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RESEARCH ARTICLE

Bioefficacy of Flupyradifurone 200 SL Against Jassids, Whiteflies and Their Impact on Natural Enemies in Brinjal

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ABSTRACT

Two field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to evaluate bioefficacy, phytotoxicity effect if any of flupyradifurone 200 SL against whiteflies and leaf hoppers and its safety to non target invertebrates in brinjal during 2015 – 16. The results revealed that flupyradifurone 200 SL@ 175 g ai ha^{-1} was effective in reducing whiteflies and leaf hoppers population. The whiteflies per cent reduction of 96.40 and 95.77 was obtained in first and second season, respectively. Similarly, regarding leaf hopper 96.35 and 97.92 per cent reduction over control was recorded. The imposed treatments were found safer to non target invertebrates like spiders and coccinellids. Furthermore, no phytotoxic effect was observed even in treatments imposed with flupyradifurone 200 SL @ 75 and 150 g a.i. ha^{-1}.

Keywords: *Flupyradifurone, whiteflies, leafhoppers, brinjal, safety.*

INTRODUCTION

Brinjal (*Solanum melongena* Linn.) commonly known as egg plant and forever as "King of Vegetables" (Thompson and Kelly, 1957) is cultivated extensively in India under diverse agro climatic conditions and throughout the year (Nayak *et al.,* 2014). The production statistics of 2014-15 divulged that brinjal is cultivated in 6, 80,000 ha with productivity of 12, 706, 000 tonnes (Saxena, 2015). It is ranked among top ten vegetables in terms of antioxidant capacity and flavonoid constituents (Timberlake, 1981; Singh *et al.,* 2009) which have been associated with various health benefits (Ames *et al.,* 1993; Hung *et al.,* 2004). The extracts from brinjal contain anthocyanins and strychnine which are effective in curing a number of diseases including cancer, high blood pressure and hepatosis (Magioli and Mansur, 2005; Silva *et al.,* 1999). In view of ecological sustainability, brinjal is also not exempted from biotic stress and more than 30 insect pests are found to cause significant damage right from germination to harvest (Ragupathy *et al.,* 1997). Nevertheless shoot and fruit borer (*Leucinodes orbonalis* Gu.) is considered to be abnoxious, sucking pests *viz.,* leaf hoppers (*Amrasca biguttula biguttula* Ishida and *A. devastans* Distant) and whiteflies (*Bemisia tabaci* Gennadius) are under prime consideration that causes inflicting level of damage and yield loss (Goshal and Chaterjee, 2013; Mahmood *et al.,* 2002; Kalawate and Dethe, 2012; Sultana *et al.,* 2012; Shrinivasan and Babu, 2001). Both leafhoppers and whiteflies are widely distributed in tropical, sub tropical and temperate regions. The nymphs and adults suck sap from the lower surface of leaves, by which nutrient translocation is disrupted in conducting vessels and also apparently introduce a toxin that affects photosynthesis in proportion to the amount of feeding resulting in hopper burn. Besides, the honeydew secretion attracts black sooty mold that impairs photosynthesis and moreover both pests are considered to be potential vectors of copious viruses (Sharma and Chander, 1998).

The management of pests by insecticide application remains to be frontline and unsurpassed technique. On the other hand as survival to the fittest, insects also develop resistance even for molecules that target unique sites as mode of action. One such group of insecticides, recognized universally for the management of sap sucking group of insects was neonicotinoids and copious numbers of insecticides had been evaluated for efficacy against sucking pests alone and in combination with shoot and fruit borer. To cite few efficacy findings in brinjal, imidacloprid @ 18 and 22.5 g ha^{-1} and thiamethoxam @ 25 and 50 g ha^{-1} against leafhopper and whitefly (Mhaske and Mote, 2005); Imidacloprid 70 WG @ 0.2 g L^{-1}, buprofezin 40 SC @ 2 mL L^{-1} and fipronil 50 SC @ 2mL and 1 mL L^{-1} against jassids and whiteflies (Das and Islam, 2014). Imidacloprid 17.8 SL @ 0.5 mL L^{-1} against aphids, leaf hoppers and whiteflies (Rajesh Kumar *et al.,* 2017); Thiamethoxam @ 0.025%, diafenthiuron @ 0.05% , thiacloprid @ 0.012% against leaf hopper; spiromesifen @ 0.024%, diafenthiuron @ 0.05% and triazophos @ 0.08% against whiteflies

