 2001, Prasad, 2003, Singh, D., 2003), was observed on *Aphis craccivora* Koch, *Aphis fabae solanella* Theobald, *Aphis gossypii* Glover, *Brevicoryne brassicae* (Linn.), *Lipaphis erysimi* (Kalt.).

8. *Ephedrus plagiator* (Nees) : It is less known aphid parasitoid recorded mostly from West Bengal, Meghalaya, Sikkim and Bihar (Stary and Ghosh, 1983). In the present survey few mummies of it were observed in the colony of *Aphis fabae solanella* Theobald and *Aphis gossypii* Glover on pea and pigeonpea, respectively.

9. *Lipolexis orygmae* Gahan : It is an oriental species found parasitising mostly citrus aphid (Hoy and Nguyen, 2000). In the present survey work its mummies wwere obtained from *Aphis craccivora* Koch, *Aphis fabae solanella* Theobald, *Aphis gossypii* Glover, *Aphis nerii* (B.d.Fonsc.), *Aphis spiraecola* Patch, *Schizaphis graminum* (Rondani), *Toxoptera aurantii* (B. d. Fonsc.), *Toxoptera odinae* (v. d. Goot). Earlier, its incidence in U.P. and Bihar was documented by Singh and Tripathi (1987) and Ahmad and Singh (1996c).

10. *Lysiphlebia mirzai* Shuja-Uddin : Indian in origin, the parasitoid species is well documented in literature (Tripathi and Singh, 1990a, b, 1991a, b, 1995, 1997) as a parasitoid of *Melanaphis sacchari* (Zehntner) and *Rhopalosiphum maidis* (Fitch) on corn and sorghum in the target area.

11. *Lysiphlebus delhiensis* (Subba Rao & Sharma) : Similar to *Lysiphlebia mirzai* Shuja-Uddin, this parasitoid is also well studied biologically in the target area on *Melanaphis sacchari* (Zehntner) and *Rhopalosiphum maidis* (Fitch) on corn and sorghum (Mishra and Singh, 1991,1993; Srivastava and Singh, 1994; Biswas and Singh, 1995; Pandey and Singh, 1998, 1999).

Table 1. Aphid hosts of the parasitoids in the terai of eastern Uttar Pradesh.

Hymenoptera : Aphelinidae
   ***Aphelinus gossypii* Timberlake**
   Aphis fabae solanella Theobald
   Aphis gossypii Glover
   Brachycaudus helichrysi (Kaltenbach)
   Melanaphis sacchari (Zehntner)
   Myzus persicae (Sulzer)
   Rhopalosiphum maidis (Fitch)
   Sitobion miscanthi (Takahashi)

Hymenoptera : Braconidae
   ***Aphidius colemani* Viereck**
   Aphis fabae solanella Theobald
   Aphis gossypii Glover
   Myzus persicae (Sulzer)

   ***Aphidius matricariae* Haliday**
   Toxoptera aurantii (B.d. Fonsc.)

   ***Aphidius smithi* Sharma & Subba Rao**
   Acyrthosiphon pisum (Harris)

***Aphidius uzbekistanicus* Luzhetzki**
   Aphis gossypii Glover
   Rhopalosiphum maidis (Fitch)
   Sitobion miscanthi (Takahashi)

***Binodoxys indicus* (S. Rao & Sharma)**
   Aphis craccivora Koch
   Aphis fabae solanella Theobald
   Aphis gossypii Glover
   Aphis nerii (B.d.Fonsc.)
   Brachycaudus helichrysi (Kaltenbach)
   Hysteroneura setariae (Thomas)
   Myzus persicae (Sulzer)
   Toxoptera aurantii (B.d. Fonsc.)

***Diaeretiella rapae* (McIntosh)**
   Aphis craccivora Koch
   Aphis fabae solanella Theobald
   Aphis gossypii Glover
   Brevicoryne brassicae (Linn.)
   Lipaphis erysimi (Kalt.)

***Ephedrus plagiator* (Nees)**
   Aphis fabae solanella Theobald
   Aphis gossypii Glover

***Lipolexis orygmae* Gahan**
   Aphis craccivora Koch
   Aphis fabae solanella Theobald
   Aphis gossypii Glover
   Aphis nerii (B.d.Fonsc.)
   Aphis spiraecola Patch
   Schizaphis graminum (Rondani)
   Toxoptera aurantii (B.d. Fonsc.)
   Toxoptera odinae (v. d. Goot)

***Lysiphlebia mirza* Shuja-uddin**
   Melanaphis sacchari (Zehntner)
   Rhopalosiphum maidis (Fitch)

Lysiphlebus delhiensis (S. Rao & Sharma)

Melanaphis sacchari (Zehntner)

Rhopalosiphum maidis (Fitch)

Table 2. Aphid-wise list of parasitoids of the aphids in terai of eastern Uttar Pradesh.

Aphis craccivora Koch
Hymenoptera : Braconidae

Binodoxys indicus (S.Rao & Sharma)

Diaeretiella rapae (McIntosh)

Lipolexis orygmae Gahan

Aphis fabae solanella Theobald
Hymenoptera : Aphelinidae

Aphelinus gossypii Timberlake

Hymenoptera : Braconidae

Aphidius colemani Viereck

Binodoxys indicus (Subba Rao & Sharma)

Diaeretiella rapae (McIntosh)

Ephedrus plagiator (Nees)

Lipolexis orygmae Gahan

Aphis gossypii Glover
Hymenoptera : Aphelinidae

Aphelinus gossypii Timberlake

Hymenoptera : Braconidae

Aphidius colemani Viereck

Aphidius uzbekistanicus Luzhetzki

Binodoxys indicus (Subba Rao & Sharma)

Diaeretiella rapae (McIntosh)

Ephedrus plagiator (Nees)

Lipolexis orygmae Gahan

Aphis nerii (B.d.Fonsc.)
Hymenoptera : Braconidae

Binodoxys indicus (Subba Rao & Sharma)

Lipolexis orygmae Gahan

Aphis spiraecola Patch
Hymenoptera : Braconidae

Lipolexis orygmae Gahan

Hysteroneura setariae (Thomas)
Hymenoptera : Braconidae

Binodoxys indicus (Subba Rao & Sharma)

Melanaphis sacchari (Zehntner)
Hymenoptera : Aphelinidae

Aphelinus gossypii Timberlake

Hymenoptera : Braconidae

Aphidius uzbekistanicus Luzhetzki

Lysiphlebia mirza Shuja-uddin

Lysiphlebus delhiensis (Subba Rao & Sharma)

Rhopalosiphum maidis (Fitch)
Hymenoptera : Aphelinidae

Aphelinus gossypii Timberlake

Hymenoptera : Braconidae

Aphidius uzbekistanicus Luzhetzki

Lysiphlebia mirza Shuja-uddin

Lysiphlebus delhiensis (Subba Rao & Sharma)

Schizaphis graminum (Rondani)
Hymenoptera : Braconidae

Lipolexis orygmae Gahan

Toxoptera aurantii (B.d. Fonsc.)
Hymenoptera : Braconidae

Aphidius matricariae Haliday

Lipolexis orygmae Gahan

Binodoxys indicus (Subba Rao & Sharma)

Toxoptera odinae (v. d. Goot)
Hymenoptera : Braconidae

Lipolexis orygmae Gahan

***Acyrthosiphon pisum* (Harris)**
   Hymenoptera : Braconidae

   Aphidius smithi Sharma & Subba Rao

***Brachycaudus helichrysi* (Kaltenbach)**
   Hymenoptera : Aphelinidae

   Aphelinus gossypii Timberlake

   Hymenoptera : Braconidae

   Binodoxys indicus (Subba Rao & Sharma)

***Brevicoryne brassicae* (Linn.)**
   Hymenoptera : Braconidae

   Diaeretiella rapae (McIntosh)

***Lipaphis erysimi* (Kalt.)**
   Hymenoptera : Braconidae

   Diaeretiella rapae (McIntosh)

***Myzus persicae* (Sulzer)**
   Hymenoptera : Aphelinidae

   Aphelinus gossypii Timberlake
   Aphidius colemani Viereck
   Binodoxys indicus (S.Rao & Sharma)

***Sitobion miscanthi* (Takahashi)**
   Hymenoptera : Aphelinidae

   Aphelinus gossypii Timberlake

   Hymenoptera : Braconidae

   Aphidius uzbekistanicus Luzhetzki

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ECONOMIC INJURY LEVEL (EIL) AND ECONOMIC THRESHOLD LEVEL (ETL) OF *LIPAPHIS ERYSIMI* (KALT.) (HOMOPTERA : APHIDIDAE) ON MUSTARD AND RAI CROPS

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Abstract : Experiments wer e conducted to find out the economic injury level (EIL) and economic threshold level (ETL) of ten varieties of mustard and rai for three growing stages in four sowing dates of three consecutive seasons. EIL and ETL varied with varieties and growing stages and also between seasons. EIL and ETL were lower in seedling stage followed by flowering stage and highest in podding stage for all varieties in four sowing dates for three seasons.

Key words : Economic injury level, economic threshold level, *Lipaphis erysimi.*

INTRODUCTION

Mustard and rai are the main oilseed crop in Bangladesh (Sarker *et al.*, 2007) and *Lipaphis erysimi* (Kalt.) (Homoptera : Aphididae) is recognised as one of the major constraints for low yield of the mustard production in Bangladesh (Ahmmad *et al.*, 2005).

The economic injury level is a theoretical value that, upon attainment by a pest population, can cause the amount of injury, which will justify the cost of treatment. The economic threshold is defined as the pest population density at which control should be initiated to prevent an increasing pest population from exceeding the economic injury level (Pedigo, 2004). The EIL is the most essential of the decision rules, was defined earlier by Stern *et al.* (1959) as the lowest population density that will cause economic damage. Economic threshold level (ETL) is a level when decision should be taken to control action, based on any of several factors including insect populations, farmer and applicator schedules, weather, equipment, farm size, intuition, and others. While theoretically there are economic injury level values for decision-makers to consider in evaluating an economic threshold, they are largely, if not completely, ignored. That is partly due to the fact that most economic injury levels are insect-specific and are not practical when one must consider the multi-

pest, multi-stress, dynamically-changing conditions (Mi *et al.*, 1998).

A number of workers (Wetzel *et al.*, 1980; Freier *et al.*, 1982; Larsson, 1986, 2005; Carter *et al.*, 1989; Wise and Lamb, 1990; Xibei *et al.*, 1994; Wise *et al.*, 1995; Hansen, 2000; Hermoso de Mendoza *et al.*, 2001, 2006; Hodgsen *et al.*, 2004; Ragsdale *et al.*, 2007) determined EILs and ETLs of different aphid pests of several crops for the justification and evaluation of appropriate time to control the pests.

In Bangladesh, information about EIL and ETL on *L. erysimi* is meager (Begum, 1995). Hence, in this work, attempt was made to determine the EIL and ETL of this pest aphid for its successful and economical management.

MATERIALS AND METHODS

Selection of mustard varieties

The most widely cultivated varieties of *Brassica rapa* subsp. *campestris* (L.) A.R. Clapham (Bari Sarisha-6, Bari Sarisha-9, Bari Sarisha-12, Tory–7, Sonaly-75), *Brassica juncea* L. Czern. (Bari Sarisha-10, Bari Sarisha-11, Rai-5), and *Brassica napus* L. (Bari Sarisha-7, Bari Sarisha-8) were selected for the present study. The seeds of these crops were collected from Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh.

Experimental design

The experiment was conducted in the research field, Department of Zoology, University of Rajshahi during the winter seasons of three consecutive years, *viz.* 2004-2005, 2005-2006 and 2006-2007. The seeds were sown in different plots in the field at four different dates (first sowing date : 28 October, second sowing date : 12 November,

third sowing date : 27 November and fourth sowing date : 12 December for all seasons). Altogether 120 plots each 1.35 m² area were used. The experimental plots in terms of varieties and sowing dates were designed as in the Figure 1.

Counting of aphids

Counting of aphid population (aphids/plant) started immediately after appearing *L. erysimi* in the plots. Aphid counting was made by eye estimation (replicated three times) without disturbing the colony and aphid counting was continued till the harvesting of the crop. Aphids were counted at least 5-6 days interval at each plot. Different morphs of *L. erysimi, viz.*, nymphs, apterae and alatae were counted from randomly selected 5 imaginary blocks of each plot. Altogether 15 plants (3 plants from each block) were selected for aphid counting. Larvae, pupae and adults of natural enemies on these 15 plants were also counted.

Yield assessment

When about 90 percent pods of mustard plants were matured, the crops were then harvested. The harvested grains of mustard were weighed to assess yields in terms of varieties and sowing dates.

