The Journal of Agricultural Sciences - Sri Lanka
Vol. 17, No 3, September 2022. Pp 416-424
http://doi.org/10.4038/jas.v17i3.9921

Feeding Potential and Development of *Chrysoperla carnea* (Neuroptera: Chrysopidae) on *Paracoccus marginatus* (Hemiptera: Pseudococcidae) under no-choice Conditions

Zaib-Un-Nisa[1], S. Saddozai[1], M. I. Mastoi[2], A. A. Gilal[3*], W. M. Achakzai[4] and Muhammad Ibrahim Kubar[3]

Received:12th October 2021 / Accepted: 06th July 2022

ABSTRACT

Purpose: *Considering the predatory effectiveness of Chrysoperla carnea (Neuroptera: Chrysopidae), studies were carried out at National Agricultural Research Centre, Islamabad, Pakistan to determine the feeding potential and developmental period of its larval instars on Paracoccus marginatus (Hemiptera: Pseudococcidae).*

Research Method: *Eggs, 1st, 2nd, and 3rd nymphal instars and adults of P. marginatus were provided to all three larval instars of C. carnea in a Completely Randomized Design experiment, replicated ten times.*

Findings: *Results indicated that all C. carnea larval instars were found to feed on all P. marginatus stages. Overall mean consumption of C. carnea larvae on P. marginatus eggs, 1st, 2nd and 3rd instar nymphs, and adults was 1359.8, 1409.1, 1012.4, 1165.7 and 130.30 individuals, respectively. Third instar C. carnea larvae were more voracious than 2nd and 1st instars. The shortest developmental period (12.40±0.37 days) of C. carnea larvae was recorded on 3rd nymphal instar of P. marginatus. Moreover, C. carnea larvae took 14.90±0.23, 14.00±0.25, 13.10±0.23, and 13.60±0.34 days on eggs, first, second nymphal instars and adults of P. marginatus, respectively to complete their development.*

Originality/ Value: *Therefore, it is suggested that C. carnea should be included as a key component in the integrated management of P. marginatus, especially its 3rd larval instar.*

Keywords: *Biological control, Lacewing, Management, Predator, Paracoccus marginatus*

INTRODUCTION

Papaya, *Carica papaya* L. is a key fruit in the tropics and subtropics. Although, native to tropical America, it has become an internationally important fruit, consumed either fresh or processed (Da Silva *et al.,* 2007). Many insect pests attack on papaya, particularly on its fruit as fruit flies, scales, aphids, leafhoppers, mites, and mealybugs are considered its major pests (Pantoja and Peña, 2007).

Papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) is considered as the most damaging and economically significant pest of papaya having quarantine concerns (Ventura *et al.,* 2004; Pena *et al.,* 2005; Pantoja and Peña, 2007). It is a highly polyphagous pest, infesting more than 200 hosts including ornamental, vegetable, and fruit crops (Schneider *et al.,* 2010). Generally, the pest appears on papaya in colonies, suck the cell sap and have the capability to transmit viral diseases (Bertin *et al.,* 2010). They also secrete honeydew on leaves, fruits, stems etc. that support the growth of a

[1] *Department of Zoology, Sardar Bahadur Khan Women University, Quetta.*
[2] *Pakistan Agricultural Research Council, Islamabad, Pakistan.*
[3*] *Department of Entomology, Faculty of Crop Protection, Sindh Agriculture University, Tandojam.*
aagilal@sau.edu.pk
[4] *Department of Zoology, University of Baluchistan, Quetta.*
https://orcid.org/0000-0002-2809-4964

black sooty mould, hindering photosynthesis, and ultimately affect the vigour and productivity of plants (Hodges *et al.,* 2005; Triplehorn and Johnson, 2005; Buss and Turner, 2006; Schneider *et al.,* 2010).

Paracoccus marginatus has never attained a serious pest status in native countries, most probably due to the presences of natural enemies (Tanwar *et al.,* 2010). Moreover, synthetic pesticides are found ineffective in managing the populations of *P. marginatus* because of the wax produced by it to cover its entire body (Chong, 2005). The application of chemicals has also caused development of insecticide resistance, environmental pollutions, pest resurgence, killing of non-target organisms including bees and natural enemies, along with disturbing the ecosystem balance (Palikhe, 2002; Atreya, 2007; Sharma *et al.,* 2012). Therefore, chemical control against *P. marginatus* is regarded as comparatively less feasible (Walker *et al.,* 2003; Pathan *et al.,* 2008; ED, 2013).