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(Shaikh and Patel, 2012); Flubendiamide 24% w/v + thiacloprid 24% sc w/v @ 84 + 84 g a.i ha^{-1} against aphids, jassids and thrips (Sangamithra *et al.,* 2018). Besides development of molecules with novel mode of action, crisis of resistance development is inevitable, hence standardization and commercialization of newer molecules of insecticides is mandate to attain sustainable pest management. New selective insecticides compatible with modern integrated pest management (IPM) principles addressing the regulatory needs for an improved toxicological and environmental profile will stepwise replace older chemistry suffering from resistance development in many invertebrate pests frequently targeted by indispensable chemical treatments in some agricultural settings (Nauen *et al.,* 2012). In search of new chemical scaffolds leading to novel chemical classes of insecticides, particularly for sucking pest control, the natural product stemofoline known as a potent agonist of insect nicotinic acetylcholine receptors (nAChRs), was considered as a good starting point and seed for the development of flupyradifurone, the first representative of the novel butenolide class of insecticides active against various sucking pests (Tamura *et al.,* 1978; Uvary, 1999). Its mode of action is similar to neonicotinoids that acts on nAcH receptors, however chemical structure differs from nitroguanidine neonicotinoids, hence placed under sub group Group 4 in IRAC classification (Jeschke *et al.,* 2013; Jeschke and Nauen, 2008). In this regard, two field experiments were conducted during two consecutive years (2015 - 2016) to evaluate bioefficacy of flupyradifurone 200 SL, phytotoxicity if any and its impact to non – target organisms.

MATERIAL AND METHODS

Two field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore during July – October 2015 and January – May 2016 (Variety: CO – 2). The experiment was laid out in Randomized Block Design with four replications. The treatment details were T1 – Flupyradifurone 200 SL @ 125 g a.i ha^{-1}; T2 - Flupyradifurone 200 SL @ 150 g a.i ha^{-1}; T3 - Flupyradifurone 200 SL @ 175 g a.i ha^{-1}; Phosphamidon 40 % SL @ 300 g a.i. ha^{-1} and T5 – Untreated control. The treatments were imposed on 30 days old crop and applied twice at weekly interval. The treatments were sprayed with pneumatic knapsack sprayer using 500 litres of spray fluid per hectare.

(i) Method of assessment of pest and natural enemies population

The population of sucking pests *viz*., whiteflies (nymphs) and leaf hopper were recorded on six leaves per plant (three leaves at top and three leaves at bottom) of five randomly selected plants per plot prior to spraying followed by 3,7,10 and 15 days after each spray and expressed as number per six leaves. The day observations were pooled, mean population and per cent reduction over control was calculated after each spray. Brinjal yield per plot was recorded from each harvest and pooled to arrive at the total yield and expressed as tonnes ha^{-1}. Five randomly selected plants per plot were thoroughly observed for population of natural enemies. The population of the predators (coccinellids and spiders) was recorded before and 3, 7, 10 and 15 days after each spraying and expressed as numbers per five plants.

(ii) Assessment of phytotoxicity

The plants were sprayed with flupyradifurone 200 SLw/w @ 175 and 350 g a.i. ha^{-1} to assess the occurrence of phytotoxicity. The plants 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 of 0 – 10 *viz*., 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 % and 10 - 91-100 %. Per cent leaf injury was calculated using the formulae

$$Per\ cent\ leaf\ injury = \frac{Total\ grade\ points}{Max.grade\ X\ No.of\ leaves\ observed}\ x\ 100$$

(iii) Statistical analysis

The corrected per cent reduction of pest population over control in the field was worked out by using the formula given by Henderson and Tilton (1955).

$$\text{Corrected per cent reduction} = \left(1-\left[\frac{T_a \times C_b}{T_b \times C_a}\right]\right) x\ 100$$

where, T_a - Number of insects in the treatment after spraying; T_b - Number of insects in the treatment before spraying; C_b - Number of insects in the untreated check before spraying; C_a - Number of insects in the untreated check after spraying

The data on percentage was transformed into arc sine values and the population number into square root values before statistical analysis. The data obtained from field experiments were analysed in randomized block design (RBD) (Gomez and Gomez, 1984). The mean values were separated using Duncan's Multiple Range Test (DMRT) (Duncan, 1951).

RESULTS AND DISCUSSION

(i) Bioefficacy of flupyradifurone 200 SL against whiteflies

The population of whiteflies before application of treatments ranged from 15.70 to 16.35 six leaves^{-1} (Table 1). Flupyradifurone 200 SL at 175 g a.i / ha significantly reduced whiteflies population and recorded lowese mean population of 4.12 nymphs six leaves^{-1} with 76.23 per cent reduction over control after first spray.

