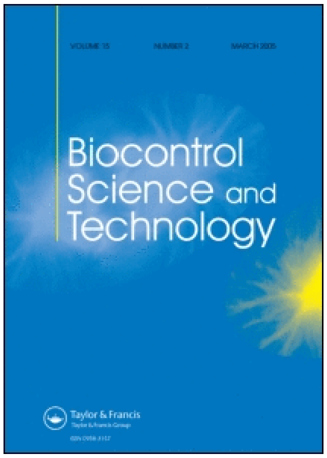

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Prey Quality Dependent Growth, Development and Reproduction of a Biocontrol Agent, *Cheilomenes sexmaculata* (Fabricius) (Coleoptera: Coccinellidae)

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Growth, development and reproduction of a ladybird beetle, Cheilomenes sexmaculata *(Fabricius) were investigated in relation to seven aphid species, viz.* Aphis craccivora *Koch,* Aphis gossypii *Glover,* Rhopalosiphum maidis *(Fitch),* Myzus persicae *(Sulzer),* Uroleucon compositae *(Theobald),* Lipaphis erysimi *(Kaltenbach) and* Aphis nerii *Boyer de Fonscolombe on specific hosts. Maximum prey consumption, percent larval survival, developmental rate, weight of different life stages, percent adult emergence, adult longevity and fecundity of* C. sexmaculata *were recorded on* A. craccivora*, and minimum on* A. nerii*. A linear relationship was found between development rate and weight of adult, daily prey consumption and relative growth rate, log weights of adult males and females, and female longevity and total fecundity. On the basis of overall performance of ladybird the order of suitability of prey species was* A. craccivora > A. gossypii > R. maidis > M. persicae > U. compositae > L. erysimi > A. nerii.

Keywords: *Biocontrol,* Cheilomenes sexmaculata*, ladybird beetle, coccinellids, aphids*

INTRODUCTION

Cheilomenes sexmaculata (Fabricius) is a common aphidophagous ladybird beetle of Oriental region with wide prey range and distribution (Omkar & Pervez, 2000). It is found almost throughout the year in agricultural fields preying on aphids, other soft-bodied insects and even pollen (Omkar & Bind, 1993). A recent review on its competitive ability and ecology including a worldwide checklist of its aphid prey (Agarwala & Yasuda, 2000) reveals that it can be used as an effective biological control agent of number of prey species, in particular, aphids. This ladybird has been introduced in North America (Cartwright *et al.*, 1977) and is currently receiving attention because of its better survival and performance in

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competitive environments (Agarwala & Yasuda, 2000). The differential efficiencies displayed by the ladybirds in the harnessing of available nutrients and energy from their prey are eventually reflected in their growth, survival and reproductive performance (Babu, 1999). It is known that different morphs of an aphid species alter the growth, egg laying sequence and total egg output amongst coccinellids (Wipperfurth *et al*., 1987). On the basis of these effects, prey have been categorized into essential, alternative and rejected prey (Hodek & Honek, 1996). The suitability of aphids also depends on its complex with the host plant (Hodek, 1960; Okamoto, 1966; Hukusima & Kamei, 1970; Obatake & Suzuki, 1985). Despite availability of adequate information on biology and ecology of aphidophagous ladybirds, very few species have been understood with regard to reproductive fitness that characterize a potential biocontrol agent of insect pests (Agarwala & Yasuda, 2000). Therefore, in the present study, we aim to assess the development, survival and reproductive responses of ladybird *C. sexmaculata* in relation to seven aphid species from specific host plants, viz. *Aphis craccivora* (on *Dolichos lablab*), *Aphis gossypii* (on *Lagenaria vulgaris*), *Aphis nerii* (on *Calotropis procera*), *Rhopalosiphum maidis* (on *Zea mays*), *Myzus persicae* (on *Solanum melongena*), *Uroleucon compositae* (on *Carthamus tinctorius*) and *Lipaphis erysimi* (on *Brassica campestris*). This study may help identify prey species most suitable for the mass multiplication of the ladybird.

