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# Evaluation of insecticides against cotton mealybug, *Phenacoccus solenopsis* Tinsley and their safety to important predators

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Cotton plays an important role in the world economy by supplying raw materials to different manufacturing units. Of late, it is being seriously attacked by the cotton mealybug, *Phenacoccus solenopsis* Tinsley. The biological control involving coccinellid beetles and chrysopids as predators could lead to ecologically sustainable mealybug control. Here, in the context of conservation of natural enemies, we exploredthe efficacy of insecticides on the cotton mealybug and also safety to other predators. Six insecticides *viz*; chlorpyrifos 20 EC (0.05%), endosulfan 35 EC (0.07%), monocrotophos 36 SL (0.04%), malathion 50 EC (0.12%), dichlorvos 76 EC (0.15%), and alphamethrin 10 EC (0.01%) were tested for their residual toxicity against the mealybug, *P. solenopsis* and its coccinellid predators. Studies revealed that, both chlorpyrifos and malathion showed highest toxicity in terms of mean mortality (100%) to female mealybugs at 24 h of exposure as against lowest in endosulfan (35%). Interestingly, chlorpyrifos and dichlorvos, which proved toxic to mealybug were less toxic to the grubs of *Cryptolaemus montrouzieri*, registering only 21.66 per cent and 34.16 per cent mortality, respectively. These insecticides when offered to the adults along with honey differed in toxicity as stomach poison at 24 hrs of exposure. Endosulfan registered mortality to the tune of 60 and 70% against *Coccinella septempunctata* and *Cheilomenes sexmaculata*, respectively. However, stomach toxicity pertaining to the insecticide-sprayed mealybugs as prey offered to all the three species of predators indicated that the insecticides, chlorpyrifos and endosulfan were lesser toxic to these wherein mean mortality ranged from 38.09 to 56.66 and 50 to 65.71%, respectively. Dichlorvos was the most toxic, registering 100% mortality for all 3 predators *viz. Nephus regularis*, *Scymnus coccivora* and *Hyperaspis maindroni*. The release of *C. montrouzieri* coupled with chlorpyrifos is likely to be a better option for the management of mealybugs infesting several agri-horticultural crops.

**Keywords:** Alphamethrin, Biological control, Chlorpyrifos Chrysopids, *Cheilomenes sexmaculata*, *Coccinella septempunctata*, Coccinellid beetles, *Cryptolaemus montrouzieri*, Dichlorvos, Endosulfan, *Hyperaspis maindroni*, IPM, Malathion, Mealybugs, Monocrotophos, *Nephus regularis*, *Scymnus coccivora*

Mealybugs (Hemiptera: Pseudococcidae) are cottony in appearance, small oval, soft-bodied sucking insects and are sometimes mistaken for soft bodied scale insects. Adults and nymphs are found on leaves, stems and roots and are covered with white mealy wax, which makes it difficult to eradicate them[1,2]. More than 100 species of mealybugs are reported to attack a variety of plant species in India[3]. The exotic Solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Sternorrhyncha: Coccioidea: Pseudococcidae), earlier reported as Solanum mealybug, *Phenacoccus solani* Ferris[4] was later reported as *P. solenopsis*[5]. Presently, this cotton mealybug has a worldwide distribution covering Central America, the Caribbean and Ecuador[6], Brazil[7], Pakistan and India[8], China[9], Nigeria[10] and Australia[11]. The cotton mealubug, *P. solenopsis* is a highly polyphagous pest with a record of 194 host plants[12], distributed in a wide range of agro-ecological zones of several countries, is now considered the most deadly invasive species of mealyubug[13], having spreadto sub-ropical and tropical parts of the world and might pose serious threats to agri-horticultural crops[14-17]. It has caused havoc among the crops of economic importance in almost all the parts of the country and warrants search for efficient bio-intensive management options including judicious use of chemical insecticides. In Punjab, mealybug pesticides worth over Rs. 500 crores were sold in just three months from June to August in 2007[18].