Table 1. Effect of flupyradifurone 200 SL against whitefly in brinjal

Treatments	Number of whitefly nymphs six leaves $^{-1}$											
	I Season						II Season					
	First spray			Second spray			First spray			Second spray		
	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC
Flupyradifurone 200 SL @ 125 g a.i/ha	15.80	6.46 (2.54)^{c}	62.70	6.28	2.91 (1.71)^{c}	86.49	17.00	8.25 (2.87)^{c}	58.56	7.10	3.60 (1.90)^{c}	84.98
Flupyradifurone 200 SL @ 150 g a.i/ha	16.20	5.19 (2.28)^{b}	70.03	5.15	1.73 (1.32)^{b}	91.99	17.12	7.08 (2.66)^{b}	64.47	5.80	2.12 (1.46)^{b}	91.15
Flupyradifurone 200 SL @ 175 g a.i/ha	15.90	4.12 (2.03)^{a}	76.23	4.07	0.78 (0.88)^{a}	96.40	18.04	5.84 (2.42)^{a}	70.66	4.58	1.01 (1.00)^{a}	95.77
Phosphamidon 40% SL @ 300 g a.i/ha	16.35	6.68 (2.58)^{d}	61.43	6.40	3.06 (1.75)^{d}	85.78	17.50	8.44 (2.91)^{d}	57.63	7.32	3.99 (2.00)^{d}	83.35
Untreated check	15.70	17.33 (4.16)^{e}	-	18.95	21.54 (4.64)^{e}	-	18.33	19.92 (4.46)^{e}	-	21.06	23.94 (4.89)^{e}	-
SE. d	-	0.01	-	-	0.02	-	-	0.01	-	-	0.03	-
CD (P = 0.05)	-	0.03	-	-	0.04	-	-	0.03	-	-	0.07	-

*Mean of four observations; Values in parantheses are square root transformed values; In a column, means followed by a common letter are not significantly different by LSD (P=0.05) PTC- Pretreatment count; DAT – Days after treatment; PRC – Percent reduction over control

This was followed by flupyradifurone 200 SL at 150 g a.i / ha (5.19 nymphs six leaves^{-1} with 70.03 per cent reduction over control) and flupyradifurone 200 SL at 125 g a.i / ha (6.46 nymphs six leaves^{-1} with 62.70 per cent reduction over control). The standard check, phosphamidon 40% SL at 300 g a.i/ ha also reduced whitefly population to 6.68 nymphs six leaves^{-1} with 61.43 per cent reduction over control. After second application, similar trend in reduction was observed and flupyradifurone 200 SL at 175 g a.i / ha reduced the population completely and recorded mean population of 0.78 nymphs six leaves^{-1} followed by flupyradifurone 200 SL at 150 g a.i / ha (1.73 nymphs six leaves^{-1}).

Table 2. Effect of flupyradifurone 200 SL against leaf hoppers in brinjal

Treatments	Number of leaf hoppers six leaves $^{-1}$											
	I Season						II Season					
	First spray			Second spray			First spray			Second spray		
	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC
Flupyradifurone 200 SL @ 125 g a.i/ha	13.95	5.13 (2.26)^{c}	67.72	5.00	3.00 (1.73)^{c}	85.66	10.15	5.72 (2.39)^{c}	60.38	4.56	2.73 (1.65)^{c}	86.81
Flupyradifurone 200 SL @ 150 g a.i/ha	14.00	4.26 (2.06)^{b}	73.20	4.56	1.91 (1.38)^{b}	90.86	10.58	4.50 (2.12)^{b}	68.83	3.48	1.45 (1.20)^{b}	93.00
Flupyradifurone 200 SL @ 175 g a.i/ha	13.70	2.91 (1.71)^{a}	81.68	3.20	0.76 (0.87)^{a}	96.35	10.34	3.31 (1.82)^{a}	77.12	2.60	0.43 (0.66)^{a}	97.92
Phosphamidon 40% SL @ 300 g a.i/ha	13.50	5.33 (2.31)^{d}	66.49	5.12	3.19 (1.79)^{d}	84.76	10.46	6.18 (2.49)^{d}	57.22	5.00	2.89 (1.70)^{d}	86.04
Untreated check	13.25	15.90 (3.99)^{e}	-	18.00	20.92 (4.57)^{e}	-	10.70	14.45 (3.80)^{e}	-	17.20	20.67 (4.55)^{e}	-
SE. d	-	0.01	-	-	0.01	-	-	0.02	-	-	0.01	-
CD (P = 0.05)	-	0.02	-	-	0.03	-	-	0.04	-	-	0.02	-

