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Sulfoximine: A novel insecticide for management of rice brown planthopper in India

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Sulfoxaflor is the first product from the new class of insecticides, will be introduced in India shortly. Sulfoxaflor acts via the insect nicotinic receptor in a complex manner. Southern parts of West Bengal are well known for the production of rice in India. Infestation of brown planthopper (BPH) is being aggravated gradually with the expanse of area and use of neonicotinoid insecticides. The present investigation was laid out to find out the bio-efficacy of sulfoxamine in controlling the rice brown planthopper in field condition as well as in laboratory. The method for laboratory rearing of BPH and bio-assay methodology was standardized in this study. The relative safety of the molecule to the major predators of brown planthopper in rice eco system was also evaluated in this experiment. Sulfoxaflor at 100 and 75 g ai/ha was found effective for management of BPH under field condition. LC_{50} value of sulfoxaflor at 24 h was 2.986 ppm against laboratory reared BPH. Sulfoxaflor was also recorded as relatively harmless against major predator of BPH such as mirid bug.

Key words: Sulfoxamine, insecticides, planthopper, neonicotinoids.

INTRODUCTION

With the continued increase in the human population and losses of arable land, there is an ever increasing need to increase rice production per unit of land. Over 800 insect species have been identified damaging either standing or stored rice (Grist and Lever, 1969). Rice brown planthopper (BPH), Nilaparvatalugens (Stål) (= Delphaxoryzae) belongs to the Family-Delphacidae and Order-Hemiptera, is probably the most important rice pest in Asia. It induces complex plant responses and potentially dramatic losses in yield, ultimately leading to plant death. Symptoms are collectively known as 'hopperburn'. Sometimes the damage may be so great that growers have to abandon the crop. The loss in grain yield ranges from 10% in moderately affected fields to 70% in those fields which are severely affected (Kulshreshtha, 1974).

The control of this pest has always been emphasized and largely relied on insecticides in most rice producing countries (Nagata et al., 1979; Gao et al., 1987). Insecticide is the only tool that is reliable for emergency action when insect pest population approaches or exceeds the economic threshold. But the heavy uses of

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broad spectrum chemicals also reduce the biodiversity of natural enemies, lift the natural control, induce outbreak of secondary pests and contaminate eco-system (Singh, 2000), resulted in resurgence of brown planthopper (Heinrichs and Mochida, 1984; Kenmore et al., 1984). Chronic outbreaks of the brown planthopper in Indonesia in the mid 1980's were attributed to excessive use of insecticides in rice fields.

Under such circumstances several new molecules selective to target pests are required to be evaluated for the justification of chemical control as the first line of defence. Sulfoxaflor is a new and safer insecticide from a novel, new class of chemistry known as sulfoximines.

The discovery of sulfoxaflor [N-[methyloxido[1-[6-(trifluoromethyl)-3-pyridinyl]ethyl]-λ^4-sulfanylidene] cyanamide] by Dow AgroSciences resulted from an investigation of the sulfoximine functional group as a novel bio-active scaffold for insecticidal activity and a subsequent extensive structure-activity relationship study. Sulfoxaflor, the first product from this new class (sulfoximines) of insect control agents, exhibits good control against a wide range of sap-feeders with levels of activity that are comparable to those of other classes of insecticides including the neonicotinoids. Sulfoxaflor seems to be acting via the insect nicotinic receptor in a complex manner (Yuanming et al., 2011).

The present investigation was, therefore, oriented to find out the bio-efficacy of sulfoxamine in controlling the rice brown planthopper in field condition as well as in laboratory condition. There was also need to check the relative safety of the molecule to the major predators of brown planthopper in rice ecosystem.

METHODOLOGY

Field experiment was conducted in farmer's plot at Sahebganj village (Block - Bhatar, Dist.-Burdwan, WB, India). The experiment was conducted during kharif, 2008 to 2009 and 2009 to 2010. Field experiment was laid out in randomised block design (RBD) with three replications for each treatment. Altogether seven treatments comprising three doses of sulfoxaflor at 50, 75 and 100 g ai/ha, buprofezin at 200 g ai/ha imidacloprid at 25 g ai/ha and acephate at 400 g ai/ha along with an untreated check were tested.

