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Feeding potential of *Cryptolaemus montrouzieri* against the mealybug *Phenacoccus solenopsis*

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Abstract *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is an exotic species native to the USA, damaging cotton and other plant families. The feeding potential of different development stages of *Cryptolaemus montrouzieri* Mulsant, a biological control agent against mealybugs, was investigated on different development stages of *P. solenopsis*. Fourth instar grubs and adults of *C. montrouzieri* were the most voracious feeders on different instars of mealybug. The number of 1st instar nymphs of mealybug consumed by 1st, 2nd, 3rd and 4th instar larvae and adult beetles of *C. montrouzieri* was 15.56, 41.01, 125.38, 162.69 and 1613.81, respectively. The respective numbers of 2nd and 3rd instar nymphs of mealybug consumed were 11.15 and 1.80, 26.35 and 6.36, 73.66 and 13.32, 76.04 and 21.16, 787.95 and 114.66. The corresponding figures for adult female mealybugs were 0.94, 3.23, 8.47, 12.71 and 73.40, respectively. The results indicate that *C. montrouzieri* has the potential to be exploited as a biocontrol agent in North India; inoculative releases of 4th instar larvae and adults may provide instant control of *P. solenopsis*. Field experiments should be conducted to determine the efficiency of the ladybird on this mealybug.

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Introduction

Mealybugs are sap-sucking insects that cause severe economic damage to a wide range of crops (Nagrare *et al*. 2009). The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), was reported originally on ornamental and fruit crops in the United States (Tinsley 1898) and regarded as an exotic pest in South East Asia, including India and Pakistan. Fuchs *et al.* (1991) provided the first report of *P. solenopsis* infesting cultivated cotton and 29 other plant species of 13 families in the USA. Due to a decrease in the number of pesticide applications in the cotton agro-ecosystem, *P. solenopsis* caused serious damage in cotton *(Gossypium hirsutum)* in Pakistan during 2005 (Abbas *et al*. 2005; Saeed *et al*. 2007) and in cotton-growing districts of Punjab (India) during 2005/06 and 2006/07. The infested plant produces fewer bolls of smaller size with improper opening, which ultimately reduces the seed-cotton yield by ~44% (Dhawan *et al.* 2007). In India, *P. solenopsis* was found to be the predominant mealybug species, infesting cotton in Punjab, Haryana, Rajasthan, Gujrat, Maharashtra, Andhra Pradesh and Tamil Nadu (Nagrare *et al.* 2009). In Punjab state, the mealybug infestation on cotton was recorded in Mansa, Bathinda, Muktsar, Faridkot and Ferozepur districts (Dhawan *et al.* 2009). Although a

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number of chemicals are effective against this mealybug (Anon. 2010), their overuse in the long term may result in insecticide resistance, resurgence, etc. Therefore, there is a strong need to investigate other options for sustainable management of *P. solenopsis*.

In India the coccinellid beetle *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) has provided spectacular control of heavy infestations of sucking pests, especially mealybugs (Mani 1990; Mani and Krishnamoorthy 2008) and some soft scales (Kumar and Prakasam 1984; Mani and Krishnamoorthy 1990). The predator was also reported to feed on citrus mealybug, *Planococcus citri* (Singh 1978), and pink mealybug, *Maconellicoccus hirsutus* (Green) (Mani and Thontadarya 1988; Reddy and Narayan 1986). *C. montrouzieri* was found to be a most efficient predator among coccinellids, *Hyperaspis maindroni, Scymnus coccivora* and *Nephus regularis* for *P. solenopsis* in New Delhi, India (Fandi *et al.* 2010). Moore (1988) also stated that despite the frequent use of predators, only the coccinellid *C. montrouzieri* can be considered successful. Keeping in mind the efficacy of *C. montrouzieri* on mealybug species, the present study was conducted with the objective to estimate the predation capacity of *C. montrouzieri* on different stages of *P. solenopsis*, a newly introduced pest of cotton in India.

