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Risk assessment of insecticides used in rice on miridbug, *Cyrtorhinus lividipennis* Reuter, the important predator of brown planthopper, *Nilaparvata lugens* (Stal.)

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ABSTRACT

The green miridbug, *Cyrtorhinus lividipennis*, an important natural enemy of the rice brown planthopper (BPH), *Nilaparvata lugens* plays a major role as a predator in suppressing the pest population. The study assessed the impact of certain potential insecticides used in the rice ecosystem on the miridbug predator and brown planthopper through contact toxicity. Eleven insecticides, including neonicotinoids, diamides, azomethine pyridines, carbamates, pyrethroids, organophosphates and cyclodienes were selected to test their toxicities against the nymphs of *C. lividipennis* and *N. lugens*. Median lethal concentration (LC_{50}) was determined for each insecticide using an insecticide-coated vial (scintillation) residue bioassay, which revealed BPMC as the highly toxic chemical with an LC_{50} of 0.003 mg a.i L^{-1} followed by ethofenprox and clothianidin with LC_{50} of 0.006 mg a.i L^{-1} at 48 HAT against *C. lividipennis* and ethofenprox as the highly toxic chemical with an LC_{50} of 0.009 mg a.i L^{-1} followed by clothianidin with an LC_{50} of 0.211 mg a.i L^{-1} at 48 h after treatment (HAT) against *N. lugens*. Among the insecticides tested, the cyclodiene compound, endosulfan had the lowest acute contact toxicity (LC_{50} = 66.65 mg a.i L^{-1} at 48 HAT) to *C. lividipennis*. Among the insecticides tested, endosulfan, chlorpyriphos, acephate and methyl parathion are regarded as safer to *C. lividipennis* based on selectivity ratio, hazard quotient and probit substitution method of risk assessments.

1. Introduction

Green revolution initiated in the mid 1960s and characterized by the successful breeding and widespread adoption of new high yielding varieties, pesticides and nitrogen fertilizers, has doubled the production of many crops, such as rice, wheat and maize. Meanwhile, the inputs of pesticides and fertilizers have resulted in some negative effects, 'unwelcome harvest', on environments and resources, as well as the considerable disturbances to plant and animal communities (Conway and Pretty, 1991; Conway, 1997). Crop losses caused by insect pests gradually increased in spite of the effective technological development in insecticide synthesis and application for pest management (Scriber, 1984).

Brown planthopper (BPH), *Nilaparvata lugens* (Stal.) is one of the most economically important insect pests attacking rice crop (Krishnaiah et al., 2006). The insect damages the plant through the removal of plant sap and as a vector of rice viruses. As a result "hopper burn" and various virus diseases grassy stunt, ragged stunt and wilted stunt occur, respectively in rice field (Hibino, 1979; Chen and Chiu, 1981). The most commonly used method of controlling brown planthopper is the application of insecticides. Many insecticides have been identified for control of rice planthoppers under green house and field conditions (Krishnaiah and Kalode, 1993; Sarupa et al., 1998; Krishnaiah et al., 2002).

Chemical control remains a major strategy in the integrated pest management (IPM) system as it is quick, efficient, easy to use and cost-effective against the insect (Zhao, 2000; Endo and Tsurumachi, 2001). However, lethal and sublethal effects of broad-spectrum and non-selective pesticides are a high risk to beneficial species (Croft, 1990; Ruberson et al., 1998). Misuse of chemical insecticides can cause outbreaks of the pest because extensive and intensive use of insecticides and development of resistance (Kilin et al., 1981; Hirai, 1993) as well as indiscriminately killing a wide range of natural enemies (Way and Heong, 1994; Tanaka et al., 2000). Dyck and Orlido (1977) reported that reduction in the population of mirid predator, *Cyrtorhinus lividipennis* Reuter after regular spraying with methyl parathion causes BPH resurgence.

In rice ecosystem, the action of predators is more conspicuous and perceptible than parasitoids of plant and leafhoppers. Among the several predators reported on hoppers, the green miridbug, *C.*

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lividipennis is widely distributed in rice fields and is a promising biocontrol agent against both leaf and planthoppers. They search the host randomly (Heong et al., 1990) and the rice volatiles also play an important role in the foraging behaviour of *C. lividipennis* (Lou and Cheng, 2003). *Cyrtorhinus lividipennis* feeding on both eggs and nymphs of hoppers (Katti et al., 2007) is the dominant predator in irrigated rice (Sigsgaard, 2007). A predator nymph consumes an average of 7.5 eggs or 1.4 hoppers per day for a period of 14 days. Adults consume about 10.2 eggs or 4.7 nymphs or 2.4 adults per day for a period of 10 days (Reyes and Gabriel, 1975). Thus a single bug can consume 66 BPH nymphs in its lifetime of 24 days.

