Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2018; 6(1): 230-234

Received: 11-11-2017
Accepted: 13-12-2017

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Evaluation of bioefficacy, phytotoxicity of imidacloprid 17.1% SL against plant and leaf hoppers and its safety to non-target invertebrates in rice

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Abstract
The two field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to evaluate bioefficacy, phytotoxicity effect if any of imidacloprid 17.1% SL against plant and leaf hoppers and its safety to non target invertebrates in rice during September – December 2014 and January – April 2016. The results revealed that imidacloprid 17.1% SL @ 60 g ai ha^{-1} was effective in reducing plant and leaf hoppers population. The pooled mean population (two consecutive seasons) of BPH, WBPH and GLH was recorded as 0.78, 0.60 and 0.60 hill^{-1} respectively. The imposed treatments were found safer to non target invertebrates like spiders, coccinellids and rove beetles. Furthermore, no phytotoxic effect was observed even in treatments imposed with imidacloprid 17.1% SL @ 60, 120 and 240 g ai ha^{-1}.

Keywords: Neonicotinoids, imidacloprid, brown plant hopper, whitebacked plant hopper and green leaf hopper

Introduction
Rice is the important staple food crop for more than two third of the population of India and more than 65 percent of the world population [1]. Rice is cholesterol free and excellent source of carbohydrate that provides about 29.4 per cent of total calories /capita /day in Asian countries [2]. India is the largest rice growing country, accounting for more than 40 per cent food grain production [3]. Unfortunately, just like any other crop, the rice production system is also infested by a host of pests-insects, weeds, diseases, rodents, etc. and exact a heavy toll on crop production efforts. Rice is vulnerable to attack by various insect pests from seedling to harvesting stage. About 300 species of insects have been reported to attack rice crop, of which, 20 were major pests [4]. Brown planthopper, *Nilaparvata lugens* (Stal) (BPH), whitebacked planthopper, *Sogatella furcifera* (Horvath) (WBPH) and green leafhopper, *Nephotettix virescens* (Distant) (GLH) are the most economically important sucking pests in early growing stages due to direct damage and as vectors of viral diseases [5]. Both the nymphs and adults of these monophagous pests are phloem and xylem feeders extracting nourishment directly from the plant which induces complex plant responses with direct and indirect deleterious effects [6].
In order to combat these insect pests, chemical insecticides are used as the frontline defence sources. Even though conventional broadspectrum insecticides like organochlorines, organophosphates and carbamates were effective, their abuse brought about resistance in insects, destruction of natural enemies and pollution in environment [7]. The latest from the armoury of insectides that solves the constraints of the conventional insecticides are the neonicotinoid group of insecticides [8]. This group of insecticides occupied preponderance in management of hemipteran pests such as aphids, whiteflies and plant hoppers but also commercialized to control many coleopteran pests and some lepidopteran pest species due to their systemic mode of action. [9]. Among, imidacloprid 1[(6-chloro-3-pyridynyl) methyl]–4–5 – dihydro – N – nitro – 1H – imidazole – 2 amine] belonging to the chloronicotinyl subfamily is the most important neonicotinoid used primarily as a systemic compound and used as seed dressing, soil application and foliar treatment in many crops in different formulations [10].
Nevertheless, imidacloprid 17.8% SL was used universally for the management of brown

plant hopper, the present study was undertaken with reduced active ingredient *viz.*, imidacloprid 17.1% SL for evaluation of bioefficacy against plant hoppers, phytotoxicity if any and its effect on generalist predators available in rice ecosystem.