The crop was raised in plots (60 sqm) under normal recommended package of practices at a spacing of 20 × 15 cm and left for natural infestation of desired pest. Two consecutive sprays of selected insecticides were done at 15 days interval with pneumatic knapsack sprayer at 500 L/ha of spray volume. Visual sampling method was followed for counting the brown planthopper population. In modification to the method standardized by Reissig et al. (1986) for visual counting of brown planthopper, five hills were selected at random across each plot. Each hill was hit several times with hands and number of nymphs and adults that fallen on the water were counted. Mature nymphs were brown and immatures were white. Mean number of BPH adults and nymphs per hill was counted at 1 day before and 1, 7 and 15 days after each spray. Among the various natural enemies found to be associated with BPH in the field condition, mirid bugs and spiders were the most abundant than the others. Among the spiders, Pardosapseudoannulata was predominant. Mean number of mirid bugs and spiders per hill up to 15 days was noted after each spray.As mirid bug had greater potential to suppress the population of BPH in the field condition and its population generally varied with the population of BPH, the ratio of brown planthopper and mirid bug was calculated at each observation.

Statistical analysis

The critical difference (CD) at 5% level of significance was worked out from the data of brown planthopper and natural enemies before and after two consecutive sprays and the mean of the population was done.

Laboratory experiment was carried out in the polycarbonated glasshouse at Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal.

Collection and rearing of test insect

An initial population of field collected insects was utilized to start the culture of the BPH. Ten days old seedlings of rice (MTU-7029) were planted in plastic pots (14 cm dia. and 15 cm ht.). Ammonium sulphate fertilizer (2 g) was added to each pot at 15 days after transplanting. Pots were placed in plastic trays full of water to maintain a standing water condition. Plants of 25 to 35 days were ideal for feeding and oviposition of hoppers. Eight potted plants in each cage (80 × 80 × 80 cm) were sufficient to maintain 500 to 700 hoppers. Separate cages were maintained for oviposition and rearing of the hoppers. Using this technique a culture of BPH was maintained in the glasshouse at temperature 30 ± 5°C and RH 70 ± 20%. Periodic examination of the cages for the presence of predators and other insect species and prompt removal of these predators were done for effective rearing.

Bioassay

In order to identify a suitable experimental procedure for bioassay study, three methods namely 'spray and insect release'; 'spraying on insect *in situ*'; and 'spraying on the anesthetized insect and releasing on the unsprayed plant' for further feeding were evaluated. The methods were assessed based on the settling behaviour of the insect and number of insects killed (mortality percentage). Bioassay that involves 'spraying on the plant and insect release' was found most suitable under laboratory condition as the method was effective in giving maximum kill on consistent basis.

Four to five rice seedlings (MTU-7029) of 30 to 40 days old were planted in plastic pots. Theses pots were put into plastic trays full of water to maintain standing water condition. Plants were sprayed by hand automiser with fixed volume of insecticides of different concentrations. One untreated check was maintained that was sprayed with water only. Plants in the pots were covered with cylindrical Mylar cages (10 cm dia. and 50 cm ht.). One to two day(s) old brachypterous adults of uniform size were collected with mouth aspirator from rearing cage and released them into the Mylar cage. Insects reared for more than two generations were taken for bioassay study. On an average 20 insects were released per Mylar cage and the open end was covered with cloth.

After exposure to treated plants, insects were observed for mortality at different time intervals. Generally moribund insects were considered as dead. Number of dead insects was recorded at 24, 48, 72 and 96 h after exposure.

Statistical analysis

The relative toxicity of insecticides was worked out in the laboratory.

Table 1. Effect of insecticides against *Nilaparvata lugens* during *kharif*, 2008 and 2009.