Data analysis

EIL was calculated using the equation of Pedigo (2004) and for the calculation of ETL, used fixed value (Hermoso de Mendoza *et al.*, 2001; Shipp *et al.*, 2006). In order to investigate the difference in EIL/ETL among the seasons (2004-2005, 2005-2006 and 2006-2007), among the growing stages (seedling, flowering and podding) of the plants, among the four sowing dates and among the 10 varieties of mustard plants, analysis of variance (ANOVA) were performed. Duncan Multiple Range Tests

Figure 1. Design for sowing plots of different varieties of mustard for four sowing dates at three consecutive seasons (2004-2005, 2005-2006 and 2006-2007) [V1=Bari sarisha-6, V2=Bari sarisha-7, V3=Bari sarisha-8, V4=Bari sarisha-9, V5=Bari sarisha-10, V6=Bari sarisha-11, V7=Bari sarisha-12, V8=Rai-5, V9=Tory-7 and V10=Sonaly-75].

V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
First Sowing Plot-A										Fourth Sowing Plot-B										First Sowing Plot-C									
V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Second Sowing Plot-A										Third Sowing Plot-B										Second Sowing Plot-C									
V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Third Sowing Plot-A										Second Sowing Plot-B										Third Sowing Plot-C									
V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Fourth Sowing Plot-A										First Sowing Plot-B										Fourth Sowing Plot-C									

Table 1. Mean values of EIL and ETL of ten varieties of mustard crops at three growing stages for three consecutive years.

Plant stage	EIL			F-values	p-values
	2004-2005	2005-2006	2006-2007		
Seedling	11.28Ab	11.35A b	6.34Aa	8.17	0.000
Flowering	18.86Bab	20.46Bc	15.73Ba	3.16	0.046
Podding	25.45Ca	34.00Cb	21.56Ca	11.13	0.001
F- value	48.67	52.44	19.88		
P- value	0.000	0.000	0.000		
	ETL				
Seedling	9.03Ab	9.08Ab	5.07Aa	8.17	0.000
Flowering	15.09Bab	16.37Bc	12.59Ba	3.16	0.046
Podding	20.36Ca	27.20Cb	17.25Ca	11.13	0.000
'F' value	48.67	52.44	19.88		
'p' value	0.000	0.000	0.000		

Means values followed by same letters did not differ significantly at <0.01 or 0.05. Small and capital letters indicate row and column, respectively.

(DMRT) was performed to rank the values of EIL and ETL.

RESULTS AND DISCUSSION

EIL and ETL values for the consecutive three seasons (2004-2005, 2005-2006 and 2006-2007) of three stages (seedling, flowering and podding) of mustard crop are provided in Table 1. In Table 2, EIL and ETL values for the aforesaid three seasons in respect of their four sowing dates are provided. The data provided in the Table 1 and 2 are variety-wise re-arranged and displyed in Table 3 and 4 for the seasons 2004-2005, 2005-2006 and 2006-2007,

respectively.

Table 1 displayed that the EIL and ETL of *L. erysimi* varied significantly (p<0.01) among the three growing stages of mustard crops (seedling, flowering and podding stages) of three years. The highest EIL and ETL values (11.35 and 9.08 aphids/plant, respectively) was observed for the season 2005-2006, and lowest EIL and ETL values (6.34 and 5.07 aphids/plant, respectively) of seedling stage was recorded for the season 2006-2007. In flowering stages, highest EIL and ETL values (20.46 and 16.37 aphids/plant, respectively) was observed for the season 2005-2006, and lowest values of EIL and ETL (15.73 and 12.59 aphids/plant, respectively) were recorded for the season 2006-2007. In the podding stages, highest EIL and ETL values (27.20 and 34.00 aphids/plant, respectively) were observed for the season 2006-2007, and lowest values of EIL and ETL (21.56 and 17.25 aphids/plant, respectively) were recorded for the season 2006-2007 (Table 1). EIL and ETL values of seedling stages for the three cropping seasons were lower than that of flowering and podding stages for three consecutive seasons (Table 1). EIL and ETL values did not differ significantly among the sowing dates for the seasons 2004-2005 and 2005-2006; however significant difference (p<0.01) for the same could be noticed for the season 2006-2007 (Table 2). In 2006-2007, aphids did not infest the mustard plants, which were sown first. Accordingly, EIL and ETL were not calculated for the first sowing mustard plants. In 2006-2007, highest EIL and ETL values (23.18 and 18.54 aphids/plant, respectively) were recorded for the fourth sowing date of mustard plants.

Among the three seasons, significant difference (p<0.01) exists for first and second sowing dates (Table 2). In first sowing date, highest values (22.31 and 17.85 aphids/plant,

respectively) of EIL and ETL were found for the season 2005-2006; and lowest values for the same were zero aphid/plant during the season 2006-2007, since no aphid infestation was noticed on the first sowing mustard plant during that period. In the second sowing plants, highest values (23.75 and 19.00 aphids/plant, respectively) were found for the season 2005-2006, and lowest (15.15 and 12.12 aphids/plant, respectively) values of EIL and ETL were found for the season 2006-2007. EIL and ETL of third and fourth sowing dates did not differ significantly among the three seasons (Table 2). EIL and ETL values at seedling stage differ significantly (p<0.05, p<0.01, respetively) among the ten varieties of mustard plants for the seasons 2004-2005, 2005-2006 and 2006-2207 (Tables 3 and 4). EIL and ETL values at flowering stage differ significantly (p<0.05) among the ten varieties of mustard plants during 2005-2006, however, the values of the same did not differ significantly for the other two seasons, *i.e.* 2004-2005 and 2006-2007 (Tables 3 and 4). No significant difference could be noticed among the ten varieties of mustard plants at their podding stage for all the three seasons.

The highest EIL and ETL values (16.25 and 13.00 aphids/plant, respectively) at seedling stage of the variety Sonali-75 were recorded for the season 2004-2005; and the lowest values (11.14 and 8.91 aphids/plant, respectively) of the same were found for the variety Bari Sharisa-10 (Tables 3 and 4). In the season 2005-2006, the highest EIL and ETL values (17.83 and 14.26 aphids/plant, respectively) were recorded at the seedling stage of the variety Sonali-75; and the lowest values (9.77 and 7.82 aphids/plant, respectively) of the same were recorded for the variety Bari Sharisa-11 at the same growing stage (Table 3 and 4). The highest EIL and ETL values (17.12 and 13.70

Table 2. Mean values of EIL and ETL of ten varieties of mustard crops at four sowing dates for three consecutive years.

Plant stage	EIL			F-values	p-values
	2004-2005	2005-2006	2006-2007		
Seedling	17.59b	22.31b	0.00Aa	21.96	0.000
Flowering	17.94a	23.75b	15.15Ba	5.477	0.006
Podding	20.82	20.42	19.85C	0.081	0.922
F- value	17.77a	21.26ab	23.18Cb	3.064	0.052
P- value	0.944	0.329	39.854		
	ETL				
Seedling	14.07b	17.85b	0.00Aa	21.96	0.000
Flowering	14.35a	19.00b	12.12Ba	5.477	0.006
Podding	16.66	16.34	15.88C	0.081	0.922
'F' value	14.22a	17.01ab	18.54Cb	3.064	0.052
'p' value	0.944	0.329	39.85		

Means values followed by same letters did not differ significantly at $p < 0.01$ or $p < 0.05$. Small and capital letters indicate row and column, respectively.

aphids/plant, respectively) were recorded at the seedling stage of the variety Tory-7 for the season 2006-2007; and the lowest values (9.10 and 7.28 aphids/plant, respectively) of the same were found for the variety Bari Sharisa-07 during the same season (Table 3 and 4).

Flowering stage highest EIL and ETL values (32.80 and 26.24 aphids/plant, respectively) were recorded for the variety Sonali-75 during 2005-2006; and lowest values (15.28 and 12.22 aphids/plant respectively) were found for the variety Bari Sharisa-11 for the same season (Table 3 and 4).

EIL and ETL values of the mustard varieties differ significantly ($p < 0.05/$ or < 0.01) among the growing stages (seedling, flowering and podding) for all the three seasons (2004-2005, 2005-2006 and 2006-2007) excepting for the varieties Bari sarisha-11, Bari sarisha-12, Rai-5 and Sonali-75 for the season 2004-2005; and Bari sarisha-7 and Bari sarisha-10 for season 2005-2006 (Table 3 and 4).

EIL and ETL values increased with the increase of growing stages of the mustard plants for all the ten varieties. Similarly EIL and ETL values were lowest at the seedling stage, thereafter increased slightly at the flowering stage; and reached to peak at their podding stage for all the 10 varieties of mustard plants (Table 3 and 4).

The parameters for calculation of the economic injury level (EIL) and its derivative, the economic threshold (ET), as defined by Stern et al. (1959) are treatment costs, yield price, insecticide efficacy, and yield loss, a pest density-dependent function (Higley and Pedigo, 1996). Harris (1990) calculated EIL of L. erysimi on canola and found 200-300 aphids /m². Sekhon and Bakhetia (1991) analysed EIL value of L. erysimi on canola as 25 aphids/10 cm shoot where aphids are found in clusters at the end of shoots. Hermoso de Mendoza et al. (2001) calculated EIL for A. gossypii Glover on Citrus clementina as 271 aphids/m² and ETL is 217 aphids/m². Wise and Lamb (1990) studied the EIL of Macrosiphum euphorbiae

Table 3. Mean values of EIL of ten varieties of mustard of three growing stages (four sowing dates) for three cropping seasons (2004-05, 2005-06 and 2006-07).

Crop seasons	Mustard vaieties	Seedling	Flowering	Podding	'p' value	All stages
2004-2005	Bari Sharisa-6	12.60ABa	18.17ab	25.43b	0.016	18.73
	Bari Sharisa-7	12.94ABCa	19.14b	23.58b	0.007	18.55
	Bari Sharisa-8	13.22ABCa	21.63ab	30.46b	0.012	22.30
	Bari Sharisa-9	11.92ABa	16.17a	27.59b	0.001	18.56
	Bari Sharisa-10	11.14Aa	13.40a	17.51b	0.002	13.09
	Bari Sharisa-11	13.17ABC	14.74	21.96	0.122	15.53
	Bari Sharisa-12	14.54ABCa	19.82ab	28.15b	0.096	19.62
	Rai-5	15.25BCa	19.16ab	24.16b	0.109	18.25
	Tory-7	12.54ABa	21.58b	24.96b	0.012	18.65
	Sonali-75	16.25C	23.21	27.89	0.127	22.03
	Mean	13.357	18.702	25.169	-	18.53
	'p' values	0.045	0.256	0.457	-	0.296
2005-2006	Bari Sharisa-6	13.76ABa	21.80Aa	51.66Cb	0.012	29.07
	Bari Sharisa-7	17.59B	26.22AB	31.32AB	0.201	25.04
	Bari Sharisa-8	13.72ABa	20.77Aa	37.63ABCb	0.001	24.04
	Bari Sharisa-9	11.08Aa	16.17Aa	31.70ABb	0.001	19.65
	Bari Sharisa-10	10.18Aa	16.54Aab	21.70Ab	0.064	15.29
	Bari Sharisa-11	9.77Aa	15.28Aab	31.58ABb	0.036	18.76
	Bari Sharisa-12	9.94Aa	18.09Aab	28.31ABb	0.011	18.11
	Rai-5	13.09ABa	20.63Aa	36.03ABCb	0.018	22.37
	Tory-7	10.98Aa	16.29Aa	25.93ABb	0.018	17.18
	Sonali-75	17.83Ba	32.80Bb	44.16BCc	0.000	30.55
	Mean	12.794	20.459	34.002	-	22.01
	'p' values	0.040	0.020	0.070	-	0.077
2006-2007	Bari Sharisa-6	9.29Aa	20.44b	26.90b	0.004	13.55
	Bari Sharisa-7	9.10Aa	23.77b	30.93b	0.003	15.19
	Bari Sharisa-8	16.29CDa	27.95b	33.33b	0.014	18.03
	Bari Sharisa-9	12.69Ba	21.37b	29.34b	0.004	14.79
	Bari Sharisa-10	10.96ABa	18.67b	26.09c	0.002	13.02
	Bari Sharisa-11	11.67ABa	16.17b	26.52c	0.000	12.62
	Bari Sharisa-12	12.28Ba	14.13a	27.36b	0.000	12.42
	Rai-5	13.96BCa	21.77b	26.63b	0.004	14.43
	Tory-7	17.12Da	21.59a	29.30b	0.006	15.57
	Sonali-75	13.52BCa	23.24b	31.09c	0.002	15.84
	Mean	12.688	20.91	28.749	-	14.55
	'p' values	0.000	0.114	0.640	-	0.992

Mean values followed by same letter did not differ significantly at p<0.01 or p<0.05. Small and capital letter indicates row and column, respectively.

