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Distribution and Biology of *Mallada desjardinsi* (Neuroptera: Chrysopidae) in India and Its Predatory Potential Against *Aleurodicus dispersus* (Hemiptera: Aleyrodidae)

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Abstract

In this study, we report the prevalence of *Mallada desjardinsi* (Navas) in seven geographical regions of India and provide the first report of its kind outlining the preying of all stages of the spiraling whitefly, *Aleurodicus dispersus* Russell, by *M. desjardinsi*. Sampling was conducted in seven regions of two provinces in India, Bengaluru (Karnataka) and Tiruppur (Tamil Nadu), which demonstrated that *M. desjardinsi* populations were most dense at the former and least at the later. To the best of our knowledge, this is the first report of its kind outlining observations regarding the biology and feeding potential of *M. desjardinsi* on *A. dispersus* under laboratory conditions. It was observed that the second nymphal stadium of *A. dispersus* was most preferred prey for *M. desjardinsi* and the least preferred was the *A. dispersus* adult. It was also seen that the third stadium of *M. desjardinsi* consumed more *A. dispersus* individuals than any other life stages. The longevity of female and the total developmental period of *M. desjardinsi* were computed as 27.6 ± 1.69 and 24.1 ± 0.99 d, respectively. The average total number of eggs laid by the *M. desjardinsi* female was 211.1 ± 6.35 eggs. *M. desjardinsi* was observed to be extremely efficient in terms of prey searching and predatory potential with respect to *A. dispersus*. The results of this study indicate strongly that *M. desjardinsi* has the potential to be used for the control of *A. dispersus*.

Key words: green lacewing, spiraling whitefly, life cycle, distribution, predator–prey interaction

The spiraling whitefly, *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae), is a polyphagous pest with an extensive host range (Srinivasa 2000, Boopathi et al. 2014). A direct damage is caused when immature and adult stages of the whiteflies pierce and the suck sap from foliage. As a byproduct of feeding, dense populations of this polyphagous pest cause premature leaf drop along with production of honeydew, which serves as a substrate for the growth of sooty mold (Akinlosotu et al. 1993, Boopathi et al. 2014). Sooty mold blackens the leaf, decreases photosynthetic activity and vigor, resulting in disfigurement of the host (Kumashiro et al. 1983, John et al. 2007). *A. dispersus* is difficult to control via use of conventional insecticides largely because the body of the insect is covered with heavy waxy flocculent materials (Waterhouse and Norris 1989). Additionally, the wide host range of this insect along with characteristics such as the ability to quickly infest and adapt to different habitats so as to inflict rapid damage, further complicate the management of *A. dispersus* using conventional chemical insecticides (Waterhouse and Norris 1989, Boopathi et al. 2013). Hence, in an attempt to control *A. dispersus* infestations, one prime area of interest wherein efforts have been focused off late is the biological control (Huffaker and Messenger 2012). Several reports in India have investigated the utility of common natural enemies of the spiraling whitefly such as predators like *Mallada astur* (Banks) and *Cybocephalus* spp., and parasitoids, like *Encarsia guadeloupae* Viggiani and *Encarsia* sp. nr. *meritoria* Gahan, as agents for biological control (Joshi and Yadav 1990, Mani and Krishnamoorthy 1999, Boopathi et al. 2015a).

In India, among the known natural enemies of *A. dispersus* that can be used in order to regulate its population are the commonly found and widespread green lacewings (Geetha 2000, Mani and Krishnamoorthy 1999). Many studies have documented the potential of green lacewings to function as natural enemies that can regulate the *A. disperses* population (Geetha 2000, Boopathi et al. 2013, Boopathi et al. 2015a). The green lacewings are considered as one of the most effective generalist predators that can be used for biological control. Green lacewings are an important group of predatory insects (Dean and Satasook 1983) that can be mass reared in the laboratory and used for the purpose of pest control (Syed et al. 2008). Their ability to adapt to a wide range of ecological conditions (Ulhaq et al. 2006) and tolerance to insecticides (Bigler 1984) has made them important in terms of both research as well as field applications (Nasreen et al. 2003).

Mallada desjardinsi (Navas) (Neuroptera: Chrysopidae) is a generalist predator that has been reported to prey on a wide variety of pests such as mealy bugs (Mani and Krishnamoorthy 1989), white flies (Joshi and Yadav 1990, Selvakumaran et al. 1996), bollworms, aphids *viz*., *Lipaphis erysimi* (Kalt.), *Brevicoryne brassicae* (L.) and *Uroleucon carthami* (H.R.L.) (Kabissa et al. 1996, Gade et al. 2011), neonates of *Helicoverpa armigera* (Hübner), *Spodoptera litura* F. and *Earias vitella* (F.) (Nagamallikadevi et al. 2013) as well as the red spider mite (Babu et al. 2011). Although generalist predators lack prey specificity, they can exert a significant impact on various pest complexes (Symondson et al. 2002). The larvae of green lacewings feed on plant-infesting pests such as aphids, whiteflies, scales, caterpillars, spider mites, etc. (McEwen et al. 2001). Green lacewing adults are commonly considered nonpredatory, as they generally feed on nectar, pollen, or honeydew although a few of them are known to be predatory in their eating habits (Coppel and Mertins 1977). Project Directorate of Biological Control ([PDBC] 1998), Mani and Krishnamoorthy (1999), and Geetha (2000) reported that the larvae of *Mallada astur* (Banks) prey on *A. dispersus*, but no information is available in literature regarding the feeding potential and biology of *M. desjardinsi* on *A. dispersus*. In recent years, green lacewings have begun to be regarded as an exceptional addition to any IPM (Integrated Pest Management) program. Other natural enemies or predators and parasitoids of *A. dispersus* suffer from crucial shortcomings that prevent them from controlling this pest efficiently. This study therefore was conducted in an attempt to study the distribution and biology of *M. desjardinsi* in order to analyze its predatory potential against *A. dispersus* with the view of exploiting it as a potential biological control agent for regulation of the whitefly population.

