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Benzpyrimoxan: An Insecticide for the Control of Rice Plant Hoppers

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Abstract**—**Rice plant hoppers (Hemiptera: Delphacidae) have been causing extensive economic damage in rice and are considered as serious threat in rice producing countries of Asia. They have developed resistance to major groups of chemical insecticide, and severe outbreaks occur commonly throughout Asia. To control these nuisance pests, Nihon Nohyaku Co., Ltd., recently discovered an insecticide, benzpyrimoxan (proposed ISO name), which is under development as NNI-1501 (development code). Benzpyrimoxan has a unique chemical structure which contains benzyloxy and cyclic acetal groups on pyrimidine moiety (5-(1,3-dioxan-2-yl)-4-[4-(trifluoromethyl)benzyloxy]pyrimidine). In order to clarify the biological properties of benzpyrimoxan, we conducted several experiments and found the following results. Benzpyrimoxan has high activity against nymphal stages of rice plant hoppers without any adulticidal activity. It provides excellent and long lasting control against rice plant hoppers, including populations that have developed resistance to several other chemical groups of insecticide. The study on its mode of action is undergoing. These features highlight the versatility of this insecticide as an effective and valuable tool from the viewpoints of insecticide resistance management and integrated pest management program. With the use of benzpyrimoxan, farmers shall be able to lead the best yield potential by keeping the population density of rice plant hoppers and associated virus diseases under control.

Keywords**—**Acetal, benzpyrimoxan, insecticide, NNI-1501, pyrimidine, rice plant hoppers.

I. Introduction

RICE is an essential crop for feeding the populations of Asian countries. The yield and quality of rice are affected by different insects and diseases on every cultivated season. Rice plant hoppers (PH) are considered as one of the serious threats in causing extensive economic damage to rice production in Asia. Particularly, the brown rice PH (BPH), *Nilaparvata lugens*, and the white backed rice PH (WBPH), *Sogatella furcifera*, damage the rice plants directly by sucking. BPHs often cause hopper burn where it turns rice plant brown and makes the large patches in paddy field just before the harvest timing by sucking the phloem sap continuously from the stems [1], [2]. Furthermore, BPHs transmit viruses such as the rice ragged stunt virus and the rice grassy stunt virus. WBPHs also transmit the southern rice black-streaked dwarf virus. In recent years, it becomes very difficult to control rice PHs due to severe outbreaks and development of resistance to several existing chemical groups of insecticide in Asian countries [3]-[7]. Hence, to control these nuisance pests, Nihon Nohyaku Co., Ltd., introduced a novel insecticide, benzpyrimoxan (proposed ISO name), which is under development as NNI-1501 (development code).

This paper reports technical and biological properties of benzpyrimoxan with special reference to the evaluations in the laboratory and the field.

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II. Materials and Methods

A. Physicochemical Properties and Chemical Structure

Physicochemical properties of benzpyrimoxan are summarized in Fig. 1. Toxicological properties are also described briefly, since the details of them will be reported elsewhere. The chemical structure of benzpyrimoxan is shown in Fig. 2.

B. Insecticides Used in the Studies on Biological Evaluation

Benzpyrimoxan was formulated by formulation research unit at research center, Nihon Nohyaku Co., Ltd., as the suspension concentrate for all experiments in this paper. The other insecticides were all commercialized products.

C. Laboratory Test

All insect pests used for biological evaluation were obtained from insect cultures reared at research center, Nihon Nohyaku Co., Ltd., or collected from the field in Japan. The biological activity against insect pests was generally evaluated by the feed-dipping method. Rice seedlings or leaf discs of some vegetable plants were dipped into a test dilution for 30 seconds and air-dried. The test plant and the treated diet were placed into a glass tube or a petri-dish and 5-20 numbers of insects were inoculated.

The treated insects were maintained at 25±1°C, 60-70% R.H. and a 16L:8D photoperiod. Each treatment consisted of two replicates. The mortality was recorded at 5-7 days after treatment.