Table 4. Economic Threshold Level (ETL) of ten varieties of mustard of three growing stages (four sowing dates) for three cropping seasons (2004-2005, 2005-2006 and 2006-2007).

Crop seasons	Mustard vaieties	Seedling	Flowering	Podding	'p' value	All stages
2004-2005	Bari Sharisa-6	10.08ABa	14.54ab	20.34b	0.016	14.98
	Bari Sharisa-7	10.35ABCa	15.31b	18.86b	0.007	14.84
	Bari Sharisa-8	10.58ABCa	17.30ab	24.37b	0.012	17.84
	Bari Sharisa-9	9.54ABa	12.94a	22.07b	0.001	14.85
	Bari Sharisa-10	8.91Aa	10.72a	14.01b	0.002	10.47
	Bari Sharisa-11	10.54ABC	11.79	17.57	0.122	12.42
	Bari Sharisa-12	11.63ABCa	15.86ab	22.52b	0.096	15.70
	Rai-5	12.20BCa	15.33ab	19.33b	0.109	14.60
	Tory-7	10.03ABa	17.26b	19.97b	0.012	14.92
	Sonali-75	13.00C	18.57	22.31	0.127	17.62
	Mean	10.69	14.96	20.14	-	14.82
	'p' values	0.045	0.256	0.457		0.296
2005-2006	Bari Sharisa-6	11.01ABa	17.44Aa	41.33Cb	0.012	23.26
	Bari Sharisa-7	14.07B	20.98AB	25.06AB	0.201	20.03
	Bari Sharisa-8	10.98ABa	16.62Aa	30.10ABCb	0.001	19.23
	Bari Sharisa-9	8.86Aa	12.94Aa	25.36ABb	0.001	15.72
	Bari Sharisa-10	8.14Aa	13.23Aab	17.36Ab	0.064	12.23
	Bari Sharisa-11	7.82Aa	12.22Aab	25.26ABb	0.036	15.01
	Bari Sharisa-12	7.95Aa	14.47Aab	22.65ABb	0.011	14.49
	Rai-5	10.09ABa	16.50Aa	28.82ABCb	0.018	17.90
	Tory-7	8.78Aa	13.03Aa	20.74ABb	0.018	13.74
	Sonali-75	14.26Ba	26.24Bb	35.33BCc	0.000	24.44
	Mean	10.24	16.37	27.20	-	17.61
	'p' values	0.040	0.020	0.070	-	0.077
2006-2007	Bari Sharisa-6	7.43Aa	16.35b	21.52b	0.004	10.84
	Bari Sharisa-7	7.28Aa	19.02b	24.74b	0.003	12.15
	Bari Sharisa-8	13.03CDa	22.36b	26.66b	0.014	14.42
	Bari Sharisa-9	10.15Ba	17.10b	23.47b	0.004	11.83
	Bari Sharisa-10	8.77ABa	14.94b	20.87c	0.002	10.42
	Bari Sharisa-11	9.34ABa	12.94b	21.22c	0.000	10.10
	Bari Sharisa-12	9.82Ba	11.30a	21.89b	0.000	9.94
	Rai-5	11.17BCa	17.42b	21.30b	0.004	11.54
	Tory-7	13.70Da	17.27a	23.44b	0.006	12.46
	Sonali-75	10.82BCa	18.59b	24.87c	0.002	12.67
	Mean	10.15	16.73	23.00	-	11.64
	'p' values	0.000	0.114	0.640	-	0.992

Mean values followed by same letter did not differ significantly at p<0.01 or p<0.05. Small and capital letter indicates row and column, respectively.

(Thomas) on oilseed flax and calculated EIL as 8-10 aphids/stem at the green boll stage. Xibei *et al.* (1994) calculated the EIL for soybean aphids as 3.36%, and the ETL was 5 aphids/plants. Wise *et al.* (1995) found ETL as 3 aphids (*M. euphorbiae*) per stem at flowering stage and 8 aphids/stem at green boll stage in oilseed flax. Hansen (2000) found the ETL of *Rhopalosiphum padi* (Linn.) in spring barley (*Hordeum vulgare* L.) is about 10 aphids/tiller. Hodgsen *et al.* (2004) measured the ETL of soybean aphid, *Aphis glycines* Matsumura in midwestern U.S. on soybean, *Glycine max* (L.) Merrill in 2000 and recorded as a mean density of 250 aphids/plant.

Larsson (2005) conducted field experiments (1977–2002) with insecticides for aphid, *Sitobion avenae* (Fabr.) on wheat. The author calculated the EIL as 7 aphids/tiller and found no damage under 4 aphids/tiller. Larsson (2005) recorded the ETL for wheat was 1 aphid/tiller at crop stage of 59 days, 4 aphids/tiller at crop stage of 69 days and 7 aphids/tiller at crop stage of 75 days.

Hermoso de Mendoza *et al.* (2006) carried out experiments on *Aphis spiraecola* Patch infested *C. clementina* and calculated the EIL and ETL as 370 and 322 aphids/m^2 of canopy, respectively. Hermoso de Mendoza *et al.* (2006) also calculated the environmental economic injury level (EEIL) and environmental economic threshold (EET) as 614 and 533 aphids/m^2 of canopy, respectively.

Various economic thresholds for the aphid *A. spiraecola* on *C. clementina* have been calculated in several countries, e.g. in England 45 aphids/ear if density is increasing (Carter *et al.*, 1989); in Germany 3–5 aphids/ear around flowering (Wetzel *et al.*, 1980; Freier *et al.*, 1982; Basedow *et al.*, 1994; Holz *et al.*, 1994; Wetzel and Schutte, 1988)

or 1–6 aphids per tiller depending on crop stage (Mittnacht, 1986); in China 4–5 aphids/ear around flowering (Shaoyou *et al.*, 1986); in Sweden 1–8 aphids/tiller modified after crop stage and expected yield level (Larsson, 1986); in Denmark 120 aphid days which corresponds to 5 aphids/tiller (Hansen, 2003).

Ragsdale *et al.* (2007) calculated the average economic threshold (ET) for *A. glycines* on *G. max* as 273±38 (range 111-567) aphids/plant and the economic injury level (EIL) as 674±95 (range 275-1,399) aphids/plant.

From the results and above discussion, it is clear that EIL and ETL are not fixed values for a pest species; but they varied in relation to the plant stages, plant varieties, sowing stages and also in relation to the cropping seasons. It is essential to know the EIL and ETL before control measure to save the excess cost of pesticide and labour and safe to the other fauna and environment from excess toxicity.

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STUDIES ON OVIPOSITION BEHAVIOUR AND EGG HATCHING PATTERN OF AN APHID PREDATOR, *EPISYRPHUS BALTEATUS* (DE GEER) (DIPTERA: SYRPHIDAE) : A PROMISING BIOCONTROL AGENT

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Abstract : Syrphids are one of the most important predators of many economically important aphid species.The adult female syrphids have four phases of site selection for oviposition of which in the second stage, short - range of optical cues are thought to operate, which involve aphid colony recognition. The decision to lay egg is based not just on the density of aphids but also on the quality of aphid colony. Two bioassays were used to examine egg laying pattern in aphid predator *Episyrphus balteatus* in which the prey species preference, density and quality of the prey colony was tested. In the first bioassay individual female *Episyrphus balteatus* showed different oviposition preferences when presented with two aphid species *Lipaphis erysimi* and *Aphis gossypii*. The difference in egg laying preference was significant in favour of *Lipaphis erysimi* as compared to *Aphis gossypii*. In the second bioassay gravid female *Episyrphus balteatus* were allowed to oviposit in glass jars (height 30 cm, diameter 10 cm) which contained flowering twigs of mustard with aphid patches of variable density. Wherein three types of aphid patches were provided viz. new (5 to 10 nymphs), medium (20 to 30 aphids more nymphs and few adults) and old (more than 50 aphids with many adults) the prey aphids used here were *Lipaphis erysimi*. The female *Episyrphus balteatus* avoided the larger and ageing aphid colonies and chose to oviposit in new colonies with few aphids. In this bioassay incubation period and egg viability were also studied and both demonstrated significant difference between egg laid in or near the aphid colonies and else where (wall and floor of jar, muslin cloth etc.) in the experimental regimen. These bioassays provided an opportunity to determine individual components of decision – making by female *Episyrphus balteatus* regarding prey species and prey density during egg laying behaviour..

Key words : oviposition behaviour, oviposition preference, prey density.

INTRODUCTION

Syrphids are one of the most important predators of many economically important aphid species and are known to regulate the prey population effectively (Tamaki et al., 1967, Chambers et al., 1983; Tenhumberg, 1995). The larvae of aphidophagous species of syrphids such as *Episyrphus baltestus* (De Geer) (Diptera: Syrphidae) are important bio-control agents of prey aphids (Ankersmit *et al.,* 1986; Chambers and Adams, 1986). For the adult female syrphids it is suggested that there are four phases of site selection for oviposition (Chandler, 1966), which involve the processing of a range of sensory cues (Guest, 1984). The first phase of searching behaviour involves the assessment of long - range of optical cues, including the size, density and colour of the stand of vegetation (Chandler, 1966). In the second stage, short range optical cues are then thought to operate, which involve aphid colony size recognition (Dixon, 1959; Kan and Sasakawa, 1986). The decision to lay eggs is not only just based on the density of aphids (Tamaki *et al.,* 1967) but also on the quality of the aphid colony (Kan, 1988 a,b). The penultimate stage involves the processing of olfactory stimuli. The aphid–locating (aphidozetic) species such as *E. balteatus* uses aphid-derived compounds (Chandler, 1986a). In the final stage gustatory stimuli are utilized and female will alight and use her labellum to monitor the substrate for the presence of honeydew (Dixon, 1959; Kan and Sasakawa, 1986). Honeydew the aphid–derived complex of sugar, amino acids and water, is known to serve as an important oviposition stimulus for syrphids (Bombosch and Volk, 1966; Budenberg and Powell, 1992).

There is good evidence from laboratory experiments and field studies, to suggest that positive density-dependent oviposition occurs in *E. balteatus.* However field observations have also suggested that female syrphids avoid large or ageing aphid colonies (Kan and Sasakawa, 1986), which is termed as 'by-future' oviposition tactic. In this process the female syrphid decides to lay egg in new colonies and not in the colonies which may crash in future.

This paper therefore, is an attempt to delve deeper into our understanding of the decision–making process by females of *E. balteatus.* In this regard two bioassays were used to investigate the oviposition behaviour of female flies. In the first set of experiments the prey-aphid preference of female flies was tested by offering them an opportunity to select between two different aphid species while in the second, aphid patches of variable density were presented and their ovipositional response was analyzed.

