Journal of Biological Control, 24 (3): 244–252, 2010

Research Article

Potential toxicity of selected insecticides to rice leafhoppers and planthoppers and their important natural enemies

V. JHANSI LAKSHMI*, N. V. KRISHNAIAH and G. R. KATTI
Directorate of Rice Research, Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India.
**Corresponding author E-mail*: jhansidrr@yahoo.co.in

ABSTRACT: Potential toxicity of selected insecticides to rice brown planthopper (BPH), *Nilaparvata lugens*, whitebacked planthopper (WBPH), *Sogatella furcifera,* green leafhopper (GLH), *Nephotettix virescens* and their important predators in rice ecosystem, *viz*., green mirid bug, *Cyrtorhinus lividipennis*, brown mirid bug, *Tytthus parviceps* and veliid predator, *Microvelia douglasi atrolineata* was assessed in the greenhouse. Among the single compound insecticides, spinosad was moderately toxic to BPH followed by flubendiamide while ethiprole and indoxacarb were not effective against BPH, WBPH and GLH. Flubendiamide was least toxic to green mirid bug compared to acephate and other insecticides. Ethiprole and spinosad were less toxic to nymphs of brown mirid bug. Individually ethiprole, spinosad, flubendiamide were less toxic to *Microvelia*, but indoxacarb was more toxic. Ethiprole+imidacloprid and thiamethoxam+lambdacyhalothrin exhibited excellent initial and persistent toxicity against BPH, WBPH and GLH, but these two combination products were also highly toxic to all the three natural enemies recording 100% mortality within 24 hours. Flubendiamide+fipronil exhibited moderate toxicity against BPH, but was less effective against WBPH and ineffective against GLH. However, this product was highly toxic to both the mirid bugs and relatively less toxic to veliid bug.

KEY WORDS: *Nilaparvata lugens, Sogatella furcifera, Nephotettix virescens*, rice, potential toxicity, insecticides, combination products, *Cyrtorhinus lividipennis, Tytthus parviceps, Microvelia douglasi atrolineata*

(Article chronicle: Received: 04.03.2010; Sent for revision: 29.05.2010; Accepted: 26.07.2010)

INTRODUCTION

Rice brown planthopper, *Nilaparvata lugens* (Stål) (BPH), whitebacked planthopper, *Sogatella furcifera* (Horvath) (WBPH) and green leafhopper, *Nephotettix virescens* (Herbst) (GLH) are the most economically important insect pests attacking rice crop. Both the nymphs and adults of these hoppers suck the sap from phloem and xylem resulting in drying up of the rice plant. Under field conditions, the damage by BPH and WBPH spreads in a circular fashion and is technically termed as "hopper burn." Green leafhopper feeding results in wilting, yellowing and drying of the plant and it acts as a vector of rice tungro virus. If timely control measures are not taken up, the entire field could be hopper burnt by the planthoppers. Green mirid bug, *Cyrtorhinus lividipennis* Reuter and brown mirid bug *Tytthus parviceps* (Reuter) are very important predators on eggs and early instar nymphs of BPH, WBPH (Basilio and Heong 1990; Pathak and Saha 1976). Veliid bug, *Microvelia douglasi atrolineata* (Bergroth) is found on water surface in flooded rice fields and feeds on nymphs of BPH and WBPH falling on water at basal portion of rice plants.

In the rice ecosystem, insecticides are used to control insect pests of varying feeding habits and niche. Even though an insecticide is meant for controlling a specific insect pest, it is necessary to evaluate its toxicity to other insect pests and safety to natural enemies, which exist together in rice ecosystem. Thus, before introducing any new pesticides into rice ecosystem, we must assess their side effects on predators and parasitoids of major insect pests. There are several instances where the use of some insecticide molecules, particularly synthetic pyrethroids led to resurgence of *N. lugens* and *S. furcifera* and complete loss of rice crop. Destruction of natural enemies has been observed to be responsible for BPH resurgence (Heinrichs *et al*., 1982; Krishnaiah and Kalode, 1987). Keeping this in view, the present investigations were carried out at Directorate of Rice Research, Rajendranagar, Hyderabad, to assess the toxicity of selected new insecticides to rice hoppers and their predators, *viz*., *C. lividipennis*, *T. parviceps* and *M. douglasi atrolineata*, under controlled glasshouse conditions.

MATERIALS AND METHODS

The test insecticides were i) spinosad 45SC (56 g a.i. ha^{-1}), a fermentation product; ii) flubendiamide 20WDP (25 g a.i. ha^{-1}), a diamide; iii) ethiprole 10EC (50 g a.i. ha^{-1}), a phenyl pyrazole; iv) indoxacarb 14.5SC (29 g a.i. ha^{-1}), an oxadiazine; three combination products, *viz*., v) ethiprole 40% + imidacloprid 40% (100 g a.i. ha^{-1}); vi) thiamethoxam 12.6% + lambda cyhalothrin 9.4% (44 g a.i. ha^{-1}); vii) flubendiamide 36% + fipronil 30% (33 g a.i. ha^{-1}) as sprays along with standard check insecticide, viii) acephate 75% WP (500 g a.i. ha^{-1}), and water spray without any insecticide. The tests were carried out under controlled greenhouse conditions at a temperature of 30 ± 5°C and RH of 60 ± 10% by following the methodology standardized by Jhansi Lakshmi *et al*. (2001, 2001a) and Krishnaiah *et al*. (2001).

