



Comparative life table analysis of chrysopids reared on *Phenacoccus solenopsis* Tinsley in laboratory

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ABSTRACT: Life tables of two chrysopid predators, viz., *Chrysoperla* sp. (*carnea*-group) and *Mallada desjardinsi* (Navas) on the invasive mealybug, *Phenacoccus solenopsis* (also reported as *P. solani*), were prepared in the laboratory to determine the efficacy of the predators as biocontrol agents of the pest. The rate of mortality (q_x) during 0-7 days age interval was higher in *Chrysoperla* sp. (*carnea*-group) (0.28) than in *M. desjardinsi* (0.22) while it was reverse during 70-77 days age interval when reared on *P. solenopsis*. In fact, q_x was higher in *M. desjardinsi* (2.50) than in *Chrysoperla* sp. (*carnea*-group) (0.00). The rate of multiplication per day was 0.1159 and 0.1414 females / female for *Chrysoperla* sp. (*carnea*-group) and *M. desjardinsi*, respectively. The intrinsic rate of increase (r_m) was found to be 0.11 for both the predators. *Chrysoperla* sp. (*carnea*-group) population multiplied 62.80 times in a generation time of 35.72 days on the mealybug, whereas *M. desjardinsi* multiplied 67.12 times in a time period of 29.75 days. Life table assays help in estimating the total number of the natural enemies to be released in biological control programmes. This study would be of paramount importance in estimating the total number of the natural enemies to be released in biological control programmes against the mealybug, which is exotic.

KEY WORDS: Green lacewing, *Chrysoperla* sp. (*carnea*-group), *Mallada desjardinsi*, *Phenacoccus solenopsis*, life table, fecundity table, intrinsic growth rate

INTRODUCTION

The solanum mealybug, *Phenacoccus solenopsis* Tinsley, an exotic mealybug also reported as *P. solani* Ferris by some workers due to identity opinions in India, is widely distributed on ornamentals, tobacco, and many other plants in the USA, Central America, Latin America, Africa, Hawaiian Islands, Italy, Pakistan and Israel (Gautam, 2007; Gautam *et al.*, 2007; Jhala *et al.*, 2008). During 2005, the sudden appearance of this pest in cotton in some parts of Pakistan destroyed the entire crop within a few days. Control of this pest is gradually becoming difficult with decrease in the efficacy of insecticides and biological control appears to be a more suitable alternative (Gautam, 2008a).

Chrysopids, commonly termed as green lacewings, are known to feed on over 80 species of insects and 12 species of tetranychid mites (Kharizanov and Babrikova, 1978; Zia *et al.*, 2008). The genus *Chrysoperla* is the dominant genus, which contains several important predatory

biological control agents that can be used in augmentation programmes (Gautam, 1994; Venkatsan *et al.*, 2008). The green lacewings, *Chrysoperla* (*carnea*-group) and *Mallada desjardinsi* (Navas) are well recognized and distributed in India, Europe, USSR, North America, South America, and Central Africa. Adults are free living and feed on honeydew and pollen. The larva, which is the predatory stage, feeds on the eggs of different insects and attacks a variety of soft bodied insects like aphids, cicadellids, psyllids, coccids, thrips (Ridgway and Murphy, 1984) and mites (Hagley and Miles, 1987).

Cohort life tables give comprehensive information on the survivorship, development and reproduction of a population and as such are fundamental to both theoretical and applied population ecology (Chi and Yang, 2003). The present study examined the biological attributes of these predators on the exotic mealybug, *P. solenopsis*, focusing on age specific survival l_x , age-specific fertility m_x and life table of each predator species in the laboratory.

MATERIALS AND METHODS

The culture of *P. solenopsis* identified by Prof. S. Suresh, TNAU (Gautam *et al.*, 2007) was established in the laboratory from cotton field collected specimens. Mealybug rearing was carried out in glass jars (15 cm x 10 cm) at $25 \pm 2^\circ\text{C}$ and $65 \pm 5\%$ RH following the method developed by Gautam (1994, 2008b). Black muslin cloth was used to cover the lid of the jars. Sprouted potato tubers were provided as food to the mealybug crawlers. The jar was checked daily for their development and any contamination. Fresh sprouted potatoes were provided to the new generation crawlers for their settlement and healthy colonization so as to get sufficient population.