Chemical and biological control are the two important strategies used in an IPM program (Zhao, 2000). Integration of chemical and biological control systems is a key for the success of any IPM program (Wright and Verkert, 1995) especially in rice fields which have a number of biocontrol agents. Chemical control should be used only when it is necessary and is least disruptive to biological control. Knowledge of compatibility and impact of pesticides (lethal and sublethal) on beneficial species is essential for active integration of chemical and biological control (Greathead, 1995).

Lethal or adverse effects of insecticides on beneficial arthropods are often expressed as acute or chronic mortality resulting from contact with or ingestion of insecticides (Haseeb et al., 2004). Desneux et al. (2007) pointed out that the determination of acute toxicity of pesticides to beneficial arthropods had traditionally and largely relied on the measurement of an acute median lethal dose or concentration and the estimated lethal dose or concentration. Chemical insecticides need to be correctly and selectively used to ensure sustainable crop protection and environmental stability (Jepson, 1989; Greathead, 1995; Haseeb et al., 2000; Haseeb, 2001).

Currently, many selective toxic organophosphates, pyrethroids and other novel insecticides are being investigated as potential alternatives to replace highly toxic and broad-spectrum insecticides. In addition to evaluating their toxicological effect against target insects, these insecticides must be assessed for their adverse impact on natural enemies, but there is little information and knowledge about the toxic and adverse effects of currently popular insecticides on *C. lividipennis*. Keeping in mind the idea of agroecosystem the research program was undertaken to assess the risk of eleven insecticides having different modes of action on rice brown planthopper, *N. lugens* and its mirid predator, *C. lividipennis*.

2. Materials and methods

2.1. Insects

TN 1 rice plants (35 days old after transplanting into earthen pots [10 × 10 cm]) were used as host plant for mass culturing the predator as well as its host. Brown planthopper (BPH) and the miridbug were collected from rice fields unexposed to insecticides at the Paddy Breeding Station, Tamil Nadu Agricultural University, Coimbatore. Uniform sized insects (BPH) were selected and reared on rice plants kept in nylon mesh cages (75 × 60 × 90 cm). TN 1 rice plants pre-oviposited by brown planthopper were used for the rearing of *C. lividipennis*. Adult mirids were confined to these plants for 2–3 days for oviposition and then plants were retained for the required period to obtain nymphs of specified age (6–7 days). All plants and insects were maintained at 27 ± 2 °C, 75 ± 5% RH in the glass house.

2.2. Insecticides

Eleven insecticides from seven classes *viz*., imidacloprid (Tatamida® 17.8 SL, 25 g a.i. ha^{-1}, Saraswati Agrochemicals India Pvt. Ltd., Jammu), chlorantraniliprole (Rynaxypyr® 20 SC, 25 g a.i. ha^{-1}, E.I. Dupont India Pvt. Ltd., Gurgaon), clothianidin (Dantop® 50 WDG, 25 g a.i. ha^{-1}, Sumitomo Chemical Takeda Agro Company Ltd., Japan), pymetrozine (Endeavor® 50 WG, 150 g a.i. ha^{-1}, Syngenta India Ltd., Mumbai), ethofenprox (Nukil® 10 EC, 50 g a.i. ha^{-1}, BPMC (Fenobucarb) (Bipkil® 50 EC, 600 g a.i. ha^{-1}, Hyderabad Chemical Supplies Ltd., Hyderabad), endosulfan (Endostar® 35 EC, 600 g a.i. ha^{-1}, United Phosphorous Ltd., Gujarat), acephate (Asataf® 75 SP, 600 g a.i. ha^{-1}, Rallis India Ltd., Mumbai), chlorpyriphos (Dursban® 20 EC, 250 g a.i. ha^{-1}, Dow Agro Sciences India Pvt. Ltd., Mumbai), deltamethrin (Decis® 11 w/w EC, 15 g a.i. ha^{-1}, Bayer CropScience Ltd., Mumbai) and methyl parathion (Paracid® 50 EC, 500 g a.i. ha^{-1}, Bharat Insecticides Ltd., New Delhi) were used for conducting bioassays. Serial dilutions of test chemicals were prepared as mg a.i L^{-1} based on the active ingredient in the formulation using analytical grade acetone and used for contact toxicity studies. A spray volume of 500 l ha^{-1} is taken for comparing the field recommended concentrations of insecticides with that of acute toxicity.