Rearing of rice hoppers and the predators

Rice hoppers, *viz*., BPH, WBPH and GLH, were separately reared on 45-day-old rice plants of TN1 variety in wooden cages in a glasshouse. The adult hoppers were separately confined to the rice plants for 2-3 days for oviposition and oviposited plants were transferred to separate cages for nymphal hatching and development to obtain nymphs or adults of required age. The predatory mirid bugs, *viz*., *C. lividipennis* and *T. parviceps*, were separately reared on rice plants of the same variety which were pre-oviposited by their natural host insect, brown planthopper *N. lugens* (BPH). The adults of the two mirid bugs were confined to pre-oviposited plants by BPH for 2-3 days for oviposition and were allowed for required period in separate cages to obtain nymphs or adults of specific age. *M. douglasi atrolineata,* which is an aquatic bug and feeds on brown planthopper nymphs, was reared in plastic pots and trays by providing planthopper nymphs as food and the adult *Microvelia* were collected and used for toxicity studies.

Toxicity tests for hoppers and mirid bugs

The insecticides at specific concentrations were sprayed up to run-off stage on 40-day-old potted rice plants. The test insects (BPH, WBPH and GLH) were confined on TN1 plants at 1, 7, 14, 21, 28 and 34 whereas mirid bugs were confined at 1, 7, 14, 21 and 28 days after spraying and separate sets were maintained for each day of confinement. For each insect, the tests were conducted separately. In the case of mirid bugs, rice plants were pre-oviposited by BPH before spraying in case of releases 1 and 7 days after spraying, whereas they were oviposited by BPH after spraying in case of releases 14, 21 and 28 days after spraying. (This was necessary to avoid death of BPH adults before oviposition). Twenty third instar nymphs (7-8 days) or adults (2-3 days old) were confined each time with the help of suitable mylar cages and observations on mortality were recorded after 24, 48 and 72 hours of exposure each time. The toxicity tests were conducted for nymphs only in the case of hoppers (BPH, WBPH and GLH) and for nymphs and adults in the case of mirid bugs and only adults in the case of *Microvelia*. Separate experiments were conducted with nymphs and adults.

Toxicity tests for Microvelia

The insecticide emulsions / solutions at specific concentrations were made in water (Table 1). Ten ml of each of the emulsion / solution was added to 1 litre of water contained in a 2 litre capacity plastic pot. Twenty *Microvelia* adults were released on the water surface and covered with muslin cloth to prevent escape of bugs and also to prevent contamination from outside. 1^{st}–2^{nd} instar BPH nymphs were provided as prey. Mortality was recorded at 24, 48 and 72 hours after release of *Microvelia* at 1, 7, 14, 21 and 28 days after treating with insecticides.

In case of all the above hopper pests and predators, persistent toxicity (PT) values were calculated for each insecticide and each exposure period, *viz*., 24, 48 and 72 hours separately according to Pradhan (1967). PT value is the product of average per cent mortality and the period in days up to which the insecticide exhibited toxicity to the hoppers/predators. PT values were subjected to square root transformation and analyzed in CRBD and means were separated by DMRT (Cochran and Cox, 1957).

RESULTS AND DISCUSSION

The results on toxicity of insecticides to BPH, WBPH and GLH are presented in Tables 1, 2 and 3, respectively, while for natural enemies the results are presented in Tables 4 to 8.

Toxicity of individual insecticides to hopper pests

Spinosad, flubendiamide and indoxacarb exhibited poor initial toxicity to BPH registering 0-21% mortality at 4 hours exposure and were inferior to check insecticide acephate (56%). At 72 hours, spinosad recorded 100% kill of BPH similar to acephate, while flubendiamide and indoxacarb were less effective (45–64%). Persistent toxicity (PT) values also revealed that indoxacarb was least persistent (PT: 424) followed by flubendiamide (1179) and spinosad (2577), but all were inferior acephate (2608) (Table 1).