Materials and methods

Two field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore during September – December 2014 and January – April 2016 (Variety: CO – 50). The experiment was laid out in Randomized Block Design with three replications. The plants were monitored regularly for pest incidence and when hoppers population reached economic threshold level the following treatments were imposed. T_1 - Imidacloprid 17.1% SL w/w @ 40 g ai ha^{-1} ; T_2 - Imidacloprid 17.1% SL w/w @ 50 g ai ha^{-1} ; T_3 - Imidacloprid 17.1% SL w/w @ 60 g ai ha^{-1}; T_4 - Imidacloprid 17.8% SL w/w @ 25 g ai ha^{-1}; T_5 - Buprofezin 25% SC @ 200 g ai ha^{-1}; T_6 – Thiamethoxam 25% WG @ 25 g ai ha^{-1}; T_7 – Untreated control. The treatments were sprayed with pneumatic knapsack sprayer using 500 litres of spray fluid per hectare.

(i) Assessment of pest and natural enemies population

Observations on the plant and leaf hoppers were recorded on ten randomly selected hills per plot a day before and 3, 5 and 7 Days after treatment (DAT) and expressed as numbers hill^{-1}. The day observations were pooled, mean population and per cent reduction over control was calculated after each spray.

$$\text{Percent reduction over control (\% ROC)} = \frac{\text{Mean population in control – mean population in treatment}}{\text{Mean population in control}} * 100$$

The population of natural enemies *viz*., spiders, rove beetles and coccinellids was recorded to assess the safety of insecticides at five randomly selected hills and expressed as numbers per five hills. Grain yield was recorded from each plot and pooled to express as tonnes ha^{-1}.

(ii) Assessment of phytotoxicity

The hills were sprayed with imidacloprid17.1% SLw/w @ 60, 120 and 240 g a.i. ha^{-1} to assess the occurrence of phytotoxicity. The hills were observed on 1, 3, 7, 10, 14 and 21 days after spraying as per the protocol of Central Insecticide Board Registration Committee (C.I.B. and R.C) for the phytotoxic symptoms like injury to leaf tip and leaf surface, Wilting, Vein clearing, Necrosis, epinasty and hyponasty which were recorded based on the following visual rating scale and per cent leaf injury was calculated

Rating	Phytotoxicity (%)
0	No phytotoxicity
1	1-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9	81-90
10	91-100

$$\text{Per cent leaf injury} = \frac{\text{Total grade points}}{\text{Max. grade x No. of leaves observed}}$$

(iii)Statistical analysis

The population of pest, predators and yield data was subjected to square root transformation before statistical analysis. The transformed data was subjected to one way ANOVA for analysis of variation between treatments. The significant difference between treatments was judged by CD at 5% level of significance. Furthermore, mean population of two seasons were pooled and subjected to statistical analysis.

Results

(i) Bioefficacy against plant and leaf hoppers

The two rounds of imidacloprid 17.1% SL foliar application were effective in reducing plant and leaf hopper population. Among, imidacloprid 17.1% SL w/w @ 60 g a.i. ha^{-1} was vastly effective against brown planthopper (BPH), white backed plant hopper (WBPH) and green leafhopper (GLH). Regarding BPH, the lowest mean population of 0.63 hill^{-1} was observed in imidacloprid 17.1% SL w/w @ 60 g a.i. ha^{-1}, followed by imidacloprid 17.1% SL w/w @ 50 g a.i. ha^{-1} (1.48 nos. hill^{-1}). As well, the standard checks, buprofezin 25% SC @ 200 g a.i. ha^{-1} and thiamethoxam 25 WG @ 20 g a.i. ha^{-1} recorded mean population of 1.77 and 2.12 nos. hill^{-1}, respectively. Imidacloprid 17.1% SL w/w @ 40 g a.i. ha^{-1} and imidacloprid 17.8% SL w/w @ 25 g a.i. ha^{-1} recorded 3.05 and 3.96 nos. hill^{-1}, besides the highest population in untreated control (12.56 nos. hill^{-1}). Pertaining to the population of WBPH and GLH, analogous observations were recorded. Imidacloprid 17.1% SL w/w @ 60 g a.i. ha^{-1} treatment exhibited lowest mean population of 0.60 nos. hill^{-1} of WBPH and GLH, respectively followed by imidacloprid 17.1% SL w/w @ 50 g a.i. ha^{-1} (1.17 and 1.36 nos. hill^{-1}, respectively). Furthermore, the population of WBPH and BPH was under reduction in standard checks, buprofezin 25% SC @ 200 g a.i. ha^{-1} (1.34 and 1.66 nos. hill^{-1}, respectively) and thiamethoxam 25 WG @ 20 g a.i. ha^{-1} (1.54 and 1.90 nos. hill^{-1}, respectively). The untreated control recorded highest WBPH and GLH population of 7.43 and 11.45 nos. hill^{-1}, respectively (Table 1).