MATERIALS AND METHODS

In the first bioassay ten-day old five gravid females of *E. balteatus* which had never been exposed to aphid/honeydew were released into an oviposition cage made of iron framework and acrylic mesh (90 x 60 x 60 cm). The oviposition cage was spacious enough to allow hovering of adults in the air. Three potted plants of mustard *Brassica rapa campestris,* and chrys-anthemum each, infested with *Lipaphis erysimi* (Kalt.) and *Aphis gossypii* Glover (Homoptera : Aphididae), respectively were placed in the cage. The pots were placed in an arrangement of 2x3, 15 cm away from the four walls of the cage and distance between them was 20 cm. The flies were provided with a diet of 50% honey and drinking water soaked in cotton swabs and contained in plastic lids as suggested by Frazer (1972). The adult diet was placed on a make shift raised platform well above the floor of the cage. Castor pollen was also provided in the
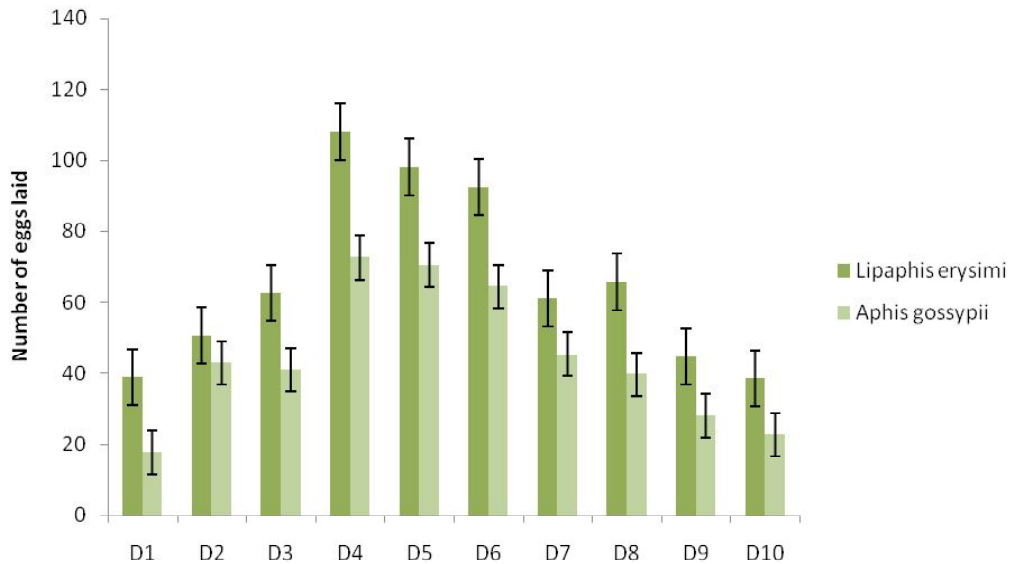
Figure 1. Influence of prey species on oviposition of *Episyrphus balteatus* the values displayed are mean number of eggs laid ??SD in aphid colonies of *Lipaphis erysimi* and *Aphis gossypii.*
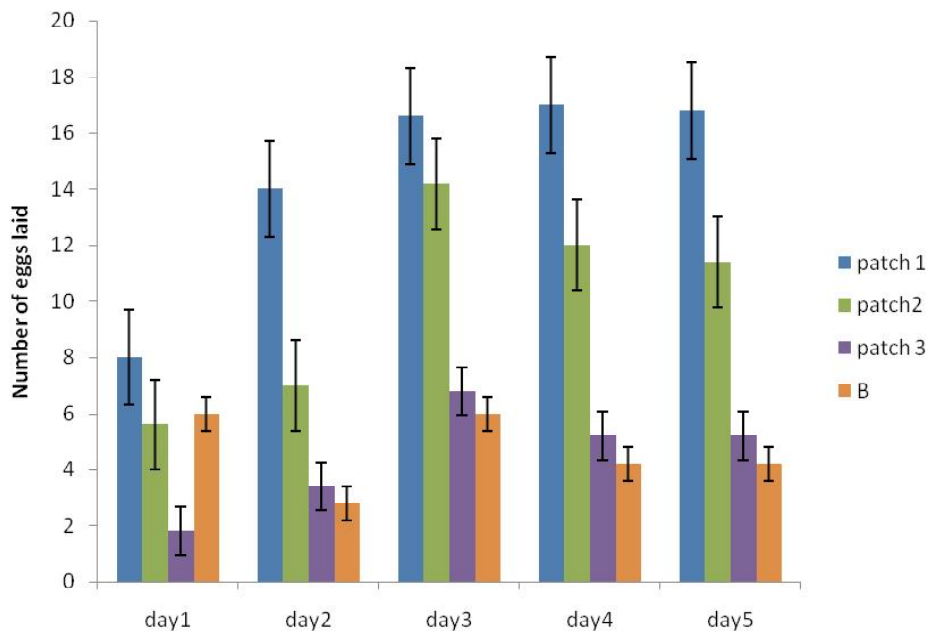

Figure 2. Influence of prey density on oviposition of *Episyrphus balteatus* the values displayed are mean number of eggs laid±SD in aphid patches of *Lipaphis erysimi*. Patch 1 is new patch (5 to 10 nymphs), Patch 2 is medium (20 to 30 aphids more nymphs and few adults), Patch 3 is old patch (more than 50 aphids with many adults) and B shows the number of eggs laid outside the aphid patches.

oviposition cage as feeding on pollen is known to be essential for normal egg production. Three replicates were arranged for this experiment and daily egg-yield was recorded in all the three replicates in relation to prey aphid species. The aphid infested potted plants were replaced by fresh ones daily. The experiment continued for 10 days and the results are displayed in Figure 1.

In the second bioassay gravid females of *E. balteatus* were allowed to oviposit in glass jars (height 30 cm, diameter 17.5 cm) covered at the top by a piece of muslin fastened by elastic bands. The jar contained flowering twigs of mustard with aphid patches of variable density. All twigs were about 15 cm in length and were placed in small water containing beakers that they may remain fresh during the experimental period. Wherein three types of aphid patches were provided viz. new (5 to 10 nymphs), medium (20 to 30 aphids more nymphs and few adults) and old (more than 50 aphids with many adults), the prey aphids used here were *L. erysimi.* Food and feeding arrangements for the fly were same as in the case of first bioassay. Five replicates were arranged to examine the effect of prey density on the oviposition of female *E. balteatus.* Twigs were examined daily and the number of eggs laid in each aphid patch was recorded with respect to prey aphid density. Eggs laid on the wall and floor of the jar and on the muslin which was used to cover the jar were also recorded, in each replicate. Each day the flies were provided with fresh flowering twigs of mustard with aphid patches of variable densities and the food was also replenished daily in each replicate. The eggs collected from each replicate were placed in separate Petri dishes on moist filter papers and viability of the egg was also taken into account in relation to the place where the eggs had been laid. The results of this experiment are displayed in Figure 2.

A control was also arranged on the same lines. In this case the fly was provided with flowering twigs of mustard which were grown separately and were never exposed to aphids. All necessary arrangements were provided for the nourishment of fly as in the experimental setup.

The experiments were conducted at $22 \pm 1^\circ$ C and 70 to 75% relative humidity.

RESULTS

For the first trial (the influence of prey aphid species on syrphid behaviour) the flies show a definite preference in favour of *L. erysimi* as compared to *A. gossypii* (two tailed P value equals to 0.0450, calculated t= 2.1546, df = 18).

In the second trial where the influence of prey density on oviposition behaviour of syrphid was tested, the female flies oviposited in all the three types of aphmid patches viz. new (5 to 10 nymphs), medium (20 to 30 aphids more nymphs and few adults) and old (more than 50 aphids with many adults) but there was a significant statistical difference between eggs laid in new patch and old patch only (two tailed P = 0.0476, calculated t= 2.3614, df = 8). The differences observed in the other two comparisons i.e. between new and medium aphid patches (two tailed P = 0.4226, calculated t= 0.8451, df = 8) and between medium and old aphid patches (two tailed P = 0.2105, calculated t= 1.3614, df = 8) were not statistically significant.

DISCUSSION

Tritrophic interaction among infested plants, herbivorous arthopods, and their natural enemies are complex because of

many semiochemicals involved. In addition to the semiochemicals emitted by herbivoure insects most of the plant species respond to insect infestation by synthesizing and releasing complex blend of volatiles. These can be used by predator and parasitoids as foraging cues, thereby enhancing the plants defense ability (Dicke *et al.,* 1990).

Syrphid larvae do not use semiochemicals to locate aphids, because of their limited dispersal abilities (Chandler, 1969), the choice of oviposition site by adult females has an impact on offspring performance. Location of herbivours prey by carnivorous arthropods is known to be mediated by many semiochemicals emitted by the prey or its host plants. (Dicke and Sabelis, 1988; Harmel *et al.,* 2007). Many studies on tritrophic interaction between plants, herbivorous insects and natural enemies have demonstrated attack-induced plant volatiles (synomones) may attract carnivorous species (Vet and Dicke, 1992; Turlings and Tumlinson, 1992). Plant infested by herbivores can qualitatively and/or quantitatively change their volatile emissions. These emissions usually consist of terpenoids (monoterpenes and sesquiterpenes) and green leaf volatiles (GLVs; alcohol, aldehydes or esters) the latter being specifically released just upon tissue damage (Pare and Tumlinson, 1997).

It has been reported that adult hoverflies are able to sense their environment by odours. In the present study the preference of female *E. balteatus* for *L. erysimi* as compared *A gossypii* may be due to semiochemicals emitted by the prey species and the host plants, which induced the hoverflies to oviposit in and near the prey colonies.

While testing the flies' oviposition behaviour in relation to prey density where the prey aphids used were *L. erysimi* a significantly high oviposition was recorded in the new and flourishing colonies, here the flies possibly considered the quality and not quantity of food. The multiplication rate of aphids is very high; the patch which may have a few nymphs at the time of oviposition may increase in size to provide sufficient nourishment for complete larval period. One well studied aspect of prey selection by females of *E. balteatus* is that they prefer to lay eggs in promising aphid colonies (Kan, 1988a, b.) and they do not like declining colonies.

This is probably related to the larval food requirement and may be one of the reasons why flies avoid the older colonies which are due to crash in near future and preferred new colonies which may grow and become well established in due course of time. This behaviour probably ensures that newly emerged larvae have enough food to develop successfully, and is important because when the larvae of *E. balteatus* are reared on below optimum amount of food resource the larvae have lengthened larval period and the adults thus produced have reduced fecundity and longevity (Ruzicka and Gonzales Cairo, 1976; Samuel *et al.,* 2005; Cornelius and Barlow, 1980). Thus from this study we could derive a clear cut conclusion that females of *E. balteatus* preferred young and promising colonies of *L. erysimi* as food resource for their larvae. However, Sutherland *et al.* (2001) demonstrated a positive density-dependent response of *E. balteatus* to aphid colony size in terms of oviposition behaviour, with a suggestion that a 'buy-futures' ovipositional tactic may be operating at higher colony sizes. Aphidophagous syrphids are know to demonstrate a positive relationship between aphid colony size and oviposition (Chandler, 1968b; Itô and Iwao, 1977; Geusen-Pfister, 1987; Tenhumberg and Poehling, 1991;

Bargen *et al.*, 1998; Scholz and Poehling, 2000).

Here it may not be out of place to mention that an in-depth study of the semiochemicals emitted by the host plants, honey dew produced by the aphids and the nutritional value of the prey aphids is required to obtain a more clear understanding of the decision making process by female *E. balteatus* for oviposition and thus an essential foundation for designing effective biological control and for better understanding when, where and how syrphids can effectively suppress aphid populations.

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POPULATION DYNAMICS OF SORGHUM APHID *MELANAPHIS SACCHARI* (HOMOPTERA : APHIDIDAE) AND COCCINELLIDS IN MARATHWADA REGION

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Abstract : The field experiment was conducted at Sorghum Research Station, Marathwada Agricultural University, Parbhani, Maharashtra during three consecutive Rabi season 2009 to 2011 with a view to study the Population dynamics of sorghum aphid *Melanaphis sacchari* (Zehntner) (Homoptera : Aphididae) and their coccinellid predators and their correlation with weather parameters. The results revealed that aphid incidence commenced in second to fourth week of December (50th-52nd Standard Meteorological Week). The peak period of aphid infestation was observed in third week of January during all these three years. Coccinellids were observed from last week of December to second week of February (52nd-6th Standard Meteorological Week) and reaches its peak in the last week of January to second week of February (4th-6th Standard Meteorological Week). The aphid population was positively significantly correlated with bright sun shine and maximum temperature. The significant positive correlation was observed between coccinellids and bright sun shine as well as maximum temperature whereas evening relative humidity had significant negative correlation.

Key words : Sorghum aphid, *Melanaphis sacchari*, coccinellids, population dynamics.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench, Family : Poaceae) is the fifth most important cereal crop in the world after wheat, maize, rice and barley. While it is third important cereal in India after rice and wheat. Insect pests are one of the major yield reducing factors in sorghum on global basis. Nearly 150 insect species have been reported to damage sorghum both in field as well as in storage. About a dozen are economically important in India, among which, in the recent past sorghum aphid, *Melanaphis sacchari* (Zehntner) (Homoptera : Aphididae) becoming a production constraint in *rabi*

tracts. Both grain and fodder of *rabi* sorghum are considered to be equally important by farming community. The aphid not only affect the grain and fodder yield but also fodder quality directly and indirectly. Balikai and Lingappa (2002) recorded 23.7% grain loss and 22% fodder yield loss in different genotypes due to aphids on *rabi* sorghum. Narayana *et al.* (1982) and Mote (1983) observed deterioration of fodder quality due to aphid infestation. Hence, an attempt was made to study the population dynamics of sorghum aphid and its coccinellid predators in relation to prevailing weather conditions in Marathwada region of Maharashtra state.

MATERIALS AND METHODS

Field studies were carried out for three consecutive *rabi* seasons 2009, 2010 and 2011 at Sorghum Research Station, Marathwada Agricultural University, Parbhani (M.S.) India. Sorghum variety M35-1

(Maldandi) was sown at 8th, 19th and 15th October during above three respective years in a 100 m^2 plot size. All the recommended agronomic practices were followed to raise the crop except crop protection measures. The observations on aphid population in terms of number of aphids per square centimeter were recorded with the help of magnifying lens on ten randomly selected plants at the end of each standard meteorological week (SMW). Five leaves of each selected plant from apex to downward excluding flag leaf as well as dried leaves at the bottom were observed for aphid population.