MATERIALS AND METHODS

Stock Maintenance

Life stages of *C. sexmaculata* were collected from local agricultural fields and brought to the laboratory. Immature stages were transferred to glass beakers containing specific aphid species, viz. *A. craccivora*, *A. gossypii*, *A. nerii*, *R. maidis*, *M. persicae*, *U. compositae* and *L. erysimi* on their host plant twigs, viz. *D. lablab*, *L. vulgaris*, *C. procera*, *Z. mays*, *M. solanum*, *C. tinctorius* and *B. campestris*, respectively, and allowed to develop into adults. Care was taken to provide the same aphid–host plant complex as available to the immature stages in field. Mating pairs were kept in beakers (height 11.0 cm and diameter 8.5 cm) with their prey on respective host plant twig. The open ends of the beakers were covered with fine muslin cloths. Eggs were collected every 24 h and allowed to hatch. On hatching, the first instars were transferred to beakers and provided with regular and sufficient supply of aphids. Dried twigs and leftover aphids were replaced with fresh ones after every 24 h. The experiments were conducted in Environmental Test Chamber at 25 ± 2°C, 65 ± 5% R.H. and 8L:16D.

Pre-Adult Development and Larval Survival

To evaluate the effect of prey species on pre-adult development and larval survival 100 eggs per replicate were taken out from the stock culture and kept in Petri dishes with moist filter papers at the bottom for maintenance of humidity. After hatching, first instars were transferred into glass beakers (height 11.0 cm and diameter 8.5 cm) with the help of a fine hairbrush (10 neonates per beaker, 10 replicates per aphid species). The open ends of beakers were covered with fine muslin fastened with rubber bands. The first instars were supplied with a specific aphid–host complex until adult emergence. Similar-sized immature instars of all seven species were selected to avoid error through their reproduction. The moulting time and survival per moult were recorded. Prepupal and pupal periods and the number of pupae surviving were also noted. Observations were taken twice per day and the mean values per replicate taken for analysis. The development rate (1/total development period), percent larval survival (number of pupae formed $\times$ 100/number of first instars hatched), percent adult emergence (number of adults emerged $\times$ 100/number of pupae), and growth index (percent adult emergence/total development period; Seth & Sharma, 2001) were calculated.

Weight of Different Life Stages

Wet weights of different life stages, viz. different instars, prepupae, pupae, and adults (male and female) in 10 replicates were measured on each aphid species. Relative growth rate (RGR = initial adult weight − initial weight of fourth instar/developmental period) was calculated.

Reproduction on Different Aphid Species

A single pair of newly emerged ladybirds were selected from the laboratory emerged adults and kept in glass beakers (height 11.0 cm and diameter 8.5 cm) with the aphid–host plant complex similar to that available to the immature stages. Pre-oviposition and oviposition periods, total fecundity and percent egg viability were recorded. The experiment was replicated ten times with each aphid species; a single ladybird pair serving as a replicate.

Consumption by Different Stages

To record the consumption of first/second instar, 100 (100 aphids ≈ 33.0 mg) of aphids were supplied daily in glass beakers and a single first/second ladybird instar was placed in each beaker. Open ends were covered by muslin with help of rubber bands. The leftover aphids were removed and replaced with respective fresh aphids every 24 h throughout the span of a particular larval instar. Similarly, the consumption of third and fourth instars, and adult male and female was calculated by providing 400 individuals of aphids daily. The experiment was repeated with every aphid species. To standardize the biomass of aphid provided, early and smaller instars of larger sized aphids, viz. *A. craccivora*, *U. compositae* and late instars of smaller sized aphids, viz., *A. gossypii*, *A. nerii*, *R. maidis*, *L. erysimi* and *M. persicae*, were selected (wet weight of 100 aphids ≈ 33.0 mg). Total number of aphid consumed by respective predatory stages were counted.

Data Analysis

Data obtained from above experiments were analyzed by analysis of variance (one-way ANOVA) using the statistical software MINITAB. Correlation analysis was performed to determine the relationship between (1) daily prey consumption and relative growth rate, (2) developmental rates and weights of adult females, (3) the weights of males and females, and (4) longevity and fecundity.

RESULTS

Pre-Adult Development and Larval Survival

Table 1 revealed that incubation period of eggs of *C. sexmaculata* varied significantly with different aphid species. The durations of first, second, third and fourth instars, prepupae, and pupae varied significantly when reared on different prey species. Total developmental period of *C. sexmaculata* was shortest when fed on *A. craccivora* and longest on *A. nerii*. The developmental rate varied from 0.08 to 0.05 when fed on seven different aphid-host plant complexes. There was significant variation in the percent larval survival and percent adult emergence on exposure to different prey (Table 1). The growth index of ladybird was highest (2.35) when fed on *A. craccivora* and lowest (0.82) on *A. nerii.*