*Mean of four observations; Values in parantheses are square root transformed values; In a column, means followed by a common letter are not significantly different by LSD(P=0.05) PTC- Pretreatment count; DAT – Days after treatment; PRC – Percent reduction over control

The untreated check recorded the whiteflies population of 21.54 nymphs six leaves^{-1}. Based on the per cent reduction in population over untreated check, the order of efficacy of different insecticidal treatments were flupyradifurone 200 SL at 175 g a.i/ha (96.40%) > flupyradifurone 200 SL at 150 g a.i/ha (91.99%) > flupyradifurone 200 SL at 125 g a.i/ha (86.49%) > phosphamidon 40% SL at 300 g a.i/ha (85.78%)

During the second season experiment, the population of whiteflies before application of treatments ranged from 17.00 to 18.33 six leaves^{-1} (Table 1). Flupyradifurone 200 SL at 175 g a.i / ha significantly reduced whiteflies population and recorded lowest mean population of 5.84 nymphs six leaves^{-1} with 70.66 per cent reduction over control after first spray. This was followed by flupyradifurone 200 SL at 150 g a.i / ha (7.08 nymphs six leaves^{-1} with 64.47 per cent reduction over control) and flupyradifurone 200 SL at 125 g a.i / ha (8.25 nymphs six leaves^{-1} with 54.56 per cent reduction over control). The standard check, phosphamidon 40% SL at 300 g a.i/ha also reduced whitefly population to 8.44 nymphs six leaves^{-1} with 57.63 per cent reduction over control. After second application, similar trend in reduction was observed and flupyradifurone 200 SL at 175 g a.i / ha reduced the population completely and recorded mean population of 1.01 nymphs six leaves^{-1} followed by flupyradifurone 200 SL at 150 g a.i / ha (2.12 nymphs six leaves^{-1}).

Table 3. Safety of flupyradifurone 200 SL to coccinellids in brinjal ecosystem

Treatments	Number of coccinellids five plants^{-1}											
	I Season						II Season					
	First spray			Second spray			First spray			Second spray		
	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC
Flupyradifurone 200 SL @ 125 g a.i/ha	6.35	5.88 (2.42)^{b}	14.16	6.40	5.43 (2.33)^{b}	32.38	7.08	6.16 (2.48)^{b}	20.72	6.48	5.30 (2.30)^{b}	38.73
Flupyradifurone 200 SL @ 150 g a.i/ha	6.55	4.89 (2.21)^{c}	28.61	5.25	4.64 (2.15)^{c}	42.22	7.14	6.07 (2.46)^{b}	21.88	6.40	5.27 (2.30)^{b}	39.08
Flupyradifurone 200 SL @ 175 g a.i/ha	6.25	4.30 (2.07)^{d}	37.23	4.85	4.21 (2.05)^{d}	47.57	7.00	4.99 (2.23)^{c}	35.78	5.20	4.45 (2.11)^{c}	48.55
Phosphamidon 40% SL @ 300 g a.i/ha	6.50	4.08 (2.02)^{e}	40.44	4.25	4.11 (2.03)^{d}	48.82	7.46	4.91 (2.22)^{c}	36.81	5.18	4.42 (2.10)^{c}	48.90
Untreated check	5.95	6.85 (2.62)^{a}	-	7.45	8.03 (2.83)^{a}	-	7.39	7.77 (2.79)^{a}	-	8.26	8.65 (2.94)^{a}	-
SE. d	-	0.01	-	-	0.02	-	-	0.01	-	-	0.03	-
CD (P = 0.05)	-	0.02	-	-	0.05	-	-	0.02	-	-	0.06	-

*Mean of four observations; Values in parantheses are square root transformed values; In a column, means followed by a common letter are not significantly different by LSD (P=0.05) PTC- Pretreatment count; DAT – Days after treatment; PRC – Percent reduction over control

The untreated check recorded the whiteflies population of 23.94 nymphs six leaves^{-1}. Based on the per cent reduction in population over untreated check, the order of efficacy of different insecticidal treatments were flupyradifurone 200 SL at 175 g a.i/ha (95.77%) > flupyradifurone 200 SL at 150 g a.i/ha (91.15%) > flupyradifurone 200 SL at 125 g a.i/ha (84.98%) > phosphamidon 40% SL at 300 g a.i/ha (83.35%)