Common name:	Benzpyrimoxan (proposed ISO name)	
Chemical name:	5-(1,3-dioxan-2-yl)-4-[4-(trifluoromethyl)benzyloxy]pyrimidine	
Code name:	NNI-1501	
Appearance:	Pale yellowish white	
Melting point:	121.1 °C	
Vapor pressure:	1.39×10-5 Pa (25 °C)	
Solubility in water:	5.04 mg /L (20 °C)	
Solubility in organic solvent:	Heptane;	1.95 g /L
	Methanol;	27.9 g /L
	Acetone;	114 g /L
	Ethyl acetate;	111 g /L
	1, 2-dichloroethane;	178 g /L
	p-Xylene;	55.8 g /L
Partition coefficient:	log P o/w = 3.42 (25 °C)	
Formulation:	10%SC (w/w)	
Toxicology:		
Acute oral:	Rat Male	LD_{50} > 2,000 mg /kg
Acute dermal:	Rat Male and Female	LD_{50} > 2,000 mg /kg
Mutagenicity:	Ames	Negative
Aquatic Organism:	Carp	LC_{50} 2.2 mg /L (96hrs)
Honey bee:	Oral / Contact	LD_{50} > 100 µg /bee (48hrs)
Bird:	Oral / Bobwhite quail	LD_{50} > 2,000 mg /kg body weight

Fig. 1 Physicochemical Properties

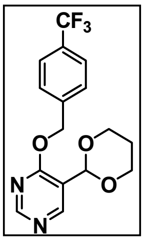

Fig. 2 Chemical Structure of benzpyrimoxan

D. Field Evaluation in Japan

Paddy fields were prepared by rice trans-planter in June, 2015 and 2016 at research center, Nihon Nohyaku Co., Ltd., in Japan. BPH adults reared in laboratory were released 5 times in the paddy field once a week from 28 to 56 days after transplanting to evaluate the efficacy of test product at heavy infestation condition. More than 300 BPH adults were released in each plot cumulatively. Each plot was designed with the plot size of 100 m^2 and all treatments were sprayed once at preventive timing (the BPH stage was mainly egg, the 1st, 2nd, and 3rd instar nymphs) by motorized sprayer with 400 L /ha at 60 to 70 days after transplanting. The field evaluation against WBPHs also conducted at same time of BPHs since they migrated a lot every June and July from other Asian countries to Japan.

The number of all the stages of BPHs and WBPHs per 40-60 randomly selected hills was recorded before application and once a week after application respectively. Because the number of observation hill was adjusted by the hopper density, the number of hopper on 10 hills were showed on the tables. The control efficacy was calculated by the below formula.

$$\% \text{ Control} = 100 - ((T1 / T0) \times (U0 / U1)) \times 100)$$

T0: The number of hopper at treated plot before application, T1: The number of hopper at treated plot after application, U0: The number of hopper at UTC plot before application, U1: The number of hopper at UTC plot after application.

E. Field Evaluation in India

Paddy field was prepared by hand transplanting as farmer's practices in the dry season of December, 2016 Rabi. The field trials were conducted in the BPH hot spot areas (Nellore and West Godavari) of Andhra Pradesh, India. Each plot was designed with the plot size of 30m^2 and each treatment consisted of three replicates. All treatments were sprayed once at preventive timing by using knapsack sprayer fitted with hollow cone nozzle with 400 L /ha at 60 to 65 days after transplanting.

The number of all the stages of BPHs per 10-20 randomly selected hills was recorded before application and once a week after application. The control effect and the number of hopper in 10 hills were calculated in the same methods as field evaluation in Japan.

III. Results and Discussion

A. Insecticidal Spectrum

The range of LC_{50} values for benzpyrimoxan against rice PHs and other insect pest species are shown in Table I. Benzpyrimoxan showed high activity against all nymphal stages of PHs, and its LC_{50} values were less than 1 mg a.i./L. It also showed good activity against the green leaf hopper and the range of LC_{50} was 3-10 mg a.i./L. As shown in the table, the insecticidal activity of benzpyrimoxan against other insect species in Hemiptera was inferior to those of PHs, indicating that benzpyrimoxan is effective very much selectively on rice PHs.