Materials and methods

Mealybug source A *Phenacoccus solenopsis* culture was maintained and mass multiplied at room temperature on potted cotton plants (LH 1556) in a screen house (approx. 4×4×4 m) of 20 mesh cm^{-2} at the Entomological Research Farm, Punjab Agricultural University, Ludhiana, Punjab, India.

Predator source Adult beetles of *C. montrouzieri* were obtained from the National Bureau of Agriculturally Important Insects (NBAII), Bangalore, and reared on *P. solenopsis* at the Biological Control Laboratory, PAU. The beetles were fed with different instar nymphs of mealybugs daily in glass jars (15× 20 cm) covered by a muslin cloth (40 mesh cm^{-2}) at 27±2°C and 70±5% r.h.

Experimental procedure The experiment was planned to identify variations in feeding potential of various stages of *C. montrouzieri* against all stages of *P. solenopsis* by confining first, second, third and fourth instar predatory grubs as well as adult beetles singly in glass vials (7.0×1.5 cm) along with small bits of cotton leaves as food to support the prey. In order to study the predation efficacy of first instar grubs, ten first instar nymphs or eight second instar nymphs or three third instar nymphs or two adult female mealybugs were provided daily per vial. Second and third instar grubs were provided with 50 first instar nymphs or 30 second instar nymphs or six third instar nymphs or three adult female mealybugs per vial daily. Fourth instar grubs and adult beetles were provided with 70 first instar nymphs, 50 second instar nymphs, eight third instar nymphs or four adult female mealybugs per vial daily. The observations on prey consumption were recorded daily until the instar change for all grub stages and until death in the case of adult beetles. The remaining individuals of prey (nymphs or adults) were counted and removed daily before providing the fresh prey and consumption was calculated. Four replications (ten individuals each) were maintained for each combination of predator and mealybug stages.

The experiment was repeated twice (May to August, in 2008 and 2009) under laboratory conditions (27±2°C and 70±5% r.h.) and the mean of both experiments was taken to determine the feeding potential of *C. montrouzieri* on *P. solenopsis*.

Biological parameters of C. montrouzieri on P. solenopsis The freshly emerged male and female beetles were paired and each of ten such pairs was kept in a glass vial (70×15 mm). The mealybugs along with cotton leaves were provided to these pairs as food and each of the pairs was observed for their pre-oviposition, oviposition, post-oviposition periods, fecundity and longevity. The total life cycle and adult longevity of both sexes were also calculated. To study the development, a portion of the cotton leaf on which there were newly laid beetle eggs was cut and each egg was placed carefully, with a camel hair brush, onto a small bit of cotton leaf in a glass vial and the vials were plugged with cotton. Twenty such replications were prepared and observed daily. The time taken from egg laying to hatching (five replications) and the duration of larval stages, pre-pupal and pupal stages, and sex ratio were recorded. The data on different biological parameters of *C. montrouzieri* on *P. solenopsis* were presented in an earlier report (Kaur *et al.* 2010).

Statistical analysis The data were subjected to analysis with Completely Randomized Design (CRD) by using square root transformation and the statistical software CPCS1 (Cheema and Singh 1990). Standard error was also worked out. The difference in mean values of number of different stages of *P. solenopsis* consumed by different stages of *C. montrouzieri* was tested at the 5% level of probability ($P<0.05$) using the least significant difference (LSD) test.

Results

Table 1 shows the significant difference in the mean consumption of the different development stages of *C. montrouzieri* across prey stages during both seasons (May to August, 2008 and 2009). Quite similar results were obtained during both years. The feeding efficiency of *C. montrouzieri* increased significantly with advancement in each development stage. The mean consumption of first instar larvae of *C. montrouzieri* on first instar nymphs of *P. solenopsis* was the lowest (15.56±0.73). The second instar larval *C. montrouzieri* consumed significantly more first instar nymphs of *P. solenopsis* (41.01±0.99) as compared with the first instar larvae but significantly less than the other development stages of *C. montrouzieri*. A similar feeding trend was observed with the third and fourth instar larval stages as well as adult beetles of *C. montrouzieri,* where each development stage consumed significantly more first instar nymphs of mealybug than the previous stage.