Materials and Methods

Assessment of Intensity of Damage Caused by *A. dispersus* and Prevalence of *M. desjardinsi*

An intensive survey was undertaken between August 2012 to March 2013 in seven different geographical regions covering the states of Tamil Nadu and Karnataka, India, in order to study the intensity of damage caused by *A. dispersus* as well as the distribution of *M. desjardinsi* (Table 1). Sampling units were selected randomly at five locations of each region and the survey was carried out on plants that are most preferred by *A. dispersus* as hosts (cassava, *Manihot esculenta* Crantz. and guava, *Psidium guajava* L.). A standard evaluation system was formulated based on the intensity of damage (%) inflicted by the *A. dispersus* infestations (Boopathi et al. 2014). The damage was categorized into seven grades based on the intensity (%) (Table 2).

Sampling Method for *A. dispersus* and Its Predator *M. desjardinsi*

For a period of eight months (August 2012 to March 2013), cassava and guava plants were sampled at monthly intervals for *A. dispersus* and its predator *M. desjardinsi*. The “leaf turn” technique was applied on 20 cassava plants at each location for computing the population of *A. disperses* nymphs as well as adults; this was based on direct counts from leaves from the top, middle, and bottom (Boopathi et al. 2014). For guava, 10 trees were selected for the population survey. In each tree, four terminal shoots were selected at random from the entire canopy. Thus, in all, 40 shoots growing in all directions were sampled per month (Boopathi et al. 2015b). For computing the population of *M. desjardinsi*, both larvae and adults, a similar technique was used: in cassava direct counts were done for 20 plants at each location while in guava four terminal shoots were selected at random from the entire canopy in 10 guava trees.

Mass Culturing of *M. desjardinsi*

Egg masses of *M. desjardinsi* were collected from the cassava ecosystem. The larvae were reared in large plastic containers (20 by 10 cm) that were covered with khada cloth (0.3531 mm) and the larvae were fed with different stages of *A. dispersus* which were replenished daily until pupation (Boopathi et al. 2014). The *M. desjardinsi* larvae pupated to round white-colored silken cocoons in 6–8 d. The cocoons were collected with a fine brush and transferred to plastic containers with a wire mesh window for the emerging adults. About 250 newly emerged adults (60% female) were sexed and pairs of male and female were introduced into a pneumatic trough (30 by 12 cm) and covered with white nylon or georgette cloth (0.15 mm) that was secured in place by a rubber band. Before releasing the adults, the adult rearing troughs were wrapped on the inside with a brown sheet which served as an egg receiving card. On the outside cloth three pieces of foam sponge (5 cm^2) soaked in water were kept. An artificial protein-rich diet was provided (Honey: Glucose: Protinex: Yeast: Water v/v @ 1:1:1:1:1) on the outside cloth for feeding and oviposition. The upper and peripheral sides of the containers were covered with opaque paper for preventing the penetration of outside light. Eggs were harvested periodically and placed in separate containers for hatching. This experiment was maintained at a constant temperature of 30 ± 2°C, 75 ± 5% RH, and a photoperiod of 12:12 (L:D) h (Gautam 1994).

Biology and Feeding Potential of *M. desjardinsi* on the *A. dispersus* Populations

Laboratory experiments were conducted in order to determine the feeding potential and biology of *M. desjardinsi*. *M. desjardinsi* individuals were placed separately in small plastic containers (10 by 5 cm) that were covered with a khada cloth (0.3531 mm). Each *M. desjardinsi* individual was examined daily and fresh leaves infested with 150 *A. dispersus* were provided so as to ensure that the predator always had an excess of prey. The leaves along with life stages of *A. dispersus* used in the experiment were examined under microscope, and the number and life stages of *A. dispersus* fed to each *M. desjardinsi* individual was counted. The study was continued till the predator died and the experiment was maintained as described previously by Gautam (1994). The stage-specific predatory potential of different larval stadia of *M. desjardinsi* on different life stages of *A. dispersus* was also studied. For this, each stage of *A. dispersus* (eggs, nymphs, pupae, and adults) were introduced separately into small plastic containers (10 by 5 cm) covered with a khada cloth (0.3531 mm) and a single larva of *M. desjardinsi* was introduced. The larvae used for each of the experiments were less than a day old and starved for 6 h prior to the start of the experiment by keeping them individually in separate plastic containers. The number of *A. dispersus* life stages consumed in 24 h was counted using a stereo

Table 1. *A. dispersus* and *M. desjardinsi* samples collected from seven different geographic regions of India

Locations	Host plants	Latitude	Longitude	Altitude (m)
Coimbatore, Tamil Nadu	*Manihot esculenta* Crantz.	11° 0′47.39″ N	76° 56′14.19″ E	434.0
Erode, Tamil Nadu	*M. esculenta*	11° 4′59.88″ N	77° 52′59.88″ E	144.0
Tiruchirappalli, Tamil Nadu	*Psidium guajava* L.	10° 53′37.56″ N	78° 32′8.02″ E	85.0
Salem, Tamil Nadu	*M. esculenta*	11° 44′16.63″ N	78° 2′6.73″ E	275.0
Namakkal, Tamil Nadu	*M. esculenta*	11° 3′26.49″ N	78° 8′33.85″ E	122.0
Tiruppur, Tamil Nadu	*M. esculenta*	11° 9′42.33″ N	77° 26′29.44″ E	295.0
Bengaluru, Karnataka	*P. guajava*	13° 1′36.90″ N	77° 35′5.07″ E	928.0

Table 2. Standard evaluation system based on the intensity of damage (%) by *A. dispersus*

Grade	Intensity of damage (%)	Damage category
1	0	Nil
2	1–10	Very low
3	11–20	Low
4	21–40	Moderate
5	41–60	High
6	61–80	Very high
7	81–100	Extreme

binocular microscope (Olympus 10 X). The experiment was replicated 10 times. The data on incubation period of eggs, developmental period of each larval stadium, prepupal period, pupal period, adult longevity, and fecundity were recorded. The larvae were provided with *A. dispersus* nymphs in plastic containers as described above. The experiment was replicated 10 times.