Treatment	Dose (g ai/ha)	PT	1 DAS	7 DAS	15 DAS	Mean after 1st spray	1 DAS	7 DAS	15 DAS	Mean after 2nd spray	Overall mean	Yield (q/ha)
Sulfoxaflor 14 SC	50	29.00 (1.46)[a]	17.17 (1.23)[b]	12.34 (1.09)[c]	14.67 (1.17)[c]	14.73	7.50 (0.88)[b]	7.00 (0.85)[c]	11.83 (1.07)[b]	8.78	11.75	40.34
Sulfoxaflor 14 SC	75	31.50 (1.50)[a]	15.67 (1.19)[b]	7.00 (0.85)[b]	7.84 (0.89)[b]	10.17	3.67 (0.56)[a]	3.00 (0.48)[b]	3.67 (0.56)[a]	3.45	6.81	49.50
Sulfoxaflor 14 SC	100	30.00 (1.48)[a]	14.34 (1.16)[b]	6.17 (0.79)[b]	7.00 (0.85)[b]	9.17	3.00 (0.48)[a]	3.00 (0.48)[b]	3.33 (0.52)[a]	3.11	6.14	49.83
Buprofezin 25 SC	200	29.84 (1.47)[a]	28.83 (1.46)[c]	1.17 (0.07)[a]	5.34 (0.73)[a]	11.78	3.50 (0.54)[a]	1.83 (0.26)[a]	3.84 (0.58)[a]	3.06	7.42	49.37
Imidacloprid 17.8 SL	25	30.67 (1.49)a	9.83 (0.99)[a]	5.50 (0.74)[b]	14.67 (1.17)[c]	10.00	3.33 (0.52)[a]	5.17 (0.71)[c]	10.50 (1.02)[b]	6.33	8.17	45.85
Acephate 75 WP	400	30.34 (1.48)[a]	16.67 (1.22)[b]	14.17 (1.15)[c]	24.00 (1.38)[d]	18.28	14.50 (1.16)[c]	15.67 (1.19)[d]	22.17 (1.35)[c]	17.44	17.86	38.15
Control	-	30.34 (1.48)[a]	30.67 (1.49)[c]	42.67 (1.63)[d]	57.17 (1.76)[e]	43.50	60.00 (1.78)[d]	81.00 (1.91)[e]	72.17 (1.86)[d]	71.06	57.28	25.40

Values in the parenthesis are $\log_{10}(x)$ transformed values; Means followed by a common letter in a column are not significantly different from each other by DMRT. DAS = days after spraying, PT = pre-treatment count.

The mortality data of test species were recorded after different exposure hours and converted to percentage-mortality by using the formula:

$$\text{Percentage of mortality} = \frac{\text{Number of dead insects}}{\text{Number of treated insects}} \times 100$$

The data were subjected to Probit analysis after correcting the mortality in the untreated check by Abbott's formula (Abbott, 1925).

$$P = \frac{P_1 - C}{100 - C} \times 100$$

(Where, P = Percentage of corrected mortality; P_1 = Percentage of observed mortality; C = Percentage of mortality in control).

The Probit analysis was done by the method adopted by Finney (1971) for the mathematical estimation of median lethal concentration (LC_{50}).

RESULTS AND DISCUSSION

Effect of insecticides was tested in field condition on the basis of number of BPH per hill, changes in the population of natural enemies and finally the yield.

The result (Table 1) indicated that the brown planthopper population did not vary significantly among the treatments before the application of insecticides. However, 1 day after imposing the

Table 2. Species associated with planthoppers.

Common name	Scientific name	Family	Order
Mirid bugs	*Cyrtorhinus lividipennis* *Tytthuschinensis*	Miridae	Hemiptera
Lady beetles	*Harmonia octomaculata* *Menochilus sexmaculata* *Micraspi* ssp.	Coccinellidae	Coleoptera
Earwig	*Euborellia stali,*	Carcinophoridae	Dermaptera
Ground beetles	*Ophionea indica* *Anoplogeniu* ssp.	Carabidae	Coleoptera
Rove beetle	*Paederus fuscipes*	Staphylinidae	Coleoptera
Ant	*Solenopsis geminata*	Formicidae	Hymenoptera
Damselflies	*Agriocnemis pygmaea* *Agriocnemis femina*	Coenagrionidae	Odonata
Dwarf spider	*Atypena formosana*	Linyphiidae	Araneae
Wolf spider	*Pardosa (=Lycosa) pesudoannulata*	Lycosidae	Araneae
Lynx spider	*Oxyopes* spp.	Oxyopidae	Araneae