Therefore, use of biological agents is considered as one of the most appropriate options to manage populations of exotic mealybugs in the world (Sagarra *et al.,* 2001; Meyerdirk *et al.,* 2004; Muniappan *et al.,* 2006; Roltsch *et al.,* 2006; Shylesha *et al.,* 2010). *Chrysoperla carnea* [Stephens, 1836 (Neuroptera: Chrysopidae)] is a broadly distributed natural enemy consuming a wide range of soft bodied insects in many regions of the world (Mallah *et al.,* 2001; Atlhan *et al.,* 2004; Aslam and Razaq, 2007; Saeed *et al.,* 2015). It voraciously feeds on many sucking insect crop pests such as whiteflies, mites, jassids, eggs of lepidoptera (Atlhan *et al.,* 2004; Shalaby *et al.,* 2008). Due to its ability to tolerate variable ecological factors, it is reared on mass scale in many countries, enabling it as one of the successful natural enemies (Ashfaq *et al.,* 2002). Considering the damage status of *P. marginatus* and potential of *C. carnea* as its natural enemy, the study was conducted to evaluate feeding potential and development period of *C. carnea* larvae on various life stages of *P. marginatus.*

MATERIALS AND METHODS

Study Location

Studies were done at Insectary, Department of Plant and Environmental Protection, National Agriculture Research Council (NARC), Islamabad. All the studies were conducted at laboratory control conditions (26.00 ± 2.00°C; 60.00 ± 5.00% relative humidity and 10: 14 hours (Light: Dark).

Rearing of P. marginatus

Mass rearing of *P. marginatus* was done on brinjal under glasshouse conditions. The cultivation of brinjal was done as per standards without the use of pesticides to promote population of *P. marginatus*. Moreover, papaya fruits and leaves were provided for the development and maintenance of *P. marginatus* culture in the laboratory.

Rearing of C. Carnea

The field around NARC were used for the collection of *C. carnea* adults that were placed in transparent, rectangular, plastic rearing cages (length = 30cm, width = 22cm, height = 28 cm). Ventilation holes were made on both sides of the cage, whereas one circular window of 13 cm diameter was made on the front wall covered with a lid. A removable lid lined with black paper sheet was placed on top of cage to facilitate the collection of eggs laid by *C. carnea* with the help of a sharp razor blade. The artificial diet comprised of distilled water, honey, and yeast (85:10:05) was provided to *C. carnea* adults in small, striped food plates of 0.5 cm diameter to enhance its fecundity. The collected eggs were placed in separate petri dishes provided with *P. marginatus* on papaya leaves.

Feeding potential and development of C. carnea larvae on P. marginatus

Fifty freshly emerged 1st instar *C. carnea* larvae were collected from the mass culture kept individually in separate petri dishes. A square hole was made at top of each petri dish and then covered with a fine net to facilitate ventilation for the test insects. Thoroughly washed and air-dried fresh papaya leaves were placed in the petri dishes with their petioles submerged in water through a hole in the petri dish to maintain their vigour.

In no-choice experiment of 1st Instar *C. carnea,* fifty freshly laid eggs, first, second, and third instar nymphs, whereas five adults of mixed sex were provided as food on leaves of papaya. The numbers of hosts were increased as the age of larvae increased and reached to seventy immature stages and eight adults of *P. marginatus.* The number of eggs, nymphal instars of *P. marginatus* provided to 2nd instar larvae of *C. carnea* ranged between 85-150 and 10-15, respectively, whereas for 3rd instar larvae of *C. carnea,* it was 150-200 and 15-30, respectively.

The observations were taken daily by counting number of remaining *P. marginatus* stages in each petri dish.

In addition to feeding potential, developmental period of *C. carnea* on various life stages of *P. marginatus* was also recorded by observing moulting in individual instar of *C. carnea* on daily basis and recorded accordingly.

Experimental design and statistical analysis

The Completely Randomized Design was used for the study where each *P. marginatus* and *C. carnea* stage was treated as treatment, as ten replications were maintained for each treatment. Two-way Analysis of Variance and the Least Significant Difference at 5% probability were used for the data analysis and mean separation with significant differences, respectively. All the analyses were performed using STATITIX 8.1 computer software.