2.3. Contact acute toxicity (LC_{50})

Median lethal concentration (LC_{50}) for miridbug and brown planthopper were determined under laboratory conditions. A preliminary range finding test was conducted to determine the range of insecticide concentrations (Desneux et al., 2006) starting with the recommended field application rate, a decreasing set of serial dilutions (10-fold) was made. Miridbug and brown planthopper nymphs were exposed to these dilutions to determine a concentration yielding approximately 50% mortality. This experimentally derived concentration was then used as a central concentration with three concentrations above that and three below to get a set of six concentrations per insecticide. The concentrations which killed the test insect in a range of 10–90% were taken for analysis. The test insects were exposed to the serial concentrations using scintillation bioassay to establish a dose-mortality relationship.

Glass scintillation vials of 15 ml capacity were evenly coated with 0.5 ml of the test insecticide and manually rotated to have a uniform coating of the insecticide all over the inner surface until no more droplets were seen on the glass wall. Then, the vials were air dried for 30 min at room temperature to allow complete evaporation of acetone before introducing the predators. Acetone alone served as control. Ten nymphs of uniform size (miridbug/BPH) were taken from the culture and released into the treated vials and the mouth was covered with a piece of muslin cloth fastened with a rubber band. Three replicates were maintained for each dose of the insecticide. The rice tillers were cut from the base at a height of 10–12 cm and it was dipped into the test tubes containing solidified agar which prevents drying of tillers. After 1 h exposure, the treated mirid nymphs were transferred into test tubes containing early instar nymphs of BPH along with rice tillers were given as feed and in the case of BPH rice tillers were given as feed. Observations on mortality of the respective nymphs were recorded at 24 and 48 h after treatment. The moribund insects without any movements when pricked were counted as dead. The per cent mortality in each treatment was corrected by Abbott (1925) formula. The data so obtained was subjected to probit analysis as described by Finney (1971) using EPA Probit Analysis Programme Version 1.5 and Log concentration probit mortality line obtained.

2.4. Risk assessment methods

The present study focuses to assess the risk imposed by insecticides used in the rice ecosystem on *C. lividipennis* with respect to *N. lugens*. The acute toxicity data of 24 HAT is used in all the risk assessment methods.

2.4.1. Selectivity ratio

Selectivity ratio was calculated as per Tanaka et al. (2000) and Sengonca and Liu (2001) using the formula given below

$$\text{Selectivity ratio} = \frac{LC_{50}\text{ of beneficial species }(\mu\text{g a.i L}^{-1})}{LC_{50}\text{ of pest species }(\mu\text{g a.i. L}^{-1})}$$

The values of 1 and <1 indicates that the chemical is more toxic to mirid than BPH (non-selective)

The values of >1 indicates that the chemical is less toxic to mirid than BPH (selective).

2.4.2. Probit substitution

This method is used to determine relative toxicities of beneficial species, at particular levels of pest mortality; say LC_{90} of pest. Probit substitution was made as per Stark et al. (1995), Kumar and Regupathy (2005) and Stanley et al. (2010).

$$Y = 5 + m(x - [\log\ LC_{50}\text{of beneficial species}])$$

where Y = probit value; m = slope of the probit line for beneficial species; x = log of the 95% fiducial limits for LC_{90} of the pest species.

Solving Y gives a probit value which is then converted to percentage of mortality using the conversion table (Finney, 1964). The chemical is considered selective if it kills less than 90% of mirids at the dose which kills 90% of pest.

2.4.3. Hazard ratio/risk quotient

Risk quotient was used to assess the ecological risk of pesticides (Peterson, 2006). It is used to assess the safety of predators and parasitoids such as coccinellids (Peveling and Ely, 2006), *Bracon hebetor* Say (Danfa et al., 1998) and *Trichogramma chilonis* (Preetha et al., 2009).

$$\text{Hazard ratio} = \frac{\text{Recommended field rate (g a.i. ha}^{-1})}{LC_{50}\text{ of beneficial insect (mg a.i L}^{-1})}$$

The hazard ratio of less than 50 for a pesticide is considered safe, 50–2500 as slightly to moderately toxic and more than 2500 as dangerous.