In India, there are about 32 insecticides and eight combination products registered with the Central Insecticide Board and Registration Committee (CIBRC) for sucking pest management in cotton,

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tomato, brinjal and papaya. Conventional insecticides, such as methyl demeton, quinalphos, fenthion, acephate, dimethoate, malathion, and white mineral oils were the earlier preferred chemicals for bringing down population levels[2]. Newer insecticides are also quite effective but are expensive than the earlier recommended insecticides, and hence not preferred by the marginal farmers for mealybug management. However, the resistant nature of the waxy coating, the toxicity against natural enemies and the need for frequent applications of pesticides, renders insecticidal treatments effective only for short period. It could be achieved by the judicious use of pesticides, which could kill the pest effectively and remain less harmful to the natural enemies. Normally, mealybugs are amenable to be controlled by naturally enemies without the need for insecticidal application. Hence, chemical control tactic should be the last resort for cotton mealybug management within the framework of IPM strategy[19].

Good number of natural enemies comprising coccinellids *viz.*, *Hyperaspis maindroni*, *Brumoides suturalis*, *Cheilomenes sexmaculata*, *Cryptolaemus montrouzieri*, *Nephus regularis* and *Scymnus coccivora*; chrysopids, *Chrysoperla carnea* and *Mallada* sp. are known to feed on *Phenacoccus* spp.[20-23]. Use of biological control agents *viz. C. montrouzieri* and *C. carnea* has already been advocated for sucking pest management[24].

Before the inclusion of insecticides in the integrated pest management (IPM) modules or advocating it for chemical control independently, they have to be tested for its bio-efficacy against the mealybug and safety to their predators[25,26]. In the present study, we tried to elucidate the bio-efficacy of recommended insecticides against the cotton mealybug, *Phenacoccus solenopsis* including their safety to coccinellid and chrysopid predators.

## Materials and Methods

A detail of the insecticides used for current studies is given in Table 1. Studies were carried out in the Biological Control Laboratory, IARI, New Delhi at 27±2°C and 60±5% RH.

### Residual toxicity of insecticides against the females and crawlers of *P. solenopsis*

Six insecticides, *viz.* chlorpyrifos (0.05 %), endosulfan (0.07 %), monocrotophos (0.04 %), malathion (0.125 %), dichlorvos (0.15 %), and alphamethrin (0.01%) were tested using field recommended doses against the females and crawlers of *P. solenopsis*. Glass Petri plates (10 cm ϴ) for females and glass cylinders (10×4 cm size) for crawlers were used in the experimentation. The inner sides of the plate and cylinders were smeared with 1.0 mL solution of respective insecticide in acetone[27,28]. A batch of Petri plates/glass cylinders coated with acetone only was kept as control and the experiment was replicated thrice. Then, the Petri plates/glass cylinders were shade dried for half hour. After shade drying, a batch of 15 females and 20 crawlers was released in to the Petri plates and glass cylinders, respectively. Females were provided with China rose leaves for feeding. The observations on mortality were recorded at 24, 48, 72 and 96 h of exposure to the insecticides for the females. Since, the life of crawlers is not more than a day; mortality data for it was recorded at 1, 2, 3, 4, 5, 6 and 24 h of exposure to the insecticides.

In case of crawlers, as they are small in size and are prone to escape from the Petri plates we used glass cylinders instead of Petri plates. The mouth of the glass cylinders was secured with paraffin wax film and punctured with entomological pins to facilitate crawler's respiration and also to prevent their outward movement. Crawlers were also provided with China rose leaves for feeding.

Table 1 — Details of insecticides used for toxicological studies on *Phenacoccus solenopsis* and its predators

| Insecticide | Trade name | Source | Concentration (%) Insecticide solution (Field dose) | Stomach poison |
|---|---|---|---|---|
| Chlorpyrifos 20 EC | Dursban | Dow Agro Sciences India Pvt. Ltd. | 0.05 | 0.1 |
| Endosulfan 35 EC | Endocel | Excel Crop Care Ltd. | 0.07 | 0.14 |
| Monocrotophos 36 SL | Chetak | Crop Chemicals India Ltd. | 0.04 | 0.08 |
| Malathion 50 EC | Surya-thion | Surya Pesticides Ltd. | 0.125 | 0.25 |
| Dichlorvos 76 EC | Doom | United phosphorous Ltd. | 0.15 | 0.3 |
| Alphamethrin 10 EC | Alfagold | Crop Chemicals India Ltd. | 0.01 | 0.02 |