Population of coccinellids (Coleoptera : Coccinellidae) (both larvae and adults) were also taken from randomly selected ten plants at each SMW. Weekly data of both aphid and coccinellids population were analysed with data of respective SMW to find out correlation between them.
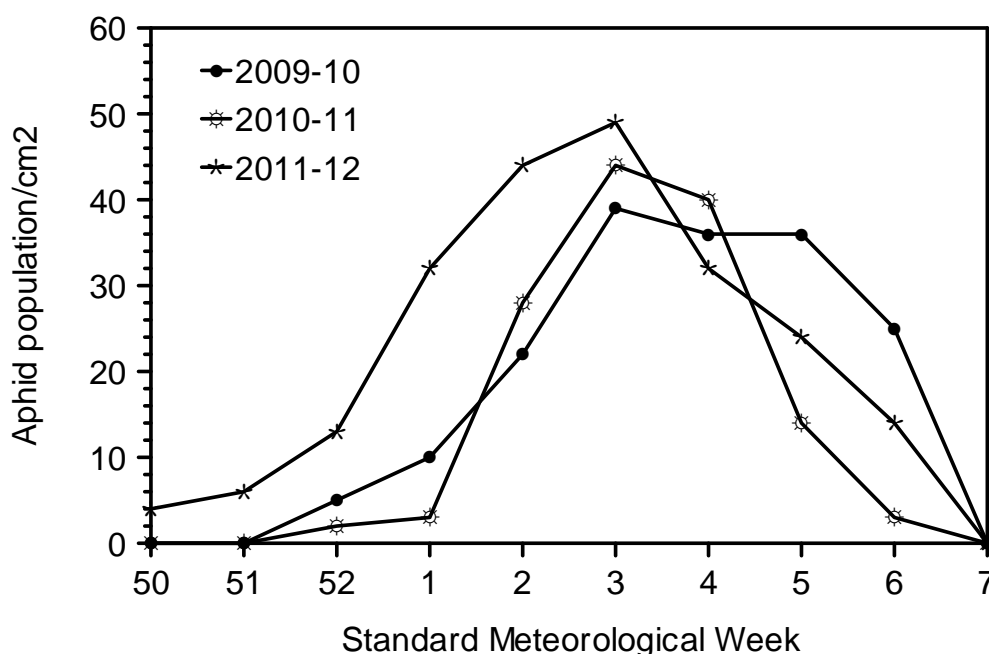

Fig.1: Population dynamics of aphid during three Rabi Seasons 2009-2011

Table 1. Population dynamics of Sorghum Aphid *M. saccari* and Coccinellids during three consecutive Rabi seasons 2009-2011.

Standard Meteoro-logical Week	Period	Aphid popu-lation/ cm^2	Coccina-lids popula-tion /10 plant	Temperature (°C)		Relative Humidity (%)		Bright Sun Shine (hours)
				min.	max.	morning	evening	
Rabi 2009-10 SD : 08.10.09								
52	24-31 Dec.	5	1	8.5	28.1	77	41	8
1	01-07 Jan.	10	2	9.8	28.9	81	33	10.3
2	08-14 Jan.	22	4	12.0	29.1	80	47	8.3
3	15-21 Jan.	39	6	9.1	28.9	77	31	10
4	22-28 Jan.	36	9	10.9	30.9	75	32	9.1
5	29-04 Feb.	36	6	13.0	32.3	71	25	8.6
6	05-11 Feb.	25	0	10.9	30.9	75	32	9.1
7	12-18 Feb.	0	0	16	34.2	75	31	9.3
Rabi 2010-11 SD : 19.10.10								
52	24-31 Dec.	2	0	11.2	29.1	71	39	9.7
1	01-07 Jan.	3	0	10.9	26.7	73	39	5.7
2	08-14 Jan.	28	0	6.0	28.7	75	22	10.9
3	15-21 Jan.	44	21	9.0	31.1	75	26	10.1
4	22-28 Jan.	40	59	10.4	34.6	73	27	10.8
5	29-04 Feb.	14	42	12.7	32.3	71	27	10.5
6	05-11 Feb.	3	38	10.8	32.9	80	24	10.7
7	12-18 Feb.	0	0	13.6	32.7	74	27	10.3
Rabi 2011-12 SD : 15.10.11								
50	10-16 Dec.	4	1	10.8	31.0	80	29	9.8
51	17-23 Dec.	6	0	9.7	25.5	78	25	9.9
52	24-31 Dec.	13	0	9.5	29.7	76	30	9.6
1	01-07 Jan.	32	0	16.2	32.3	78	36	8.3
2	08-14 Jan.	44	1	8.8	28.2	70	22	10.4
3	15-21 Jan.	49	3	8.1	29.2	72	23	10.5
4	22-28 Jan.	32	4	14.3	30.4	66	31	8.7
5	29-04 Feb.	24	13	14.5	30.3	74	31	9.6
6	05-11 Feb.	14	27	11.4	30.6	68	24	9.4
7	12-18 Feb.	0	0	11.6	24.0	44	15	6.9

RESULTS AND DISCUSSION

Population dynamics of aphid *M. sacchari* during three consecutive rabi seasons 2009-2011

    Rabi 2009-10 : The results indicated that aphid infestation commenced in last week of December (52nd SMW) from 5 aphids/cm^2, continuously increased there after till 3rd week of January (3rd SMW) when 39 aphids/cm^2 were noticed. Thereafter aphid population was declined and completely

Table 2. Correlation coefficients (r) of aphid *M.sacchari* incidence and Coccinellids incidence with Weather Parameters.

S.N.	Weather Parameters	*M. sacchari*	Coccinellids
1	Minimum Temperature (°C)	-0.11635	0.044
2	Maximum Temperature (°C)	0.20765	0.532**
3	Morning Relative Humidity (%)	0.12907	-0.137
4	Evening Relative Humidity (%)	0.00451	-0.343*
5	Bright Sun Shine (hours) Table(r) value : 0.324	0.26115	0.360*

disappeared in 3rd week of February (7th SMW).

Rabi 2010-11 : Aphid incidence started from last week of December (52nd SMW) with 2 aphids per cm^2, reached its peak (44 aphids/cm^2) in 3rd week of January (3rd SMW) and decreased thereafter before disappearing in 3rd week of February (7th SMW).

Rabi 2011-12 : The incidence of aphids were appeared in 2nd week of

December (50th SMW) with 4 aphids/cm^2 and reached its peak (49 aphid/cm^2) in 3rd week of January (3rd SMW), decline thereafter gradually and disappeared completely in 3rd week of February (7th SMW) (Table 1, Figure 1)

Present findings are more or less coinciding with the findings of following scientists Balikai (2007), Balikai and Lingappa (2002) who recorded incidence of aphid started from 2nd to 3rd week of
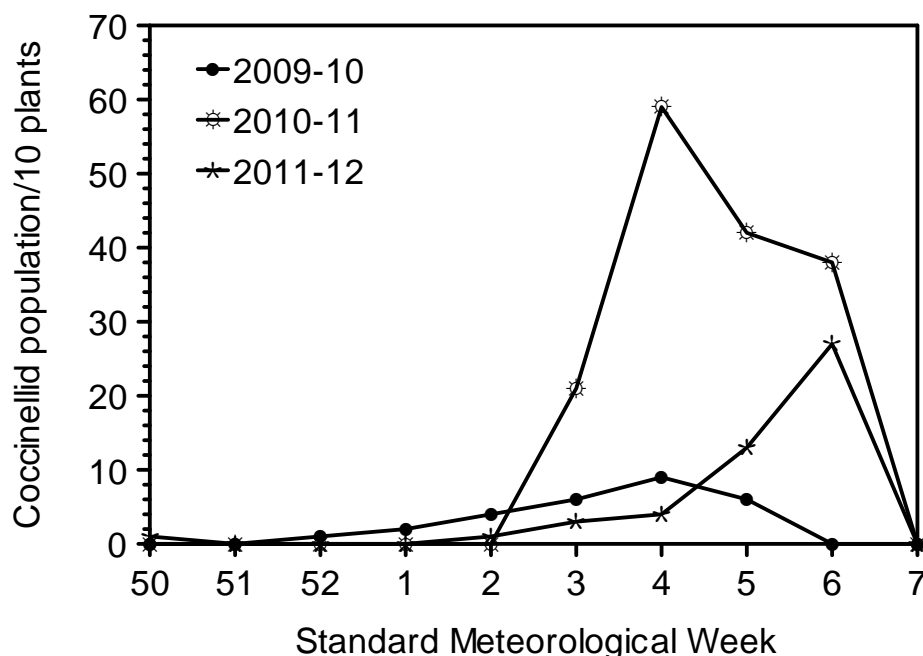

Fig.2 : Population dynamics of Coccinellids during three Rabi Seasons 2009-2011

December and reached its peak in 3rd to 4th week of January. Balikai (1997) reported that heavy incidence of *M. sacchari* occurred during the 2nd fortnight of January.

Population dynamics of coccinellids during three consecutive Rabi seasons 2009-2011

Rabi 2009-10 : The data revealed that the coccinellids population starts from last week of December (52nd SMW) and attained its peak (9/10 plants) during 4th week of January and completely disappeared in 2nd week of February (6th SMW).

Rabi 2010-11 : The coccinellids observed in 3rd week of January ,reaches its peak in 4th week of January (59/10 plants) thereafter starts decline and disappeared completely in 3rd week of February (7th SMW).

Rabi 2011-12 : The coccinellids appeared in 2nd week of January thereafter population of them increases continuously, attained its maximum (27/10 plants) in 2nd week of February (6th SMW) and disappeared then completely in 3rd week of February (7th SMW) (Table 1 and Figure 2).

Balikai (2007) and Patil and Sathe (2001) also recorded peak population of coccinellids during 1st week of February.

Correlation between aphid *M. sacchari* incidence and weather parameters : It is evident from the data that aphid incidence in terms of aphid population per cm^2 had non significant positive correlation with bright sun shine (r = 0.261), maximum temperature (r = 0.208) and morning relative humidity (r = 0.129) where as non significant negative correlation with minimum temperature (r = - 0.116) (Table 2). Balikai (2007) also reported the significant negative correlation between aphid population and minimum temperature where as positive correlation between aphid activity and morning relative humidity.

Correlation between Coccinellids incidence and weather parameters : The data indicated that maximum temperature (r = 0.532) and bright Sun shine (r = 0.360) showed significant positive correlation with coccinellid population where as evening relative humidity(r = -0.343) had significant negative correlation with coccinellid population (Table 2). Meena and Kanwat (2010) also reported the significant negative correlation of coccinellids with minimum temperature and relative humidity where as non significant positive correlation with maximum temperature.

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BIOLOGY AND ECOLOGY OF THE CABBAGE APHID, *BREVICORYNE BRASSICAE* (LINN.) (HOMOPTERA : APHIDIDAE) : A REVIEW

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Abstract : The cabbage aphid, *Brevicoryne brassicae* (Linn.) (Homoptera : Aphididae) is regarded as one of the major insect pest of brassica crops throughout the world. The present article reviews its biology, host plant relations, distribution, population dynamics, biocontrol, natural enemies with reference to Indian climates.

Key words : *Brevicoryne brassicae*, cabbage aphid, brassica crops, host plants.

INTRODUCTION

The cabbage aphid, *Brevicoryne brassicae* (Linn.) (Homoptera : Aphididae) was reported as early as 1734 by Frisch in Germany (Essig, 1948). In India, Lefroy and Howlett (1909) reported the species for the first time on brassica crops. There exists a considerable proportion of literature that deals with mainly geographical distribution, host plants, economic injury to the brassica crops, bionomics and studies of its chemical control. It is a destructive aphid native to Europe that is now found in many other areas of the world.

Earlier, several workers have studied its biology in different countries, e.g., Herrick and Hungate (1911) in New York State; Petherbridge and Wright (1938) in England; Elze (1944) in Palestine; Markkula (1953) in south Finland; Bodenheimer and Swirski (1957) in Middle East; and Amin and Defray (1981) in Egypt. Essig (1948) stated that its hosts belong to almost entirely to the family Brassicaceae and listed 51 species or varieties as host plants. Bonnemaison (1951) carried out an extensive study of the factors which affect the appearance of alate and sexual forms of *B. brassicae* and studied the morphology and biology of the different instars and forms. He worked out its bionomics and seasonal history and tested the suitability of several host plants. Hafez (1961) extensively studied its biology and seasonal history in Netherlands. The earliest record of the aphid from India is that by Lefroy and Howlett (1909). Later, it was also recorded by Das (1918) and Ghulalm-Ullah (1940).

Hafez (1961) studied the biology and ecology of *Brevicoryne brassicae* on brussels sprout fields located on a heavy clay soil

near Wageningen, the Netherlands and furnished basic information on its life history, development, population dynamics, biological control etc.