The green lacewings present in the cotton ecosystem and interacting with the mealybug were collected, identified and maintained in the laboratory to obtain the stock culture. Larvae of *Chrysoperla sp. (carnea-group)* and *M. desjardinsi* were reared in individual vials (6.5 cm x 1.0 cm) at $25 \pm 2^\circ\text{C}$, $65 \pm 5\%$ RH, and a photoperiod of 12L:12D (Gautam, 1994). In each vial, a single fertile egg of the predator was placed along with five crawler producing mealybugs as prey. The prey availability was monitored on alternate days and supplemented based on requirement till the larvae entered into cocoon formation. The emerging adults were collected daily and kept in the mating cage (25 cm x 25 cm), supplied with a diet mixture of protein: water: honey: yeast in the ratio of 1:1:1:1 (by volume) glued on the inner side of the rearing cage. Besides, 10% honey solution soaked in absorbent cotton was placed in a separate petri dish as additional food supplement (unpublished). The adults (8-10 days old) used for the tests were sexed following the morphological characters (Reddy *et al.*, 2004; Sudhida *et al.*, 2008). A total of 100 eggs laid by 10-day-old females were chosen as hatching gets affected with the advancement of age, environmental conditions and food availability (Gautam and Paul, 1988; Gautam, 1994; Adane and Gautam, 2003; Elsiddig *et al.*, 2006a). After hatching, the larvae were fed on the mealybugs. Daily observations on survival and development were taken and recorded till adult emergence. Adults were pooled, provided with the adult food mentioned earlier and were subjected to longevity and fecundity studies.

The fecundity and mortality were recorded for each female till death of last female (Elsiddig *et al.*, 2006b). The experiment was replicated five times wherein each replication had a set of 20 larvae placed in individual vials. The life tables were constructed as described by Andrewartha and Birch (1954), Southwood (1966) and Jervis *et al.* (2005) with the following columns:

Life table

x pivotal age for the class in units of time
 l_x numbers surviving at the beginning of age class x

d_x numbers dying during the age interval x
 L_x number of individuals alive between age x and $x+1 = (L_x + L_{x+1})/2$
 T_x total number of individuals of X age units beyond the age $x = L_x + L_{x+1} + L_{x+2} + \dots + L_n$
 e_x expectation of life remaining for individuals of age $x = T_x / l_x$

Fecundity table

x pivotal age for the class in units of time
 l_x numbers surviving at the beginning of age class x
 m_x number of female eggs laid by female of age class x , i.e., total number of eggs laid by the female/ sex ratio
 $l_x m_x$ total number of female eggs laid in age class x

The various parameters calculated were gross reproductive age ($GRR = \sum m_x$), net reproductive age ($R_o = \sum l_x m_x$), approximate generation time ($T_c = \sum x \cdot l_x m_x / \sum l_x m_x$), innate capacity for increase ($rc = \log_e R_o / T_c$), intrinsic rate of natural increase ($r_m = \sum e^{-rx} \cdot l_x m_{x-1}$), finite rate of increase ($\lambda = e^{r_m}$), mean generation time ($\bar{T} = \log_e R_o / r_m$) and doubling time ($DT = \log_e 2 / r_m$) (Birch 1948, Jervis and Copland 1996).

RESULTS AND DISCUSSION

Mortality of immature stages

Results on stage-specific mortality of immature stages of *Chrysoperla sp. (carnea-group)* and *M. desjardinsi* [Table 1(a) and (b)] revealed that the total immature mortality was less (48%) in case of *Chrysoperla sp. (carnea-group)* than *M. desjardinsi* (70%). This included egg, larval and cocoon mortality as well as malformed adults. However, larval mortality was almost similar as it ranged between 33 and 35 per cent. There was no egg mortality in any of the predators, as observed by earlier workers (Gautam and Paul, 1988; Gautam, 1994; Adane and Gautam, 2003). Elsiddig *et al.* (2006a) reported female lays maximum fertile eggs between 2nd to third week under optimum conditions. Our results indicated that both the predators were able to complete the life cycle on the mealybug indicating that the exotic mealybug is suitable for development. This finding is in conformity with Gautam (2007) who reported these predators feeding on the mealybug and supported by Viji and Gautam (2005). More pupal mortality (35%) was recorded in *M. desjardinsi* as compared to minimum (15%) in *Chrysoperla sp. (carnea-group)*, which may be due to variations in food suitability. These predators could be effectively used for controlling the mealybug due to their potential.