Weight of Different Life Stages

There was significant variation in the weights of first, second, third and fourth instars when they were fed on different aphid species (Table 2). The weights of prepupae, pupae, adult males and females also varied significantly on different aphid species. The reproductive growth rate (RGR) was highest on *A. craccivora* and lowest on *A. nerii* (Table 2). RGR and daily prey consumption ($r = 0.97$; $P < 0.001$; Figure 1a), developmental rate and female

TABLE 1. Duration and weight of life stages of *C. sexmaculata* on different aphid species ($n = 10$)

Aphid species		*A. craccivora*	*A gossypii*	*R. maidis*	*M. persicae*	*U. compositae*	*L. erysimi*	*A. nerii*	*F* value
Incubation period		3.08 ± 0.34	3.21 ± 0.39	3.37 ± 0.61	3.98 ± 0.76	4.26 ± 0.68	4.85 ± 0.92	4.86 ± 0.10	13.90
First instar	Duration	1.39 ± 0.16	1.75 ± 0.40	2.00 ± 0.37	2.12 ± 0.37	2.16 ± 0.35	2.49 ± 0.44	2.55 ± 0.41	12.25
	Weight	1.92 ± 0.12	1.89 ± 0.21	1.63 ± 0.27	1.55 ± 0.12	1.50 ± 0.12	1.45 ± 0.28	1.30 ± 0.15	14.22
Second instar	Duration	1.32 ± 0.16	1.67 ± 0.36	1.84 ± 0.55	1.91 ± 0.46	2.00 ± 0.49	2.12 ± 0.42	2.15 ± 0.37	4.82
	Weight	3.59 ± 0.38	3.32 ± 0.53	3.24 ± 0.46	3.13 ± 0.49	3.10 ± 0.52	3.03 ± 0.64	2.54 ± 0.48	3.99
Third instar	Duration	1.95 ± 0.29	2.55 ± 0.32	2.69 ± 0.24	2.83 ± 0.29	3.12 ± 0.51	3.19 ± 0.44	3.44 ± 0.61	14.92
	Weight	6.78 ± 0.88	5.70 ± 0.91	5.51 ± 0.93	5.34 ± 1.42	5.01 ± 0.71	4.73 ± 0.62	4.59 ± 0.53	6.74
Fourth instar	Duration	2.39 ± 0.37	3.19 ± 0.54	3.39 ± 0.65	3.76 ± 0.51	3.84 ± 0.53	4.18 ± 0.47	4.32 ± 0.62	15.68
	Weight	14.68 ± 0.52	14.08 ± 0.73	12.69 ± 0.61	12.54 ± 1.51	9.59 ± 0.51	7.77 ± 0.92	7.17 ± 0.51	128.69
Prepupal period	Duration	0.66 ± 0.17	0.68 ± 0.14	0.92 ± 0.08	1.00 ± 0.13	1.02 ± 0.09	1.16 ± 0.13	1.27 ± 0.12	32.69
	Weight	13.73 ± 0.28	12.69 ± 2.29	11.70 ± 1.57	11.58 ± 1.30	10.54 ± 1.09	10.36 ± 0.67	9.05 ± 0.66	36.75
Pupal period	Duration	2.50 ± 0.59	2.90 ± 0.36	2.95 ± 0.36	3.36 ± 0.37	3.36 ± 0.38	3.59 ± 0.40	3.60 ± 0.40	9.68
	Weight	13.40 ± 0.42	12.89 ± 0.64	11.67 ± 0.59	10.39 ± 0.87	8.79 ± 0.52	7.03 ± 0.79	6.05 ± 0.61	193.51
Total Development Period	Duration	13.28 ± 1.00	15.95 ± 1.41	17.17 ± 0.82	19.09 ± 1.25	19.64 ± 0.68	21.62 ± 0.79	22.06 ± 0.71	102.40
	Weight Male	13.04 ± 1.69	12.74 ± 1.28	11.71 ± 0.79	10.59 ± 1.64	9.51 ± 4.49	7.90 ± 0.68	7.03 ± 0.60	43.22
	Female	16.91 ± 0.74	16.33 ± 1.07	14.64 ± 1.01	14.13 ± 1.49	11.72 ± 1.67	9.76 ± 0.82	8.41 ± 1.03	78.57

Values are Mean ± S.D and significant at $P < 0.01$; durations in days; weight in mg.