### Residual toxicity of insecticides against the predators of *P. solenopsis*

The same six insecticides mentioned above were tested at field doses against the adults and grubs of predators namely *Coccinella setempunctata*, *Cheilomenes sexmaculata*, *N. regularis*, *S. coccivora* and *H. maindroni* and only grubs of *Cryptolaemus montrouzieri* (last instar) and *Mallada* sp. (2nd instar). Petri plates (10×4 cm size) were used for adult and grubs of all predators except *N. regularis* and *S. coccivora* for which glass cylinders were used. Procedure of treating the Petri plates and glass cylinders remains same as discussed above. Experiment was replicated thrice. After shade drying of the Petri plates and glass cylinders, a batch of (10 each adults/grub (24 h old) of *C. septempunctata* and *C. sexmaculata*; 15 each adults/grubs of *N. regularis* and *S. coccivora*; 10 each adults/grubs of *H. maindroni* and 10 grubs each of *C. montrouzieri* and *Mallada* sp. was released. The mouth of the glass cylinders was secured with black muslin cloth and tied with the rubber band. Live adults/grubs of predators after 24 h were transferred to new fresh Petri plates/glass cylinders and fed with mealybugs. The observations on the mortality were taken at 24, 48, 72 and 96 h of exposure to insecticides.

#### Toxicity of insecticides incorporated honey (stomach poison) against the predators

Adults of two coccinellid predators *viz. C. septempunctata* and *C. sexmaculata* were tested for stomach toxicity of these test insecticides. Honey (0.5 g) was taken in six homeopathic glass vials and 1ml of field dose of each insecticidal solution prepared in acetone was added in each vial. In case of control, only one mL of acetone along with honey (0.5 g) was used. Then the vials were left overnight during which insecticides got homogenized with honey and acetone evaporated. Fresh solutions were prepared for stomach poison experiment. Petri plates (10 cm Θ) were taken and batches of 10 (24 h old) well-fed adult predators were released in to the Petri plates. The inner walls of Petri-plates were smeared with respective stomach poisons. Batch of glass cylinders smeared with acetone treated honey were kept as control and the experiment was replicated thrice. After completion of 24 h, live predators were transferred to the fresh untreated Petri plates and fed with honey. The observations on the mortality were taken at 24, 48, 72 and 96 h of exposure to insecticides.

#### Stomach toxicity of insecticides treated *P. solenopsis* against the predators

The same six insecticides mentioned above were used at field doses against the adults of predators *viz. N. regularis*, *S. coccivora* and *H. maindroni*. A total 30 mealybugs consisting of different instars were kept in seven glass cylinders (10×4 cm) and sprayed with one mL of each six insecticide solution made in acetone One mL acetone, along with control (only acetone). All the treatments were sprayed with the help of hand glass atomizer. Treated glass cylinders were shade dried for 30 min. Then, treated mealybugs were removed and offered for consumption to the starving cocccinellids kept in separate individual glass cylinders. Experiment was replicated thrice. After completion of six h, live predators were transferred to the fresh untreated glass cylinders and fed with fresh mealybugs. The observations on the mortality were recorded at 1, 2, 3, 4, 5, 6 and 24 h of exposure to the insecticides[28].

## Results and Discussion

#### Residual toxicity of insecticides against female and crawlers of *P. solenopsis*

Results of film residual toxicity of insecticides applied at field dose to females of *P. solenopsis* are given in Table 2. Findings indicated that, both chlorpyrifos and malathion showed high toxicity (100% mortality) to female mealybug at 24 h of exposure followed by dichlorvos (95.54%), monocrotophos (82.84%), alphamethrin (58.34%) and endosulfan (35%). The China rose leaves which were offered for feeding to *P. solenopsis*, exhibited phytotoxicity when treated with dichlorvos. In case of residual toxicity to crawlers of *P. solenopsis* (Table 2) results showed that, all the insecticides registered 100% mortality except endosulfan (25%) after 1 h of exposure.