Age-specific life tables

The data on the age-specific cohort life tables of *Chrysoperla sp. (carnea-group)* and *M. desjardinsi* on the

mealybug (Table 1a, b and Fig. 1a, b) indicated similar patterns with regard to log survival and life expectancy. The total life span of the predator at the age interval of seven days was long (more than 80 days). The rate of mortality (q_x) indicated that during 0-7days age interval, the mortality was higher in *Chrysoperla* sp. (*carnea*-group) (0.28) than in *M. desjardinsi* (0.22) when reared on

Survivorship curves (Fig. 1(a)) showed that the curves on two predators were more or less type I, which implies relatively lower rate of mortality during immature stages and a relatively high rate during the late 1 stage. The curve is relatively higher for *Chrysoperla* sp. (*carnea*-group) for the age interval of 0-7 to 28-35 days except during the remaining age, which is slightly higher for *M. desjardinsi*.

Table 1(a). Life-table analysis of *Chrysoperla* sp. (*carnea*-group) on *P. solenopsis* in the laboratory

Biological attributes of <i>Chrysoperla</i> sp. (<i>carnea</i> -group)						
Age intervals (days) (x)	Number surviving at start of age, x (l_x)	Number dying during age interval, x (d_x)	Rate of mortality during age interval, x (q_x)	Number alive on average during age interval (l_x to l_{x+1}) (L_x)	Individuals X time units (T_x)	Mean expectation of future life x: T_x/l_x (e_x)
0-7	100.0	28.0	0.280	86.0	267.0	2.670
7-14	72.0	24.0	0.330	60.0	181.0	2.513
14-28	48.0	6.0	0.125	45.0	121.0	2.520
28-35	42.0	22.0	0.550	31.0	76.0	1.800
35-42	20.0	8.0	0.400	16.0	45.0	2.250
42-49	12.0	3.0	0.250	10.5	29.0	2.410
49-56	9.0	2.0	0.220	8.0	18.5	2.050
56-63	7.0	4.0	0.570	5.0	10.5	1.500
63-70	3.0	1.0	0.330	2.5	5.5	1.833
70-77	2.0	0.0	0.000	2.0	3.0	1.500
77-84	2.0	2.0	1.000	1.0	1.0	0.500
84-91	0.0	0.0	0.0	0.0	0.0	0.000

Mortality of immature stages (out of 100 eggs) of *Chrysoperla* sp. (*carnea*-group) reared on *P. solenopsis*

Egg mortality	0
Larval mortality	33
Cocoon mortality	15
Malformed adults	6
Total immature mortality	48

P. solenopsis, while during 70-77 days age interval, the (q_x) was higher in *M. desjardinsi* (0.50) than in *Chrysoperla* sp. (*carnea*-group) (0.00) when reared on *P. solenopsis*. The life expectancy column (e_x) (Table 1 (a), 1 (b) and Fig. 1 (b)) showed that life expectancy for the 1st age interval (0-7 days) for *Chrysoperla* sp. (*carnea*-group) was 2.67 weeks (18.69 days) as compared to 2.52 weeks (17.64 days) in *M. desjardinsi* when reared on the mealybug. Subsequently, during 11th age interval (77-84 days), it was 0.50 weeks (3.5 days) and 2 weeks (14 days) for *Chrysoperla* sp. (*carnea*-group) and *M. desjardinsi*, respectively.