(ii) Impact on non – target invertebrates and yield

The generalist predators that is commonly available in rice ecosystem viz., spiders, coccinellids and rove beetles were choosen as non – target invertebrates and their population was assessed to study the impact of insecticide treatments. Imidacloprid 17.1% SL w/w, irrespective of doses was found to be relatively safer to spiders, coccinellids and rove beetles. Imidacloprid 17.1% SL w/w@ 40 g a.i ha^{-1} was observed to host highest number of spiders (5.01 five hills^{-1}), coccinellids (6.78 five hills^{-1}) and rove beetle (4.93 five hills^{-1}) subsequent to untreated control. As well imidacloprid 17.1% SL w/w@ 50 and 60 g a.i ha^{-1} also recorded higher mean population of spiders (4.69 and 4.50 five hills^{-1}, respectively), coccinellids (6.27 and 6.05 five hills^{-1}) and rove beetles (4.50 and 4.30 five hills^{-1}, respectively). On the subject of standard checks, buprofezin 25% SC @ 200 g a.i. ha^{-1}, thiamethoxam 25%WG @ 25 g a.i. ha^{-1} and imidacloprid 17.8% SL @ 25 g a.i. ha^{-1}, mean spider population of 4.35, 4.17 and 3.63 five hills^{-1}, respectively, mean coccinellid population of 5.93, 5.84 and 5.19 five hills^{-1} respectively and mean rove beetle

population as 4.20, 4.04 and 3.38 five hills^{-1} respectively was recorded (Table 2).
The average grain yield in all the treatments ranged from 4.38 to 4.97 t ha^{-1} whereas 2.54 t ha^{-1} was observed in untreated control. Among, treatment imposed with imidacloprid 17.1% SL @ 60 g a.i. ha^{-1} recorded highest grain yield of 4.97 t ha^{-1} and straw yield (5.88 t ha^{-1}) (Table 3). The hills sprayed with imidacloprid 17.1% SL @ 60, 120 and 240 g a.i. ha^{-1} did not show any phhytototoxic symptoms like leaf tip injury, wilting, vein clearing, necrosis, epinasty, hyponasty

Table 1: Bioefficacy of imidacloprid 17.1% SL against plant and leaf hoppers in rice

S.No	Treatment	Dose (g a.i ha^{-1})	Mean population (Nymphs and adults)/ hill								
			Brown planthopper			White backed planthopper			Green leaf hopper		
			I Season	II Season	Mean	I Season	II Season	Mean	I Season	II Season	Mean
1.	Imidacloprid 17.1% SL w/w	40	2.90	3.21	3.05	2.56	2.06	2.31	2.62	2.65	2.64
2.	Imidacloprid 17.1% SL w/w	50	1.68	1.27	1.48	1.37	0.96	1.17	1.48	1.11	1.30
3.	Imidacloprid 17.1% SL w/w	60	0.97	0.29	0.63	0.78	0.42	0.60	0.79	0.40	0.60
4.	Imidacloprid 17. 8% SL w/w	25	3.65	4.17	3.91	3.46	2.62	3.04	3.33	3.42	3.38
5.	Buprofezin 25% SC	200	1.81	1.73	1.77	1.43	1.24	1.34	1.59	1.49	1.54
6.	Thiamethoxam 25% WG	25	2.17	2.22	2.12	1.80	1.52	1.66	1.92	1.88	1.90
7.	Untreated control	-	11.63	13.49	12.56	7.80	7.06	7.43	11.71	10.98	11.35