Results indicated that except endosulfan and alphamethrin (in case of adults), the residual toxicity of all the test insecticides was significantly higher and caused significant mortality to the crawler and female mealybugs. The results were in agreement with[29] who reported that synthetic pyrethroids are less effective against Japanese mealybug, *Planococcus kraunhiae* than organophosphates. In the present study, endosulfan was less toxic to *P. solenopsis* and is in conformity with[30]. Similar observations with regards to efficacy of chlorpyrifos and dichlorvos are in conformity with earlier studies[31,32]. Phytotoxic effects of dichlorvos observed on the China rose leaves in the laboratory may probably be due to fumigant action of the insecticide. Chlorosis and white blotch symptoms have already been observed in maize when sprayed with dichlorvos 76EC @ 2 mL/L for the management of maize stem borer[33].

**Residual toxicity of insecticides against the predators of *P. solenopsis***

Results indicated that residual toxicity of all the test insecticides was very high and caused 100% mortality to the adults of *C. septempunctata* as against lowest in endosulfan (53.33 %) at 24 h (Table 3). Similar trend was observed for the grubs of *C. septempunctata*, wherein treatments did not statistically differ significantly among each other and recorded 100% mortality for all the insecticides including endosulfan and hence table is omitted. With regards to residual toxicity of insecticides to the adults of *C. sexmaculata* all the insecticides registered 100% mortality at 24 h of exposure except endosulfan

Table 2 — Residual toxicity of insecticides applied at field dose to *Phenacoccus solenopsis* females and crawlers

| Treatments (T) | Females | | | | | Crawlers | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mortality (%) at different periods (P) | | | | Mean | Mortality (%) at different periods (P) | | | | | | | Mean |
| | 24 h | 48 h | 72 h | 96 h | | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 24 h | |
| Chlorpyrifos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Endosulfan | 15.53 | 35.53 | 44.47 | 44.47 | 35.00 | 25.00 | 25.00 | 26.66 | 26.66 | 35.00 | 36.67 | 85.00 | 37.14 |
| | 23.13 | 36.63 | 41.83 | 41.83 | 35.86 | 29.94 | 29.94 | 30.96 | 30.96 | 36.26 | 37.28 | 67.44 | 37.54 |
| Monocrotophos | 79.20 | 79.20 | 83.37 | 89.60 | 82.84 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 63.23 | 63.23 | 66.03 | 74.57 | 66.77 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Malathion | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Dichlorvos | 91.10 | 95.53 | 97.77 | 97.77 | 95.54 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 72.86 | 80.00 | 85.00 | 85.00 | 80.71 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Alphamethrin | 33.33 | 62.23 | 68.90 | 68.90 | 58.34 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 35.23 | 52.13 | 56.17 | 56.17 | 49.93 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Control | 0.00 | 0.00 | 2.20 | 2.20 | 1.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 28.33 | 4.04 |
| | 0.00 | 0.00 | 4.97 | 4.97 | 2.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.16 | 4.59 |
| Mean | 59.88 | 67.50 | 70.96 | 71.85 | | 75.00 | 75.00 | 75.24 | 75.24 | 76.43 | 76.67 | 87.62 | |
| | 53.50 | 58.86 | 62.00 | 63.22 | | 68.60 | 68.60 | 68.75 | 68.75 | 69.50 | 69.65 | 78.55 | |
| | | C.D. at 5% | S.E. (d) | S.E. (m)± | | | C.D. at 5% | S.E (d) | S.E (m)± | | | | |
| Treatments (T) | | 4.17 | 2.08 | 1.47 | | | 0.88 | 0.44 | 0.31 | | | | |
| Period (P) | | 3.15 | 1.57 | 1.11 | | | 0.88 | 0.44 | 0.31 | | | | |
| T× P | | 8.34 | 4.16 | 2.94 | | | 2.34 | 1.18 | 0.83 | | | | |

[Figures in second row for each treatment & mean are arc sine transformed values]