Statistical Analysis

The survey data of *M. desjardinsi* in different geographical regions of India were subjected to one-way analysis of variance (ANOVA) followed by Tukey's test at $P \leq 0.05$. The data regarding predatory potential of *M. desjardinsi* was subjected to both one- and two-way ANOVA followed by least squares means (LSD) under completely randomized design (Panse and Sukhatme 1981). The statistical analysis of the data was done using SAS Software Version 9.3 (SAS 2011).

Results

Survey of Intensity of Damage Inflicted by *A. dispersus*

Results regarding the distribution and intensity of damage inflicted by *A. dispersus* in seven geographic regions of India demonstrated an extreme intensity of damage in Coimbatore (99.2 ± 0.348%), Erode (98.7 ± 0.406%), Salem (97.4 ± 1.811%), Tiruppur (96.9 ± 0.537%), Bengaluru (95.3 ± 1.522%), and Namakkal (91.7 ± 2.975%; Table 3). The population density of *A. dispersus* was maximum in Tiruppur, Tamil Nadu (209.8 ± 5.588 per leaf), followed by that at Tiruchirappalli, Tamil Nadu (187.3 ± 6.074 per leaf). The least dense *A. dispersus* population was found in Bengaluru, Karnataka (89.3 ± 3.449 per leaf). Differences in the population of *A. dispersus* in seven geographic regions of India was statistically significant ($F = 103.03$; df = 9; $P < 0.000$; Table 4).

Distribution of *M. desjardinsi*

The occurrence and distribution of *M. desjardinsi* feeding on *A. dispersus* in seven different geographical regions of India are presented in Table 3. The density (number per plant) and percent distribution (percent distribution was calculated by the *M. desjardinsi* population from each location divided by total *M. desjardinsi* population and multiplied by 100) of *M. desjardinsi* was highest in Bengaluru, Karnataka (5.05 ± 0.108 and 26.6%, respectively), followed by that at Salem, Tamil Nadu (4.25 ± 0.086 and 22.4%, respectively), and Coimbatore, Tamil Nadu (3.92 ± 0.096 and 20.6%, respectively). The least dense *M. desjardinsi* population was found at Tiruppur, Tamil Nadu (0.26 ± 0.028, 1.4%). Differences observed in the population density of *M. desjardinsi* from seven geographical regions of India were statistically significant ($F = 1335.23$; df = 9; $P < 0.000$; Table 4).

Feeding Efficiency of *M. desjardinsi*

This is the first report that documents the predatory potential of *M. desjardinsi* for *A. dispersus*. The mean consumption for different stages of *M. desjardinsi* on different prey stages of *A. dispersus* is statistically significant (Table 5). The feeding efficiency of *M. desjardinsi* increased with advancement in each developmental stage. The first instar of *M. desjardinsi* consumed significantly less *A. dispersus* eggs (54.0 ± 0.316), first-instar nymph (58.0 ± 0.316), second-instar nymph (57.8 ± 0.490), third-instar nymph (50.6 ± 0.678), fourth-instar nymph (45.0 ± 0.447), pupae (40.2 ± 0.583), and adults (20.8 ± 0.374) as compared to the second instar and third instar of *M. desjardinsi*. The second instar of *M. desjardinsi* consumed more number of *A. dispersus* eggs (77.8 ± 0.663), first-instar nymph (77.6 ± 0.510), second-instar nymph (79.2 ± 0.374), third-instar nymph (78.6 ± 0.510), fourth-instar nymph (67.2 ± 0.860), pupae (78.6 ± 0.748), and adults (59.8 ± 0.490) as compared to the first instar but significantly less than the third instar of *M. desjardinsi*. The third instar of *M. desjardinsi* consumed significantly more number of *A. dispersus* eggs (79.8 ± 0.374), first-instar nymph (78.2 ± 0.583), second-instar nymph (124.0 ± 0.775), third-instar nymph (78.8 ± 0.374), fourth-instar nymph (79.2 ± 0.374), pupae (78.8 ± 0.374), and adults (62.2 ± 0.800) than any of the previous stages. The differences between different developmental stages of *A. dispersus* ($F = 1350.75$; df = 6; $P < 0.000$), different developmental stages of *M. desjardinsi* ($F = 8237.26$; df = 2; $P < 0.000$), and the interaction between different developmental stages of *A. dispersus* × different developmental stages of *M. desjardinsi* ($F = 320.91$; df = 12; $P < 0.000$; Table 6) were statistically significant.