In the sixth age interval, m_x for *Chrysoperla* sp. (*carnea*-group) is higher (79.52) than that for *M. desjardinsi* (56.55). Higher m_x shows more number of eggs being laid in this period in *Chrysoperla* sp. (*carnea*-group) than *M. desjardinsi* when fed on the mealybug diet and this is responsible for the higher GRR also. Better GRR could be attributed to more predation of the mealybug. According to Huffaker *et al.* (1976) and Iziquel and Le (1992), high *Ro* means that these natural enemies can be effective against the pest. Theoretically the natural enemies all have the ability to reproduce faster and in doing so are able to exert some measure of control. The doubling time was shorter (4.90 days) for *M. desjardinsi* than for *Chrysoperla* sp. (*carnea*-group) (5.98 days). The shorter doubling time of *M. desjardinsi* might be due to the formation of the pupa within the trash carried by larvae, which saves the time for finding a pupation site.

Age-specific fecundity tables

Results of the age-specific fecundity (Table 2a and b) revealed that the predators reared on the mealybug

Table 1 (b). Life-table analysis of *M. desjardinsi* on *P. solenopsis* in the laboratory

<i>M. desjardinsi</i>						
Age intervals (days)	Numbers surviving at start of age, x	Numbers dying during age interval, x	Rate of mortality during age interval, x	No. alive on average during age interval (l_x to l_{x+1})	Individuals X time units	Mean expectation of future life x : T_x/l_x
(x)	(l_x)	(d_x)	(q_x)	(L_x)	(T_x)	(e_x)
0-7	100	22	0.22	89.00	252	2.52
7-14	78	27	0.35	64.50	163	2.09
14-28	51	8	0.16	47.00	98.5	1.87
28-35	43	33	0.77	26.50	51.5	1.20
35-42	10	7	0.7	6.50	25.00	2.50
42-49	3	0	0	3	18.50	6.17
49-56	3	0	0	3	15.50	5.17
56-63	3	0	0	3	12.50	4.17
63-70	3	0	0	3	9.50	3.17
70-77	2	1	0.5	2.5	6.50	3.25
77-84	2	0	0	2	4.00	2.00
84-91	2	1	0.5	1.5	2.00	1.00
91-98	1	0	0	0.5	0.50	0.50
98-105	0	0	0	0	0	0

Mortality of immature stages (out of 100 eggs) of *M. desjardinsi* reared on *P. solenopsis*

Egg mortality	0
Larval mortality	35
Cocoon mortality	35
Malformed adults	2
Total immature mortality	70

started egg laying during the 5th age interval of the lifecycle (28-35 days), which corresponds to the first week of adult emergence. The maximum female progeny (m_x) (sex ratio considered 1:1.08 (M:F) for *Chrysoperla* sp. (*carnea*-group) and 1:1.9 for *M. desjardinsi*) was produced during the 6th age interval (35-42 days). The maximum female progeny was 56.55 and 75.92 eggs/female/age interval for *M. desjardinsi* and *Chrysoperla* sp. (*carnea*-group), respectively. Last surviving females from both stocks died during 63-70 days age interval, which is supported by several workers who reported varying longevity of these predators depending on adult food supplements and the diet intake during larval stage (Joshi and Yadav, 1990; Nehare *et al.*, 2004; Senthilkumar and Gautam, 2007, 2008).

The data (Table 3a,b and 4) showed arbitrary r_m values $r=0.11$ and 0.12 for the predators. The intrinsic rate of increase (r_m) was found to be 0.11 for the two predators. According to these statistics, the populations of *Chrysoperla* sp. (*carnea*-group) multiplied 62.8 times in a generation time of 35.7 days on the mealybug whereas *M. desjardinsi* multiplied 67.12 times in a time period of 29.75 days. The rate of multiplication per day was 0.1159 and 0.1414 females /female for *Chrysoperla* sp. (*carnea*-group) and *M. desjardinsi*, respectively. Jarvis *et al.* (2005) stated that prey species can influence the intrinsic rate of natural increase of predators. Lee and Shih (1981) estimated r_m , R_o and T for *M. desjardinsi* reared on *Pauropsylla psylloptera* as 0.0964, 181.5 and 54.2, respectively, but the estimates of Bakthavatsalam *et al.* (1994) for these statistics for *M. desjardinsi* reared on *C. cephalonica* eggs were different. Their estimates of r_m , R_o and T as 0.3329, 191.71 and 17.999 were too low and this period is not sufficient even to complete the developmental period of immature stages of the predator (development from egg to egg is not less than 25 days) and oviposition period of immature stages of the adults can be up to 36.9–46.6 days (Nehare *et al.*, 2004; Joshi and Yadav, 1990).