TABLE 2. Growth and reproduction of *C. sexmaculata* on different aphid species

Aphid species	*A. craccivora*	*A. gossypii*	*R. maidis*	*M. persicae*	*U. compositae*	*L. erysimi*	*A. nerii*	*F* value
% immature survival	59.50	56.90	52.20	48.50	46.30	40.30	32.30	51.63
Growth index	2.35	1.73	1.57	1.31	1.19	0.91	0.82	–
Adult emergence (%)	71.80	63.70	61.90	57.50	53.90	45.20	41.50	61.17
Larval consumption	859.50 ± 43.25	786.40 ± 33.25	739.60 ± 56.93	638.20 ± 56.93	552.20 ± 37.21	505.20 ± 43.76	363.00 ± 27.52	185.76
Daily consumption of male	39.07 ± 3.86	33.54 ± 1.73	30.38 ± 2.42	27.07 ± 3.99	26.12 ± 2.70	25.62 ± 2.75	20.18 ± 4.56	34.45
Daily consumption of female	36.29 ± 3.24	39.26 ± 3.36	34.62 ± 2.35	27.48 ± 2.86	26.60 ± 2.32	24.96 ± 1.63	22.61 ± 2.67	56.12
Male longevity (days)	68.00 ± 6.43	57.80 ± 3.52	56.90 ± 3.84	53.80 ± 4.54	50.20 ± 4.85	35.90 ± 4.31	33.50 ± 5.87	64.27
Female longevity (days)	77.70 ± 6.43	64.30 ± 4.42	61.70 ± 5.12	56.20 ± 4.23	55.00 ± 2.83	45.10 ± 4.80	40.40 ± 4.86	67.61
Development rate (day^{-1})	0.08	0.06	0.06	0.05	0.05	0.05	0.05	
Relative growth rate (RGR)	0.16 ± 0.07	0.14 ± 0.10	0.11 ± 0.06	0.10 ± 0.93	0.95 ± 0.50	0.80 ± 0.08	0.56 ± 0.04	2.44
Preoviposition period (days)	5.51 ± 0.70	5.85 ± 0.88	6.57 ± 0.87	7.04 ± 0.73	8.00 ± 0.89	8.81 ± 0.92	9.79 ± 0.81	35.92
Oviposition period (days)	57.80 ± 7.54	53.40 ± 6.15	47.70 ± 7.20	46.50 ± 6.75	41.50 ± 5.76	36.60 ± 5.68	30.20 ± 5.49	22.12
Fecundity (no. of eggs)	1096.90 ± 75.64	932.90 ± 75.64	904.00 ± 106.26	816.70 ± 91.83	720.20 ± 71.57	505.40 ± 94.89	294.80 ± 60.30	102.49
%Hatchability	62.10	59.30	53.70	50.60	48.20	42.10	32.10	66.34

Values are Mean ± S.D and significant at $P < 0.001$.

weight ($r = 0.98$; $P < 0.001$; Figure 1b), and log weights of adult males and females ($r = 0.85$; $P < 0.001$; Figure 1c) exhibited linear relationship when correlated with different aphid species.

Reproduction on Different Aphid Species

The pre-oviposition and oviposition periods of *C. sexmaculata* differed significantly after rearing on different aphid species (Table 2). The fecundity of the ladybird was highest when fed on *A. craccivora* than on other aphid species. Reproduction was much reduced when reared on *A. nerii.* A positive correlation was found between female longevity and fecundity ($r = 0.99$; $P > 0.001$; Figure 1d). The hatching percent varied between 32.10 and 62.10% (Table 1) and was highest when larvae and adult beetles were fed on *A. craccivora–D. lablab* complex. Female and male longevities also varied significantly on different prey species.

Consumption by Different Stages

The total prey consumption during the larval period of *C. sexmaculata* varied from 859.50 ± 43.25 to 363.00 ± 27.52 on different aphid species (Table 2). The daily prey consumption by male and female also varied significantly in relation to prey species.