treatments imidacloprid recorded lowest number of BPH per hill followed by sulfoxaflor at 100, 75 and 50 g ai/ha.Sulfoxaflor at 100 and 75 g ai/ha showed better control than imidacloprid after 15 days of 1st spray. After 2nd spray, sulfoxaflor at 100 and 75 g ai/ha, buprofezin and imidaclopridwere found effective in suppressing BPH population. Sulfoxaflor at 100 and 75 g ai/ha maintained its superiority along with buprofezin over the other treatments upto 15 days after 2nd spray. After 1 day, imidacloprid provided good control but gradually sulfoxaflor at 100 and 75 g ai/ha turned out as more effective against BPH. The overall mean number of BPH per hill after two sprays was also lower in sulfoxaflor at 100 and 75 g ai/ha followed by buprofezin,imidacloprid, sulfoxaflor at 50 g ai/ha and acephate. Highest yield was recorded in sulfoxaflor at 100 and 75 g ai/ha treated plots followed by buprofezin.

Effect of insecticides on natural enemies associated with brown planthopper

In the experimental location, population of natural enemies was moderate to good in both seasons. The following species were recorded to be associated with planthoppers during on the course of our experiment (Table 2).

Among the mentioned species (Table 2), mirid bug and wolf spider were more abundant. Mirid bug is an efficient predator of BPH and its population was found to be highly dependent on the availability of prey, that is, BPH. This might be due to the density dependent nature of mirid bug. Number of mirid bug was higher with more availability of BPH and vice-versa in normal condition. But, spider population was observed to be independent of BPH population unlike mirid bug. The effect of insecticides on mirid bug and spider was evaluated during the course of experiment.

It was evident from the Table 3 that mean number of mirid bug per hill after 15 days of first spray was comparatively low in all insecticide treated plots than the untreated control. A predator favourable low BPH and mirid bug ratio was maintained in case of sulfoxaflor treated plots along with buprofezin that connoted their safety to mirid bug. Same trend was noticed after second spray also. Table 1 showed that there was no significant effect of insecticides on the mean number of spider population up to 15 days after both the sprays.

Dose-mortality response and LC_{50} value of sulfoxaflor against brown planthopper

It was evident from Table 4 that LC_{50} value of sulfoxaflor at 24 h was 2.986 ppm against laboratory reared BPH. After 72 h of exposure, LC_{50} value of sulfoxaflor steadily declined. The increased use of the resurgence-inducing insecticides has been considered as the major cause of

Table 3. Effect of insecticides on natural enemies associated with *Nilaparvata lugens* during *kharif*, 2008 and 2009.

Treatment	Pretreatment			15 days after 1st spray				15 days after 2nd spray			
	BPH/hill	MB/hill	BPH/MB	Mean no. BPH/hill	Mean no. MB/hill	BPH/MB	Mean no. Spider/hill	Mean no. BPH/hill	Mean no. MB/hill	BPH/MB	Mean no. Spider/hill
Sulfoxaflor 14 SC	29.00	3.00 (1.87)[a]	9.67	14.73	1.67 (1.47)[b]	7.17	3.00 (1.87)[a]	8.78	1.43 (1.39)[b]	6.12	3.33 (1.96)[a]
Sulfoxaflor 14 SC	31.50	2.92 (1.85)[a]	10.78	10.17	1.33 (1.35)[bc]	7.68	3.00 (1.87)[a]	3.45	0.55 (1.02)[bc]	6.3	3.33 (1.96)[a]
Sulfoxaflor 14 SC	30.00	2.90 (1.84)[a]	10.34	9.17	1.33 (1.35)[bc]	7.89	2.67 (1.78)[a]	3.11	0.44 (0.97)[c]	7.00	3.00 (1.87)[a]
Buprofezin 25 SC	29.84	3.18 (1.92)[a]	9.38	11.78	1.67 (1.47)[b]	7.51	2.67 (1.78)[a]	3.06	0.52 (1.01)[bc]	5.85	3.67 (2.04)[a]
Imidacloprid 17.8 SL	30.67	3.32 (1.95)[a]	9.25	10.00	0.49 (0.99)[d]	18.24	3.67 (2.04)[a]	6.33	0.38 (0.94)[c]	16.51	3.00 (1.87)[a]
Acephate 75 WP	30.34	2.87 (1.84)[a]	10.56	18.28	0.83 (1.15)[cd]	22.02	4.00 (2.12)[a]	17.44	0.95 (1.20)[bc]	18.38	3.67 (2.04)[a]
Control	30.34	2.83 (1.83)[a]	10.71	43.50	2.91 (1.85)[a]	10.57	4.00 (2.12)[a]	71.06	7.07 (2.75)[a]	10.05	3.67 (2.04)[a]