Table 3 — Residual toxicity of insecticides applied at field dose to *C. septempunctata* and *C. sexmaculata* adults

| Treatments (T) | *C. septempunctata* | | | | | *C. sexmaculata* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mortality (%) at different periods (P) | | | | Mean | Mortality (%) at different periods (P) | | | | Mean |
| | 24 h | 48 h | 72 h | 96 h | | 24 h | 48 h | 72 h | 96 h | |
| Chlorpyrifos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Endosulfan | 53.33 | 63.33 | 96.67 | 100.00 | 78.33 | 66.67 | 73.33 | 100.00 | 100.00 | 85.00 |
| | 46.93 | 52.80 | 83.87 | 90.00 | 68.40 | 55.10 | 59.27 | 90.00 | 90.00 | 73.59 |
| Monocrotophos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Malathion | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Dichlorvos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Alphamethrin | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Control | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 79.05 | 80.48 | 85.24 | 85.71 | | 80.95 | 81.91 | 85.71 | 85.71 | |
| | 70.99 | 71.83 | 76.27 | 77.14 | | | 72.43 | 73.31 | 73.31 | |
| | | C.D. at 5% | S.E (d) | S.E (m)± | | | C.D. at 5% | S.E (d) | S.E (m)± | |
| Treatments (T) | | 1.80 | 0.90 | 0.64 | | | 1.84 | 0.92 | 0.65 | |
| Period (P) | | 1.36 | 0.68 | 0.48 | | | 1.39 | 0.69 | 0.49 | |
| T× P | | 3.61 | 1.80 | 1.27 | | | 3.68 | 1.84 | 1.30 | |

[Figures in second row for each treatment & mean are arc sine transformed values]

(66.67%). Based on mean mortality (85%) four days after treatment, endosulfan was found less toxic compared to other insecticides (Table 3). Residual toxicity of all the insecticides was extremely high, registering 100% mortality at 24 h of exposure to the grubs of *C. sexmaculata*, adults and grubs of *N. regularis*, adults and grubs of *S. coccivora*, adults and grubs of *H. maindroni*. As there was no significant difference among the insecticides tested against these stages of predators, respective data have been omitted.

Interestingly, chlorpyrifos registered 0% mortality to the grubs of *C. montrouzieri*, followed by endosulfan and dichlorvos (26.66%), at 24 h of exposure period. Other insecticides namely monocrotophos and malathion registered 100% mortality. Considering the mean mortality chlorpyrifos (21.66%) followed by dichlorvos (34.16%) was safer to the grubs of *C. montrouzieri* (Table 4). The insecticides *viz*. chlorpyrifos, monocrotophos, malathion, dichlorvos and alphamethrin registered 100 per cent mortality to the grubs *Mallada* sp. at 24 h of exposure as compared to 46.66% in endosulfan (Table 4).

Regarding residual toxicity of insecticides to adults and grubs of predators, results indicate that only endosulfan was safer to adults of *C. septempunctata* and *C. sexmaculata*. However, all the insecticides were very toxic (100%) to grubs of *C. septempunctata*, *C. sexmaculata*, *N. regularis and S. coccivora* and *H. maindroni*. Endosulfan was found safer to the adults of *C. septempunctata* and *C. sexmaculata* due to its low residual toxicity than organophosphates[34]. Researchers in the past have already reported safety of endosulfan to the predatory coccinellid. In case of alphamethrin, grubs got knock down immediately after its exposure and remained moribund for quite some time[35-39].

Interestingly, grubs of *Cryptolaemus* were selective to chlorpyrifos and dichlorvos and susceptible (100%) to monocrotophos and malathion followed with alphamethrin (95%). The studies are in agreement with Ramesh & Azam[40], who reported dichlorvos as safest and synthetic pyrethroids to be highly toxic to *C. montrouzieri*. It is inferred that the insecticides (chlorpyrifos and dichlorvos) known for toxicity to coccinellids are safe to *Cryptolaemus*, which may probably be due to arrested activity and slow spreading nature of *Cryptolaemus* grubs compared to other active coccinellids grubs[41]. It was noted that other coccinellid grubs had profuse activity and thus imbibed lot of insecticides, leading to enhanced toxicity. Adults, which emerged from chlorpyrifos treated grubs were faint in color, and appeared a case of de-melanization. The behavioral resistance of