3. Results

3.1. Contact toxicity (LC_{50}) – miridbug

Data of contact toxicity of the insecticides to *C. lividipennis* nymphs are summarized in Table 1 and 2. Based on LC_{50} values (mg a.i L^{-1}), the order of toxicity of the insecticides were as follows: At 24 HAT, BPMC (0.02) > ethofenprox (0.04) > clothianidin (0.08) > imidacloprid (1.39) > pymetrozine (3.29) > deltamethrin (4.22) > chlorantraniliprole (5.95) > acephate (32.07) > chlorpyriphos (36.59) > methyl parathion (45.25) > endosulfan (212.59) (Table 1). At 48 HAT also, BPMC was found to be the highly toxic insecticide with an LC_{50} of 0.003 mg a.i L^{-1}, where as the least toxic chemical was endosulfan with an LC_{50} of 66.65 mg a.i L^{-1} (Table 2). Among all the eleven insecticides, the contact toxicity of BPMC was the highest, and its LC_{50} was 0.02 and 0.003 mg a.i L^{-1} at 24 and 48 HAT, respectively. The conventional insecticide, endosulfan showed the least toxicity (212.59 and 66.65 at 24 and 48 HAT) to *C. lividipennis*.

3.2. Contact toxicity (LC_{50}) – BPH

Ethofenprox was found to be the most toxic and deltamethrin was least toxic to the nymphs of BPH. The LC_{50} values of imidacloprid, chlorantraniliprole, BPMC, endosulfan and methyl parathion were 29.70, 2.30, 3.24, 6.96 and 4.73 mg a.i L^{-1}, respectively at 24 HAT (Table 1). The descending order of toxicity for dry film method at 48 HAT (mg a.i L^{-1}) was ethofenprox (0.01) > clothianidin (0.21) > chlorantraniliprole (0.52) > methyl parathion (1.56) > BPMC (1.59) > pymetrozine (1.93) > acephate (2.17) > chlorpyrifos (2.28) > endosulfan (3.28) > imidacloprid (23.60) > deltamethrin (24.76) (Table 2).

3.3. Risk assessment

The classification of insecticides based on selectivity ratio, probit substitution method and risk quotient values are presented in Table 3. Among all the eleven insecticides tested, endosulfan, chlorpyriphos, acephate, methyl parathion, chlorantraniliprole and ethofenprox are found selective to *C. lividipennis*. By probit substitution method, it was predicted that imidacloprid, clothianidin, pymetrozine, BPMC and deltamethrin at their doses which cause 90% mortality to BPH will cause cent per cent mortality to mirids. Based on risk quotient, imidacloprid, chlorantraniliprole, pymetrozine, endosulfan, acephate, chlorpyriphos, deltamethrin

Table 1
Median lethal dose of insecticides to mirid, *Cyrtorhinus lividipennis* and BPH, *Nilaparvata lugens* at 24 HAT.