RESULTS

Feeding potential of C. carnea larvae on P. marginatus

A highly significant ($F = 65.60$, $P < 0.001$) difference was observed in the feeding ability of 1st instar *C. carnea* larvae on various stages of *P. marginatus* as the maximum and minimum consumption of the larvae was recorded on eggs (220.60 ± 14.03) and adults (8.30 ± 0.78), respectively. Moreover, the mean consumption rate of 1st instar larvae of *C. carnea* on 1st, 2nd, and 3rd instar nymphs of *P. marginatus* was 201.00 ± 12.86, 128.00 ± 12.25 and 132.50 ± 4.08, respectively (Table 01).

The highest mean feeding of 2nd instar larvae of *C. carnea* among various *P. marginatus* stages was recorded on 1st instar nymphs (365.7 ± 14.47), whereas adults (23.7 ± 2.066) were the least consumed. The mean consumption rate of 2nd *C. carnea* larvae instar fed on eggs, 2nd and 3rd instar *P. marginatus* nymphs was 347.40 ± 19.87, 291.20 ± 14.39, and 340.60 ± 28.42, respectively. Overall, a highly significant ($F = 62.50$, $P < 0.001$) difference was recorded in the feeding level of 2nd instar *C. carnea* larvae on various *P. marginatus* developmental stages under no choice conditions (Table 01).

Like 2nd instar, the 3rd instar *C. carnea* larvae also exhibited a significant difference ($F = 88.10$, $P < 0.001$) in its feeding on various *P. marginatus* life stages. The maximum mean feeding was observed on 1st instar *P. marginatus* (842.40 ± 43.55), whereas adults were the least consumed (98.3 ± 5.51). The mean feeding of 3rd instar *C. carnea* larvae on eggs, 1st and 3rd instar nymphs of *P. marginatus* was 791.80 ± 29.16, 595.00 ± 21.59 and 692.60 ± 42.46, respectively (Table 01).

Overall, the maximum (1409.1 ± 50.69) feeding potential of various *C. carnea* larval instars was recorded on 1st instar *P. marginatus* nymphs, whereas minimum consumption (130.30 ± 5.93) was recorded on adults. The mean consumption of all *C. carnea* larvae on eggs, 2nd and 3rd instar *P. marginatus* nymphs were 1359.80 ± 43.33, 1012.40 ± 26.53 and 1165.70 ± 57.60, respectively (Table 01).

Table 01: Feeding potential of *Chrysoperla carnea* on different stages of *Paracoccus marginatus* under no-choice conditions in laboratory

Developmental stages of *P. marginatus*	Development duration of *C. carnea* larvae Mean ± SE			
	1st instar	2nd instar	3rd instar	Overall
Eggs	220.6±14.03a	347.40±19.87a	791.80±29.16a	1359.8±43.33a
1st instar nymph	201.0±12.86a	365.70±14.47a	842.40±43.55a	1409.1±50.69a
2nd instar nymph	128.00 ±12.25b	291.20±14.397b	595.00±21.59c	1012.4±26.53c
3rd instar nymph	132.50±4.08b	340.60±28.42ab	692.60±42.46b	1165.7±57.60b
Adults	8.3±0.77c	23.7±2.06c	98.3±5.51d	130.30±5.93d
LSD Value	29.314	51.324	90.490	117.47

**Means followed by same letters within same column are not significantly different.*

Development of C. carnea larvae on P. marginatus under no choice feeding condition

No significant (F = 1.56, P < 0.20) effect of the various stages of *P. marginatus* as food was observed on the developmental period of 1st instar *C. carnea* larvae. The mean developmental periods of 1st instar *C. carnea* larvae i.e., 3.7 ± 0.15, 3.40 ± 0.16, 3.20 ± 0.20 and 3.40 ± 0.16 days were recorded when feeding on eggs, 1st, 2nd instar nymphs, and adults *P. marginatus,* respectively (Table 02).

The developmental period of 2nd instar *C. carnea* larvae varied significantly (F 5.48, P < 0.01) on different *P. marginatus* developmental stages. *Paracoccus marginatus* eggs supported the highest mean developmental duration (4.5 ± 0.17 days) of *C. carnea* larvae, whereas their lowest developmental time was recorded on 3rd instar nymphs (3.7 ± 0.15 days). Moreover, it took 4.10 ± 0.10, 4.30 ± 0.15 and 3.80 ± 0.13 days to complete its development while feeding on *P. marginatus* 1st instar, 2nd instar nymphs and adults, respectively (Table 02).