Distribution

B. brassicae is a cosmopolitan species and well distributed throughout the temperate and warm temperate parts of the world (Raychaudhuri, 1980; Blackman and Eastop, 2000; Carvalho *et al.*, 2002) and is spread in Europe, Anterior and Middle Asia, North America, North Africa, Australia, and New Zealand (Carter and Sorensen, 2013). The species occurs widely throughout the territory of the former USSR, except for the Far North. In India it has been reported from Himachal Pradesh (Tandon *et al.*, 1977), Meghalaya (Sachan and Gangwar, 1990), Manipur (Raychaudhuri, 1978) and Uttar Pradesh (Singh *et al.*, 1999), Himachal Pradesh, Uttarakhand, Punjab, West Bengal, Karnataka (Basavaraju *et al.*, 1995), Andhra Pradesh, Tamil Nadu, Maharshtra, Gujarat, Jammu and Kashmir, Manipur, Tripura and other states where cabbage is grown (Ghosh, L.K. *et al.*, 1980). *B. brassicae* prefers for more cool climate than other brassica aphid, e.g., *Lipaphis erysimi* (Kalt.)(Ghosh, L.K. *et al.*, 1980).

Economic importance

B. brassicae is the predominant species infesting cabbage and cauliflower grown for seed production in northwest Himalayas (Bhalla and Pawar, 1977; Kotwal *et al.*, 1984). Major economic hosts include: broccoli, brussels sprouts, cauliflower, and head cabbage. It attacks carrot, celery, Chinese broccoli, Chinese cabbage, daikon, radish, kale, rape and most other members of the genus *Brassica*, however, damage is usually less severe than on cabbage (Opfer and McGrath, 2013). However, the pest prefers such cultural plants as cabbage, mustard, radish, rape, turnip; and such weeds as wild radish, bittercress, pennycress, and sheperd's purse. It feeds on both leaves and flowers of seed plants. Infested plants retard growing and flowers fall down, not forming fruits. Yellow spots are observed on leaves of food cabbage; these leaves twist and dry up. Plants produce small heads much later. Sticky faecal masses (honeydew) pollute the leaves. At high insect numbers, the yield may decrease by 34-62%.

B. brassicae attacks different parts of plant, but mainly underside of the inter–spaces in the curd in cauliflower. In flowering plants including radish and turnip, the main shoots are attacked turning pale and sucking quickly, even the mature seed obtained were shriveled and unfit for sowing. Moreover, in oil–seed rape, heavy infestation caused reduction in seed yield and subsequently death of the young plants (Batra, 1960; Wanjama, 1978; Bahana and Karuhize, 1986). *B. brassicae* transfer dangerous viral diseases. It has been reported that it transmits at least 23 viral diseases within the family Brassicaceae (Hill, 1975). It transmit turnip mosaic virus in Zimbabwe (Chivasa *et al.*, 2002). Cioni *et al.* (2001) reported that *B. brassicae* transmits yellows closterovirus (BYV) and beet mild yellow virus [beet western yellows luteovirus] (BMYV) in Italy. *B. brassicae* virus (BrBV), has been identified in the cabbage aphid by Ryabov (2007) which was similar to those of iflaviruses identified for the first time in aphids. In Manipur, it attacks about eight species of brassica plants including indigenous varieties of cabbage causing great economic damage.

The cabbage aphid, *B. brassicae* is considered as key pest of cabbage and cauliflower in Himachal Pradesh (Bhalla, 1990; Barwal, 1997). The aphid infestation not only deteriorates the quality of the crop

but also the yield. Direct injury results in the loss of plant vigour and stunted growth. Indirectly, the honeydew excreted by the aphids and sooty mould hinders causing cauliflower mosaic, blackening spot of cabbage and cabbage viruses A and B (Gupta, 1978).

Biology

The cabbage aphid, *B. brassicae* are grayish-green with a waxy covering that gives them a grayish-white appearance. They have short siphunculus. Adults are present in both wingless and winged form. However, wingless females producing live young (nymphs), are the most common. It is one of the most serious sucking pest of brassica plants. It is a cosmopolitan species available in different agro-climatic conditions of the world where brassica crops are grown, particularly cabbage. It attacks all the parts of the brassica plants like fruits, inflorescence, leaves and shoots but mainly underside of the leaves as well as inner leaves of the head in cabbage and inter-spaces in the curd in cauliflower. Heavy infestation caused reduction in seed yield and subsequently death of the young plants (Batra, 1960; Bahana and Karuhize, 1986). It has been reported that *B. brassicae* is a vector of at least 23 viral diseases within the family Brassicaceae (Hill, 1975).

Because of their rapid development time (8-12 days from first instar nymph to adult), asexual reproduction (males not needed), and extended reproductive life-span (30+ days at 4-6 nymphs per day), cabbage aphid complete up to 15 generations (often overlapping) during the growing season.

Debaraj *et al.* (1995) studied the biology of *B. brassicae* on six food plants in the laboratory at average room temperature, 16.3 ± 0.2 °C and average RH 50.2 ± 1.4 % R.H.). They could not observe any significant difference in the total nymphal

development period on all the tested food plants. However, the reported that the nymphs of *B. brassicae* survived for slightly shorter period of 12.91 and 13.23 days on knoll-khol and cabbage-II (local variety) than the other food plants. Moreover, they found that the aphid was more fecund on knoll-khol (30.4 nymphs/female) and cabbage-II (28.6 nymphs/female) than others (mustard, cauliflower, radish and cabbage-I) and also survived longer on the above food plants.

The type of life cycle of *B. brassicae* depends on the climatic conditions during winter. In colder regions it is holocyclic (sexual forms - winged males and apterous oviparous females - appear in autumn; females release a sex pheromone, nepetalactone, and after mating they lay overwintering eggs). Where the winter is mild, they are anholocyclic (aphids reproduce parthenogenetically throughout the year). Parthenogenetic females are viviparous (they give birth to nymphs). Depending on the temperature and humidity conditions, one cabbage aphid generation develops in 7-10 days (Markkula, 1953; Hafez, 1961).

Sexuales of *B. brassicae* which plays a significant role in its biology occur usually at the higher altitudes where cold climate prevails and day length is short. David (1958) and Ghosh, A.K. *et al.* (1969) recorded male and female of *B. brassicae* occurring on Brassicaceae at an elevation of above *ca* 1525 m in the western Himalayas. This suggests that the *B. brassicae* reproduces holocyclically at the higher elevations.

Ulusoy and Olmez. (2006) studied the development time, mortality, survivorship and reproduction of the cabbage aphid *B. brassicae* on detached leaves of six *Brassica* species at a constant temperature of 20 °C. Total development time of *B. brassicae* was reported to be shortest (8.9 days) on

cauliflower and the longest (10.4 days) on cabbage. Mortality of immature stages varied from 16% on cabbage to 88% on turnip. Longevity of the cabbage aphid was the shortest (6.2 days) on mustard, and the longest (21.8 days) on cauliflower. The net reproductive rate was highest (35.98) on cauliflower, and lowest (1.89) on turnip. The intrinsic rate of increase was 0.2345 on cauliflower, followed by 0.2009 on cabbage, 0.1976 on broccoli, 0.1662 on mustard, 0.1357 on rapeseed, and 0.0465 on turnip. Cabbage, cauliflower and broccoli were susceptible host plants for the cabbage aphid. Rapeseed, turnip and mustard showed resistance to the pest.

Food plants

The food plant of *B. brassicae* is mainly different cultivars/varieties of *B. o.* (Brassicaceae) throughout the world. These are : *B. o.* var. *alboglabra* (Chinese broccoli, Chinese kale, Malayasian), *B. o.* var. *botrytis* (Cauliflower, Chou brocoli, Blumenkohl, Cavolfiore, Couve-flor, Coliflor), *B. o.* var. *capitata* (Cabbage, red cabbage, white cabbage, chou cabus, rotkohl, repolho, col, lombarda), *B. o.* var. *costata* (Bedford cabbage, braganza, Portuguese cole, Portuguese kale, seakale cabbage, tronchuda cabbage), *B. o.* var. *gemmifera* (Brussels sprouts group), *B. o.* var. *gongylodes* (Cabbage turnip, kohlrabi, stem turnip, knol-khol), *B. o.* var. *italica* (Asparagus broccoli, broccoli, calabrese, cape broccoli, heading broccoli, purple cauliflower, sprouting broccoli, winter broccoli), *B. o.* var. *medullosa* (Marrow kale, marrow-stem kale, chou moellier, Markkohl), *B. o.* var. *oleracea* (Wild cabbage), *B. o.* var. *palmifolia* (Jersey kale, palm-tree kale), *B. o.* var. *ramosa* (Branching bush kale, branching cabbage), *B. o.* var. *sabauda* (Saboy cabbage), *B. o.* var. *sabellica* (Borecole, curly kale, dwarf Siberian kale,

kitchen kale, Scottish kale), *B. o.* var. *viridis* (Collards, cow cabbage, fodder kale). However, a number of plants belonging to distantly related families were reported as food plant of *B. brassicae* (Blackman and Eastop, 2000; Holman, 2008).

The food plants of *B. brassicae* recorded from India are listed in Table 1 which display that 18 out of 31 food plants under 10 families recorded in India belong to the family Brassicaceae. Among the Brassicaceae 11 food plants belong to the genus *Brassica.* Only 5 plants of the family Solanaceae are reported to serve as host plant of *B. brassicae.* One plant species each of the families Chenopodiaceae, Cleomaceae, Fabaceae, Lamiaceae, Moraceae, Plantaginaceae, Poaceae, and Rubiaceae is recorded as host plant of the cabbage aphid but it seems that these plants may be occasionally or accidently visited by the aphid during swarming and may not serve as food plant.

Table 1. Record of food plants of *B. brassicae* from India and elsewhere.

Plant families/species/References

1.   **Family : Brassicaceae**
     Brassica juncea L. Czern.[1]
     Brassica napus L.[2]
     Brassica nigra (L.) W.D.J. Koch[3]
     Brassica oleracea L. [4]
     Brassica oleracea L. var. *viridis* DC. (=*Brassica oleracea* var. *acephala*)[5]
     Brassica oleracea var. *botrytis* L. (=*Brassica oleracea* var. *cauliflora*)[1]
     Brassica oleracea var. *capitata* L.[1]
     Brassica oleracea var. *gongyloides* L.[6]
     Brassica rapa L.[1]
     Brassica rapa ssp. *campestris* (L.) A.R. Clapham (= *Brassica campestris* L.)[1]
     Brassica rapa subsp. *dichotoma* (Roxb.) Hanelt   (=*Brassica campestris* var.

dichotoma (Roxb.) G. Watt ; = *Brassica dichotoma* misident.)[7]

Capsella bursapastoris (L.) Medik[2]

Cardamine hirsuta L.[2]

Cardamine impatiens L.[8]

Iberis sp.[9]

Nasturtium officinale R. Br.[10]

Raphanus sativus L.[11]

2. **Family : Chenopodiaceae**
   Beta vulgaris L.[2]

3. **Family : Cleomaceae**
   Cleome gyandra L. (= *Cleome pentaphylla* L.; *Gynandropsis pentaphylla* (L.) DC)[12]

4. **Family : Fabaceae**
   Cajanus cajan (L.) Millsp.[13]

5. **Family : Lamiaceae**
   Scutellaria scandens Buch.-Ham. ex D. Don[8]

6. **Family : Moraceae**
   Ficus sp.[8]

7. **Family : Plantaginaceae**
   Veronica agrestis L. [14]

8. **Family : Poaceae**
   Zea mays L.[14]

9. **Family : Rubiaceae**
   Guettarda acreana K. Krause (= *Guttarda incana* misident. ?)[8]

10. **Family : Solanaceae**
    Atropa belladonna L.[8]
    Lycopersicon esculentum Mill.[15]
    Petunia integifolia (Hook) Schinz and Thell. (= *Petunia violacea* Lindl.)[8]
    Solanum tuberosum L.[8]
    Solanum virginianum L. (= *Solanum xanthocarpum* Schrad.; *Solanum surattense* Burm. f.)[8]

[1]Behura, 1963; [2]Raychaudhuri, 1980; [3]Agarwala *et al.,* 1980; [4]Basu and Raychaudhuri, 1980; [5]Bhagat, 1984; [6]Agarwala *et al.,* 1982; [7]Behura, 1965; [8]Chakrabarti, 1972; [9]Chakrabarti, 1977; [10]Chakrabarti and Sarkar, 2001; [11]Ghosh, L.K. *et al.,* 1980; [12]Joshi and Poorani, 2007; [13]Lefroy and Howlett, 1909; [14]Ghosh, L.K., 1977; [15]Agarwala and Raychaudhuri, 1980).

In addition, following plants were also recorded as food plant of *B. brassicae* elsewhere (Blackman and Eastop, 2006; Hines and Hutchison, 2013).