The average number of second instar nymphs of mealybug consumed by first instar larval *C. montrouzieri* was significantly less than the other development stages of the *C. montrouzieri*. The mean consumption among all development stages of *C. montrouzieri* on second instar *P. solenopsis* was the highest in the case of adult beetles followed by fourth, third, second and first larval instars (Table 1).

The average number of third instar nymphs of mealybug consumed by first instar larval *C. montrouzieri* was also significantly less than the other development stages of *C. montrouzieri*. Second, third and fourth larval instars of *C. montrouzieri* showed an increasing consumption trend with advancement in each development stage of the predatory beetle. The mean comparison for total consumption on third instar cotton mealybug by *C. montrouzieri* showed that adult *C. montrouzieri* consumed the maximum number of third instar *P. solenopsis* nymphs, which was statistically different from all other predator stages (Table 1).

The average number of adult females of *P. solenopsis* consumed by first instar larval *C. montrouzieri* was significantly lower than the other development stages of *C. montrouzieri*. The prey consumption (adult female *P. solenopsis*) of *C. montrouzieri* showed an increasing trend with advancement of each development stage of

Table 1 Feeding potential of *Cryptolaemus montrouzieri* against *Phenacoccus solenopsis* under laboratory conditions (mean of two seasons)

Different stages of *C. montrouzeri*	Number of different stages of prey consumed (mean of four replications±SE)				LSD ($P=0.05$)
	1st instar nymph	2nd instar nymph	3rd instar nymph	Adult	
1st instar larva	15.56±0.73 (4.07)[z]	11.15±0.46 (3.49)	1.80±0.07 (1.67)	0.94±0.04 (1.39)	(0.08)
2nd instar larva	41.01±0.99 (6.48)	26.35±0.68 (5.23)	6.36±0.21 (2.71)	3.23±0.15 (2.06)	(0.09)
3rd instar larva	125.38±3.93 (11.24)	73.66±1.50 (8.64)	13.32±0.42 (3.78)	8.47±0.24 (3.08)	(0.12)
4th instar larva	162.69±3.88 (12.79)	76.04±2.09 (8.78)	21.16±0.74 (4.71)	12.71±0.61 (3.70)	(0.14)
Adult beetle	1613.81±47.57 (40.18)	787.95±21.78 (28.09)	114.66±3.17 (10.75)	73.40±3.55 (8.62)	(0.44)
LSD ($P=0.05$)	(0.37)	(0.13)	(0.13)	(0.10)	

[z] Figures in parenthesis indicate square root transformation

the predator. The mean consumption among all development stages of *C. montrouzieri* on adult female *P. solenopsis* was again greatest in the case of adult beetles (Table 1).

Significant variations in the feeding potential of *C. montrouzieri* were observed. These variations depend upon the size of food (*P. solenopsis*) offered to different stages of *C. montrouzieri* as well as the size and longevity of different stages of *C. montrouzieri*. The consumption on adult female mealybugs of *P. solenopsis* was comparatively less than consumption on other stages of mealybug. The adult *C. montrouzieri* beetles were voracious feeders and consumed maximum numbers of all stages of mealybug during their life span.

There was a decreasing consumption trend by different stages of *C. montrouzieri* with an increase in each development stage of *P. solenopsis* from first instar nymph to adult female (Table 2).

Discussion

The predator was able to reproduce by feeding on *P. solenopsis* alone (Kaur *et al.* 2010). All stages of *C. montrouzieri* were observed to feed on all stages of *P. solenopsis*. The prey consumption values were significantly higher with the advancement in each development stage of *C. montrouzieri*. The increase in feeding potential with age of the larvae is in line with earlier findings (Ali and Rizvi 2007; Babu 1999). Fourth instar larval *C. montrouzieri* consumed the greatest quantities of all stages of mealybug when compared with the other larval stages of the predator. These findings corroborate those of Mani and Thontadarya (1987), who reported that fourth instar larval *C. montrouzieri* consumed more *Maconellicoccus hirsutus* nymphs and adult females than other larval stages of the predator. Fourth instar larvae were voracious feeders and consumed 63% of the total food requirement for *Planococcus citri* and *Dactylopius tomentosus* as against 30% by third instar larva and the remaining amount by first and second instar larvae (Baskaran *et al.* 1999). In general, fourth instar coccinellids are known to consume greater quantities of prey than other stages (Fandi *et al*. 2010; Lucas *et al.* 2004).