Against WBPH (Table 2), spinosad and flubendiamide exhibited poor initial toxicity (30 – 38 % mortality at 72 hrs exposure) compared to 100% in acephate. PT values for spinosad and flubendiamide were far less (170–271) compared to acephate (643). Indoxacarb was on par to acephate in both initial (100%) and in persistent toxicity (600). The results on GLH (Table 3) clearly showed that spinosad, flubendiamide and indoxacarb

Table 1. Toxicity and persistent toxicity of new insecticides to nymphs of brown planthopper at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release					Persistent toxicity		
		1h	4h	24h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	51.3 (45.7)^{b}	83.8 (69.5)^{b}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1318 (36.2)^{a}	2593 (50.9)^{a}	2826 (53.2)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4%	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.96)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1604 (40.0)^{a}	2332 (48.3)^{a}	2800 (52.9)^{a}
Spinosad	56g	0.0 (0.0)^{e}	0.0 (0.0)^{e}	51.3 (45.7)^{c}	65.0 (54.1)^{b}	100 (89.9)^{a}	1206 (34.6)^{ab}	1822 (42.6)^{a}	2577 (50.7)^{ab}
Acephate	500g	21.25 (26.4)^{c}	56.3 (48.7)^{c}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1444 (37.9)^{a}	2104 (45.8)^{a}	2608 (51.1)^{ab}
Flubendiamide	25g	0.0 (0.0)^{e}	0.0 (0.0)^{e}	13.8 (18.6)^{e}	30.0 (32.5)^{cd}	45.0 (42.1)^{c}	430 (16.0)^{cd}	504 (19.7)^{b}	1179 (34.2)^{c}
Flubendiamide 36% + Fipronil 30%	50g	0.0 (0.0)^{e}	0.0 (0.0)^{e}	78.8 (63.5)^{b}	97.5 (85.4)^{a}	97.5 (85.4)^{a}	677 (25.7)^{bc}	1658 (40.7)^{a}	2013 (44.9)^{b}
Ethiprole	50g	2.5 (4.6)^{e}	2.5 (4.6)^{e}	8.8 (13.5)^{e}	21.32 (25.9)^{d}	3.8 (27.8)^{d}	290 (16.1)^{cd}	578 (22.6)^{b}	845 (28.4)^{c}
Indoxacarb	29g	8.8 (14.9)^{d}	21.3 (26.9)^{d}	28.8 (31.6)^{d}	40.0 (39.1)^{c}	63.8 (53)^{b}	82.0 (8.3)^{de}	219 (14.5)^{b}	424 (19.8)^{d}
Untreated control		0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.7)^{e}	0.0 (0.7)^{c}	0.0 (0.7)^{e}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

exhibited poor initial toxicity (0-4% mortality at 4 h exposure) and poor PT (0 -750) compared to acephate (100% initial toxicity and PT of 1133). These results are in conformity with the findings published in progress reports of DRR (2000–2008) and by Ramudu and Misra (2006). Ethiprole, a phenyl pyrazole insecticide, exhibited poor initial toxicity against BPH (24% mortality at 72 hrs) and PT (845). It was very poor against WBPH both initially (8%) and in PT (49) and practically non-toxic to GLH (0% kill) (Tables 1, 2 and 3). Earlier studies by Krishnaiah *et al.* (2004) also corroborate the present findings.

Toxicity of combination products to hopper pests

The combination product, ethiprole + imidacloprid exercised good efficacy against BPH initially (100% kill at 24 hrs) and in PT (2826) and was superior to acephate (check). In case of WBPH and GLH also this product was highly effective (100% initial kill and PT of 2763-3379) (Tables 1-3). Earlier studies by Krishnaiah *et al.* (2004) corroborate the present findings. The combination product, thiamethoxam + lambda cyhalothrin exercised very high initial toxicity against BPH, WBPH and GLH (100% kill in 1 hr) together with very high PT (2800–3294) and far superior to acephate (Tables 1-3). Thiamethoxam, a neonicotinoid insecticide, alone is highly effective against BPH and WBPH both initially and exhibited good persistency but moderately effective against GLH (Krishnaiah *et al.*, 2003). Combination of a synthetic pyrethroid and a neonicotinoid proved to be successful for the management of BPH and leaf folder (Krishnaiah *et al.*, 2003). However, BPH has started developing resistance to thiamethoxam (Jhansi lakshmi *et al.*, 2010 in press). Once there is control failure of BPH due to resistance development to thiamethoxam, the presence of any synthetic pyrethroid including lambda cyhalothrin in rice ecosystem will push up the population of BPH due to its proven resurgence causing effect. Hence, the combination thiamethoxam + lamda cyhalothrin should be discouraged in rice ecosystem. Flubendiamide + fipronil exhibited moderate initial toxicity against BPH nymphs (79% mortality at 24 hrs exposure) and moderate PT (2013) (Table 1). Against WBPH, flubendiamide + fipronil was still less effective (59% mortality at 72 hrs and PT of 314) (Table 2). Against GLH, this combination product was practically not toxic (Table 3). Fipronil also exerts poor initial and PT against BPH and WBPH (Krishnaiah *et al.*, 2003). Therefore, moderate toxicity of flubendiamide + fipronil against BPH and WBPH