A significant difference was observed when consumption of different developmental stages of *A. dispersus* by *M. desjardinsi* was analyzed. The mean consumption of the second-instar nymphs of *A. dispersus* by *M. desjardinsi* was the highest (261.0 ± 1.6856) as compared to all the other developmental stages. The average number of *A. dispersus* adults consumed by *M. desjardinsi* was significantly less (142.8 ± 2.4713) as compared to other developmental stages (Fig. 1). Significant variations in the predatory potential of *M. desjardinsi* were observed. These variations were found to be dependent upon the size and quantity of food (*A. dispersus*) offered to different

Table 3. Distribution of *A. dispersus* and its predator, *M. desjardinsi*, in the seven geographic regions of India

Locations	*A. dispersus*				*M. desjardinsi*	
	No. per leaf (mean ± SE)	Intensity of damage (%)	Grade	Category	No. per plant (mean ± SE)	Distribution (%)
Coimbatore, Tamil Nadu	107.3d ± 4.498	99.2 ± 0.348	7	Extreme	3.92b ± 0.096	21.0
Erode, Tamil Nadu	158.0c ± 3.873	98.7 ± 0.406	7	Extreme	2.14d ± 0.045	11.0
Tiruchirappalli, Tamil Nadu	187.3b ± 6.074	79.2 ± 0.862	6	Very high	0.95e ± 0.039	5.0
Salem, Tamil Nadu	96.0de ± 3.488	97.4 ± 1.811	7	Extreme	4.25b ± 0.086	22.0
Namakkal, Tamil Nadu	156.0c ± 2.799	91.7 ± 2.975	7	Extreme	2.44c ± 0.071	13.0
Tiruppur, Tamil Nadu	209.8a ± 5.588	96.9 ± 0.537	7	Extreme	0.26f ± 0.028	1.0
Bengaluru, Karnataka	89.3e ± 3.449	95.3 ± 1.522	7	Extreme	5.05a ± 0.108	27.0

SE, standard error. Data were analyzed and means were categorized using Tukey's test ($P \leq 0.05$). Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

Table 4. Analysis of variance (ANOVA) of data on distribution of *A. dispersus* and its predator, *M. desjardinsi*, from seven different geographic regions of India

Source	Degrees of freedom (df)	*F* value	SE	CD ($P \leq 0.01$)	Probability
1. *A. dispersus*	9	103.03	6.5308	18.8014	0.000**
2. *M. desjardinsi*	9	1335.23	0.0685	0.1972	0.000**

**Significant at $P \leq 0.01$, ANOVA.

Table 5. Predatory potential of *M. desjardinsi* feeding on *A. dispersus* ($n = 150$)

Different stages of *M. desjardinsi*	Number of *A. dispersus* individuals consumed by *M. desjardinsi* (mean ± SE)						
	Eggs	1st instar nymph	2nd instar nymph	3rd instar nymph	4th instar nymph	Pupae	Adults
1st instar larva	54.0c ± 0.316	58.0b ± 0.316	57.8c ± 0.490	50.6b ± 0.678	45.0c ± 0.447	40.2b ± 0.583	20.8c ± 0.374
2nd instar larva	77.8b ± 0.663	77.6a ± 0.510	79.2b ± 0.374	78.6a ± 0.510	67.2b ± 0.860	78.6a ± 0.748	59.8b ± 0.490
3rd instar larva	79.8a ± 0.374	78.2a ± 0.583	124.0a ± 0.775	78.8a ± 0.374	79.2a ± 0.374	78.8a ± 0.374	62.2a ± 0.800

Data were analyzed and means were categorized using LSD ($P \leq 0.05$). Means followed by the same letter are not significantly different ($P = 0.05$, LSD).

Table 6. Analysis of variance (ANOVA) of data on predatory potential of *M. desjardinsi* feeding on *A. dispersus*

Source	Number of *A. dispersus* individuals consumed by *M. desjardinsi*				
	Degrees of freedom (df)	*F* value	SE	CD ($P \leq 0.01$)	Probability
Life stages of *A. dispersus* (AD)	6	1350.75	0.4493	1.1843	0.000**
Life stages of *M. desjardinsi* (MD)	2	8237.26	0.2942	0.7753	0.000**
Interaction					
AD × MD	12	320.91	0.7783	2.0513	0.000**
Error	84	1.000	–	–	–

**Significant at $P \leq 0.01$, ANOVA.

developmental stages of *M. desjardinsi* as well as the size and longevity of different developmental stages of *M. desjardinsi*. The third larval instar of *M. desjardinsi* was observed to be voracious feeder and found to consume maximum number *A. dispersus* of all the stages during its life span (578.4 ± 2.0396) as compared to the first (326.4 ± 1.0296) and second (521.4 ± 1.7493) instars (Fig. 2).

Biology of *M. desjardinsi*

The predator was seen to lay stalked eggs in groups of 12–23 (Fig. 3) and the duration was observed to be around 3.2 ± 0.63 d (Table 7). The durations of the first, second, and third stadia of *M. desjardinsi* larvae averaged 2.7 ± 0.48, 4.6 ± 0.52, and 4.8 ± 0.42 d, respectively. The short prepupal and pupal periods averaged 1.6 ± 0.52 and 7.2 ± 0.63 d, respectively, and the total larval period averaged 12.1 ± 0.57 d. For *M. desjardinsi* that preyed on *A. dispersus*, the total developmental period averaged 24.1 ± 0.99 d. The average longevity of females was seen to be 27.6 ± 1.69 d and the total number of eggs laid per female averaged 211.1 ± 6.35.

Discussion

To the best of our knowledge this is the first report of its kind regarding the occurrence and distribution of *M. desjardinsi* feeding on *A. dispersus* in India (2012–2013) under field conditions. In the

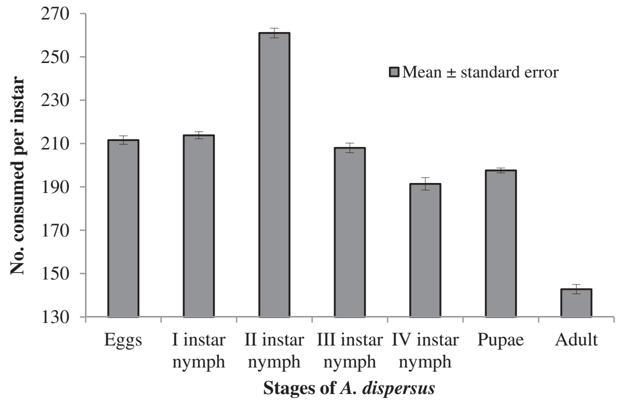

Fig. 1. Total number (±SE) of different stages of prey (*A. dispersus*) consumed by a single individual of *M. desjardinsi* during its entire life cycle.