Table 4 — Residual toxicity of insecticides applied at field dose to *C. montrouzieri* and *Mallada* sp. grubs

| Treatments (T) | *C. montrouzieri* | | | | | *Mallada* sp. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mortality (%) at different periods (P) | | | | Mean | Mortality (%) at different periods (P) | | | | Mean |
| | 24 h | 48 h | 72 h | 96 h | | 24 h | 48 h | 72 h | 96 h | |
| Chlorpyrifos | 0.00 | 16.66 | 26.66 | 43.33 | 21.66 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 0.00 | 23.86 | 30.83 | 40.80 | 23.87 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Endosulfan | 26.66 | 70.00 | 100.00 | 100.00 | 74.16 | 46.66 | 60.00 | 70.00 | 70.00 | 61.67 |
| | 30.30 | 57.03 | 90.00 | 90.00 | 66.83 | 43.10 | 50.87 | 57.03 | 57.03 | 52.01 |
| Monocrotophos | 100.00 | 100.0 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Malathion | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Dichlorvos | 26.66 | 36.66 | 36.66 | 36.66 | 34.16 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 31.00 | 37.26 | 37.26 | 37.26 | 35.70 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Alphamethrin | 80.00 | 100.00 | 100.00 | 100.00 | 95.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 68.10 | 90.00 | 90.00 | 90.00 | 84.52 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Control | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.33 | 3.33 | 3.33 | 3.33 | 3.33 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.13 | 6.13 | 6.13 | 6.13 | 6.13 |
| Mean | 47.61 | 60.47 | 66.19 | 68.57 | | 78.571 | 80.476 | 81.905 | 81.905 | |
| | 44.20 | 55.45 | 61.15 | 62.58 | | 71.319 | 72.429 | 73.310 | 73.310 | |
| | | C.D. at 5% | S.E (d) | S.E (m)± | | | C.D. at 5% | S.E (d) | S.E (m)± | |
| Treatments (T) | | 4.48 | 2.24 | 1.58 | | | 3.71 | 1.85 | 1.31 | |
| Period (P) | | 3.39 | 1.69 | 1.19 | | | N..S. | 1.40 | 0.99 | |
| T× P | | 8.97 | 4.48 | 3.16 | | | N..S. | 3.71 | 2.62 | |

[Figures in second row for each treatment & mean are arc sine transformed values]

*C. montrouzieri* against chlorpyrifos and dichlorvos affecting activity of spiracles is worth investigating by the Physiologists and Toxicologists.

With respect to *Mallada* sp. only endosulfan at field dose was found safer at various periods of intervals and was found in agreement with earlier work which reported residual toxicity of endosulfan as safer (mortality <50 %) for 2nd instar grubs of Chrysopid, *C. carnea*[42].

**Toxicity of insecticides incorporated honey (stomach poison) against the predators**

With respect to stomach toxicity against the adults of *C. septempunctata* and *C. sexmaculata*, all the insecticides were very toxic and registered 100 per cent mortality at 24 h of exposure as against 60 to 70% in endosulfan (Table 5).

Result related to the stomach toxicity of insecticides incorporated honey revealed that only endosulfan was found safer to the adults of *C. septempunctata* and *C. sexmaculata*. As discussed above, the safety of endosulfan is again evidenced. So, it may be inferred that endosulfan is safer both as contact and stomach poison to the adult coccinellids. However, it was found less effective against cotton mealybug, *P. solenopsis*.

**Stomach toxicity of insecticides sprayed mealybugs against the predators**

Result revealed that no mortality to the adults of *N. regularis* at 1.0 h of exposure was noted due to treatment with chlorpyrifos and endosulfan. Besides, malathion caused very low (13.33%) mortality as against 100% by the dichlorvos (Table 6). Similar trend was noticed in case of *S. coccivora* and *H. maindroni* adults (Table 6).

Table 5 — Stomach toxicity of insecticides incorporated honey to *C. septempunctata* and *C. sexmaculata* adults