Insecticides	*Cyrtorhinus lividipennis*				*Nilaparvata lugens*			
	LC_{50} (mg a.i L^{-1})	LC_{90} (mg a.i L^{-1})	Regression equation	χ^2 value[a]	LC_{50} (mg a.i L^{-1})	LC_{90} (mg a.i L^{-1})	Regression equation	χ^2 value[a]
BPMC	0.02	0.29 (0.10–2.90)	$y = 3.67 + 1.06\ x$	0.52	3.24	19.23 (9.78–37.84)	$y = -0.83 + 1.66x$	1.20
Endosulfan	212.59	555.06 (403.06–1121.96)	$y = -11.38 + 3.08x$	0.73	6.96	54.89 (30.47–147.86)	$y = 3.79 + 1.43x$	2.54
Acephate	32.07	101.78 (72.33–191.65)	$y = -6.45 + 2.54x$	5.08	3.82	31.21 (19.84–85.61)	$y = 4.18 + 1.41x$	5.19
Chlorpyriphos	36.59	238.85 (123.84–959.92)	$y = -2.17 + 1.57x$	0.99	4.32	20.30 (13.75–39.80)	$y = -1.09 + 1.68x$	1.67
Methyl parathion	45.25	94.70 (73.61–175.79)	$y = -13.52 + 3.98x$	0.38	4.73	28.11 (12.86–132.68)	$y = -0.07 + 1.33x$	4.02
Deltamethrin	4.22	28.74 (15.51–103.95)	$y = -0.52 + 1.52x$	4.26	43.03	208.26 (121.66–551.47)	$y = -4.12 + 1.98x$	1.28
Ethofenprox	0.04	2.90 (0.82–21.00)	$y = 3.92 + 0.68x$	5.25	0.03	0.37 (0.25–0.61)	$y = 3.27 + 1.17x$	0.75
Imidacloprid	1.39	16.69 (8.07–64.93)	$y = 1.36 + 1.16x$	0.94	29.70	120.58 (72.75–199.84)	$y = -4.42 + 2.11x$	3.45
Clothianidin	0.08	7.09 (1.91–64.67)	$y = 3.75 + 0.66x$	0.51	4.71	66.49 (26.61 127.95)	$y = 4.25 + 1.12x$	2.54
Pymetrozine	3.29	16.76 (9.70–47.09)	$y = -1.36 + 1.81x$	0.68	3.54	29.36 (22.53–58.80)	$y = 0.05 + 1.39x$	1.95
Chlorantraniliprole	5.95	41.42 (20.74–184.20)	$y = -0.74 + 1.52x$	3.61	2.30	18.20 (13.63–42.31)	$y = 4.59 + 1.12x$	4.71

[a] All the log concentration probit mortality lines are significantly a good fit at $p = 0.05$.

Table 2
Median lethal dose of insecticides to mirid, *Cyrtorhinus lividipennis* and BPH, *Nilaparvata lugens* at 48 HAT.

Insecticides	*Cyrtorhinus lividipennis*				*Nilaparvata lugens*			
	LC_{50} (mg a.i L^{-1})	LC_{90} (mg a.i L^{-1})	Regression equation	χ^2 value[a]	LC_{50} (mg a.i L^{-1})	LC_{90} (mg a.i L^{-1})	Regression equation	χ^2 value[a]
BPMC	0.003	0.05 (0.02–0.72)	$y = 4.52 + 1.03x$	1.91	1.59	13.57 (6.02–30.59)	$y = 0.60 + 1.38x$	4.22
Endosulfan	66.65	274.69 (186.15–934.47)	$y = -5.04 + 2.08x$	0.93	3.28	49.09 (25.23–153.86)	$y = 4.44 + 1.09x$	3.44
Acephate	12.41	89.30 (52.42–250.32)	$y = -0.32 + 1.30x$	5.65	2.17	16.38 (8.97–50.09)	$y = 4.51 + 1.46x$	1.51
Chlorpyriphos	13.68	101.40 (54.53–418.35)	$y = -1.07 + 1.47x$	0.38	2.28	11.93 (7.92–23.22)	$y = -0.91 + 1.76x$	2.06
Methyl parathion	28.60	55.77 (45.33–90.60)	$y = -14.61 + 4.40x$	0.61	1.56	22.18 (13.68–55.78)	$y = 4.82 + 0.92x$	10.44
Deltamethrin	2.34	18.13 (10.31–51.06)	$y = 0.17 + 1.44x$	1.56	18.39	137.77 (87.79–298.70)	$y = 3.14 + 1.47x$	2.51
Ethofenprox	0.006	0.37 (0.11–3.24)	$y = 4.42 + 0.73x$	1.00	0.01	0.08 (0.03–0.18)	$y = 3.69 + 1.37x$	1.18
Imidacloprid	0.49	5.94 (3.08–21.11)	$y = 1.84 + 1.18x$	1.33	23.60	88.38 (56.66–137.85)	$y = -4.77 + 2.24x$	2.08
Clothianidin	0.006	0.34 (0.11–2.28)	$y = 4.44 + 0.73x$	0.48	0.21	6.55 (2.97–24.00)	$y = 5.58 + 0.86x$	2.20
Pymetrozine	1.13	4.28 (2.86–9.36)	$y = -1.74 + 2.21x$	0.14	1.93	16.69 (8.35–33.35)	$y = 0.50 + 1.37x$	0.35
Chlorantraniliprole	1.30	6.29 (3.97–14.87)	$y = -0.81 + 1.87x$	0.17	0.52	7.83 (3.90–20.85)	$y = 5.31 + 1.09x$	2.90

[a] All the log concentration probit mortality lines are significantly a good fit at $p = 0$.