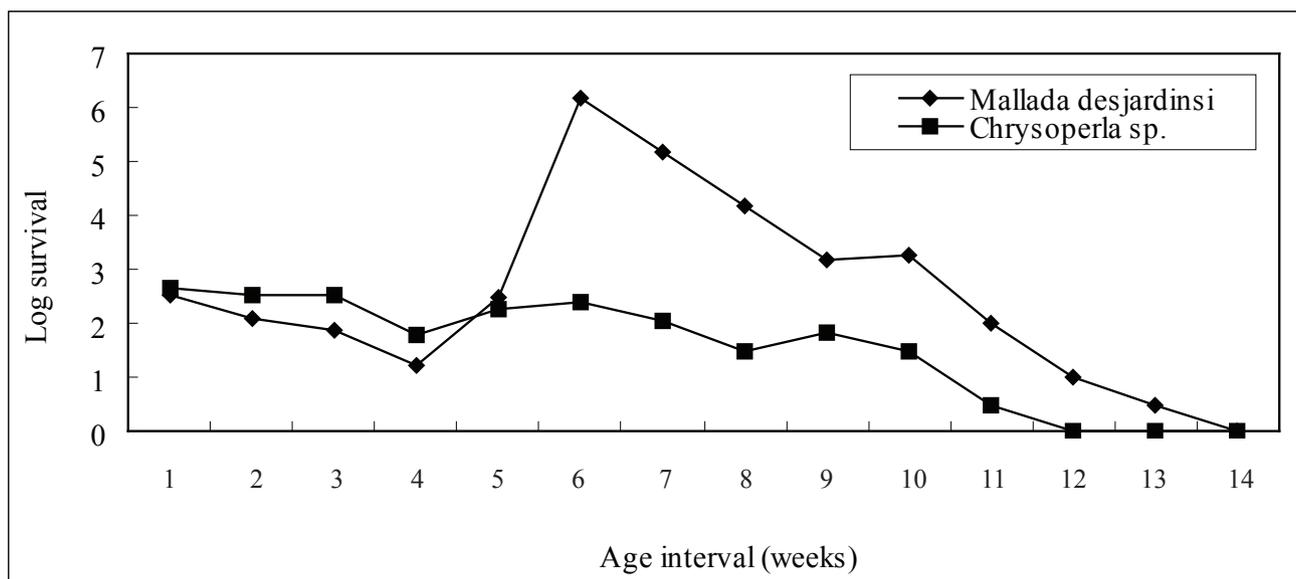


Fig. 1(a). Survivourship curve of *M. desjardinsi* and *Chrysoperla sp.* (*carnea*-group) reared on *P. solenopsis*