Table 2. Toxicity and persistent toxicity of new insecticides to nymphs of whitebacked planthopper at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release					Persistent toxicity		
		1h	4h	24h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2571 (50.5)^{a}	2566 (50.6)^{a}	2763 (52.6)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4 %	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2408 (49.1)^{a}	2705 (52)^{a}	2938 (54.2)^{a}
Spinosad	56g	11.3 (19.5)^{de}	17.5 (24.7)^{c}	20.0 (26.5)^{c}	32.5 (34.7)^{c}	37.5 (37.7)^{c}	125 (11.1)^{cd}	199 (14.1)^{cd}	271 (16.5)^{c}
Acephate	500g	62.5 (56.2)^{b}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	507 (22.5)^{b}	606 (24.5)^{b}	643 (25.4)^{b}
Flubendiamide	25g	15.0 (19.6)^{de}	23.8 (28.8)^{c}	25.0 (29.7)^{c}	27.5 (31.4)^{c}	30.0 (33.1)^{c}	111 (9.9)^{d}	128 (10.6)^{d}	170 (12.2)^{d}
Flubendiamide 36% + Fipronil 30%	50g	35.0 (35.5)^{cd}	52.5 (46.3)^{b}	53.8 (47.1)^{b}	58.8 (50.1)^{b}	58.8 (50.1)^{b}	236 (15.3)^{cd}	305 (17.4)^{c}	314 (17.6)^{c}
Ethiprole	50g	6.3 (12.5)^{ef}	7.5 (13.5)^{d}	7.5 (13.5)^{d}	7.5 (13.5)^{d}	7.5 (13.5)^{d}	8.0 (2.6)^{e}	31.0 (4.7)^{e}	49.0 (5.8)^{e}
Indoxacarb	29g	50.0 (44.9)^{bc}	95.0 (83.3)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	304 (16.2)^{c}	508 (22.5)^{b}	600 (24.3)^{b}
Untreated control		0.0 (0.0)^{f}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.71)^{e}	0.0 (0.71)^{e}	0.0 (0.7)^{f}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

Table 3. Toxicity and persistent toxicity of new insecticides to nymphs of green leafhopper at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release					Persistent toxicity		
		1h	4h	24h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2975 (54.5)^{a}	3225 (56.8)^{a}	3379 (58.1)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4 %	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2917 (54.0)^{a}	3065 (55.4)^{a}	3294 (57.4)^{a}
Spinosad	56g	0.0 (0.0)^{c}	0.0 (0.0)^{b}	45.0 (42.5)^{b}	92.5 (90.0)^{ab}	100.0 (89.9)^{a}	288 (16.6)^{c}	680 (26)^{c}	750 (27.4)^{c}
Acephate	500g	27.5 (31.2)^{b}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	863 (29.4)^{b}	1065 (32.5)^{b}	1133 (33.6)^{b}
Flubendiamide	25g	0.0 (0.0)^{c}	0.0 (0.0)^{b}	1.3 (3.2)^{c}	1.3 (3.2)^{d}	2.5 (4.6)^{c}	0.0 (0.71)^{d}	0.0 (0.71)^{e}	0.0 (0.7)^{e}
Flubendiamide 36% + Fipronil 30%	50g	0.0 (0.0)^{c}	0.0 (0.0)^{b}	0.0 (0.0)^{c}	1.3 (3.2)^{d}	6.3 (7.5)^{c}	0.0 (0.71)^{d}	0.0 (0.71)^{e}	0.0 (0.7)^{e}
Ethiprole	50g	1.3 (3.2)^{b}	1.3(3.2)^{b} (3.2)^{b}	1.3 (3.2)^{c}	1.3 (3.2)^{d}	1.3 (3.2)^{c}	0.0 (0.71)^{d}	0.0 (0.71)^{e}	0.0 (0.7)^{e}
Indoxacarb	29g	1.3 (3.2)^{b}	3.8 (7.8)^{b}	1.3 (3.2)^{c}	11.3 (18.6)^{c}	32.5 (34.4)^{b}	0.0 (0.71)^{d}	88 (9.3)^{d}	266 (16.2)^{d}
Untreated control		0.0(0.0)^{c} (0.0)^{c}	0.0 (0.0)^{b}	0.0 (0.0)^{c}	0.0(0.0)^{c} (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.71)^{d}	0.0 (0.71)^{e}	0.0 (0.7)^{e}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