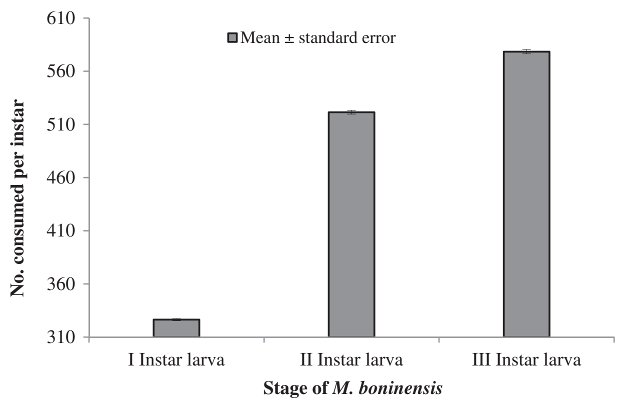

Fig. 2. Total number (±SE) of prey (*A. dispersus*) consumed by different stages of *M. desjardinsi* during its entire life cycle.

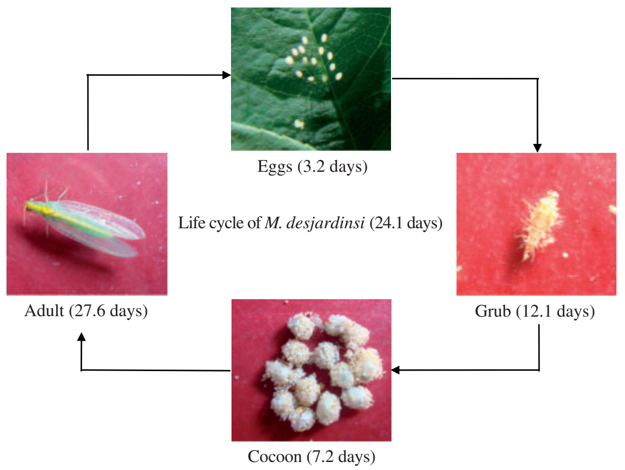

Fig. 3. Life cycle of *M. desjardinsi* feeding on *A. dispersus*.

Table 7. Life cycle parameters of *M. desjardinsi* on *A. dispersus* (each datapoint is an average of 10 replicates)

Life stages	Developmental period (d)	
	Average ± SE	Range
Egg (d)	3.2 ± 0.63	2.0–4.0
First stadium (d)	2.7 ± 0.48	2.0–3.0
Second stadium (d)	4.6 ± 0.52	4.0–5.0
Third stadium (d)	4.8 ± 0.42	4.0–5.0
Total larval period (d)	12.1 ± 0.57	12.0–13.0
Prepupal period (d)	1.6 ± 0.52	1.0–2.0
Pupal period (d)	7.2 ± 0.63	6.0–8.0
Total development period (d)	24.1 ± 0.99	23.0–26.0
Longevity of adult female (d)	27.6 ± 1.69	18.0–35.0
Fecundity per female (no.)	211.1 ± 6.35	180.0–241.0

current investigation, Bengaluru, Karnataka, was observed to have the highest density of *M. desjardinsi* population (26.6% and 5.05 ± 0.108 per plant). Earlier, Geetha (2000) reported the occurrence of a related species, *M. astur*, to be preying on all stages of *A. dispersus* in Coimbatore, Tamil Nadu, and Mani and Krishnamoorthy (1999) reported the same in Bengaluru, Karnataka, India.

Furthermore, this is the first report that analyzes the predatory potential of *M. desjardinsi* feeding on different stages of *A. dispersus* under laboratory conditions. Studies by Joshi and Yadav (1990) reported the feeding potential of *M. desjardinsi* (=*M. boninensis*) on *Bemisia tabaci* (Gennadius) under laboratory conditions. In the current investigation, the third stadium of *M. desjardinsi* was seen to be the most voracious predator of all life stages of *A. dispersus*, but it is to be noted that second stadium demonstrated an equal propensity for the consumption of the first and third instar as well as pupae of *A. dispersus*. As expected, *M. desjardinsi* first stadium presented with the least capacity to consume various life stages of *A. dispersus*. Our findings are largely in agreement with the observations reported by Huang and Enkegaard (2009) and Babu et al. (2011) who claimed that the first stadium of *M. desjardinsi* (=*M. boninensis*) consumed the least numbers of red spider mites. *M. desjardinsi* larvae easily removed the waxy material covering of *A. dispersus* by using their well-developed setae and mandibles, and thus demonstrated a great efficiency in prey searching and predatory potential on *A. dispersus*. The *M. desjardinsi* larvae consumed on an average 487.4 *A. dispersus* individuals. This is in parallel with a study conducted by Joshi and Yadav (1990) who reported that an *M. desjardinsi* (=*M. boninensis*) larva consumes on an average 453 nymphs of *B. tabaci*. It has also been reported that a single larva of *M. astur* can consume a total of 200 nymphs (Mani and Krishnamoorthy 1999). Earlier, it was reported that a single individual of the *Mallada* sp. can consume on an average 23,490 whiteflies during its entire life cycle (PDBC 1998). Ingole et al. (2005) reported that the release of *M. desjardinsi* (=*M. boninensis*) had reduced the *Aleurocanthus woglumi* Ashby population in citrus plants by 34.6–36.7%.