Table 2 Total number (± SE) of different stages of prey (*Phenacoccus solenopsis*) consumed by a single individual of *Cryptolaemus montrouzieri* during its entire life cycle

Different stages of *P. solenopsis*	Total prey consumed by *C. montrouzieri*
1st instar nymph	1958.45±195.53 d[z]
2nd instar nymph	975.15±94.79 c
3rd instar nymph	157.30±13.42 b
Adult	98.75±8.75 a

[z] Figures followed by different letters indicate significant difference among different stages of *P. solenopsis* at $P<0.05$

In the present study, first instar larval *C. montrouzieri* consumed the lowest number of all stages of mealybug when compared with the other larval stages of the predator. The reason for lower predatory efficiency of first instar *C. montrouzieri* might be due to its small size, compared with other development stages of the predator. Previous research by Rosas-Garcia *et al.* (2009), who studied the predatory efficiency of *C. montrouzieri* on *P. citri,* reported that the first instar larvae preyed on significantly fewer mealybugs as compared with other development stages of the predator.

Predatory adult beetles consumed a maximum number of *P. solenopsis* nymphs and adult females—on an average 2516.42 nymphs or 73.40 adult female mealyugs—compared with larval stages. Similar results were reported by Rosas-Garcia *et al.* (2009) that the adult stage of *C. montrouzieri* was the most efficient predatory stage as compared with the other development stages of the predator. This is due to the fact that adult beetles have a greater longevity than their larval instars. Previous research on different biological parameters of *C. montrouzieri* against *P. solenopsis* has shown that the duration of first, second, third and fourth instar larvae was 2.78, 4.64, 6.13 and 3.79 days, respectively, whereas the longevity of male and female adults was 68.30 and 61.78 days, respectively (Kaur *et al.* 2010). Mani and Krishnamoorthy (1997) reported the duration of *C. montrouzieri* larval and adult stages to be 3–8 days and 52–80 days, respectively.

The total number of *M. hirsutus* nymphs consumed by immature stages of *C. montrouzieri* (from first to fourth instar larva) was reported to be 259 nymphs or 27.55 adult females (Mani and Thontadarya 1987) and 300–400 nymphs or 30 adult females (Mani 1990). The results of our studies on consumption of *P. solenopsis* nymphs by larval *C. montrouzieri* are at variance with the previous study, showing higher consumption by larval *C. montrouzieri* (574.48 nymphs),

whereas the results on consumption of *P. solenopsis* adult females by larval *C. montrouzieri* are slightly lower (25.35 adult females) than the previous studies. The number of adult female mealybugs required for a larval *C. montrouzieri* was less than that of nymphs because of larger body size. Thus, *C. montrouzieri* average feeding was the most on first instar nymphs (344.64), followed by second (187.2) and third (42.64) instar nymphs and adult female mealybugs (27.55). The body size of first instar *P. solenopsis* was smallest (length: 12.27±1.20 mm; width: 0.74±0.63 mm), whereas the body size of adult female *P. solenopsis* (length: 16.81±1.20 mm; width: 10.96±0.63 mm) was largest (Akintola and Ande 2008). Bhat *et al.* (1981) observed that the average number of adult citrus mealybugs consumed by first to fourth larval instars was one mealybug in 3 days, one mealybug in 2 days, one mealybug per day and three mealybugs in 2 days, respectively.