The longest and shortest developmental duration of 3rd instar *C. carnea* larvae was observed on eggs (6.70 ± 0.15 days) and 3rd instar nymphs (5.50 ± 0.41 days), respectively. Moreover, it took 6.50 ± 0.17, 5.60 ± 0.16 and 6.40 ± 0.22 days to complete its development when fed on 1st and 2nd instar nymphs, and adults of *P. marginatus,* respectively (Table 02).

Table 02: Developmental duration of larval instars of *C. Carnea* on different stages of *Paracoccus marginatus* under no-choice feeding conditions in laboratory

Developmental stages of *P. marginatus*	Development duration of *C. carnea* larvae Mean ± SE			
	1st instar	2nd instar	3rd instar	Overall
Eggs	3.70±0.15a	4.50±0.17a	6.70±0.15a	14.90±0.23a
1st instar nymph	3.40±0.16ab	4.10±0.10ab	6.50±0.17a	14.00±0.25b
2nd instar nymph	3.20±0.20b	4.30±0.15a	5.60±0.16b	13.10±0.23cd
3rd instar nymph	3.20±0.13b	3.70±0.15b	5.50±0.41b	12.40±0.37d
Adults	3.40±0.16ab	3.80±0.13b	6.40±0.22a	13.60±0.34bc
LSD Value	0.4671	0.4073	0.6833	0.8342

**Means followed by same letters within same column are not significantly different.*

Overall, all three *C. carnea* larval instars showed a highly significant difference in their development period when fed on various *P. marginatus* life stages (F = 10.00, P < 0.00) difference. The maximum and minimum developmental period of *C. carnea* larvae was recorded on eggs (14.90±0.23 days), and 3rd instar *P. marginatus* nymphs (12.40 ± 0.37 days), respectively. Moreover, overall larval development period of *C. carnea* when fed on 1st and 2nd instar nymphs, and adults of *P. marginatus* was 14.00 ± 0.25, 13.10 ± 0.23 and 13.60 ± 0.34, respectively (Table 02).

DISCUSSION

Chrysoperla carnea is a polyphagous predator that has played a key role in population reduction of many soft bodied pests, especially sucking insect pests including mealybugs (Fazlullah *et al.,* 2017; Sajjad *et al.,* 2021). Accordingly, in the study undertaken, all the *C. carnea* larval instars showed their predatory potential on various life stages of *P. marginatus* with significant differences among individual instars. Third instar *C. carnea* was found the most voracious consuming average 791.80 ± 29.16 eggs, 842.40 ± 43.55 1st instar nymphs, 595.00 ± 21.59 2nd instar nymphs, 692.60 ± 42.46 3rd instar nymphs and 98.3 ± 5.51 adults of *P. marginatus* in its development period. Moreover, 1st instar *C. carnea* larvae was the least effective consuming 220.6 ± 14.03 eggs, 201.0 ± 12.86 1st instar, 128.00 ± 12.25 2nd instar, 132.50 ± 4.08 and 8.3 ± 0.77 adults of *P. marginatus.*

Finding of Rajan and Krishnakumar (2013) also supported the findings of current research as 3rd instar *C. zestrowi* larvae were found to be the most aggressive consuming comparatively a large number of various immature host stages of mealybug than first and second instar larvae. A recent study on biology, lifetable and functional response of various larval instars of *C. carnea* on *P. marginatus* confirmed that all the instars are capable to consume the mealy bug, with 2nd and 3rd instars exhibiting type-III functional response that is most desirable for an efficient predator. Moreover, a lot of studies have been carried out on the predatory potential of *Chrysoperla* spp. on other mealybug species particularly *P. solenopsis.* All such studies confirmed that 3rd instar larvae of *C. carnea* are more aggressive on various stages mealybugs than 1st and 2nd instar larvae (Rashid *et al.,* 2012; Hameed *et al.,* 2013). A comparative study of *C. carnea* and *Cryptolaemus montrouzi* on various stages of *P. solenopsis* showed that although *C. montrouzi* was comparatively more effective against *P. solenopsis,* but 3rd instar larvae of both the species were more voracious than 1st and 2nd instar larvae (Khan *et al.,* 2012). Hameed *et al.* (2013) also confirmed that 3rd instar *C. carnea* larvae are the most voracious than remaining instars on *P. solenopsis,* whereas 3rd instar nymphs of *P. solenopsis* supported maximum biological parameters of the lacewing. It has been suggested that the differences in the mean consumption of various life stages of *P. marginatus* by *C. carnea* larval instar may be due to their size, and handling of their hosts in addition to their nutritional requirements (Rashid *et al.,* 2012; Sajjad *et al.,* 2021).