Table 4. Relative toxicity (% mortality) of selected insecticides to nymphs of C. *lividipennis* at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release			Persistent toxicity		
		4h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2282 (47.7)^{a}	2310 (48.1)^{a}	2429 (49.3)^{a}
Thiamethoxam 12.6% +lamdacyhalothrin 9.4%	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2345 (48.4)^{a}	2408 (49.1)^{a}	2492 (49.9)^{a}
Spinosad	56g	16.3 (23.5)^{c}	31.3 (38.1)^{b}	46.3 (42.8)^{b}	42.0 (5.7)^{d}	220.8 (14.1)^{c}	560 (23.6)^{c}
Acephate	500g	96.3 (80.3)^{ab}	100 (89.9)^{a}	100.0 (89.9)^{a}	1519 (38.9)^{b}	2107 (45.8)^{a}	2660 (51.6)^{a}
Flubendiamide	25g	3.8 (5.7)^{d}	15.0 (22.4)^{bc}	28.8 (32.2)^{b}	4.0 (0.96)^{de}	54.0 (7.3)^{d}	199 (13.2)^{d}
Flubendiamide 36% + Fipronil 30%	50g	63.8 (70.1)^{b}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	872 (33.6)^{bc}	1771 (48.9)^{a}	2100 (52.9)^{a}
Ethiprole	50g	5.0 (6.6)^{d}	11.3 (13.7)^{c}	11.3 ((9.1)^{c}	64.0 (5.4)^{d}	101 (6.5)^{d}	273 (15.8)^{d}
Indoxacarb	29g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	917 (30.0)^{c}	1449 (38.1)^{b}	1757 (41.9)^{b}
Untreated control		0.0 (0.0)^{d}	0.0 (0.0)^{d}	0.0 (0.0)^{c}	0.0 (0.0)^{e}	0.0 (0.0)^{e}	0.0 (0.0)^{e}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

Table 5. Relative toxicity (% mortality) of selected insecticides to adults of *C. lividipennis* at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release			Persistent toxicity		
		4h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4%	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}	2802 (52.9)^{a}
Spinosad	56g	25 (29.4)^{b}	87.5 (75.0)^{b}	100.0 (89.9)^{a}	328 (16.6)^{d}	1348 (36.6)^{d}	1897 (43.5)^{c}
Acephate	500g	100 (89.9)^{a}	100 (89.9)^{a}	100.0 (89.9)^{a}	916 (30.1)^{c}	1973 (44.4)^{c}	2373 (48.7)^{b}
Flubendiamide	25g	7.5 (8.3)^{c}	22.5 (28.2)^{d}	47.5 (43.5)^{b}	8.0 (1.9)^{e}	23.0 (4.8)^{f}	8.0 (6.9)^{d}
Flubendiamide 36% + Fipronil 30%	50g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1883 (43.3)^{b}	2373 (48.7)^{b}	2723 (52.2)^{a}
Ethiprole	50g	30.0 (51.0)^{c}	60.0 (51.0)^{c}	92.5 (81.7)^{a}	219 (12.8)^{d}	1043 31.9)^{e}	1946 (44.1)^{c}
Indoxacarb	29g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1281 (35.6)^{c}	2065 (45.4)^{bc}	2429 (49.3)^{b}
Untreated control		0.0 (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.0)^{c}	0.0 (0.71)^{e}	0.0 (0.71)^{g}	0.0 (0.71)^{e}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

Table 6. Relative toxicity (% mortality) of selected insecticides to nymphs of *T. parviceps* at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release			Persistent toxicity		
		4h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2016 (44.9)^{b}	2331 (48.3)^{b}	2716 (52.1)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4%	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100 (89.9)^{a}	2534 (50.3)^{a}	2674 (51.7)^{a}	2800 (52.9)^{a}
Spinosad	56g	23.75 (29.1)^{b}	52.5 (46.5)^{b}	92.5 (79.2)^{ab}	165 (12.0)^{d}	548 23-4)^{r}	1384 (37.2)^{c}
Acephate	500g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1341 (36.4)^{c}	2026 (44.9)^{c}	2478 (49.8)^{ab}
Flubendiamide	25g	15.0 (22.4)^{c}	82.5 (68.3)^{b}	93.75 (82.5)^{ab}	152 (12.1)^{d}	1049 (32.3)^{c}	1598 (39.8)^{c}
Flubendiamide 36% + Fipronil 30%	50g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1715 (41.4)^{b}	2800 (52.9)^{a}	2801 (52.9)^{a}
Ethiprole	50g	25.0 (29.9)^{b}	42.5 (40.6)^{c}	82.5 (71.9)^{b}	248 (15.6)^{d}	625 (25.0)^{f}	986 (28.9)^{d}
Indoxacarb	29g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1035 (32)^{c}	1484 (38.5)^{d}	1877 (43.3)^{bc}
Untreated control		0.0 (0.0)^{d}	0.0 (0.0)^{d}	0.0 (0.0)^{c}	0.0 (0.7)^{e}	0.0 (0.7)^{e}	0.0 (0.7)^{e}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