1. **Asteraceae**
   Gonospermum fruticosum (Buch) Less
   Sonchus oleraceus L.

2. **Brassicaceae**
   Alliaria petiolata (M. Bieb.) Cavara and Grande (= *Alliaria officinalis* Andrz. ex M. Bieb.)
   Armoracia rusticana G. Gaertn. et al. (= *Armoracia lapathifolia* Gilib. ex Usteri)
   Aurinia saxatilis (L.) Desv. subsp. *saxatilis* (= *Alyssum saxatile* L.)
   Brassica fimbriata Hort.ex Steud.
   Brassica juncea var. *crispifolia* L. H. Bailey
   Brassica juncea var. *integrifolia* (H. West) Sinskaya (= *Brassica integrifolia* (H. West) Rupr.)
   Brassica juncea var. *juncea* (= *Brassica cernua* (Thunb.) F. B. Forbes and Hemsl.)
   Brassica napus var. *napobrassica* (L.) Rchb. (= *Brassica napobrassica* (L.) Mill.; = *Brassica napus* ssp. *rapifera* (Metzg.) Sinskaya)
   Brassica oleracea var. *ramosa* DC.
   Brassica rapa L. ssp. *dichotoma* (Roxb.) Hanelt (= *Brassica dichotoma* Roxb.)
   Brassica rapa ssp. *chinensis* (L.) Hanelt

(= *Brassica chinensis* L.)

Brassica rapa ssp. *pekinensis* (Lour.) Hanelt (=*Brassica pekinensis* (Lour.) Rupr.)

Brassica tournefortii Gouan

Bunias erucago L.

Cakile maritima Scop.

Camelina sp.

Cardamine chenopodifolia Pers.

Cardamine flexuosa With.

Crambe maritima L.

Descurainia sophia (L.) Webb ex Prantl

Diplotaxis harra (Forssk.) Boiss.

Diplotaxis muralis (L.) DC.

Diplotaxis tenuifolia (L.) DC.

Eruca sativa Mill. (=*Eruca vesicaria* subsp. *sativa* (Mill.) Thell.)

Erucaria sp.

Erucastrum gallicum (Willd.) O. E. Schulz

Erysimum canescens Roth.

Erysimum cheiri (L.) Crantz

Erysimum cheiranthoides L.

Erysimum diffusum Ehrh.

Heliophila sp.

Hesperis matronalis L.

Hirschfeldia incana (L.) Lagr.-Foss.

Iberis affinis Jord.

Isatis tinctoria L.

Lepidium draba L.

Lepidium perfoliatum L.

Lepidium ruderale L.

Lepidium sativum L.

Lunaria annua L. (=*Lunaria biennis* Moench)

Matthiola ovatifolia (Boiss.) Boiss. (=*Matthiola odoratissima* Boiss.)

Myagrum sp.

Ochthodium aegyptiorum DC.

Raphanus landroides

Raphanus raphanistrum L.

Raphanus sativus L. (= *Raphanus acanthiformis* Morel ex Sisley)

Rapistrum rugosum (L.) All.

Sinapidendron rupestre Lowe

Sinapis alba L.

Sinapis arvensis L.

Sinapis arvensis L. ssp. *arvensis* (=*Brassica arvensis* (L.) Rabenh.)

Sisymbrium officinale (L.) Scop.

Turritis glabra L. (=*Arabis glabra* (L.) Bernh.)

3. **Chenopodiaceae**

Beta vulgaris ssp. *vulgaris* L. (=*Beta vulgaris* var. *cicla* L.)

4. **Crassulaceae**

Sedum sp.

5. **Cucurbitaceae**

Cucumis melo L.

6. **Lamiaceae**

Moluccella laevis L.

7. **Limnanthaceae**

Limnanthes douglasii R. Br.

8. **Linaceae**

Linum sp.

9. **Resedaciae**

Reseda sp.

10. **Scrophulariaceae**

Veronica agrestis L.

11. **Solanaceae**

Atropa belladonna L.

Capsicum annuum L.

Capsicum baccatum L.

Capsicum frutescens L.

Solanum sarrachoides Sendtn.

12. **Tropaeoleaceae**

Tropaeolum majus L.

Food plants selection and chemical ecology

During flight, cabbage aphid responds to physical and chemical stimuli. Shape, size, and density of plants, as well as light of high intensity (especially wavelengths of 550 to 590 nm) are significant cues. Particularly important is the contrast between light reflected from bare soil and plants. Summer migrants do not respond to host plant volatiles from large distances; however, they do react positively to host plant volatiles in close proximity, especially the volatile products of glucosinolate breakdown (Nault and Styers, 1972; Gabrys, 1999).

While the plant surface, *B. brassicae* is relatively unaffected by mechanical barriers. However, exceptionally dense hairs can protect plant parts against aphid infestation. Epicuticular wax structure also is important; cabbage aphids drop off smooth surfaces. Glucosinolates typical of a given plant species, and n-alkane mixture in epicuticular waxes present on the plant surface, can be recognized by cabbage aphids. It is not clear whether these chemicals bear any importance in host selection. The existence of external contact chemoreceptors at the tips of aphid antennae is not well documented. It is assumed that aphids tend to initiate stylet probes into plant tissues regardless of the nature of surface chemicals. Landing on an unsuitable plant motivates cabbage aphids for new flights. Flight muscle autolysis occurs several days after settling and the start of reproduction.

When probing (i.e. inserting and moving the stylets within plant tissues), cabbage aphid selects for high turgor and high amino acid, sucrose and glucosinolate content in young and growing plants parts of its host plants. When aphid stylets are in peripheral tissues (epidermis and mesophyll),

the continuation of probing depends on detection of chemical stimulants – glucosinolates – in mesophyll cells. Aphids are able to sample mesophyll cell content during brief cell punctures along the stylet pathway. Feeding deterrents may impede stylet penetration at epidermis and parenchymatous tissues as well as at vascular tissue level. When aphid stylets are in vascular tissues (phloem and xylem), cabbage aphid responds positively to a high content of amino-acid nitrogen, and at the same time it is relatively resistant to its loss. High nitrogen fertilization of soil promotes cabbage aphid population development under field conditions. The development of *B. brassicae* is positively correlated with threonine, tyrosin, alanin, leucine, and glutamic acid content, and negatively correlated with phenylalanine content. A minimum of 15% sucrose content stimulates feeding by the cabbage aphid. Such concentration occurs in phloem sap of growing leaves. Among plant allelochemicals, the glucosinolate concentration reaches 10 mM. However, most glucosinolates do not have direct effect on aphid performance. Cabbage aphid fecundity is positively correlated with some alkenyl glucosiolates (e.g., progoitrin, sinigrin) content, and a negative correlation is found for indole ones (e.g. glucobrassicanapin, neoglucobrassicin). Glucosinolate metabolism in the aphid is not known. Some amount of the ingested glucosinolates is sequestered in cabbage aphid haemolymph. The glucosinolates may also be hydrolyzed by endogenous aphid myrosinases (aphid myrosinases are not identical with plant myrosinases). High lectin content in phloem sap causes high mortality of *Brevicoryne brassicae*. The possible mechanism for this toxicity may be binding of lectin to chitinous structures in the stylets and foregut (Klingauf, 1987).

The cabbage aphid, *B. brassicae*, has

developed a chemical defence system that exploits and mimics that of its host plants, involving sequestration of the major plant secondary metabolites (glucosinolates). Like its host plants, the aphid produces a myrosinase (â-thioglucoside glucohydrolase) to catalyse the hydrolysis of glucosinolates, yielding biologically active products. Kazana *et al.* (2007) demonstrated that aphid myrosinase expression in head/thoracic muscle starts during embryonic development and protein levels continue to accumulate after the nymphs are born. However, aphids are entirely dependent on the host plant for the glucosinolate substrate, which they store in the haemolymph. Kazana *et al.* (2007) also investigated the uptake of a glucosinolate (sinigrin) when aphids fed on plants or an in vitro system and followed a different developmental pattern in winged and wingless aphid morphs. In nymphs of the wingless aphid morph, glucosinolate level continued to increase throughout the development to the adult stage, but the quantity in nymphs of the winged form peaked before eclosion (at day 7) and subsequently declined. Winged aphids excreted significantly higher amounts of glucosinolate in the honeydew when compared with wingless aphids, suggesting regulated transport across the gut. The higher level of sinigrin in wingless aphids had a significant negative impact on survival of a ladybird predator. Larvae of *Adalia bipunctata* (L.) were unable to survive when fed adult wingless aphids from a 1% sinigrin diet, but survived successfully when fed aphids from a glucosinolate-free diet (wingless or winged), or winged aphids from 1% sinigrin. The apparent lack of an effective chemical defence system in adult winged aphids possibly reflects their energetic investment in flight as an alternative predator avoidance mechanism.

Seasonal activities

B. brassicae is basically monocious, its host range consists of primarily of plants in the family Brassicaceae in summer as well as in winter, including such important crops as oilseed rape and cabbage vegetable (head cabbage, brussels sprouts, cauliflower, kale, collards). The host plant may be divided in to three groups depending on their ability to support aphid populations: permanent, temporal, and accidental host plants. Permanent host plants support the cabbage aphid populations throughout the whole vegetation period. A female may give birth to about 20 nymphs in 10 days (on *B. napus, B. oleracea, Sinapis alba* (L.)). Temporal host-plants support 2 to 3 aphid generations. A female feeding on temporal host plants produces about 10 larvae in 10 days (such plant as *Lepidium sativum* (L.), *Isatis tinctoria* L.). On accidental host-plants, aphids may develop less than one generation (*Thlaspi arvense* L. (10 nymphs/10 days/female), *Capsella bursa-pastoris* (L.) (5 nymphs/10 days/female), *Lunaria annua* L. (4 nymphs/ 10 days/female), *Erysimum cheiranthoides* L. (0 larvae/10days/female) (Klingauf, 1987). In Florida, generations are overlapping, with up to 15 generations during the crop season (Hines and Hutchison, 2013).

Older nymphs and adult apterae leave plants in response to overcrowding and decline in plant quality. They move within a plant or between plants via touching stems or the soil. Winged morphs appears following overcrowding and decline in plant quality, or in reaction to environmental factors such as temperature (below 10-15p C for at least 24 hours), and seasonal changes in day length (photoperiod). Overcrowding alone is not responsible for appearance of winged forms in cabbage aphid colonies (Klingauf, 1987). In In northern part of India, all stages in the life cycle, wingless adults and nymphs, are present throughout the year in the following Table 2.

Table 2. Seasonal occurrence of *B. brassicae* in the fields of eastern Uttar Pradesh.

Development stage	Bar indicating periods of peak activity in each of the life cycle stages											
Nymphs			▨	▨	▨					▨	▨	▨
Wingless Adults			▤	▤	▤					▤	▤	▤
Alate adults		▧	▧	▧						▧	▧	▧
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Female aphids are parthenogenic and viviparous, that is, producing live nymphs without mating. Although small numbers of winged (alate) aphids fly throughout the year, large numbers are produced in spring (October/November) and autumn (February/ March) when the main dispersal flights to other crops occur. New colonies are then initiated by the winged aphids. Established colonies are made up of individuals of several generations of sedentary apterous aphids, with a single adult producing 22-26 nymphs. The rate of growth is dependent mainly on temperature, during summer development from nymph to reproducing adult takes 7-16 days, while m cooler winter conditions this period may be prolonged to 40-60 days. The life span of the aphid is usually about 28 days.

Population dynamics and seasonal history

Population dynamics of *B. brassicae* in relation to abiotic and biotic factors have been studied by various workers in different agro-climatic conditions in India and abroad (George,1957; Lamb, 1961; Hughes,1963; Rao,1969; Herakly and El- Ezz, 1970; Tandon *et al.*, 1977; Bahana and Karuhize, 1986; Pal and Singh, 2012). Further, studies on the population growth and other bioecological aspects of this aphid are referable to the works of Hafez (1961), Otake (1961), Lamb and Lowe (1967), Shiga (1967), Daiber (1971a, b), Kotwal (1981), Raworth (1984) and Debaraj *et al.*, (1994). Out of three species studied at Solan (Himachal Pradesh), Kotwal *et al.* (1998) observed that *B. brassicae* was abundant among them on cauliflower (81.4% of the total catch of alate aphids). Maximum flight activity occurred during February and March in both seasons when the emigrant population also reached its peak density.

The multiplication of this aphid has been observed to be favoured by various climatic factors. Tandon *et al.* (1977) and Pal and Singh (2012) recorded the maximum aphid population when the average maximum temperature was 16-37°C and Hughes (1963) gave 4.1°C as the threshold of development for the cabbage aphid. In addition to this, high temperature, rain and wind have been reported to be important natural mortality factors for the aphid (Deloach, 1974).