In the study, in addition to effect the feeding ability of *C. carnea* larvae, various *P. marginatus* stages also showed a profound influence on the developmental period of *C. carnea* larvae. Although, the developmental period of 1st instar larvae did not show any significant difference while feeding on various life stages of *P. marginatus*, but 2nd and 3rd instar *C. carnea* larvae exhibited a significant difference in their development when fed on various life stages of *P. marginatus.* All the larval instars completed their development in minimum time when fed on third instar *P. marginatus* nymphs. These findings are supported by the outcomes of Khan *et al.* (2012), who reported a significant effect of various host stages of *P. solenopsis* on the feeding and developmental duration of *C. carnea*. Hameed *et al.* (2013) also reported that developmental duration of *C. carnea* larvae was significantly lower when fed on 2nd and 3rd instar nymphs of *P. solenopsis* in comparison to 1st nymphal instar. The reason behind the minimum developmental period of *C. carnea* larvae on 3rd nymphal instar of *P. marginatus* may be due the presence of enough food in them to support rapid growth and development of predator along with its slower movement nable *C. carnea* larvae to handle them easily. It has been found in previous studies on feeding preference of *C. carnea* on *P. solenopsis* developmental stages that third instar nymph of *P. solenopsis* proved to be a comparatively better diet for the rapid growth of *C. carnea* and the same may be attributed to high amount of lipids and carbohydrates in it (Hameed *et al.,* 2013: El-Zahi, 2017).

CONCLUSION

Chrysoperla carnea larvae showed their predatory potential against all stages of *P. marginatus* as they significantly fed more on either 1st instar nymphs or eggs. Moreover, *P. marginatus* adults were least preferred by the *C. carnea* larvae. The lowest developmental period of all *C. carnea* larval instars was recorded on 3rd nymphal instar of *P. marginatus.* Therefore, it is suggested that 3rd nymphal instars of *P. marginatus* should be used for the mass rearing of *C. carnea*. Therefore, it is suggested that 3rd nymphal instars of *P. marginatus* should be used for the mass rearing of *C. carnea*.

Conflict of Interest

The authors declare that there is no conflict of interest for this study.

REFERENCES

Ashfaq, M., Nasreen, A. and Cheema, G.M. (2002). A new technique for mass rearing of Green Lacewing on commercial scale. *Journal of Applied Sciences.* 2(9), pp.925-926. DOI:10.3923/jas.2002.925.926.

Aslam, M. and Razaq, M. (2007). Arthropod fauna of *Brassica napus* and *Brassica juncea* from Southern Punjab (Pakistan). *Journal of Agriculture and Urban Entomology.* 24(2), pp.49-50. https://doi.org/10.3954/1523-5475-24.2.49

Atlhan, R., Kaydan, B. and Özgökçe, M.S. (2004). Fed activity and life history characteristics of the generalist predator, *Chrysoperla carnea* (Neuroptera: Chrysopidae) at different prey densities. *Journal of Pest Science.* 77, pp.17–21. https://doi.org/10.1007/s10340-003-0021-6

Atreya, K. (2007). Pesticide Use in Nepal: Understanding health costs from short-term exposure. SANDEE working papers, 28-07. South Asian Network for Development and Environmental Economics (SANDEE), Kathmandu, Nepal. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/4366

Bertin, S., Cavalieri, V., Graziano, C. and Bosco, D. (2010). Survey of mealybug (Hemiptera: Pseudococcidae) vectors of *Ampelovirus* and *Vitivirus* in vineyards of northwestern Italy. *Phytoparasitica,* 38(4), pp. 401-409. https://doi.org/10.1007/s12600-010-0109-5

Buss, E. and Turner, J. (2006). Scale insects and mealybugs on ornamental plants. EENY- 323. Featured creatures. Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL, pp. 1-6.