DISCUSSION

Pre-Adult Development and Larval Survival

The increased growth, development and survival rates of *C. sexmaculata* fed on *A. craccivora* may be ascribed to: (1) the possible higher nutritive value of *A. craccivora* and/or (2) the increased consumption of this species, possibly due to its higher palatability. Earlier, Rajmohan & Jayraj (1974) reported fastest larval development and maximum larval survival of C. *sexmaculata* on *A. craccivora* over that on *R. maidis*, *A. gossypii* and *Aphis malae*. The decreasing order of development rate of ladybeetle was *A. craccivora* > *A. gossypii* > *R. maidis* > *M. persicae* > *U. compositae* > *L. erysimi* > *A. nerii* with a similar order for the amount of food consumed by the larvae. The lower consumption of some aphid species may be ascribed to the (1) sensory perception prior to consumption, or (2) to a bad-learning experience, leading to reduced growth and development. The consumption of certain aphids in lesser amounts may be a strategy of ladybirds to keep levels of harmful chemicals below injurious levels (Hodek, 1956: Okamoto, 1966). High mortality of immature stages on the lesser consumed aphids may be due to the (1) slow starvation due to lesser consumption, and (2) the inability of the ladybird to cope with the presence of alkaloids and chemicals (Olszak, 1986, 1988; Obrycki & Orr, 1990). The aphid *A. craccivora* on the host plant *D. lablab* was found suitable for *C. sexmaculata*, but *A. craccivora* from other host plants has been previously reported lethal for many ladybirds viz. *Coccinella septempunctata* (Azam & Ali, 1970), *Harmonia axyridis* (Hukusima & Kamei, 1970), and *Semiadalia undecimnotata* (Hodek, 1960). Rarely have ladybirds been reported reproducing well on *A. craccivora* (Hodek, 1960; Omkar & Srivastava, 2003). *A. craccivora* from any one of seven host plants, viz. *Robinia pseudoaccacia*, *Astragalus sinicus*, *Vicia hirsuta*, *Capsella bursa-pastoris*, *Cardamine flexuosa*, *Rorippa palustris*, *Hemistepa carthamoides* and *Vicia faba* has been found toxic for *H. axyridis* (Okamoto, 1966; Hukusima & Kamei, 1970). But both larvae and adults of *Proplylea japonica* were found to be resistant to the detrimental effect of *A. craccivora* on *R. pseudoaccacia* (Hukusima & Kamei, 1970). Responses of *C. sexmaculata* after feeding on the aphid *A. nerii* on the host plant *C. procera* were also interesting because *A. nerii* on the host plant *Nerium oleander* has been found toxic to the ladybeetles, *C. septempunctata*, *Semiadalia undecimnotata*, *Propylea quatuordecimpunctata*, *Adalia bipunctata*, *Harmonia dimidiata*, and *Coccinella repanda* (Iperti, 1966; Tao & Chiu, 1971). Earlier *A. nerii* on *C. procera* was not found toxic to *C. septempunctata* (Omkar & Srivastava, 2003)