Table 7. Relative toxicity (% mortality) of selected insecticides to adults of *T. parviceps* at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release			Persistent toxicity		
		4h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2352 (48.5)^{ab}	2464 (49.6)^{ab}	2800 (52.9)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4%	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2408 (49.1)^{ab}	2590 (50.9)^{a}	2800 (52.9)^{a}
Spinosad	56g	85.0 (70.4)^{b}	95.0 (83.3)^{ab}	100.0 (89.9)^{a}	776 (27.6)^{c}	1932 (43.9)^{ab}	2086 (45.7)^{c}
Acephate	500g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1932 (43.9)^{b}	2100 (45.8)^{ab}	2660 (51.6)^{ab}
Flubendiamide	25g	22.5 (27.3)^{c}	67.5 (56.2)^{ac}	82.5 (69.5)^{b}	278 (15.0)^{d}	1295 (35.2)^{b}	1958 (44.1)^{c}
Flubendiamide 36% + Fipronil 30%	50g	100.0 (89.96)^{a}	100.0 (89.96)^{a}	100.0 (89.96)^{a}	2744 (52.4)^{a}	800 (52.9)^{a}	2801 (52.9)^{a}
Ethiprole	50g	12.5 (20.4)^{c}	87.5 (75.0)^{abc}	100.0 (89.9)^{a}	(15.5)^{d} (15.5)^{d}	(43.7)^{ab} (43.7)^{ab}	(49.8)^{b} (49.8)^{b}
Indoxacarb	29g	92.5 (78.7)^{ab}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	1117 (32.7)^{c}	2282 (47.6)^{ab}	2632 (51.3)^{ab}
Untreated control		0.0 (0.0)^{d}	0.0 (0.0)^{d}	0.0 (0.0)^{c}	0.0 (0.71)^{e}	0.0 (0.71)^{e}	0.0 (0.71)^{d}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

Table 8. Relative toxicity (% mortality) of selected insecticides to *Microvelia douglasi atrolineata* at different days after treatment and exposure periods

Treatment	Conc. of a.i. in spray fluid (a.i ha^{-1})	% mortality 1day after release			Persistent toxicity		
		4h	48h	72h	24h	48h	72h
Ethiprole 40% + imidacloprid 40%	100g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}
Thiamethoxam 12.6% + lamdacyhalothrin 9.4%	44g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}	2800 (52.9)^{a}
Spinosad	56g	18.75 (25.39)^{c}	25.0 (29.7)^{cd}	33.75 (33.2)^{c}	82.0 (8.8)^{c}	184 (13.5)^{c}	255 (15.8)^{d}
Acephate	500g	78.75 (63.2)^{b}	88.75 (73.8)^{b}	90.0 (75.2)^{b}	362 (18.3)^{b}	699 (26.4)^{b}	808 (28.4)^{b}
Flubendiamide	25g	0.0 (0.0)^{d}	7.5 (13.0)^{e}	16.25 (23.3)^{d}	0.0 (0.7)^{d}	58.0 (6.8)^{d}	329 (18.1)^{d}
Flubendiamide 36% + Fipronil 30%	50g	22.5 (28.2)^{c}	30.0 (33.2)^{c}	41.25 (39.9)^{c}	149 (12.1)^{c}	228 (14.9)^{c}	567 (23.7)^{c}
Ethiprole	50g	0.0 (0.0)^{d}	13.75 (18.9)^{de}	13.75 (18.9)^{d}	0.0 (0.71)^{d}	13.8 (3.4)^{e}	13.8 (3.4)^{e}
Indoxacarb	29g	100.0 (89.9)^{a}	100.0 (89.9)^{a}	100.0 (89.9)^{a}	466 (21.5)^{b}	756 (27.3)^{b}	928 (30.1)^{b}
Untreated control		0.0 (0.0)^{d}	0.0 (0.0)^{f}	0.0 (0.0)^{e}	0.0 (0.71)^{d}	0.0 (0.71)^{e}	0.0 (0.71)^{e}

Figures in a column followed by the same letter are not significantly different at $P = 0.05$ by DMRT; figures in parentheses are arcsine transformed values for % mortality and square root transformed values for persistent toxicity

appears to be due to the combined effect of two weak insecticides.

Relative toxicity of individual insecticides to natural enemies

Green mirid bug (GMB) nymphs and adults

Spinosad, flubendiamide and ethiprole recorded very low initial toxicity against nymphs of GMB (11–46% mortality at 72 hrs) compared to 100% mortality in check insecticide, acephate (Tables 4 and 5). Indoxacarb exerted 100% initial kill. PT values for spinosad (570), flubendiamide (199) and indoxacarb (1757) were significantly lower than acephate (2660). Against GMB adults, the results were very similar. Spinosad, flubendiamide and ethiprole exerted low initial toxicity (8–30%) compared to 100% kill in acephate and indoxacarb. However, flubendiamide was least persistent (PT of 48) for GMB adults compared to spinosad (1897), ethiprole (1946), indoxacarb (2429) and acephate (2429). Kumaran *et al*. (2009) also reported that ethiprole was less toxic than acephate for GMB under field conditions.

Brown mirid bug (BMB) nymphs and adults

For nymphs of BMB, spinosad, flubendiamide and ethiprole exhibited low initial toxicity (15–25% at 24 hrs.), while indoxacarb and acephate recorded 100% mortality (Tables 6 and 7). The test insecticides also showed lower PT values (986–1877) for BMB nymphs compared to acephate (2478). Against BMB adults also, spinosad, flubendiamide, ethiprole and indoxacarb were less toxic initially (13–93%) compared to acephate (100%). Persistent toxicity values also showed a similar trend. All the test insecticides registered lower PT values (1958 – 2632) compared to acephate (2660).