(ii) Bioefficacy of flupyradifurone 200 SL against leafhoppers

The population of leafhoppers before application of treatments ranged from 13.25 to 14.00 six leaves^{-1} (Table 2). Flupyradifurone 200 SL at 175 g a.i / ha significantly reduced leafhopper population and recorded lowest mean population of 2.91 six leaves^{-1} with 81.68 per cent reduction over control after first spray. This was followed by flupyradifurone 200 SL at 150 g a.i / ha (4.26 six leaves^{-1} with 73.20 per cent reduction over control) and flupyradifurone 200 SL at 125 g a.i / ha (5.13six leaves^{-1} with 67.72 per cent reduction over control). The standard check, phosphamidon 40% SL at 300 g a.i/ha also reduced leafhopper population to 5.33 six leaves^{-1} with 66.49 per cent reduction over control. After second application, similar trend in reduction was observed and flupyradifurone 200 SL at 175 g a.i / ha reduced the population completely and recorded mean population of 0.76 six leaves^{-1} followed by flupyradifurone 200 SL at 150 g a.i / ha (1.91 six leaves^{-1}). The untreated check recorded the whiteflies population of 20.92 nymphs six leaves^{-1}. Based on the per cent reduction in population over untreated check, the order of efficacy of different insecticidal treatments were flupyradifurone 200 SL at 175 g a.i/ha (96.35%) > flupyradifurone 200 SL at 150 g a.i/ha (90.86%) > flupyradifurone 200 SL at 125 g a.i/ha (85.66%) > phosphamidon 40% SL at 300 g a.i/ha (84.76%)

During the second season experiment, the population of leafhopper before application of treatments ranged from 10.15 to 10.70 six leaves^{-1} (Table 2). Flupyradifurone 200 SL at 175 g a.i / ha significantly reduced leafhopper population and recorded lowest mean population of 3.31 six leaves^{-1} with 77.12 per cent reduction over control after first spray. This was followed by flupyradifurone 200 SL at 150 g a.i / ha (4.50 six leaves^{-1} with 68.83 per cent reduction over control) and flupyradifurone 200 SL at 125 g a.i / ha (5.72 nymphs six leaves^{-1} with 60.38 per cent reduction over control). The standard check, phosphamidon 40% SL at 300 g a.i/ha also reduced whitefly population to 6.18 six leaves^{-1} with 57.22 per cent reduction over control.

After second application, similar trend in reduction was observed and flupyradifurone 200 SL at 175 g a.i / ha reduced the population completely and recorded mean population of 0.43 six leaves^{-1} followed by flupyradifurone 200 SL at 150 g a.i / ha (1.45 six leaves^{-1}). The untreated check recorded the whiteflies population of 20.67 nymphs six leaves^{-1}. Based on the per cent reduction in population over untreated check, the order of efficacy of different insecticidal treatments were flupyradifurone 200 SL at 175 g a.i/ha (97.92%) > flupyradifurone 200 SL at 150 g a.i/ha (93.00%) > flupyradifurone 200 SL at 125 g a.i/ha (86.81%) > phosphamidon 40% SL at 300 g a.i/ha (86.04%)

(iii) Impact on non target vertebrates and yield

The generalist predators that are commonly available in brinjal ecosystem viz., spiders and coccinellids were choosen as non – target invertebrates and their population assessed to study the impact of insecticide treatments. Flupyradifurone 200 SL, irrespective of doses found to be relatively safer to spiders and coccinellids.

Table 4. Safety of flupyradifurone 200 SL to spiders in brinjal ecosystem

Treatments	Number of spiders five plants^{-1}											
	I Season						II Season					
	First spray			Second spray			First spray			Second spray		
	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC	PTC	Mean*	PRC
Flupyradifurone 200 SL @ 125 g a.i/ha	9.55	8.50 (2.92)^b	14.40	9.05	7.94 (2.82)^b	25.79	8.04	6.98 (2.64)^b	18.08	7.34	6.32 (2.51)^b	33.82
Flupyradifurone 200 SL @ 150 g a.i/ha	9.40	8.10 (2.85)^c	18.43	8.4	7.26 (2.69)^c	32.15	8.33	6.75 (2.60)^b	20.77	7.00	6.15 (2.48)^b	35.60
Flupyradifurone 200 SL @ 175 g a.i/ha	8.55	7.26 (2.69)^d	26.89	7.7	6.66 (2.58)^d	37.76	8.56	6.03 (2.46)^c	29.23	6.28	4.95 (2.22)^c	48.17
Phosphamidon 40% SL @ 300 g a.i/ha	9.80	6.80 (2.61)^e	31.52	6.95	6.25 (2.50)^e	41.59	8.11	5.76 (2.40)^c	32.39	5.80	4.87 (2.21)^c	49.01
Untreated check	9.30	9.93 (3.15)^a	-	10.25	10.70 (3.27)^a	-	8.00	8.52 (2.92)^a	-	9.06	9.55 (3.09)^a	-
SE. d	-	0.03	-	-	0.02	-	-	0.03	-	-	0.02	-
CD (P = 0.05)	-	0.06	-	-	0.04	-	-	0.06	-	-	0.04	-