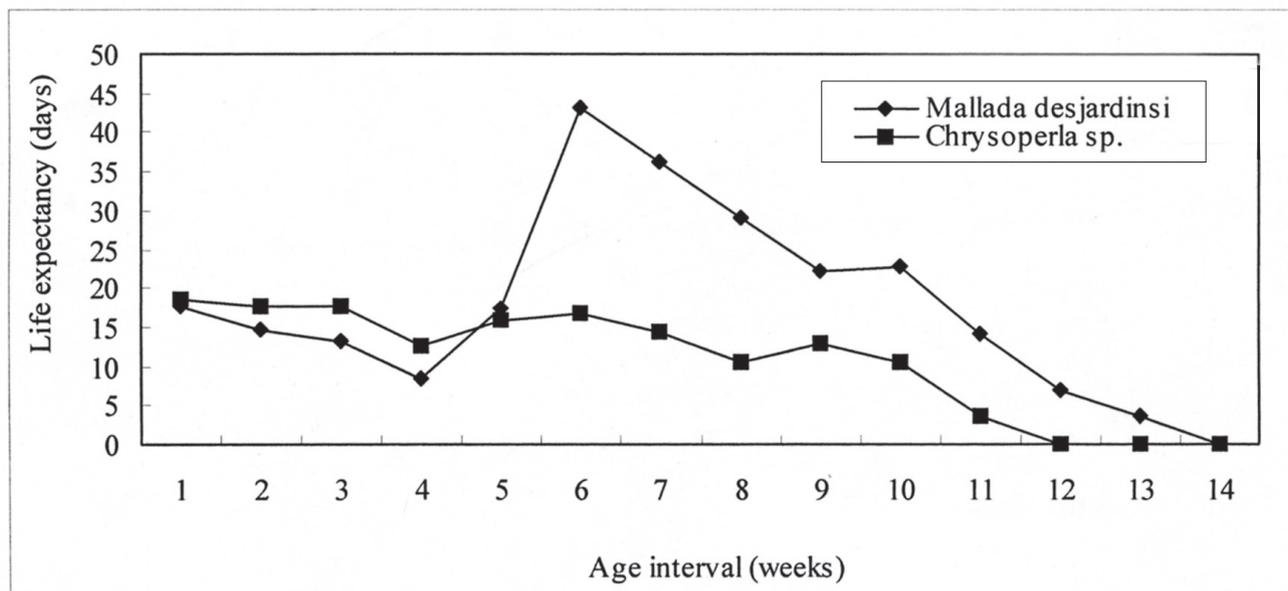


Fig. 1(b). Life expectancy of *M. de sjardinsi* and *Chrysoperla sp.* (*carnea*-group) reared on *P. solenopsis*

Table 2(a). Fecundity table of *Chrysoperla* sp. (*carnea*-group) reared on *P. solenopsis*

Biological attributes of <i>C. carnea</i>						
Age intervals (days) (x)	Pivotal Age (Days) (x)	(l _x)		(m _x)	(l _x m _x)	x.l _x m _x
		Numbers	Probability			
0-7	3.5					
7-14	10.5					
14-21	17.5					
21-28	24.5					
28-35	31.5	11	0.55	25	13.75	433.125
35-42	38.5	6	0.50	75.92	37.96	1461.46
42-49	45.5	4	0.44	13.88	6.10	277.55
49-56	59.5	4	0.57	5.55	3.16	188.02
56-63	66.5	2	0.66	2.78	1.83	122.01
63-70	73.5	2	1	0	0	0
70-77	80.5	0	0	0	0	0
			∑	123.13	62.80	2482.16

Table 2(b). Fecundity table of *M. desjardinsi* reared on *P. solenopsis*

Biological attributes of <i>M. desjardinsi</i>						
Age intervals (days) (x)	Pivotal Age (Days) (x)	(l _x)		(m _x)	(l _x m _x)	x.l _x m _x
		Numbers	Probability			
0-7	3.5					
7-14	10.5					
14-21	17.5					
21-28	24.5					
28-35	31.5	12	0.60	31.03	18.61	586.21
35-42	38.5	8	0.66	56.55	37.32	1436.82
42-49	45.5	7	0.77	10.34	7.96	362.18
49-56	59.5	2	0.28	4.14	1.16	69.02
56-63	66.5	2	1	2.07	2.07	137.65
63-70	73.5	2	1	0	0	0
70-77	80.5	0	0	0	0	0
			∑	104.13	67.12	2591.88

The comparison of life statistics of both the predators on the mealybug (Table 4) suggests that the gross reproductive rate (GRR) was 123.13 females/female/generation for *Chrysoperla* sp. (*carnea*-group) and 104.13 females /female/generation for *M. desjardinsi*. The net reproductive rate (R_0) was 62.80 and 67.12 females/female/

generation for *Chrysoperla* sp. (*carnea*-group) and *M. desjardinsi*, respectively. Mean generation time (T) was 35.72 and 29.75 days for *Chrysoperla* sp. (*carnea*-group) and *M. desjardinsi*, respectively. This is in agreement with Adane and Gautam, (2003) and Elsidig *et al.* (2006a).