TABLE I
INSECTICIDAL SPECTRUM

Species	Stage a)	Range of LC_{50} (mg a.i. /L)
Hemiptera		
Nilaparvata lugens	N	0.1-0.3
Laodelphax striatellus	N	0.3-1
Sogatella furcifera	N	0.3-1
Nephotettix cincticeps	N	3-10
Aphis gossypii	Mix	30-100
Bemisia tabaci / typeQ	E	30-100
Stenotus rubrovittatus	N	>100
Lepidoptera		
Plutella xylostella	L	>100
Spodoptera litura	L	>100
Thysanoptera		
Frankliniella occidentalis	N	>100
Diptera		
Liriomyza sativae	E	>100
Acari		
Tetranychus urticae	A	>100

a) E: egg, N: nymph, L: larva, A: adult.

B. Cross Resistance

The activity of benzpyrimoxan against the 3rd instar nymphs of BPH collected from rice paddy fields in Japan, 2015 is shown in Table II. The collected BPH strain has developed resistance to several existing chemical insecticides, such as fipronil, etofenprox, buprofezin, and imidacloprid. The activity of benzpyrimoxan against the resistant strains was as high as susceptibility strain collected in 1983 and its R/S ratio was only 2. Lack of any cross resistance between benzpyrimoxan and conventional insecticides suggests that benzpyrimoxan would have the different mode of action from those of existing insecticides.

TABLE II
BIOLOGICAL ACTIVITY OF BENZPYRIMOXAN AGAINST THE 3RD INSTAR NYMPHS OF BPHS

Insecticide	LC_{50} value (mg a.i. /L, 5DAT)		Resistance factor (R / S ratio)
	Resistant strain	Susceptible strain	
	2015 a)	1983	
Benzpyrimoxan	0.23	0.12	1.9
Fipronil	1.67	0.31	5.4
Etofenprox	19.31	2.27	8.5
Buprofezin	60.05	0.11	545.9
Imidacloprid	34.81	0.02	1740.5

a) collected year in Japan

C. Insecticidal Activity on Different Development Stages

The activity of benzpyrimoxan against different developmental stages of BPH susceptibility strain is shown in Table III including the reference compounds. Benzpyrimoxan was most effective on the 1st to 3rd instar nymphs incontrast to adults. The range of LC_{50} values of benzpyrimoxan against nymphs were 10-30 times higher than etofenprox and comparable to buprofezin; however, it has no adult activity as same as buprofezin. Based on those results, benzpyrimoxan is recommended to be positioned as preventive product in the spray calendar of BPH.

TABLE III
ACTIVITY ON DIFFERENT DEVELOPMENTAL STAGES OF BPHS

Insecticide	Range of LC_{50} (mg a.i. /L, 5DAT)		
	Nymph		Adult
	1st instar	3rd instar	
Benzpyrimoxan	0.1-0.3	0.1-0.3	>100
Buprofezin	0.1-0.3	0.1-0.3	>100
Etofenprox	1-3	1-3	1-3

D. Field Evaluation

The performance of benzpyrimoxan against important rice PHs such as BPHs and WBPHs were evaluated at paddy fields in Japan and India, respectively. As exemplified in Tables IV-VIII, benzpyrimoxan provided excellent control efficacy at the dose of 50 to 75 g a.i./ha against BPHs and WBPHs which were reported to be resistant to conventional insecticides. Once benzpyrimoxan was sprayed at preventive timing particularly when the BPH population was in egg, the 1st, 2nd, and 3rd instar nymphs, further population increase was completely kept under control, and the residual effect lasted for at least three weeks.