*Mean of four observations; Values in parantheses are square root transformed values; In a column, means followed by a common letter are not significantly different by LSD(P=0.05) PTC- Pretreatment count; DAT – Days after treatment; PRC – Percent reduction over control

During first and season experiment the mean population after two rounds of spray indicated that flupyradifurone 200 SL @ 125 g a.i. ha^{-1} housed highest number of coccinellid population (5.43 and 5.30 five plants^{-1}, respectively) next to untreated check (8.03 and 8.65 five plants^{-1}, respectively). Subsequently flupyradifurone 200 SL @ 150 g a.i. ha^{-1} recorded 4.64 and 5.27 coccinellids five plants^{-1}, respectively. The coccinellid population of 4.21 and 4.45 five plants^{-1} observed in flupyradifurone 200 SL @ 175 g a.i. ha^{-1}. The standard check phosphamidon 40% SL @ 300 g a.i. ha^{-1} recorded coccinellid population of 4.11 and 4.42 five plants^{-1} (Table 3). Regarding the spider population, comparable influence was exhibited by the treatments in both the seasons. The mean population after two rounds of spray in both seasons revealed that flupyradifurone 200 SL @ 125 g a.i. ha^{-1} housed highest number of spider population (7.94 and 6.32 five plants^{-1}, respectively) next to untreated check (10.70 and 9.55 five plants^{-1}, respectively). Flupyradifurone 200 SL @ 175 g a.i. ha^{-1} recorded spider population as 6.66 and 4.95 five plants^{-1}, respectively (Table 4).

The plants sprayed with flupyradifurone 200 SL @ 75 and 150 g a.i. ha did not show any phytototoxic symptoms like leaf tip injury, wilting, vein clearing, necrosis, epinasty and hyponasty. The average fruit yield in all the treatments ranged from 42.54 to 46.00 t ha^{-1} during first season and 45.00 to 47.12 t ha^{-1} during second season whereas 41.60 and 42.38 t ha^{-1}, respectively was observed in untreated control in both seasons. Among, treatment imposed with flupyradifurone 200 SL @ 175 g a.i ha^{-1} recorded highest yield of 46.00 and 47.12 t ha^{-1}, respectively in two consecutive seasons (Table 5).

The contemporary experimental results infers flupyradifurone 200 SL @ 175 g a.i ha^{-1} followed by 150 g a.i. ha^{-1} as effective dose for the management of leaf hopper and white fly population in brinjal. Together with greater efficacy in pest management, it exhibits good safety profile for generalist predators viz., spiders and coccinellids in brinjal ecosystem. The precedent findings regarding flupyradifurone in brinjal and other crops also depict the same conclusions which are discussed hereunder. The efficacy of flupyradifurone 200 SL against rosy apple aphid (*Dysaphis plantaginea* (Passerini)) and green apple apid (*Aphis pomi* (De Geer)) was investigated (Alston and Lindstrom, 2012).

Table 5. Effect of flupyrdifurone 200 SL on fruit yield in brinjal

Treatments	Yield* (t ha^{-1})	
	I Season	II Season
Flupyradifurone 200 SL @ 125 g a.i/ha	43.28[b]	45.40[b]
Flupyradifurone 200 SL @ 150 g a.i/ha	45.70[a]	47.00[a]
Flupyradifurone 200 SL @ 175 g a.i/ha	46.00[a]	47.12[a]
Phosphamidon 40% SL @ 300 g a.i/ha	42.54[c]	45.00[c]
Untreated check	41.60[d]	42.38[d]
SE(d)	0.38	0.41
CD (P = 0.05)	0.76	0.82

*Mean of four observations; In a column, means followed by a common letter are not significantly different by LSD(P=0.05)

Flupyradifurone 200 SL @ 5.2 and 8.7 oz per acre performed well in reducing *D. plantaginea* faster and efficacy persisted for longer time (26 days post treatment). None of the treatments significantly reduced predator densities and recorded mean as 1.2 total predators per shoot. Parasitism was significantly reduced in all insecticide treatments as compared to the untreated control but as per authors, this was primarily caused by the higher densities of rosy apple aphids available in the untreated control plots. Flupyradifurone 200 SL possess waiting period of 15 days as similar to imidacloprid, while in management of mulberry thrips and toxicants does not show any deleterious effects on growth of silkworm larvae as evidenced through non-significant differences in economic and survival parameters of mulberry silkworm (Patil *et al.,* 2013).