Raj and Sharma (1991) reported that *B. brassicae* appeared in the fields during last week of January and peaked in the first week of April and observed that temperature and relative humidity had no significant impact on it while rainfall caused a sudden reduction in its population. Field studies carried out by Singh *et al.* (1992) in

cauliflowers and cabbages during 1988-89 in New Delhi, India, showed that populations of the aphids *B. brassicae* followed a negative binomial distribution pattern. Boyd and Lentz (1994) worked on seasonal incidence of aphids and the aphid parasitoid *Diaeretiella rapae* (McIntosh) (Hymenoptera: Aphidiidae) on rapeseed in Tennessee and reported that aphid infestations were observed to cause substantial damage to rapeseed stands in 1990. However, the lack of quantitative yield-loss data precludes the effective integration of natural and chemical control strategies on rapeseed. Basavaraju *et al.* (1995) worked on seasonal abundance of aphids on mustard *B. juncea* at Bangalore (Karnataka, India) and reported that the peak incidence of *B. brassicae* during kharif 1991, summer 1992, kharif 1992 and rabi 1992. Ceron *et al.* (1995) reported that the distribution and population fluctuations of *B. brassicae* (85%) on broccoli plant during March-June 1993 in Guatemala. Choi *et al.* (1996) reported that the *B. brassicae* showed a clumped distribution throughout the growing season in Korea. Kumar *et al.* (2000) while working on the effect of date of planting on the incidence of insect-pest and extent of loss in summer cabbage in lower Kullu Valley, Himachal Pradesh reported that *B. brassicae* were found to infest only the crops planted in March and April.

Dogra *et al.* (2001) reported that the peak population of *B. brassicae* was recorded during the second week of March 1999, with maximum and minimum temperatures of 10.3 °C in Palampur (H.P.). *B. brassicae* showed a positive correlation with temperature.

De Carvalho *et al.* (2002) observed that *B. brassicae* peaked during July in Brazil during 1997-98. Rain and low temperatures adversely affected the alate aphid population, where rain was the main regulating factor for population increase.

Raj *et al.* (2002) observed the impact of weather factors on population build up of aphids infesting rapeseed mustard at Palampur (H.P.) crop seasons and reported that *B. brassicae* appeared during the first week of February in 1993 and last week of January in 1994 and the peak population of *B. brassicae* (46.07 aphids/10 cm apical shoot) in last week of February 1993 and (98.95 aphids/10 cm shoot) were recorded in the first week of March. Population counts exhibited low correlation coefficient (r) with abiotic factors during 1993 but highly positive correlations with minimum and maximum temperature, wind velocity and sunshine were observed during 1994.

Pal and Singh (2012) also observed positive correlation between temperature and population build up of *B. bassicae* and negatively correlated to relative humidity and total rainfall. Plants of *Brassica napus* inoculated with *B. brassicae* at various growth stages of the plant (1-8 head/plant at seedling stage, bolting, silique development and no inoculation for the full growing period, Wang *et al.* (1997) demonstrated that the aphid infestation had significant effects on vegetative growth and formation of reproductive organs. Plant height and silique number/plant were negatively correlated with aphid density. The critical aphid densities were 12-15 heads/plant at the seedling stage, 50-100 heads/plant at bolting and 90-110 heads/plant at silique, causing yield losses of 16.3, 17.5 and 13.9% respectively. The action threshold for control of the aphids was recommended as 12 aphids/plant.

Defense mechanism against natural enemies

The cabbage aphid, *B. brassicae* have a unique defense mechanism against predators. The aphids produce a myrosinase

(beta-thioglucoside glucohydrolase) enzyme in head and thoracic muscles; the aphids also uptake glucosinolates, particularly sinigrin, from the plants on which they feed, storing the glucosinolates in their haemolymph. Glucosinolates are natural defenses for plants in the order Brassicales against pests and herbivores. The combination of the glucosinolates and the myrosinase enzyme produces a violent chemical reaction that releases the mustard oil chemical allyl isothiocyanate. The defense mechanism has a dramatic negative effect on the survival of the larval ladybird predator *A. bipunctata*. The chemical defence of the aphids has been likened to a *walking mustard oil bomb*.

The myrosinase from *B. brassicae* appears to have evolved separately from myrosinases found in plants, possibly a case of convergent evolution. Aphid myrosinase appears to have greater similarity to animal â-O-glucosidases than to plant myrosinases (Jones *et al.*, 2001; Pontoppidan *et al.* 2001; Bridges *et al.* 2002; Husebye *et al.* 2005).

Pratt *et al.* (2008) demonstrated that the presence of sinigrin in the diet of *B. brassicae* makes this aphid unsuitable as a food source for *Adalia bipunctata* but not for *Coccinella septempunctata*, although for this ladybird species, there appear to be costs associated with feeding on aphids that contain this secondary metabolite as the presence of sinigrin in the aphid diet decreased larval growth and increased the time necessary for larvae to reach second instar for this species of ladybird.

Biological/natural control

Naturally occurring parasitoids and predators are important factors in regulating population densities of *B. brassicae*. Table 3 displays the record of natural enemies (parasites/parasitoids/predators) of *B. brassicae*.

Table 3. Records of natural enemies (parasites/parasitoids/predators) of *B. brassicae*.

A.   Predators

   Coleoptera : Coccinellidae.
   Adalia bipunctata (L.)[1]
   Adalia tetraspilota (Hope)[2]
   Anegleis cardoni (Weise)[2]
   Cheilomenes sexmaculata (F.)[3]
   Chilocorus nigrita (Fabr.)[4]
   Coccinella septempunctata L. [2]
   Coccinella transversalis F.[2]
   Coccinella undecimpunctata L.[2]
   Harmonia axyridis (Pallas)[5]
   Harmonia dimidiata (F.)[2]
   Harmonia eucharis (Mulsant)[2]
   Hippodamia variegata (Goeze)[2]
   Nephus regularis Sicard[2]
   Oenopia kirbyi Mulsant[2]
   Oenopia sauzeti Mulsant[2]
   Oenopia sexareata (Mulsant)[2]
   Propylea dissecta (Mulsant)[6]
   Propylea japonica (Thunberg)[2]
   Scymnus (Pullus) xerampelinus Mulsant[2]

   Diptera : Syrphidae
   Betasyrphus serarius (Wied.)[7]
   Melanostoma orientale Wied.[7]
   Metasyrphus corollae (F.)[8]
   Sphaerophoria bengalensis Macqaurt[9]
   Episyrphus balteatus (De Geer)[10]
   Eupeodes confrater (Wied.)[10]
   Ischiodon scutellaris (F.)[10]
   Xanthogramma sp.[10]

   Neuroptera : Chrysopidae
   Chrysopa formosa Brauer[11]
   Chrysoperla carnea (Stephens)[11]

B.   Parasitoids
   Hymenoptera: Aphelinidae
   Aphelinus albipodus Hayat and Fatima[12]
   Aphelinus asychis (Walker)[12]

   Hymenoptera : Braconidae
   Aphidius colemani Haliday[13]
   Aphidius matricariae Haliday[13]
   Diaeretiella rapae (M'Intosh)[13]
   Ephedrus lacertosus (Haliday)[14]
   Ephedrus persicae (Frogatt)[15]
   Lysiphlebus sp.[16]
   Trioxys brevicornis (Haliday)[14]
   Trioxys rubicola Shujauddin[14]
   Trioxys sp.[16]

C.   Fungal Parasites
   Zygomycetes: Entomophthorales
   Entomophthora aphidis Hoffman[17]
   Pandora neoaphidis (Remaudière and Hennebert)[18]
   Verticillium lecanii (Zimmerman)[19]

[1]Francis *et al.* (2004), [2]Agarwala and Ghosh (1988), [3]Agarwala and Yasuda (2000), [4]Omkar and Bind (1995), [5]Tsaganou *et al.* (2004), [6]Pervez and Omkar (2004), [7]Kumar and Kapoor (1992), [8]Du and Chen (1993), [9]Kumar and Kapoor (1992), [10]Ghorpade (1981), [11]Singh and Jalali (1991), [12]Hayat (1998), [13]Starý and Ghosh (1983), [14]Raychaudhuri (1990), [15]Valestin (1975), [16]Cruz de *et al.* (1992), [17]Raj and Lakhanpal (1998), [18]Shah *et al.* (2004), [19]Derakhshan *et al.* (2007)

D. rapae, is the most common parasitoid of *B. brassicae.* The female is dark brown and 3 mm in length. Eggs are deposited into half-grown nymphs, preferring second to fourth instars over first instar nymphs or adults. Wasp larvae develop inside the aphid and emerge from the aphid mummy (light brown harden shell of the host aphid) by cutting an exit hole in the mummy. The wasp overwinters as a fully grown larva in the mummy (Singh and Singh, 2002; Singh *et al.*, 2004; Prasad *et al.*, 2005; Singh *et al.*, 2006). Although, *D. rapae* is a very common parasitoid, it is not always effective in controlling aphid populations. When wasp populations are large enough to be effective, the aphid population has usually exceeded damage thresholds (Pal and Singh, 2012). Also, *D. rapae* itself may often be killed by hyperparasitoids.

Duchovskien and Raudonis (2008) studied the rate of parasitism of *B. braassicae* by *D. rapae* in Italy. The highest parasitation was observed when the number of aphids on the plants was the lowest, *i. e.* at the end of their occurrence on the plants. When the abundance of cabbage aphids increases, the abundance of *D. rapae* increases, too. *D. rapae* reduced the populations of cabbage aphid by 23.9–26.2% and higher number of aphids and *D. rapae* was recorded in manure-fertilized cabbage as compared with non-fertilized cabbage plants.

Variable rates of parasitism of *B. brassicae* by *D. rapae* in *Brassica* cropping systems have been found in interplantings compared with clean cultivated monocultures (Smith, 1976; Altieri *et al.*, 1985; Horn, 1988; Kloen and Altieri, 1990). Main crop growth parameters are often lower when inter-planting with non-crop vegetation (Dempster and Coaker, 1974; O'Donnell and Coaker, 1975; Andow *et al.*, 1986; Horn, 1988), making it difficult to determine whether effects seen on aphid populations are the results of parasitism or changes in plant quality.

Small colonies of aphids can be effectively controlled by predators. Syrphid fly (Diptera : Syrphidae) maggots and lady beetles (Coleoptera : Coccinellidae) are

efficient predators of aphids. Syrphid maggots are more common of the two types of predators. Lacewing (Neuroptera : Chrysopidae) larvae are often found among aphid colonies. These larvae are called aphid lions. They are less efficient predators than syrphid maggots and lady beetles. Also, in wet or humid weather, fungal epidemics can help control aphid populations. *Bacillus thuringiensis* (*Bt*) products are not active on aphids.

In Monterey County (California, USA), the cabbage aphids predominately colonised the outer leaves of a broccoli plant (*B. oleracea*) but did not significantly influence infestation at harvest (Nieto *et al.*, 2006). Center-located aphids were reported to be correlated with head infestation for both field seasons, as were aphids on leaf 2 in 2002. Aphid arrival time into a field was strongly correlated with infestation at harvest, with early arriving aphids being less likely to infest a head. This was in part caused by natural enemies, particularly syrphid larvae, which were in greatest abundance in response to early aphid colonisers. Natural enemies showed a capability to positively affect infestation at harvest, although their success seemed dependent on sufficient early season cabbage aphid arrivals.

Hyperparasitoids

Hyperparasitoids are secondary insect parasitoids that develop at the expense of a primary parasitoid, thereby representing a highly evolved fourth trophic level. Aphid hyperparasitoid communities consist of ecto- and endohyperparasitoids, with ectohyperparasitoids being less host specific than endohyperparasitoids. Lifetime fecundity and intrinsic rate of increase of hyperparasitoids are generally lower than those of their primary hosts. Aphid ectohyperparasitoids search randomly for

hosts and do not use specific cues, whereas endohyperparasitoids gain information that originates from host plants or hosts for long-range search. Interactions with adult primary parasitoids do not influence hyperparasitoid searches, but aphid-attending ants typically prevent successful hyperparasitoid foraging (Sullivan, 1987). Singh and Tripathi (1991) recorded the Indian species of aphid hyperparasitoids. Most common hyperparasitoid of *B. brassicae* are : *Alloxysta brassicae* (Ashmead), *A. fuscicornis* (Hartig), *A. infuscate* (Kieffer), *Asaphes vulgaris* (Walker), *A. suspensus* (Nees), *Pachyneuron aphidis* (Bouche), *P. minutissimum* (Förster), *Dendroerus carpenterii* (Curtis), *Phaenoglyphis piciceps* (Thomson) (Valestin, 1975; Chua, 1977; Singh and Tripathi, 1991; Carver, 1992).

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