Kabissa et al. (1996), Nehare et al. (2004), and Huang and Enkegaard (2009) have reported that the prey consumption of lacewings increases with advancement in larval instars. Second and third stadia of *M. desjardinsi* consumed a much larger number of *A. dispersus* individuals. This clearly demonstrates that the third-instar lacewings are far more voracious than the second and first instars (Atlihan et al. 2004, Huang and Enkegaard 2009). In the present study, when the prey stages were offered separately, the third stadium of *M. desjardinsi* was seen to consume more eggs and more first and second instar of *A. dispersus* than any other stage of *M. desjardinsi*. These findings are largely in agreement with the observations reported by Joshi and Yadav (1990) regarding the predation by *M. desjardinsi* (=*M. boninensis*) on *B. tabaci*. A possible reason for the higher consumption of eggs as well as first and second instar nymphs of *A. dispersus* could be that the size of the prey is smaller and has less waxy flocculent substance as compared to the body size of third and fourth instar nymphs and adults, and also the static state.

When all the life stages of *A. dispersus* were offered together, all three stadia of *M. desjardinsi* were seen to accept every stage of prey. The foraging behavior of many predators is observed to be dependent on the relation between the body size of the predator and prey (Sabelis 1992). Mean prey size increases with the body size of the predator (Werner and Gilliam 1984, Cisneros and Rosenheim 1997). In our study, we found that all three instars of *M. desjardinsi* accepted all life stages of *A. dispersus* including the adults. The reason for the acceptance of all life stages of *A. dispersus* by *M. desjardinsi* larvae may be that the body size of *A. dispersus* is much smaller than that of *M. desjardinsi* as has been hypothesized previously by Cheng et al. (2010) who reported that the green lacewing, *Mallada basalis* (Walker), larvae did not demonstrate any noticeable preference for any particular life stage of mites but rather accepted all the life stages equally.

Developmental stages of *M. desjardinsi* consist of an egg, three stadia, prepupae, pupae, and an adult form. The female is known to be marginally larger than male. Nagamallikadevi et al. (2013) studied the biology of *M. desjardinsi* on three different neonates of *H. armigera*, *S. litura* and *E. vitella*. Larval stages of many chrysopids cover the dorsum with debris including their own cast cuticles, remains of prey, and the fragments of vegetables or other materials; such larvae are called trash carriers or debris carriers. This is hypothesized to be a protective mechanism employed by larvae to guard against other predators (Canard and Principi 1984). Similarly, in our study we also noticed this camouflaging behavior in *M. desjardinsi*. The third stadium of *M. desjardinsi* spins a silken cocoon within which it becomes enclosed. In the present investigation, the total developmental period of *M. desjardinsi* averaged 24.1 ±0.99 d on *A. dispersus*. Studies by Joshi and Yadav (1990) have reported that the total developmental period of *M. desjardinsi* (=*M. boninensis*) feeding on *B. tabaci* averaged 32.64 d. Similarly, Babu et al. (2011) have reported that the developmental period of *M. desjardinsi* (=*M. boninensis*) on red spider mites is around 31.7 d. Earlier research indicated that the average developmental periods of a related species, *M. astur*, on nymphs of *A. dispersus* were 13.5 d (PDBC 1998) and 14.2 d (Geetha 2000). The larval duration of *M. desjardinsi* averaged 12.1 ±0.57 d. Similarly, the larval duration of *C. zastrowi sillemi* is reported as 24.8 d (Gerling 1986) for *M. astur* it is known to be 11.6 d (Venkatesan et al. 2002) and for *M. basalis* the same is computed to be 11.8 d (Chang 2000). The latter value is closer to our observations in this study. We found that the longevity of *M. desjardinsi* female was 27.6 ± 1.69 d on *A. dispersus* population. However, Joshi and Yadav (1990) have reported that the average longevity of *M. desjardinsi* (=*M. boninensis*) females and males was 64.8 ± 15.97 and 27.36 ± 8.03 d, respectively, which is higher than our findings. Nagamallikadevi et al. (2013) observed that the male and female longevity of *M. desjardinsi* (=*M. boninensis*) is superior over that for neonates of *S. litura* (21.16, 35.58 d, respectively) rather than *H. armigera* and *E. vitella*. The average number of eggs laid by the *M. desjardinsi* female was 211.1 ± 6.35 eggs. Joshi and Yadav (1990) reported that the total number of eggs laid by the *M. desjardinsi* (=*M. boninensis*) female averaged 431 ± 38.62 eggs when fed with *B. tabaci* nymphs which is higher than those obtained in our investigations. Nagamallikadevi et al. (2013) observed that reproductive potential of *M. desjardinsi* (=*M. boninensis*) (94.50 eggs per female) was enhanced by the neonates of *S. litura*. However, Gerling (1986) reported that the fecundity of *M. astur* ranged from 315 to 386 eggs per female. This difference in the fecundity of green lacewings might be due to different species of chrysopids, host insects, and environmental conditions used in the different studies.

Biological pest control is an exciting and promising alternative to chemical control (Huffaker and Messenger 2012). In our study results clearly demonstrated that the *M. desjardinsi* larvae are able to easily remove the waxy material covering of *A. dispersus* by using their well-developed setae and mandibles, and thus they were observed to demonstrate great efficiency in prey searching as well as predatory potential on *A. dispersus*. Our findings proved conclusively that *M. desjardinsi* is an efficient predator of *A. dispersus* under laboratory conditions, which corroborates the findings of Joshi and Yadav (1990) and Babu et al. (2011), who reported that *M. desjardinsi* (=*M. boninensis*) is the best biological control agent against *B. tabaci* and red spider mites, respectively. Lastly, larval instars of *M. desjardinsi* were the most voracious feeders of spiraling whiteflies. Thus, this predatory green lacewing has the potential to be exploited for the management of *A. dispersus* by mass rearing and release on different crops in southern India. However, before drawing firm conclusions about the effectiveness of *M. desjardinsi* on *A. dispersus*, further experiments, under field conditions are warranted.