Flupyradifurone 20 SC @ 200 g a.i ha^{-1} was elucidated as an effective alternate to neonicotinoids in cotton ecosystem (Rao *et al.,* 2014). Flupyradifurone 200 SL @ 250 and 200 g a.i. ha^{-1} provided superior control against leaf hoppers, aphids, whiteflies and the population reduction was finer than neonicotinoids viz., imidacloprid 200 SL @ 20g ai/ha and acetamiprid 20 SP @ 20 g a.i. ha^{-1} even at lower dose of 150 g a.i ha^{-1}. Besides their efficacy, highest seed cotton yield was obtained and did not influence population of natural enemies (Prasad, 2017). Flupyradifurone 200 SL @ 125, 150 and 175 g a.i ha^{-1} was reported as effective management practice for leafhoppers and whiteflies against standard, phosphamidon 40% SL @ 300 g a.i. ha^{-1} in brinjal at Rahuri, Maharshtra. The highest yield of brinjal fruits i.e. 76.96 and 79.03 q

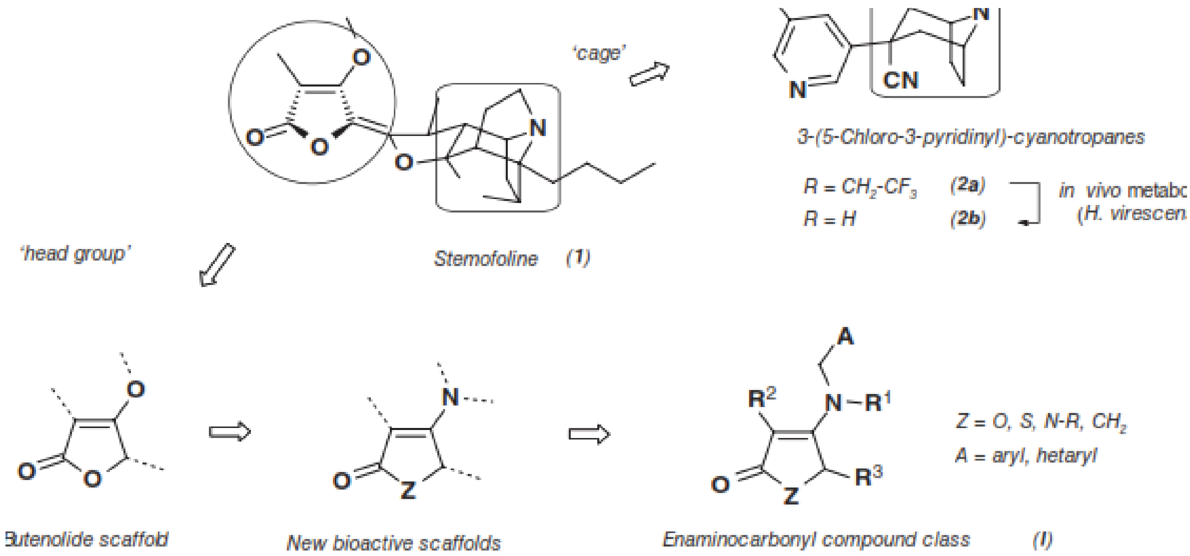

Figure 1. Natural product stemofoline 1 as the lead structure for novel ligands

ha^{-1}, respectively was recorded in flupyradifurone 200 SL @ 150 and 175 g a.i. ha^{-1} and also found relatively safer to coccinellid population in brinjal ecosystem (Wale *et al.,* 2017). Similar findings were reported in brinjal at Vidisha, Madhya Pradesh (Vinod Kumar Garg *et al.,* 2018).

In the above field investigations of flupyradifurone 200 SL, the mainstream to be observed is use of neonicotinoids as comparable standard check and superiority of flupyradifurone. Nevertheless both groups of compounds seems to have same mode of action as an nAChR agonist, flupyradifurone is depicted as an effective alternate tool in resistance management strategies especially to sucking pest species that developed resistance to virtually all chemical classes of insecticides introduced to control them (Bass *et al.,* 2014). In this regard, higher efficacy may be attributed towards its unique structural moiety known as butenolide that had been developed from natural product stemofoline. Stemofoline, isolated from leaves and stem of oriental medicinal plant *Stemona japonica* (Blume) Miq. (Stemonaceae) shows fast-acting insecticidal, antifeedant and repellent activities, but its activity is significantly lower than that of commercial products acting on insect nAChRs (Kalteneggar *et al.,* 2003; Jeschke *et al.,* 2013; Mungkornasawakul *et al.,* 2004). Therefore, stemofoline was broadly used as a potent lead structure for development of novel active ingredients like flupyradifurone.