Our findings showed that *C. montrouzieri* is an efficient predator of *P. solenopsis*, which corroborates the findings of Gautam *et al.* (1998), Kairo *et al.* (2000) and Moses *et al.* (2002), who reported that *C. montrouzieri* is the best biological control agent for hibiscus mealybug, *M. hirsutus*. Last larval instars and adult beetles of *C. montrouzieri* are the most voracious feeders of mealybugs. Thus, this predatory beetle has the potential to be exploited for the management of *P. solenopsis* on different crops in northern India. Inoculative releases in the field may provide satisfactory control of *P. solenopsis*. However, before drawing firm conclusions about the effectiveness of *C. montrouzieri* on *P. solenopsis*, further experiments, under field conditions, are needed.

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References

Abbas, G., Arif, M. J., & Saeed, S. (2005). Systematic status of a new species of the genus *Phenacoccus* Cockerell (Pseudococcidae), a serious pest of cotton, *Gossypium hirsutum* L., in Pakistan. *Pakistan Entomology, 27*, 83–84.

Akintola, A. J., & Ande, A. T. (2008). First record of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on *Hibiscus rosa-sinensis* in Nigeria. *Agricultural Journal, 3*, 1–3.

Ali, A., & Rizvi, P. Q. (2007). Development and predatory performance of *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) on different aphid species. *Journal of Biological Sciences, 7*, 1478–1483.

Anon. (2010). *Package of practices for kharif crops*. Ludhiana, India: Punjab Agricultural University.

Babu, A. (1999). Influence of prey species on feeding preference, post-embryonic development and reproduction of *Coccinella transversalis* F. (Coleoptera: Coccinellidae). *Entomon, 24*, 221–228.

Baskaran, R. K. M., Lakshmi, L. G., & Uthamasamy, S. (1999). Comparative biology and predatory potential of Australian ladybird beetle (*Cryptolaemus montrouzieri*) on *Planococcus citri* and *Dactylopius tomentosus*. *Indian Journal of Agricultural Science, 69*, 605–606.

Bhat, P. K., Chako, M. J., & Sreedharan, K. (1981). Biology of the lady bird beetle, *Cryptolaemus montrouzieri* Mulsant, a predator of mealy bugs. *Proceedings of 2nd Annual Symposium on Plantation Crops* (Ootacamund, India), pp. 221–226.

Cheema, S. S., & Singh, B. (1990). *CPCS1: A computer programs package for the analysis of commonly used experimental designs*. Ludhiana, India: Punjab Agricultural University.

Dhawan, A. K., Singh, K., Aneja, A., & Saini, S. (2009). Distribution of mealybug, *Phenacoccus solenopsis* Tinsley in cotton with relation to weather factors in South-Western districts of Punjab. *Journal of Entomological Research, 33*, 59–63.

Dhawan, A. K., Singh, K., Saini, S., Mohindru, B., Kaur, A., Singh, G., *et al*. (2007). Incidence and damage potential of mealy bug, *Phenacoccus solenopsis* Tinsley on cotton in Punjab. *Indian Journal of Ecology, 34*, 166–172.

Fandi, B. B., Gautam, R. D., & Suroshe, S. S. (2010). Effect of developmental stage and density of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on the predatory performance of four coccinellid predators. *Journal of Biological Control, 24*, 110–115.

Fuchs, T. W., Stewart, J. W., Mizenmayer, R., & Rose, M. (1991). First record of *Phenacoccus solenopsis* Tinsley in cultivated cotton in the United States. *Southwestern Entomologist, 16*, 215–221.

Gautam, R. D., Chi, W. D., & Lessey, M. (1998). Preliminary studies on inoculative releases of Australian beetle *Cryptolaemus montrouzieri* Mulsant and another Indian ladybird, *Scymnus coccivora* Aiyar against pink mealybug, *Maconellicoccus hirsutus* Green at point Fortin. *Proceedings of the First Symposium on the Hibiscus Mealybug* (Centeno, Trinidad and Tobago, pp. 25–29).

Kairo, M. T. K., Pollard, G. V., Peterkin, D. D., & Lopez, V. F. (2000). Biological control of the hibiscus mealybug, *Maconellicoccus hirsutus* Green (Hemiptera: Pseudococcidae) in the Caribbean. *Integrated Pest Management Reviews, 5*, 241–254.