Table 3(a). Estimation of intrinsic rate of natural increase (r_m) *Chrysoperla* sp. (*carnea*-group)

Pivotal age (days) (x)	$l_x m_x$	$e^{-rx} \cdot l_x m_x$ (r = 0.11)	$e^{-rx} \cdot l_x m_x$ (r = 0.12)
31.5	13.75	0.4300	0.3138
38.5	37.96	0.5496	0.3740
45.5	6.10	0.0489	0.0259
59.5	3.16	0.004 (4.5418*10 ⁻⁰³)	0.0025 (2.5050*10 ⁻⁰³)
66.5	1.83	0.001 (1.217*10 ⁻⁰³)	0.0006 (6.29*10 ⁻⁰⁴)
	Σ	1.0335	0.7168

Arbitrary values of 'rm' are 0.11 and 0.12

Arbitrary 'rm'	0.11	0.12	Difference
	1.335	0.7618	0.5669
	1.336		

$$\Sigma e^{-rx} \cdot l_x m_x = 1.335$$

$$1.335 - 0.7618 = 0.5669, \quad 1.335 - 1.00 = 0.335$$

For 0.01, difference is 0.5669, difference will be $0.335 \times 0.01 / 0.5669 = 0.00590$ (5.909×10^{-03}); therefore, corrected 'rm' will be, $0.11 + 0.0059 = 0.1159$

Table 3(b). Estimation of intrinsic rate of natural increase (r_m) *M. desjardinsi*

Pivotal age (days) (x)	$l_x m_x$	$e^{-rx} \cdot l_x m_x$ (r = 0.11)	$e^{-rx} \cdot l_x m_x$ (r = 0.12)
31.5	18.61	0.5819	0.4247
38.5	37.32	0.5403	0.3677
45.5	7.96	0.05336	0.0338
59.5	1.16	0.0016 (1.667x10 ⁻⁰³)	0.0009 (9.195x10 ⁻⁰⁴)
66.5	2.07	0.0013 (1.3775x10 ⁻⁰³)	0.0007 (7.0843x10 ⁻⁰⁴)
	Σ	1.17846	0.8278

Arbitrary values of 'rm' are 0.11 and 0.12

Arbitrary 'rm'	0.11	0.12	Difference
	1.1785	0.8278	0.3507

$$\Sigma e^{-rx} \cdot l_x m_x = 1.1785$$

$$1.1785 - 0.8278 = 0.3507, \quad 1.1785 - 1.00 = 0.1785$$

For 0.01, difference is 0.3507, difference will be $0.1785 \times 0.01 / 0.3507 = 0.03148$; therefore, corrected 'rm' will be, $0.11 + 0.03148 = 0.14148$

The significantly higher population parameters of the natural enemies, coupled with their shorter doubling times, mean that their population can grow faster and thus exert a controlling effect on pest numbers. Life table assays help in evaluating the future progeny and estimating

the total number of the natural enemies to be released in biological control programmes. This study would be of paramount importance due to the fact that the mealybug host is exotic and no information with regard to these predators was available earlier.

Table 4. Life table statistics of the predators reared on *P. solenopsis*

Life/ Fecundity table statistics	Formula	Predators	
		<i>Chrysoperla</i> sp. (<i>carnea</i> -group)	<i>M. desjardinsi</i>
Gross reproductive rate, GRR (females/female/generation)	$= \sum m_x$	123.13	104.13
Net reproductive rate, R_o (females/female/generation)	$= \sum l_x m_x$	62.80	67.12
Approximate generation time, T_c (days)	$= \frac{\sum x.l_x m_x}{\sum l_x m_x}$	39.52	38.61
Innate capacity for increase, r_c (females/female/day)	$= \log_e R_o$	0.105 = 0.11	0.108 = 0.11
Intrinsic rate of natural increase, r_m (females/female/day)	$\sum e^{-rx}.l_x m_{x=1}$	0.1159	0.1414
Finite rate of increase, λ (females/female/day)	$= e^{r_m}$	1.123	1.152
Mean generation time, T (days)	$\frac{\log_e R_o}{r_m}$	35.72	29.75
Doubling time, DT (days)	$\frac{\log_e 2}{r_m}$	5.980	4.9020

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