Table 2: Effect of imidacloprid 17.1% SL on non target invertebrates in rice

S.No	Treatment	Dose (g a.i ha^{-1})	Mean population / five hills								
			Spiders			Coccinellids			Rove beetles		
			I Season	II Season	Mean	I Season	II Season	Mean	I Season	II Season	Mean
1.	Imidacloprid 17.1% SL w/w	40	6.13	3.88	5.01	7.70	5.85	6.78	4.30	5.55	4.93
2.	Imidacloprid 17.1% SL w/w	50	5.68	3.70	4.69	6.96	5.58	6.27	3.76	5.24	4.50
3.	Imidacloprid 17.1% SL w/w	60	5.48	3.51	4.50	6.83	5.27	6.05	3.63	4.96	4.30
4.	Imidacloprid 17. 8% SL w/w	25	4.23	3.03	3.63	5.74	4.63	5.19	2.45	4.31	3.38
5.	Buprofezin 25% SC	200	5.25	3.45	4.35	6.63	5.22	5.93	3.47	4.92	4.20
6.	Thiamethoxam 25% WG	25	4.93	3.40	4.17	6.50	5.18	5.84	3.22	4.86	4.04
7.	Untreated control	-	7.17	5.82	6.50	9.07	7.94	8.51	7.45	8.65	8.05

Table 3: Impact of imidacloprid 17.1% SL on straw and grain yield in rice

S. No.	Treatments	Dose (g a.i. ha^{-1})	Straw yield (t ha^{-1})			Grain yield (t ha^{-1})		
			I Season	II Season	Mean	I Season	II Season	Mean
1.	Imidacloprid 17.1% SL w/w	40	5.76	5.74	5.75	4.60	4.70	4.65
2.	Imidacloprid 17.1% SL w/w	50	5.81	6.00	5.91	4.72	4.86	4.79
3.	Imidacloprid 17.1% SL w/w	60	5.90	5.85	5.88	4.90	5.03	4.97
4.	Imidacloprid 17.8% SL w/w	25	5.54	5.65	5.60	4.25	4.50	4.38
5.	Buprofezin 25% SC	200	5.80	5.84	5.82	4.71	4.72	4.72
6.	Thiamethoxam 25% WG	25	5.76	5.83	5.80	4.68	4.75	4.72
7.	Untreated check	-	4.34	4.56	4.45	2.07	3.00	2.54

Discussion

The above investigation reveals imidacloprid 17.1% SL @ 60 g a.i. ha^{-1} as preeminent among the treatments in control of plant and leaf hoppers. Neonicotinoids can be considered substances acting as agonists on nAChRs opening cation channels [11]. Voltage-gated calcium channels are also involved [12] in their insecticidal activity [13-17] and [18]. Neonicotinoid insecticides represent the fastest growing class of insecticides introduced to the market since the launch of pyrethroids [19]. The current market share of this group of insecticides is well above 600 million Euros per year, including imidacloprid as the biggest selling insecticide worldwide [20]. Electrophysiological studies have shown that the binding potency of neonicotinoids to brain membranes is well and positively correlated with their agonistic and insecticidal activity. This suggests that the channel opening of nAChRs induced by the binding of neonicotinoids to receptors leads to insecticidal activity [15, 21]. As a result, their agonistic action induces continuous excitation of the neuronal membranes, producing discharges leading to paralyses and cell energy exhaustion. This binding potency is conferred by a unique molecular conformation [22]. However, the interaction of this conformation with the receptor may vary depending on their different chemical substituents and on the species considered [23]. Imidacloprid selectively inhibits desensitizing nicotinic currents, while displaying a selective desensitization toward certain nAChR subtypes [24]. This indicates that selective desensitization of certain nAChR subtypes can account for the insecticidal actions of imidacloprid. This indicates that selective desensitization of certain nAChR subtypes can account for the insecticidal actions of imidacloprid. The electronegative toxicophore of neonicotinoids and the cationic toxicophore of nicotinoids (nicotine, epibatidine, and desnitro-imidacloprid) lead to them docking in opposite directions at the binding sites [17, 25].
The copious findings had been reported on the efficacy of imidacloprid 17.8% SL against hoppers in rice and sucking pests in other crops. Set against this, the scant works are available with efficacy of imidacloprid 17.1% SL. Imidacloprid 17.5% SL @ 0.25 ml litre^{-1} was found highly effective in reducing brown plant hopper population with knock down effect [26]. In the evaluation of different insecticides against plant and leaf hoppers, conducted at Dept. of Entomology, IGKV, Raipur, application of buprofezin 25% SC @ 800 ml ha^{-1} and imidacloprid 17.1% SL @ 300 ml ha^{-1} were found to be highly effective against BPH and WBPH