Kaur, H., Virk, J. S., & Kaur, R. (2010). Biology of Australian ladybird beetle, *Cryptolaemus montrouzieri* Mulsant on *Phenacoccus solenopsis* Tinsley. *Journal of Biological Control, 24*, 123–125.

Kumar, M. G., & Prakasam, C. B. (1984). The recovery of *Cryptolaemus montrouzieri* Muls. on the coffee green scale, *Coccus viridis* (Green) on the Shevaroy Hills. *Journal of Coffee Research, 14*, 34–35.

Lucas, E., Labrecque, C., & Coderre, D. (2004). *Delphastus catalinae* and *Coleomegilla maculate lengi* (Coleoptera: Coccinellidae) as biological control agents of the greenhouse whitefly, *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). *Pest Management Science, 60*, 1073–1078.

Mani, M. (1990). The grapevine mealybug. *Indian Horticulture, 35*, 28–29.

Mani, M., & Krishnamoorthy, A. (1990). Evaluation of the exotic predator, *Cryptolaemus montrouzieri* Muls (Coccinellidae, Coleoptera) in the suppression of green scale, *Chloropulvinaria psii* (Mask.) (Coccidae, Homoptera). *Entomon, 15*, 45–48.

Mani, M., & Krishnamoorthy, A. (1997). Australian lady bird beetle *Cryptolaemus montrouzieri*. *Madras Agricultural Journal, 84*, 237–249.

Mani, M., & Krishnamoorthy, A. (2008). Biological suppression of the mealy bugs *Planococcus citri* (Risso), *Ferrisia virgata* (Cockerell) and *Nipaecoccus viridis* (Newstead) on pummelo with *Cryptolaemus montrouzieri* Mulsant in India. *Journal of Biological Control, 22*, 169–172.

Mani, M., & Thontadarya, T. S. (1987). Development and feeding potential of Coccinellid predator, *Cryptolaemus montrouzieri* Muls. on the grape mealybug, *Maconellicoccus hirsutus* (Green). *Journal of Biological Control, 1*, 19–22.

Mani, M., & Thontadarya, T. S. (1988). Field evaluation of *Cryptolaemus montrouzieri* Muls. in the suppression of grape mealybug, *Maconellicoccus hirsutus* (Green). *Journal of Biological Control, 2*, 14–16.

Moore, D. (1988). Agents used for biological control of mealybugs (Pseudococcidae). *Biocontrol News and Information, 9*, 209–225.

Moses, T. K., Pollard, G. V., Peterkin, D. D., & Lopez, F. (2002). Biological control of the hibiscus mealybug, *Maconellicoccus hirsutus* Green (Hemiptera: Pseudococcidae) in the Caribbean. *Integrated Pest Management Reviews, 5*, 241–254.

Nagrare, V. S., Kranthi, S., Biradar, V. K., Zade, N. N., Sangode, V., Kakde, G., *et al*. (2009). Widespread infestation of the exotic mealybug species, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae), on cotton in India. *Bulletin of Entomological Research, 99*, 537–541.

Reddy, R. A., & Narayan, L. K. (1986). Biology and control of the grape mealybug. *Indian Grape Journal, 2*, 30–39.

Rosas-Garcia, N. M., Martinez, D. E. P., de Luna-Santillana, E. D. J., & Villegas-Mendoza, J. M. (2009). Potential of depredation of *Cryptolaemus montrouzieri* Mulsant Hacia. *Planococcus citri Risso*. *Southwestern Entomologist, 34*, 179–188.

Saeed, S., Ahmad, M., & Kwon, Y. J. (2007). Insecticidal control of the mealy bug *Phenacoccus gossypiphilous* (Hemiptera: Pseudococcidae), a new pest of cotton in Pakistan. *Entomological Research, 37*, 76–80.

Singh, S. P. (1978). *Propagation of a Coccinellid beetle for the biological control of citrus and coffee mealybugs. Scientific Conference CPA*. Bangalore, India: Indian Institute of Horticultural Research.

Tinsley, J. D. (1898). Notes on Coccidae, with descriptions of new species. *Canadian Entomologist, 30*, 317–320.