Chong, J.H. (2005). Biology of the mealybug parasitoid, *Anagyrus loecki*, and its potential as a biological control agent of the Madeira mealybug, *Phenacoccus madeirensis.* Ph.D. Thesis, University of Georgia, USA. http://purl.galileo.usg.edu/uga_etd/chong_juang_h_200505_phd

ED. (2013). Entomology Division- Annual report 2069/2070 (2012/13). NARC, Khumaltar, Lalitpur, Nepal. 90 pp. http://opac.narc.gov.np/opac_css/index.php?lvl=etagere_see&id=26

El-Zahi, E.Z.S. (2017). Preference and Predatory Potential of *Chrysoperla carnea* (Stephens) and *Coccinella undecimpunctata* Linnaeus on *Phenacoccus solenopsis* Tinsley: A new threat to the Egyptian economic crops. *Alexandria Science Exchange Journal*. 38(4), pp.837-843. DOI: 10.21608/ASEJAIQJSAE.2017.4592.

Fazlullah., Mastoi, M.I., Ehsan-ul-Haq., Mahmood, T., Gilal, A.A., Aqsa, A., Bhatti, A.R. and Anjum, S. (2017). Exploration of natural enemy fauna of papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) on different host plants at Islamabad Pakistan. *Pakistan Entomologist.* 39(1), pp.23-27.

Hameed, A., Saleem, M., Saghir, A., Aziz, M.I. and Karar, H. (2013). Influence of prey consumption on life parameters and predatory potential of *Chrysoperla carnea* against cotton mealy bug. *Pakistan Journal of Zoology.* 45(1), pp.177-182.

Hodges, A.C., Hodges, G.S. and Wisler, G.C. (2005). Exotic scale insects (Hemiptera: Coccoidea) and whiteflies (Hemiptera: Aleyrodidae) in Florida's tropical fruits: an example of the vital role of early detection in pest prevention and management. In: Proceedings of the Florida State Horticultural Society, Florida State Horticultural Society. Volume. 118. 215-217. http://journals.fcla.edu/.../82919

Khan, H.A.A., Sayyed, A.H., Akram, W., Razald, S. and Ali, M. (2012). Predatory potential of *Chrysoperla carnea* and *Cryptolaemus montrouzieri* larvae on different stages of the mealybug, *Phenacoccus solenopsis*: A threat to cotton in South Asia. *Journal of Insect Science.* 12(1): pp.147. https://doi.org/10.1673/031.012.14701

Mallah, G.H., Korejo, A.K., Soomoro, A.R. and Soomoro, A.W. (2001). Population dynamics of predatory insects and biological control of cotton pests in Pakistan. *Journal of Biological Science.* 1(24), pp.5-248. DOI: 10.3923/jbs.2001.245.248

Meyerdirk, D., Muniappan, R., Warkentin, R., Bamba, R.J. and Reddy, G. (2004). Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Guam. *Plant Protection Quarterly.* 19(3), pp.110-114.

Muniappan, R., Meyerdirk, D.E., Sengebau, F.M., Berringer, D.D. and Reddy, G.V.P. (2006). Classical biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the Republic of Palau. *Florida Entomologist.* 89(2), pp.212-217. https://doi.org/10.1653/0015-4040(2006)89[212:CBCOTP]2.0.CO;2

Palikhe, B.R. (2002). Challenges and options of pesticide use in the context of Nepal. *Landschaftsökologie und Umweltforschung,* 38, pp.130-141.

Pantoja, A. and Peña, J.E. (2007). Papaya insects: Ecology and control. In: Encyclopedia of Pest Management. (D. Pimentel, Ed.). Taylor and Francis.

Pathan, A.K., Sayyed, A.H., Aslam, M., Razaq, M., Jilani, G. and Saleem, M.A. (2008). Evidence of field-evolved resistance to organophosphates and pyrethroids in *Chrysoperla carnea* (Neuroptera: Chrysopidae). *Journal of Ecology and Entomology.* 101(5), pp.1676-1684. https://doi.org/10.1093/jee/101.5.1676.

Pena, J.E., Pantoja, A., Osborne, L., Duncan, R., Coss-Flores, M.D., Meister, C. and Hammon, A. (2005). Homopteran and mite pests of papaya and their control. *Proceedings of the Florida State Horticultural Society.* 118: pp.221-227.