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References Cited

Akinlosotu, T. A., L.E.N. Jackai, N. N. Nitonifor, A. T. Hassan, G. W. Agyakwa, J. A. Odfbiyi, A. E. Akingbohungbe, and H. W. Rossel. 1993. Spiralling whitefly, *Aleurodicus dispersus* in Nigeria. FAO Plant Protec. Bull. 41: 127–129.

Atlihan, R., B. Kaydan, and M. S. Ozgokce. 2004. Feeding activity and life history characteristics of the generalist predator, *Chrysoperla carnea* (Neuroptera: Chrysopidae) at different prey densities. J. Pestic. Sci. 77: 17–21.

Babu, A., D. Vasantha Kumar, V. K. Jasin Rahman, A. Roobak Kumar, and C. Sundaravadivelan. 2011. Potential of *Mallada boninensis* Okamoto (Neuroptera: Chrysophidae), as a biocontrol agent of *Oligonychus coffeae* Nietner (Acarina: Tetranychidae) infesting tea. J. Plantat. Crops 39: 193–195.

Bigler, F. 1984. Biological control by Chrysopids: Integration with pesticides. pp. 233–245. *In* M. Canard, Y. Semeria and T. R. New (eds.), Biology of chrysopids. Dr. W. Junk Publication Junk, Boston, The Netherland.

Boopathi, T., P. Karuppuchamy, M. Kalyanasundaram, S. Mohankumar, and M. Ravi. 2013. Pathogenicity, ovicidal action, and median lethal concentrations (LC_{50}) of entomopathogenic fungi against exotic spiralling whitefly, *Aleurodicus dispersus* Russell. J. Pathog. 2013: 1–7. DOI: http://dx.doi.org/10.1155/2013/393787.

Boopathi, T., P. Karuppuchamy, M. Kalyanasundaram, S. Mohankumar, M. Ravi, and S. B. Singh. 2015a. Microbial control of the exotic spiralling whitefly, *Aleurodicus dispersus* (Hemiptera: Aleyrodidae) on eggplant using entomopathogenic fungi. Afr. J. Microbiol. Res. 9: 39–46.

Boopathi, T., S. B. Singh, T. Manju, Y. Ramakrishna, R. S. Akoijam, S. Chowdhury, N. Hemanta Singh, and S. V. Ngachan. 2015b. Development of temporal modeling for forecasting and prediction of the incidence of lychee, *Tessaratoma papillosa* (Hemiptera: Tessaratomidae), using time-series (ARIMA) analysis. J. Insect Sci. 15: 1–5.

Boopathi, T., S. Mohankumar, P. Karuppuchamy, M. Kalyanasundaram, M. Ravi, B. Preetha, and R. Aravintharaj. 2014. Genetic evidence for diversity of spiralling whitefly, *Aleurodicus dispersus* (Hemiptera: Aleyrodidae) populations in India. Fla. Entomol. 97: 1115–1122. DOI: http://dx.doi.org/10.1653/024.097.0318

Canard, M., and M. M. Principi. 1984. Development of Chrysopidae, pp. 57–75. *In* M. Canard Y. Semeria T. R. New (eds.), Biology of Chrysopids. Dr. W. Junk Publication Junk, Boston, The Netherland.

Chang, C. P. 2000. Investigation on the life history of *Mallada basalis* (Walker) (Neuroptera: Chrysopidae) and the effects of temperatures on its development. Chin. J. Entomol. 20: 73–87.

Cheng, L. L., J. R. Nechols, D. C. Margolies, J. F. Campbell, and P. S. Yang. 2010. Assessment of prey preference by the mass-produced generalist predator, *Mallada basalis* (Walker) (Neuroptera: Chrysopidae), when offered two species of spider mites, *Tetranychus kanzawai* kishida and *Panonychus citri* (Mcgregor) (Acari: Tetranychidae), on papaya. Biol. Control 53: 267–272.

Cisneros, J., and J. Rosenheim. 1997. Ontogenetic change of prey preference in the generalist predator *Zelus renardii* and its influence on predator-predator interactions. Ecol. Entomol. 22: 399–407.

Coppel, H. C., and J. W. Mertins. 1977. Biological insect pest suppression. Springer, Berlin.

Dean, G. J., and C. Satasook. 1983. Response of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) to some potential attractants. Bull. Entomol. Res. 73: 619–624.

Gade, R. S., S. S. Shetgar, and S. L. Chavan. 2011. Biology of *Mallada boninensis* (Okamoto) on three species of aphids. J. Entomol. Res. 35: 139–141.

Gautam, R. D. 1994. Present status of rearing of chrysopids in India. Bull. Entomol. 35: 31–39.

Geetha, B. 2000. Biology and management of spiralling whitefly, *Aleurodicus dispersus* Russell (Homoptera: Aleyrodidae). Ph. D. dissertation, Department of Agricultural Entomology, Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Gerling, D. 1986. Natural enemies of *Bemisia tabaci*, biological characteristics and potential as biocontrol agents: a review. Agric. Ecosyst. Environ. 17: 99–110.

Huang, N., and A. Enkegaard. 2009. Predation capacity and prey preference of *Chrysoperla carnea* on *Pieris brassicae*. BioControl 55: 379–385.