and found superior to imidacloprid 17.8% SL. The treatments were found safe to non-target invertebrates (Spiders and coccinellids) and recorded higher yield. On the basis of mean population after two consecutive sprays at weekly interval, the lowest mean population was recorded as 2.62 hill^{-1} in buprofezin 25% SC @ 800 ml ha $^{-1}$ and 3.25 hill^{-1} in imidacloprid 17.1% SL @ 300 ml ha^{-1} and both treatments were found to be statistically on par. Alike, mean population of WBPH was recorded as 1.08 and 1.62 hill^{-1}, respectively in buprofezin 25% SC @ 800 ml ha $^{-1}$ and imidacloprid 17.1% SL @ 300 ml ha^{-1}. Besides, thiamethoxam 25% WG and buprofezin 25% SC @ 800 ml ha $^{-1}$ was found effective against GLH. The mean population of spiders and coccinellids was recorded as 0.97 and 0.52 five hills^{-1}, respectively in imidacloprid 17.1% SL @ 300 ml ha^{-1} and the same recorded 9.33 q ha^{-1} increase in yield over control [27].

The efficacy may be attributed towards its (i) systemic nature, viz., Irrespective of their mode of application, neonicotinoids become distributed throughout the plant, including the apices of new vegetation growth, making them particularly effective against sucking pests, both above ground and below (ii) their multiple binding sites, which is relatively common feature of neonicotinoids. The existence of two imidacloprid binding sites has been confirmed in the brown planthopper (N. lugens) [28]. Two [3 H]-imidacloprid binding sites have been identified with different affinities (Kd=3.5 pM and Kd=1.5 nM) and subunit co-assemblies (α1, α2, and β1 for the low-affinity nAChR and α3, α8, and β1 for the high-affinity nAChR) and (iii) persistence of metabolites. Contrary to acetylcholine, acetylcholinesterase does not act on nicotine nor imidacloprid, and possibly on the other neonicotinoids, leading to their prolonged action on the nAChRs [29]. Furthermore, poor neuronal detoxification mechanisms may contribute to a prolonged action at this level [30]. 6-chloronicotinic acid (6-CNA) is a metabolite common to chloropyridinyl neonicotinoids [31] and [32]. As well, imidacloprid has been shown to stimulate plant growth of genetically modified stress tolerant plants, even in the absence of damaging pest species, leading to increase in crop yield. As a result, treated plants respond better to the effects of abiotic stressors such as drought [33]. The metabolite 6-CNA has been suggested to be responsible for the physiological plant changes as it is known to induce a plant’s own defenses against plant disease [34].

Hence, foliar spray of imidacloprid 17.1% SL @ 60 g a.i. ha^{-1} can be recommended for management of plant and leaf hoppers, since they exhibit no phytotoxicity and found to be safer to non-target invertebrates and also does not cause any interruption in ecosystem.

Acknowledgement

The authors are grateful to Bayer Crop Science Ltd for sponsoring the trial and Dept. of Agrl. Entomology, TNAU, Coimbatore for successful conduct of the experiment.

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