| Treatments (T) | *C. septempunctata* Mortality (%) at different periods (P) | | | | | *C. sexmaculata* Mortality (%) at different periods (P) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 24 h | 48 h | 72 h | 96 h | Mean | 24 h | 48 h | 72 h | 96 h | Mean |
| Chlorpyrifos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Endosulfan | 60.00 | 63.33 | 83.33 | 90.00 | 74.17 | 70.00 | 76.67 | 96.67 | 100.00 | 85.83 |
| | 50.86 | 52.80 | 66.20 | 71.60 | 60.36 | 57.03 | 61.27 | 83.87 | 90.00 | 73.04 |
| Monocrotophos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Malathion | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Dichlorvos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Alphamethrin | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Control | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 79.05 | 80.48 | 83.33 | 84.29 | | 81.43 | 82.38 | 85.24 | 85.71 | |
| | 71.55 | 71.83 | 73.74 | 74.51 | | 72.43 | 73.04 | 76.27 | 77.14 | |
| | | C.D. at 5% | S.E (d) | S.E (m)± | | | C.D. at 5% | S.E (d) | S.E (m)± | |
| Treatments (T) | | 1.28 | 0.64 | 0.45 | | | 2.00 | 1.00 | 0.71 | |
| Period (P) | | 0.97 | 0.48 | 0.34 | | | 1.52 | 0.76 | 0.53 | |
| T× P | | 2.56 | 1.28 | 0.90 | | | 4.01 | 2.00 | 1.42 | |

[Figures in second row for each treatment & mean are arc sine transformed values]

Table 6 — Stomach toxicity of insecticide sprayed mealybugs to *N. regularis*, *S. coccivora* and *H. maindroni* adults

| Treatments (T) | *N. regularis* Mortality (%) at different Period (P) | | | | | | | | *S. coccivora* Mortality (%) at different Period (P) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 24 h | Mean | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 24 h | Mean |
| Chlorpyrifos | 0.00 | 13.33 | 30.00 | 60.00 | 80.00 | 96.67 | 100.00 | 54.29 | 0.00 | 16.67 | 33.33 | 63.33 | 83.33 | 100.00 | 100.00 | 56.66 |
| | 0.00 | 17.22 | 33.02 | 50.88 | 63.96 | 83.90 | 90.05 | 48.43 | 0.00 | 23.87 | 35.24 | 52.80 | 66.18 | 90.05 | 90.05 | 51.16 |
| Endosulfan | 0.00 | 20.00 | 53.33 | 76.67 | 86.67 | 100.00 | 100.00 | 62.38 | 0.00 | 26.67 | 56.67 | 83.33 | 93.33 | 100.00 | 100.00 | 65.71 |
| | 0.00 | 26.58 | 46.94 | 61.25 | 68.89 | 90.05 | 90.05 | 54.82 | 0.00 | 31.01 | 48.87 | 66.18 | 77.75 | 90.05 | 90.05 | 57.70 |
| Mono- | 60.00 | 90.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 92.86 | 63.33 | 93.33 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 93.81 |
| crotophos | 50.88 | 71.60 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 81.82 | 52.80 | 77.75 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 82.97 |
| Malathion | 13.33 | 30.00 | 36.67 | 63.33 | 83.33 | 100.00 | 100.00 | 60.95 | 16.67 | 33.33 | 43.33 | 70.00 | 86.66 | 100.00 | 100.00 | 64.28 |
| | 21.15 | 33.02 | 37.24 | 52.89 | 66.18 | 90.05 | 90.05 | 55.80 | 23.87 | 35.03 | 41.17 | 56.82 | 68.89 | 90.05 | 90.05 | 57.98 |

(*Contd.*)

Table 6 — Stomach toxicity of insecticide sprayed mealybugs to *N. regularis*, *S. coccivora* and *H. maindroni* adults (*Contd.*)

| Treatments | *N. regularis* | | | | | | | | *S. coccivora* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mortality (%) at different Period (P) | | | | | | | Mean | Mortality (%) at different Period (P) | | | | | | | Mean |
| (T) | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 24 h | | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 24 h | |
| Dichlorvos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Alpha- | 60.00 | 96.67 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 93.81 | 66.67 | 96.67 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 94.76 |
| methrin | 50.88 | 83.90 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 83.58 | 54.81 | 83.90 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 84.13 |
| Control | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 33.33 | 50.00 | 60.00 | 71.43 | 78.57 | 85.24 | 85.71 | | 35.23 | 52.38 | 61.90 | 73.81 | 80.47 | 85.71 | 85.71 | |
| | 30.42 | 46.05 | 55.34 | 62.17 | 67.03 | 76.31 | 77.19 | | 31.64 | 48.80 | 56.49 | 63.70 | 68.99 | 77.18 | 77.18 | |
| | | C.D. at 5% | S.E (d) | S.E (m)± | | | | | | C.D. at 5% | S.E (d) | S.E (m)± | | | | |
| Treatments (T) | | 2.62 | 1.32 | 0.93 | | | | | | 2.12 | 1.07 | 0.76 | | | | |
| Period (P) | | 2.62 | 1.32 | 0.93 | | | | | | 2.12 | 1.07 | 0.76 | | | | |
| T × P | | 6.92 | 3.49 | 2.47 | | | | | | 5.62 | 2.83 | 2.00 | | | | |