Huffaker, C. B., and P. S. Messenger. 2012. Theory and practice of biological control. Academic Press, Inc. (London) Ltd., London NW1.

Ingole, D. A., V. Y. Deotale, R. O. Deotale, and J. Ramkumar. 2005. Preliminary study on the performance of *Mallada boninensis* (Okamoto) against *Aleurocanthus woglumi* Ashby on citrus. J. Biol. Control 19: 77–80.

John, B., H. Darryl, and P. Greg. 2007. Spiralling whitefly *Aleurodicus dispersus* exotic threat to Western Australia. Hort Guard TM Initiative AGWEST. (www.agric.wa.gov.au/objtwr/imported_assets/.../pw/.../fs01800.pdf)

Joshi, B. C., and D. N. Yadav. 1990. Biology and feeding potential of *Mallada boninensis* (Okamoto), a chrysopid predator of whitefly *Bemisia tabaci* Gennadius. J. Biol. Control 4: 18–21.

Kabissa, J.C.B., J. C. Yarro, H. Y. Kayumbo, and S. A. Juliano. 1996. Functional responses of two chrysopid predators feeding on *Helicoverpa armigera* (Lep.: Noctuidae) and *Aphis gosssypii* (Hom.: Aphididae). Entomophaga 41: 141–151.

Kumashiro, B. R., P. Y. Lai, G. Y. Funasaki, and K. K. Teramoto. 1983. Efficacy of *Nephaspis amnicola* and *Encarsia haitiensis* in controlling *Aleurodicus dispersus* in Hawaii. Proc. Hawaiian Entomol. Soc. 24: 261–269.

Mani, M., and A. Krishnamoorthy. 1989. Feeding potential and development of green lace wing, *M. boninensi*s (Okamoto) on grape mealy bug *Maconelicoccus hirsutus* (Green). Entomon 14: 19–20.

Mani, M., and A. Krishnamoorthy. 1999. Development and predatory potential of the green lacewing, *Mallada astur* (Banks) (Neuroptera: Chrysopidae) on the spiralling whitefly *Aleurodicus dispersus* Russell (Homoptera: Aleyrodidae). J. Biol. Control 13: 45–49.

McEwen, P. K., T. R. New, and A. Whittington. 2001. Lacewings in the crop environment. Cambridge University Press, Cambridge, United Kingdom.

Nagamallikadevi, M., D. B. Undirwade, N. B. Reddy, A. Ramadevi, and G. Srasvankumar. 2013. Biology of *Mallada boninensis* (Okamoto) [Chrysopidae: Neuroptera] on Aphids and Neonate Noctuids. Trends Biosci. 6: 827–830.

Nasreen, A., M. Ghulam, and A. Muhammad. 2003. Selectivity of some insecticides to *Chrysoperla carnea* (stephen) (neuroptera: chrysopidae) in laboratory. Pak. J. Biol. Sci. 6: 536–538.

Nehare, S. K., V. Y. Deotale, R. Q. Deotale, and P. Dawane. 2004. Biology and predatory potential of *Mallada boninensis* (Okamoto) against sucking pests. J. Soils Crops 14: 427–432.

Panse, G. V., and P. V. Sukhatme. 1981. Statistical methods for agricultural workers, Indian Council of Agricultural Research, New Delhi, India.

(PDBC) Project Directorate of Biological Control. 1998. Predatory potential and development of *Mallada astur* on spiralling whitefly, p. 96. *In* Annual Report 1997-1998, Project Directorate of Biological Control, Bangalore, Karnataka, India.

Sabelis, M. W. 1992. Predatory arthropods, pp. 225–264. *In* M.J. Crawley (ed.), Natural enemies: the population biology of predators, parasites and diseases. Blackwell, Oxford, United Kingdom.

SAS 2011. SAS® 9.3 System options: reference, 2nd edition. SAS Institute Inc., SAS Campus Drive, Cary, North Carolina.

Selvakumaran, S., M. Kallil, and S. Devasahayam. 1996. Natural enemies of two major species of scale insects infesting black pepper *(Piper nigrum* L.) in India. Pest Manage. Hort. Ecosys. 2: 79–83.

Srinivasa, M. V. 2000. Host plants of the spiralling whitefly *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae). Pest Manage. Hort. Ecosyst. 6: 79–105.

Syed, A. N., M. Ashfaq, and S. Ahmad. 2008. Comparative effect of various diets on development of *Chrysoperla carnea* (Neuroptera: Chrysopidae). Inter. J. Agric. Biol. 10: 728–730.

Symondson, W.O.C., K. D. Sunderland, and M. H. Greenstone. 2002. Can generalist predators be effective biocontrol agents? Ann. Rev. Entomol. 47: 561–594.

Ulhaq, M. M., A. Sattar, Z. Salihah, A. Farid, A. Usman, and S.U.K. Khattak. 2006. Effect of different artificial diets on the biology of adult green lacewing (*Chrysoperla carnea*) Stephens Songkanakarin. J. Sci. Technol. 28: 1–8.

Venkatesan, T., S. P. Singh, S. K. Jalali, and P. Sadhana. 2002. Rearing of *Mallada astur* (Banks) (Neuroptera: Chrysopidae) on a semi-synthetic diet. Pest Manage. Hort. Ecosyst. 8: 121–125.

Waterhouse, D. F., and K. R. Norris. 1989. Biological control: Pacific prospects - Supplement 1. Australian Centre for International Agricultural Research (ACIAR) Monograph No.12, ACIAR, Canberra, Australia.

Werner, E. E., and J. F. Gilliam. 1984. The ontogenetic niche and species interactions in size-structured populations. Ann. Rev. Ecol. Syst. 15: 393–425.