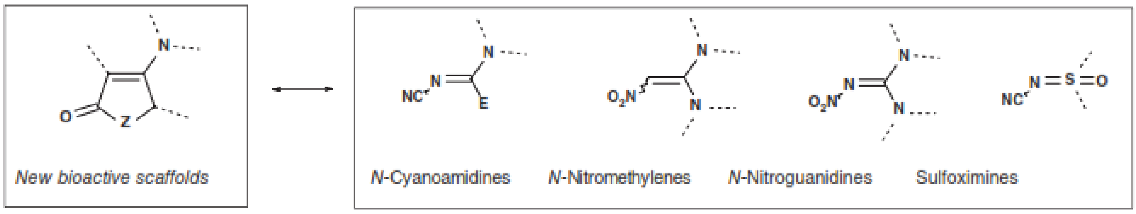

Figure 2. New bioactive scaffold versus pharmacophore systems of known nAchR agonists (Nauen *et al.,* 2015)

In the above fig. 1 head group which was identified as butenolide scaffold undergoes certain chemical changes to form enaminocarbonyl compound. It undergoes further chemical evolution via the butenolide subclasses resulting in discovery of flupyradifurone (Nauen *et al.,* 2015).

Furthermore distinct moiety of flupyradifurone can be explained by comparing with already commercialised nAChR agonists such as N-cyanoamidines (acetamiprid, thiacloprid), nitroenamines (nitenpyram), N-nitroguanidines (imidacloprid, clothianidin, thiamethoxam or dinotefuran) or sulfoximines (sulfoxaflor), the butenolide flupyradifurone 4 (Z =O) contains a different pharmacophore system as a new bioactive scaffold (Fig. 2). Besides, distinct structural moiety, efficacy of flupyradifurone may be explored with their agonist affinity and relative efficacy. Radioligand [^{3}H] imidacloprid displacement studies was conducted to depict binding site and affinity of flupyradifurone and efficacy was inferred by whole cell clamp technique (Patch clamping) with holding potential of -70 mV. Results inferred that flupyradifurone displaces [^{3}H] imidacloprid bound to *Musca domestica* (Linn.) nAChRs from its binding site with nanomolar affinity, and an I_{50} value of 2.38 ±1.93 nM was calculated. It activates endogenously expressed insect nAChRs by reverse binding and acts as a partial agonist with a relative agonist efficacy of 0.56 relative to the amplitude elicited by 1 mM of acetylcholine (Nauen *et al.,* 2015). Flupyradifurone shows good translocation in short time after application in planta, hence suggesting a good systemic activity. It is mainly translocated in the xylem, as shown by its accumulation in distal leaf regions when taken up by the leaf lamina, roots and stems. Rapid action on sucking pests, was exemplified by a translaminar study on the suppression of honeydew excretion in green peach aphid feeding on the abaxial site of adaxially treated oilseed rape leaves (Nauen *et al.,* 2015). Within a short time interval, most of the aphids stopped feeding and died 2 days later, suggesting a high potential of flupyradifurone to prevent the transmission of plant pathogenic viruses at recommended field rates. It can be foliarly applied even during flowering, as it shows no adverse effects on actively foraging honey bees in long-term field trials in oilseed rape when applied at rates as high as 205 g ha $^{-1}$ (Nauen *et al.,* 2015)

The distinct chemical structure of the novel butenolide pharmacophore and the lack of metabolic cross-resistance of flupyradifurone led to the formation of a new subgroup (4D) within the IRAC mode-of-action classification and evolve as a tool for setting up resistance management strategies based on modeof action. Hence, flupyradifurone, occupies a place of best alternative to neonicotinoids and can be recommended for management of sucking pests in brinjal.

CONCLUSION

Flupyradifurone @ 150 and 175 g a.i. ha^{-1} exhibit the excellent control of sucking pests in brinjal agroecosystem without causing any phytotoxicity to the plant. The distinct chemical structure of the novel butenolide pharmacophore and the lack of metabolic cross-resistance of flupyradifurone led to the formation of a new subgroup (4D) within the IRAC mode of action classification and evolve as a tool for setting up resistance management strategies based on mode of action. Hence, flupyradifurone, occupies a place of best alternative to neonicotinoids and can be recommended for management of sucking pests in brinjal.

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