Values in the parenthesis are √(x+0.5) transformed values, Means followed by a common letter in a column are not significantly different from each other by DMRT. DAS= days after spraying.

intensified brown planthopper problem. Resurgence-inducing insecticides are selectively toxic to the predators of brown planthopper and result in a dramatic increase of brown planthopper population after insecticide application. Because of its highly adaptive capacity to changing cultural practices and high reproductive potential, frequent chemical treatment in every generation is necessary to bring the population of the insect under control. In our overall findings, we found that sulfoxaflor and buprofezin performed very good spectrum of action throughout the seasons against BPH population and no resurgence phenomenon was noted at all. Sulfoxaflor showed quick knock down in action and restrained to build up the population of BPH to build up the population up to harvesting stage. Buprofezin also performed extremely well to check the population of BPH inspite of its slow in action. Slow action of buprofezin was also witnessed by Asai et al. (1983). Among the traditional neonicotinoids, imidacloprid showed lower efficacy than sulfoxaflor. In the present study, sulfoxaflor was found to be quite safe to nymphs and adults of mirid bug (*C. lividipennis*) along with buprofezin. Heinrichs et al. (1984), Krishnaiah et al. (1996), and Hedge and Nidagundi (2009) also observed that buprofezin exhibited good degree of safety to mirid bug, *C. lividipennis*. In all observations favourable ratio of BPH and

Table 4. LC_{50} values of sulfoxaflor at different interval against laboratory reared *Nilaparvata lugens*.

Treatment	df	Heterogeneity (χ^2)	Regression equation (y=)	LC_{50} (ppm)	Fuducial limit
24 h	3	0.384	4.465 + 1.126x	2.986	2.357 - 3.956
48 h	3	1.648	5.083 + 1.167x	0.849	0.597 - 1.099
72 h	3	2.739	5.689 + 1.647x	0.382	0.246 - 0.510

mirid bug was noted after sulfoxaflor and buprofezin treatments which indicated that these insecticides were safe to the population of mirid bug. Available data on sulfoxaflor regarding efficacy against BPH and safety to predators are scanty as this product is now on schedule to launch in the Indian market. Spider population did not exhibit appreciable differences among the treatments, corroborated by Krishnaiah et al. (2003) and Vijayaraghavan and Regupathy (2006)

Sulfoxaflor is one of the latest entrances with strong insecticidal activity against sap feeders. It has novel mode of action with high acute toxicity to all hemipteran pests (Galindez, 2010), because of insecticidal symptoms accompanied by discriminative action with quick knock down effect. Sulfoxaflor is very safe to non-target organisms that prove the high selectivity action to hemipteran group of insect pests particularly planthoppers and leafhoppers.

Since last several decades there had been attempt by different workers to screen various chemicals for their pesticidal activities. Most of the studies are both for academic and practical interests. Some had met complete, some with moderate and some had no success at all. Inspite of all these, we are still equally more disturbed by the insect pest. The present attempt is a part of the continuous efforts to fight against the insect pests, launched by man since the introduction of agriculture.