Table 3
Risk assessment of different insecticides on *Cyrtorhinus lividipennis* (based on LC_{50} at 24 HAT).

Insecticides	Recommended dose (g a.i ha^{-1})	Selectivity		Probit substitution method (% mirid mortality at LC_{90} of BPH)	Hazard quotient	
		Selectivity ratio	Category		Hazard quotient	Category
BPMC	600	0.01	Non-selective	100%	300 000	Dangerous
Endosulfan	600	30.54	Selective	0%	2.82	Safe
Acephate	600	8.39	Selective	0–3.8%	18.71	Safe
Chlorpyriphos	250	8.47	Selective	0%	6.83	Safe
Methyl parathion	500	9.57	Selective	0–21.2%	11.05	Safe
Deltamethrin	15	0.10	Non-selective	100%	3.55	Safe
Ethofenprox	50	1.26	Selective	32.8–96.0%	1250.00	Slightly to moderately harmful
Imidacloprid	25	0.05	Non-selective	100%	17.98	Safe
Clothianidin	25	0.02	Non-selective	100%	312.50	Slightly to moderately harmful
Pymetrozine	150	0.93	Non-selective	100%	45.59	Safe
Chlorantraniliprole	25	2.59	Selective	0.3–41.8%	4.20	Safe

and methyl parathion were found to be harmless to *C. lividipennis*, whereas clothianidin and ethofenprox were found to be slightly to moderately harmful and BPMC was the dangerous insecticide to *C. lividipennis*.

4. Discussion

This study indicated that insecticides present significantly different risks to *C. lividipennis*, and this can provide more choices for integration of chemical control with biological control. Neonicotinoids/chloronicotinyls were introduced into the market in the early 1990s and are currently used to control sucking insects (Nauen et al., 2001). However, the use of neonicotinoid insecticides should be evaluated carefully in IPM programs (Poletti et al., 2007) and these results have shown that imidacloprid and clothianidin are non-selective and have a high acute contact toxicity to the predator. Imidacloprid was reported to be toxic to *C. lividipennis* by Tanaka et al. (2000). Imidacloprid was toxic to miridbug, when confined to sprayed plants in the laboratory (Lakshmi et al., 2001). Thus it was rightly reported by Katti et al. (2007) that imidacloprid (25 mg a.i L^{-1}) was highly toxic to *C. lividipennis*.

The acute toxicity of the diamide group of insecticide chlorantraniliprole was more than acephate and endosulfan. Pymetrozine is the first insecticide in the group of azomethine pyridines, a novel class of insecticides being used against BPH and WBPH with contact action (Sato et al., 1996). Pymetrozine was more toxic than the conventional insecticides like endosulfan, chlorpyriphos, acephate and methyl parathion. Sechser et al. (2002) reported that in laboratory tests pymetrozine demonstrated selectivity against predaceous Coleoptera, Heteroptera, Neuroptera and the predatory mite, *Typhlodromus pyri* Scheuten. Following a single application at 250/200 g a.i. ha^{-1} on cotton in Egypt and in USA, the regular sampling of predators over a period of three weeks revealed a similar predator population development in the pymetrozine and the untreated control plots. In Egypt, pymetrozine suppressed populations of *Aphis gossypii* in okra with two sprays at a lesser concentration of 100 g a.i. ha^{-1} for the whole observation period of 23 days but allowed the survival of predators (Sechser et al., 2002). Owing to the high toxicity of the carbamate insecticide, BPMC its usage in rice field should be avoided. Among these, BPMC and deltamethrin are non-selective and cause 100% mortality to mirids at the concentration which causes 90% mortality to BPH. Tanaka et al. (2000) reported the decrease in population of *C. lividipennis* in deltamethrin and ethofenprox treated rice fields. Fabellar and Heinrichs (1984) reported that deltamethrin was toxic to *C. lividipennis* when they fed on treated *N. lugens* prey. Though ethofenprox is highly effective against BPH, WBPH and GLH in rice (Yoshimoto et al., 1989; Krishnaiah et al., 2008), it should not be used when mirids are there in the rice field.