Veliid bug predator

Spinosad, flubendiamide and ethiprole were less toxic initially (8–25% mortality at 48 hrs) compared to acephate (89%) (Table 8). Indoxacarb was more toxic (100%). PT was also very low for spinosad, flubendiamide and ethiprole (14–255) as against 808 in check insecticide acephate and 928 for indoxacarb.

Toxicity of combination products to natural enemies

GMB nymphs and adults

Ethiprole + imidacloprid and thiamethoxam + lambda cyhalothrin were more toxic to GMB nymphs (100% kill at 24 hrs) compared to acephate (96%) while flubendiamide + fipronil exhibited lower toxicity (64%) (Tables 4 and 5). However, PT of all the combination products (2100–2492) was lower than check insecticide acephate (2660). For GMB

adults, all the combination products were as toxic as acephate (100% mortality in 24 hrs) initially; but exhibited significantly higher PT (2723–2802) than acephate (2373). Imidacloprid was found to be toxic to green mirid bug (Mao and Liang, 1995; Tanaka *et al*., 2000; Widiarta, 2001). Ethiprole was found to be non-toxic to green mirid bug, which is in conformity with the findings of Kumaran *et al.* (2009).

BMB nymphs and adults

All the combination products were highly toxic to BMB nymphs recording 100% kill at 24 hrs exposure and were on par with acephate (Tables 6 and 7). PT values were also very high (2718–2800) for all the combination products and on par with acephate (2478). Against adults of BMB also, the trends were very similar where combination products and acephate registered 100% mortality (at 24 hrs.) initially and high persistent toxicity (PT of 2660–2800).

Veliid bug predator

Initially, ethiprole + imidacloprid and thiamethoxam + lambda cyhalothrin were more toxic (100% kill in 24 hrs) to veliid bug than acephate (79%) but flubendiamide + fipronil was less toxic (23% initial mortality) (Table 8). PT also showed similar trend wherein ethiprole + imidacloprid and thiamethoxam + lambda cyhalothrin recorded far higher PT (2800) compared to acephate (808) and flubendiamide + fipronil (567). Among the single compound insecticides included in the present study, spinosad, flubendiamide and indoxacarb are effective against rice yellow stem borer (YSB) and leaf folder (LF) (DRR 2000–2008). The present results have clearly shown that spinosad and flubendiamide are less toxic or relatively safer to nymphs and adults of GMB, BMB and VB compared to indoxacarb. Hence, flubendiamide and spinosad have to be preferred for need-based application against YSB and LF. This will result in conservation of GMB, BMB and VB which will keep the populations of BPH and WBPH at low level for up to 45-50 DAT. On the other hand, if indoxacarb is used for the management of YSB around 40 DAT, there will be serious adverse effect on planthopper predators resulting in the upset of planthopper / predator balance because it is highly toxic to predators and has practically no toxicity to planthoppers. Hence, spinosad or flubendiamide needs to be preferred to indoxacarb for such situations. For the management of BPH, WBPH and GLH, ethiprole should be avoided, as this compound is less effective against all the pests compared to acephate. The lower toxicity of ethiprole to predators should not be the criterion for selection in the absence of effectiveness for target pests.

Flubendiamide + fipronil is moderately effective against BPH, practically ineffective against WBPH and GLH, effective against YSB and LF due to the presence of flubendiamide, but highly toxic to planthopper natural enemies. Hence, this combination product should be discouraged in all areas where BPH / WBPH are prevalent at non destructive levels.

Among the other two combination products, ethiprole 40% + imidacloprid 40% can be an effective management strategy when BPH and WBPH are predominant in rice ecosystem. However, this product has to be used only after booting or at flowering stage as last application against BPH and WBPH. This caution is necessary as this combination product can almost wipe out all the predators (GMB, BMB and VB) due to very high initial and persistent toxicity. Ethiprole has only poor toxicity to leaf and planthoppers and the toxicity is due to imidacloprid. But 30 – 40 fold resistance development is reported to imidacloprid. However, as the two molecules have different modes of action, the process of resistance development against imidacloprid is likely to be slowed down and it can be used where planthoppers are the only problem. If BPH and WBPH cross ETL in early stage, *i.e.*, 40 – 45 DAT, insecticides like buprofezin (150 g a. i. ha^{-1}) or ethofenprox (100 g a. i. ha^{-1}) that are specific to hoppers with least toxicity to GMB, BMB and spiders should be preferred.

The combination product imidacloprid + lambda-cyhalothrin need to be put to very restricted use in rice ecosystem, or preferably discouraged, because of the reported development of resistance in planthoppers, resurgence causing nature of the synthetic pyrethroid, lambdacyhalothrin and its high toxicity nature to the natural enemies.