Conclusion

It is evident from the present investigation that Sulfoxaflor 14SC is effective against Nilaparvatalugens at 75 g ai/ha and is very safe to the important predators fauna recorded in rice eco-system.

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REFERENCES

Abbott WS (1925). Method for computing the effectiveness of insecticide. J. Econ. Entomol. 18:265-267.

Asai T, Fukada M, Maekawa S, Ikeda K, Kanno H (1983). Studies on the mode of action of buprofezin. I Nymphicidal and ovicidal activities on the brown rice planthopper, NilaparvatalugensStal (Homoptera: Delphacidae). Appl. Entomol. Zool. 18:550-552.

Galindez A (2010). Dow AgroSciences: The Growth Equation. February 10, 2010. http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9MzEwOT Z8 Q2hpb GRJRD0tMXxUeXBlPTM=&t=1(accessed on 20.07.2010).

Gao HH, Wang YC, Tan FJ, You ZP (1987). Studies on the sensitivity-level of the brown planthopper, NilaparvatalugensStål. to insecticides. J. Nanjing Agric. Univ. 4:65-71.

Grist DH, Lever RJAW (1969). Pests of Rice.Longmans, Green & Co. Ltd., London. P. 520.

Hedge M, Nidagundi J (2009). Effect of newer chemicals on planthoppers and their mirid predator in rice. Karnataka J. Agric. Sci. 22(3):511-513.

Heinrichs EA, Mochida O (1984). From secondary to major pest status.The case of insecticide-induced rice brown planthopper, Nilaparvatalugensresurgence. Prot. Ecol. 7:201-218.

Heinrichs EA, Basilio RP, Valencia SL (1984). Buprofezin, a selective insecticide for the management of rice planthoppers (Homoptera: Delphacidae) and leafhoppers (Homoptera: Cicadellidae). Environ. Entomol. 13:515-521.

Kenmore PE, Carino FD, Perez CA, Dyck VA, Gutierrez AP (1984). Population regulation of the rice brown planthopper(NilaparvatalugensStal) within rice fields in the Philippines. J. Plant Protect. Trop. 1:19-37.

Krishnaiah NV, Rama Prasad AS, Lingaiah T, Mahesh Kumar K (2003). Utilization of thiamethoxam and imidacloprid for the management of insect pest complex in rice. Indian J. Plant Prot. 31(1):51-55.

Krishnaiah NV, Reddy AA, Ramaprasad AS (1996). Studies on buprofezin and sybtheticpyrethroids against hoppers in rice. Indian J. Plant Prot. 24(1&2):53-60.

Kulshreshtha JP (1974). Field problems in 1974. 2. Brown planthopper epidemic in Kerala (India). Rice Entomol. Newslett. 1:3-4.

Nagata T, Masuda T, Moriya S (1979). Development of insecticide resistance in the brown planthopper, Nilaparvatalugens (Stål) (Homoptera: Delphacidae). Appl. Entomol. Zool. 14:264-269.

Reissig WH, Heinrichs EA, Litsinger JA, Moody K, Fiedler L, Mew TW, Barrion AT (1986). Insect pests of rice. In: Illustrated guide to integrated pest management in rice in tropical Asia. IRRI, Phillipines. pp. 175-186.

Singh SP (2000). Bio-intensive approach helpful. The Hindu Survey of Indian Agriculture. pp. 159-163.

Vijayaraghavan C, Regupathy A (2006). Impact of thiamethoxam on spiders in sugarcane ecosystem. J. Plant Prot. Environ. 3(1):36-39.

Yuanming Z, Michael RL, Gerald BW, Thomas CS, Richard BR, Jim XH, Clifford B, Jonathan G, Donald MB, Vidyadhar K, Benjamin BH, James MN, Ian MR, Kevin D, Gerrit G, James JD, Thomas H, James M, Thomas D (2011). Discovery and Characterization of Sulfoxaflor, a Novel Insecticide Targeting Sap-Feeding Pests. J. Agric. Food Chem. 59(7):2950-2957.