| | *H. maindroni* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mortality (%) at different Period (P) | | | | | | | Mean |
| | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 24 h | |
| Chlorpyrifos | 0.00 | 3.33 | 13.33 | 30.00 | 50.00 | 70.00 | 100.00 | 38.09 |
| | 0.00 | 6.15 | 21.15 | 33.02 | 45.02 | 57.03 | 90.05 | 36.06 |
| Endosulfan | 0.00 | 6.67 | 30.00 | 50.00 | 73.33 | 90.00 | 100.00 | 50.00 |
| | 0.00 | 12.29 | 33.02 | 45.02 | 59.04 | 71.60 | 90.05 | 44.43 |
| Mono- | 36.67 | 60.00 | 80.00 | 96.66 | 100.00 | 100.00 | 100.00 | 81.91 |
| crotophos | 37.24 | 50.79 | 63.96 | 83.90 | 90.05 | 90.05 | 90.05 | 72.29 |
| Malathion | 3.33 | 10.00 | 20.00 | 40.00 | 66.67 | 80.00 | 100.00 | 45.71 |
| | 6.15 | 18.44 | 26.58 | 39.17 | 54.81 | 63.96 | 90.05 | 42.74 |
| Dichlorvos | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 | 90.05 |
| Alpha- | 43.33 | 70.00 | 90.00 | 100.00 | 100.00 | 100.00 | 100.00 | 86.19 |
| methrin | 41.17 | 57.03 | 75.04 | 90.05 | 90.05 | 90.05 | 90.05 | 76.21 |
| Control | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mean | 26.19 | 35.71 | 47.62 | 59.52 | 70.00 | 77.14 | 85.71 | |
| | 24.95 | 33.54 | 44.26 | 54.46 | 61.29 | 66.11 | 77.19 | |
| | 0.00 | 3.33 | 13.33 | 30.00 | 50.00 | 70.00 | 100.00 | 38.09 |
| | | C.D. at 5% | S.E (d) | S.E (m)± | | | | |
| Treatments (T) | | 2.88 | 1.45 | 1.03 | | | | |
| Period (P) | | 2.88 | 1.45 | 1.03 | | | | |
| T × P | | 7.62 | 3.84 | 2.71 | | | | |

[Figures in second row for each treatment & mean are arc sine transformed values]

Result related to the stomach toxicity of insecticides treated mealybugs against the predators revealed that insecticides namely chlorpyrifos and endosulfan were safer while dichlorvos, most toxic. Present studies indicate the mean mortality range from 38.09 to 56.66% for chlorpyrifos against the *N. regularis*, *S. coccivora* and *H. maindroni*. It was found on par with earlier studies which reported the effects of six insecticides on the adults of the coccinellids, *Adalia bipunctata*, *C. septempunctata* and *Oenopia conglobata* in fruit orchards; it revealed that chlorpyrifos caused 40.2 and 63% mortality in apples and peach, respectively[43].

## Conclusion

The insecticides *viz.* chlorpyrifos and dichlorvos were highly toxic to mealybugs as well as to the majority of coccinellid and chrysopid predators. Among the insecticide studied, chlorpyrifos was found safer to *C. montrouzieri* and semi-selective to *N. regularis*, *S. coccivora* and *H. maindroni*. Chlorpyrifos being also a fumigant in action probably was found selective and safer to *Cryptolaemus* and warrants further investigations. It may be noted that release of *C. montrouzieri* coupled with chlorpyrifos is likely to be a better option for the management of mealybugs infesting several agri-horticultural crops.

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## Conflict of interest

Authors declare no conflict of interest.

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