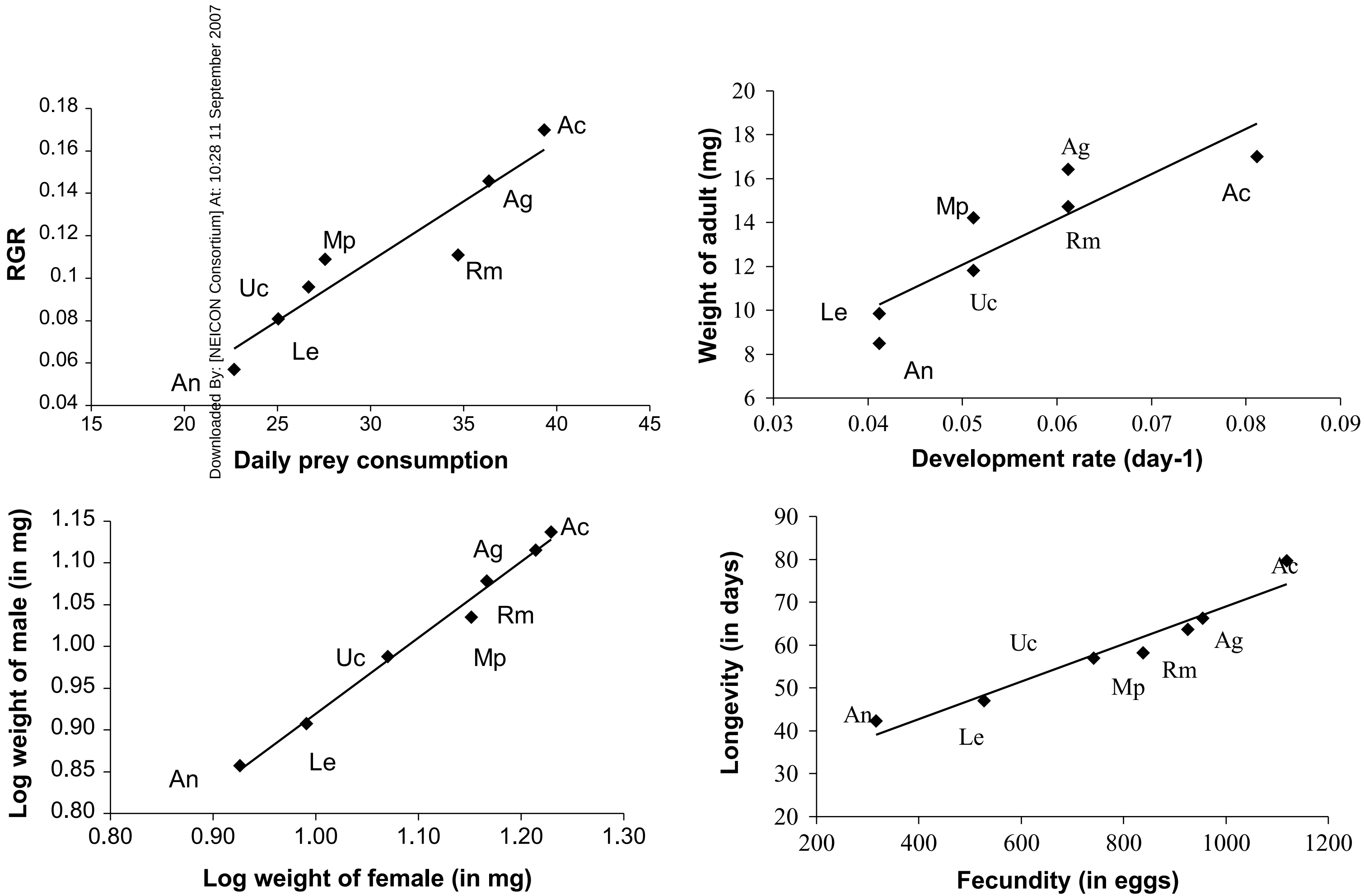

FIGURE 1. Relationships between (a) RGR and daily prey consumption by adult females; (b) weights of adult females and development rate, (c) log weights of adult males and females, and (d) female longevity and fecundity of C. sexmaculata on different aphid species, viz. *A. craccivora* (Ac), *A. gossypii* (Ag), *R. maidis* (Rm), *M. persicae* (Mp), *U. compositae* (Uc), *L. erysimi* (Le) and *A. nerii* (An).

and in fact relatively rapid pupal development of *C. sexmaculata* has been recorded on *A. nerii* (Chaudhary *et al.*, 1983).

Weight of Different Life Stages

Immature stages reared on *A. craccivora* were heavier than those on other aphid species while being lightest on *A. nerii*. Similarly weight of larvae of *C. sexmaculata* was found highest on *A. pisum* than that on *R. maidis* (Smith, 1965). Pupae were lighter than the prepupae and this can be attributed to the immense biochemical changes during the process of pupation in preparation for emergence of adults (Sidhu & Mukesh, 1979).

Reproduction on Different Aphid Species

The longest reproductive and shortest non-reproductive periods were observed when female *C. sexmaculata* were fed on *A. craccivora* confirming the nutritive suitability of *A. craccivora* over other aphid species. Long oviposition duration of *C. sexmaculata* on *A. craccivora* has also been reported (Rajmohan & Jayraj, 1974). The marked variation in fecundity may be attributed to the nutritional quality of aphid species. Previous studies have also found *C. sexmaculata* reproducing well on *A. craccivora* (Rajmohan & Jayraj, 1974; Islam & Haque, 1978). Chaudhary *et al*. (1983) found *C. sexmaculata* reaching relatively high fecundity levels when feeding on *A. nerii*, in contrast to our findings. However, plants used to support *A. nerii* in our study differed from those used by Chaudhary *et al*. (1983), showing the importance of plant taxa in host suitability to coccinelids. As in this study, maximum hatching percentage of eggs of *C. sexmaculata* has previously been reported on *A. craccivora* (Haque & Islam, 1978).

The present study confirms that: (i) *C. sexmaculata* feeds on all tested aphid–host plant complexes, (ii) the most suitable hosts, beginning with the best may be arranged as *A. craccivora*, *A. gossypii*, *R. maidis*, *M. persicae*, *U. compositae*, *L. erysimi* and *A. nerii* in descending order of suitability, (iii) *A. craccivora* on *D. lablab* is the most suitable amongst the tested aphid species, which is interesting because of the numerous reports on its unsuitability when in combination with many host plants, (iv) the aphid prey *U. compositae*, *L. erysimi* and *A. nerii* may be acceptable prey species in the absence of other suitable prey. These results provide insight into prey selection for the mass multiplication of *C. sexmaculata*.

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