Rajan, V.P. and Krishnakumar, R. (2013). Predatory potential Of *Chrysoperla zestrowi* Sillemittenry and *Cryptolaemus montrouzieri* (Mulsant) on papaya mealybug, *Paracoccus marginatus* (Williams and Granara De Willink). *Entomon,* 38(4), pp. 221-226. http://www.entomon.in/index.php/Entomon/article/view/11

Rashid, M.M.U., Khattak, M.K., Abdullah, K., Amir, M., Tariq, M. and Nawaz, S. (2012). Feeding potential of *Chrysoperla carnea* and *Cryptolaemus montrouzieri* on cotton mealybug, *Phenacoccus solenopsis*. *Journal of Animal Plant Science.* 22(3), pp. 639-64.

Roltsch, W.J., Meyerdirk, D.E., Warkentin, D.R., Andress, E.R. and Carrera, K. (2006). Classical biological control of the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green), in southern California. *Biological Control,* 37(2), pp.155-166. https://doi.org/10.1016/j.biocontrol.2006.01.006

Saeed, R., Razaq, M. and Hardy, I.C. (2015). The importance of alternative host plants as reservoirs of the cotton leaf hopper, *Amrasca devastans,* and its natural enemies. *Journal of Pest Science.* 88(3), pp.517-531. https://doi.org/10.1007/s10340-014-0638-7

Sagarra, L., Vincent, C. and Stewart, R. (2001). Body size as an indicator of parasitoid quality in male and female *Anagyrus kamali* (Hymenoptera: Encyrtidae). *Bulletin of Entomological Research.* 91(5), pp.363-368. https://doi.org/10.1079/BER2001121

Sajjad, S., Sultan, A., Khan, M.F., Keerio, I.D., Channa, M.S. and Akbar, M. (2021). Biology, life table parameters, and functional response of *Chrysoperla carnea* (Neuroptera: Chrysopidae) on different stages of invasive *Paracoccus marginatus* (Hemiptera: Pseudococcidae). *Journal of Asia Pacific Biodiversity.* 14(2), pp.174-182. https://doi.org/10.1016/j.japb.2021.02.003

Schneider, S.A. and LaPolla, J.S. (2010). Phylogeny and taxonomy of the mealybug tribe Xenococcini (Hemiptera: Coccoideae: Pseudococcidae) with a discussion of trophobiotic associations with *Acropyga roger* ants. *Systematic Entomology,* 114(2), pp.162-180.

Shalaby, F.F., El-Heneidy, A.H., Hafez, A.A. and El-Din, I.B. (2008). Seasonal abundances of common coccinellid species in some economic field crops in Egypt. *Egyptian Journal of Agriculture Research.* 86(1), pp. 303-317.

Sharma, D.R., Thapa, R.B., Manandhar, H.K., Shrestha, S.M. and Pradhan, S.B. (2012). Use of pesticides in Nepal and impacts on human health and environment. *Journal of Agriculture and Environment.* 13: pp.67-74. https://doi.org/10.3126/aej.v13i0.7590

Shylesha, A.N., Joshi, S., Rabindra, R.J. and Bhumannavar, B.S. (2010). Classical biological control of the papaya mealybug. National Bureau of Agriculturally Important Insects, Banglore, India. 1-4 pp.

Silva, J.D., Rashid, Z., Nhut, D.T., Sivakumar, D., Gera, A., Souza, M.T. and Tennant, P. (2007). Papaya (*Carica papaya* L.) biology and biotechnology. *Tree and Forestry Science and Biotechnology.* 1(1), pp.47-73.

Tanwar, R.K., Jeyakumar, P. and Vennila, S. (2010). Papaya mealybug and its management strategies. Technical Bulletin 22. National Centre for Integrated Pest Management, New Delhi. 1-20 pp.

Triplehorn, C.A. and Johnson, N.F. (2005). Borror and Delong's Introduction to Study of Insects, 7th Ediiton. Belmont, CA: Thompson Brooks/Cole.

Ventura, J.A., Costa, H. and Tatagiba, J.D.S. (2004). Papaya diseases and integrated control. In: Diseases of Fruits and Vegetables: Volume II. Springer, Dordrecht. 201-268 pp.

Walker, A., Hoy, M. and Meyerdirk, D. (2003). Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Insecta: Hemiptera: Pseudococcidae) EENY- 302. Featured creatures. Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. 1-7 pp.

Williams, D.J. and Granara de Willink, M.C. (1992). Mealybugs of Central and South America. CAB International.