ACKNOWLEDGEMENT

The authors are grateful to Dr. B. C. Viraktamath, Project Director, Directorate of Rice Research, Hyderabad, for his encouragement and providing facilities.

REFERENCES

Basilio, R. P. and Heong, K. L. 1990. Brown mirid bug, a new predator of brown planthopper (BPH) in the Philippines. *International Rice Research Newsletter*, **15**: 27–28.

Cochran, W. G. and Cox, G. M. 1957. Experimental Designs. 2nd edition, John Wiley, New York, USA, 611 pp.

Directorate of Rice Research (DRR). 2000–2008. Progress report, kharif and rabi: Vol. 2., Entomology and Pathology, All India Coordinated Rice Improvement Programme (ICAR), Directorate of Rice Research, Rajendranagar, Hyderabad, Andhra Pradesh, India.

Heinrichs, E. A., Ressig, W. H., Valencia, S. L. and Chelliah, S. 1982. Rates and effect of resurgence inducing insecticides on populations of *Nilaparvata lugens* (Homoptera: Delphacidae) and its predators. *Environmental Entomology*, **11**: 1269–1273.

Jhansi Lakshmi, V., Krishnaiah, N. V., Katti, G., Pasalu, I. C. and Vasantha Bhanu, K. 2009. Insecticide resistance development in rice brown planthopper *Nilaparvata lugens*

(Stal) and white-backed planthopper *Sogatella furcifera* (Horvath) in Godavari delta of Andhra Pradesh, India. *Indian Journal of Plant Protection* (in press).

Jhansi Lakshmi, V., Krishnaiah, N. V., Pasalu, I.C., Lingaiah T. and Krishnaiah, K. 2001a. Safety of some insecticides to brown mirid bug, *Tytthus parviceps* (Reut.) (Hemiptera: Miridae), a predator of brown planthopper *Nilaparvata lugens* (Stal) in rice. *Journal of Biological Control*, **15**: 43–48.

Jhansi Lakshmi, V., Krishnaiah, N. V., Pasalu, I. C., Lingaiah, T. and Krishnaiah. K. 2001b. Safety of thiamethoxam to *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae), a predator of brown planthopper*, Nilaparvata lugens* (Stal) in rice. *Journal of Biological Control*, **15**: 53–58.

Krishnaiah, N. V., Jhansi Lakshmi, V., Pasalu, I. C., Lingaiah, T. and Krishnaiah, K. 2001. Relative safety of some new insecticides *to Microvelia douglasi atrolineata* Bergroth, an aquatic predator of hoppers in rice ecosystem. *Journal of Biological Control*, **15**: 49–52.

Krishnaiah, N. V. and Kalode, M. B. 1987. Studies on resurgence in rice brown planthopper, *Nilaparvata lugens* (Stal). *Indian Journal of Entomology*, **49**: 220–229.

Krishnaiah, N. V., Prasad, A. S. R., Lingaiah, T., Lakshminarayanamma, V., Raju, G. and Srinivas, S. 2004. Comparative toxicity of neonicotinoid and phenyl pyrazole insecticides against rice hoppers. *Indian Journal of Plant Protection,* **32**: 24–30.

Krishnaiah, N. V., Rama Prasad, A. S., Lingaiah, T. and Mahesh Kumar, K. 2003. Utilization of thiamethoxam and imidacloprid for the management of insect pest complex in rice. *Indian Journal of Plant Protection,* **31**: 51–55.

Kumaran, N., Kumar, B. V., Boomathi, N., Kuttalam, S. and Gunasekaran, K. 2009. Non-target effect of ethiprole 10 SC to predators of rice planthoppers. *Madras Agricultural Journal*, **96**: 208–212.

Mao, L.X. and Liang, T. X. 1995. An evaluation of the effect of imidacloprid on rice planthopper and its natural enemies. *Plant Protection*, **21**: 42–44.

Pathak, P. K. and Saha, S. P. 1976. Mirids as predators of *Sogatella furcifera* and *Nilaparvata lugens* in India. *Rice Entomology Newsletter*, **4**: 20–21.

Pradhan, S. 1967. Strategy in integrated pest control. *Indian Journal of Entomology*, **29**: 105–122.

Ramudu, D.R. and Misra, H.P. 2006. Chemical control of the rice brown planthopper, *Nilaparvata lugens* Stal. *Journal of Plant Protection and Environment*, **3**: 59–62.

Tanaka, K., Endo, S. and Kazano, H. 2000. Toxicity of insecticides to predators of rice planthoppers: spiders, the mirid bug and the dryinid wasp. *Applied Entomology and Zoology*, **35**: 177–187.

Widiarta, I. N., Matsumura, M., Suzuki, Y. and Nakasuji, F. 2001. Effects of sublethal doses of imidacloprid on the fecundity of green leafhoppers, *Nephotettix* spp. (Hemiptera: Cicadellidae) and their natural enemies. *Applied Entomology and Zoology*, **36**: 501–507.