The present contact toxicity studies indicated that the organophosphate insecticides *viz*., acephate, chlorpyriphos and methyl parathion are selective and less toxic to miridbug. Katti et al. (2007) reported that acephate was relatively safe to predatory bugs like *C. lividipennis*. Acephate was reported to have least toxicity to *C. lividipennis* in green house conditions (Lakshmi et al., 2001). Though the LC_{50} of acephate was high (32.07 mg a.i L^{-1} at 24 HAT) revealing less toxicity, its field recommended dose should also be taken into consideration. When comparing the field recommended dose of 1200 mg a.i L^{-1}, the chemical cannot be regarded as a safe chemical to *C. lividipennis* (Fig 1). About 90% of the pred-

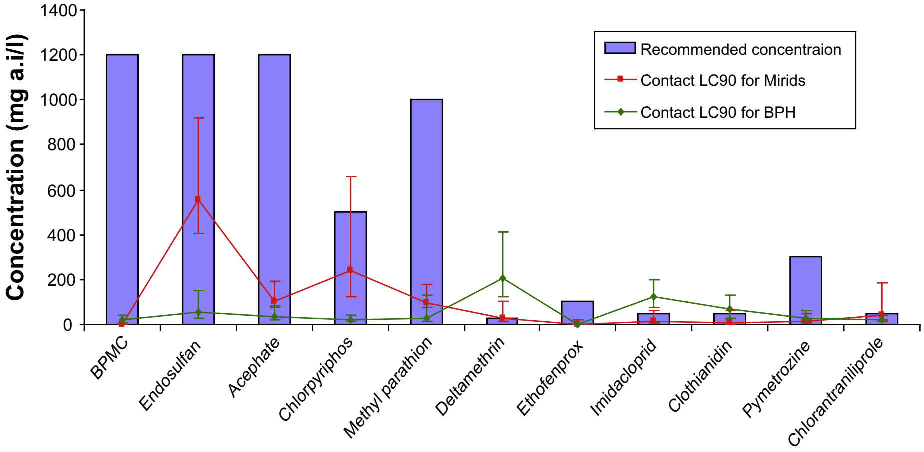

Fig. 1. Comparison of contact LC_{90} values of insecticides to BPH and mirid with their field recommended concentrations.

ator nymphs will be killed by acephate at 101.78 mg a.i L^{-1} in 24 HAT (Table 1). Wang et al. (2008) reported that chlorpyriphos had the highest contact toxicity to *Anagrus nilaparvatae* (Pang et Wang). A similar result was also obtained with *Aphidius ervi* (Desneux et al., 2004), whereas in the present study chlorpyriphos was found to be selective and harmless to miridbug in selectivity ratio and hazard quotient of risk assessment. The cyclodiene compound, endosulfan was found to be relatively safe to *C. lividipennis* by recording higher LC_{50} values both at 24 and 48 h after treatment. Endosulfan was reported to be compatible with the predatory mirid, *Dicyphus tamanimii* with a persistence of only 3 days (Figuls et al., 1999).

Almost all the chemicals tested are highly toxic to miridbug except endosulfan, chlorpyriphos, acephate and methyl parathion in the contact toxicity test. Complete evaluation of an insecticide on natural enemies should include not only its acute toxicity but also its sublethal and chronic effects (Desneux et al., 2007). A recent study indicated that the sublethal effects of insecticides on natural enemies may ultimately cause beneficial insects to become less effective as biological control agents in the field due to their low performance in parasitizing and preying on hosts (Poletti et al., 2007). Therefore, in addition to mortality, an assessment of the impact of an insecticide on beneficial insects together with information on the residual activity of insecticides is also important (Tipping and Burbutis, 1983). Further studies on the chronic effects, physiology and behaviour may be necessary to fully understand the impact of these insecticides.

In summary, eleven insecticides belonging to seven classes were evaluated for their contact toxicity on the rice BPH and its major predator, *C. lividipennis*. In case of BPMC, the recommended dose was 1200 mg a.i L^{-1} but 90% of the miridbug were found to be killed at 0.29 mg a.i L^{-1} at 24 HAT and 0.05 mg a.i L^{-1} at 48 HAT. Thus, even a 1000-fold reduced dose from the recommended dose will cause 100% mortality of the BPH predator, *C. lividipennis*. Even though, hazard ratio showed deltamethrin as harmless, it caused 100% mortality to mirids at the concentration causing 90% mortality to BPH and non-selective. Among the chemicals tested, endosulfan, chlorpyriphos, acephate and methyl parathion can be regarded as safer chemicals to mirids. This study provided important information for implementing compatible biological and chemical control for rice planthopper IPM.

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