IV. CONCLUSION

Benzpyrimoxan is an extremely promising hopper insecticide with low impact on non-target organisms including pollinators and beneficial arthropods (data not shown). The field biological performance of benzpyrimoxan revealed favorable environmental profile without any resurgence and with high activity even against PHs that had developed resistance to major chemical class of insecticide. Due to severe outbreaks and quick resistance development nature, controlling PHs is a herculean task, and benzpyrimoxan provides an effective solution for PHs menace in rice ecosystem.

TABLE IV
EFFICACY OF BENZPYRIMOXAN AGAINST BPHS ON PADDY FIELDS IN JAPAN, 2015

Insecticide	Dosage (g a.i. /ha)	Number of BPH per 10 hills					% control			
		0DAT a)	6DAT	14DAT	26DAT	36DAT	6DAT	14DAT	26DAT	36DAT
Benzpyrimoxan	75	66	4	1	39	44	98	99	92	96
	50	128	20	10	53	159	95	96	94	93
Pymetrozine	150	143	25	6	16	25	94	98	98	99
	100	109	10	1	21	58	97	99	97	97
Untreated control	-	133	406	256	932	2235	0	0	0	0

a) days after treatment. Date of applied: August 7th, 2015

TABLE V
EFFICACY OF BENZPYRIMOXAN AGAINST BPHS ON PADDY FIELDS IN JAPAN, 2016

Insecticide	Dosage (g a.i. /ha)	Number of BPH per 10 hills					% control			
		0DAT a)	8DAT	14DAT	21DAT	28DAT	8DAT	14DAT	21DAT	28DAT
Benzpyrimoxan	75	169	5	0	0	6	98	100	100	99
	50	204	6	1	10	25	98	99	96	95
Pymetrozine	150	283	5	1	0	17	99	99	100	98
Untreated control	-	249	310	138	280	606	0	0	0	0

a) days after treatment. Date of applied: August 2nd, 2016

TABLE VI
EFFICACY OF BENZPYRIMOXAN AGAINST WBPHS ON PADDY FIELDS IN JAPAN, 2016

Insecticide	Dosage (g a.i. /ha)	Number of BPH per 10 hills			% control	
		0DAT a)	7DAT	14DAT	7DAT	14DAT
Benzpyrimoxan	75	61	2	4	99	98
	50	92	12	16	95	94
Pymetrozine	150	39	14	8	87	93
	100	47	15	9	88	93
Untreated control	-	38	105	107	0	0

a) days after treatment. Date of applied: August 4th, 2016

TABLE VII
EFFICACY OF BENZPYRIMOXAN AGAINST BPHS ON PADDY FIELDS IN WEST GODAVARI, INDIA, 2016-17 RABI

Insecticide	Dosage (g a.i. /ha)	Number of BPH per 10 hills					% control			
		0DAT a)	7DAT	14DAT	21DAT	28DAT	7DAT	14DAT	21DAT	28DAT
Benzpyrimoxan	75	1145	163	23	8	4	94	99	100	98
	50	796	403	46	18	7	78	96	99	96
BPMC	750	511	1405	903	990	67	0	0	38	43
Fipronil	75	1052	1057	562	640	69	57	64	80	72
Untreated control	-	645	1503	957	2012	149	0	0	0	0

a) days after treatment. Date of applied: March 5th, 2016

TABLE VIII
EFFICACY OF BENZPYRIMOXAN AGAINST BPHS ON PADDY FIELDS IN NELLORE, INDIA, 2016-17 RABI

Insecticide	Dosage (g a.i. /ha)	Number of BPH per 10 hills				% control		
		0DAT a)	7DAT	14DAT	21DAT	7DAT	14DAT	21DAT
Benzpyrimoxan	75	114	86	11	5	90	97	91
	50	101	127	21	10	83	95	78
Pymetrozine	150	118	78	6	11	91	99	81
	100	115	173	19	11	80	96	79
Untreated control	-	128	969	487	61	0	0	0

a) days after treatment. Date of applied: October 16th, 2016

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