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RESEARCH PAPER

Relative toxicity of some newer insecticide molecules against vector and sucking pest complex of okra

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Abstract

Sucking pest like leaf hoppers or jassid (*Amrasca biguttula biguttula* (Ishida)) and vectors *i.e.,* whitefly (*Bemisia tabaci* (Gennadius)) are regarded as one of the major biotic stresses in okra cultivation in India. Apart from direct sucking the plant sap and thereby devitalizing the crop through their specially adapted mouthparts, many of them also act as vectors for important plant diseases like okra yellow vein mosaic and okra enation leaf curl disease. To control these sucking pests and vectors, several newer insecticide molecules were tested under open field conditions during *Kharif* seasons of 2021 and 2022. Based up on the two years of pooled data, among the tested insecticides, Tolfenpyrad 15% EC @ 2 ml/L was the best molecule in reducing leaf hopper population in okra (5.40 per leaf) with 63.49% reduction over control (PROC). The next best molecule was flupyradifurone 17.09% SL (5.70 jassids per leaf with 61.46 PROC). In the case of whitefly, flupyradifurone 17.09% SL was the most promising during both years with percent population reductions of 69.90 over control. The next best molecule in the list was tolfenpyrad 15% EC with 67.08 PROC. Interestingly, Imidacloprid-treated plots had the highest leaf hopper (10.39 per leaf) and whitefly (9.55 per leaf) population among all treatments indicating its low activity against these sucking pests of okra. The highest healthy green fruit yields (152 q/ha) were obtained from the plots treated with tolfenpyrad 15% EC with a maximum cost-benefit ratio of 1:2.19 followed by dinotefuran 20% SG (1:2.16) and acetamiprid 20% SP (1:2.15).

Keywords: Newer insecticide molecules, Sucking pests, Okra, Cost-benefit ratio.

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Introduction

Sucking pests are regarded as a serious issue in the production of vegetables. Depending on the host plants and the severity of the damage, affected plant parts exhibit symptoms like upward cupping, curling, withering, browning, and yellowing. They secrete copious amounts of sugar-rich, sweet honeydew on the plant parts while sucking the sap from the plants with their specially adapted mouthparts. Affected plants also lose their vitality as a result of their feeding. Deposited honeydews on plant surfaces attract the fungus and result in black sooty mould which further inhibits the plants' photosynthetic activity (Halder *et al*., 2011). Many of them also act as a vector in the transmission of many viral diseases in addition to sucking the sap and thereby devitalizing the plants (Rai *et al*., 2014).

Okra [*Abelmoschus esculentus* (L.)], the only vegetable crop of significance in the Malvaceae family, is very popular in the Indian subcontinent (Singh *et al*., 2023). It is one of the oldest cultivated crops and is widely distributed from Africa to Asia, southern Europe, and America (Kumar *et al*., 2013). It is an oligo-purpose crop, but it is usually consumed for its green tender fruits as a vegetable in a variety of ways (Halder *et al*., 2015). These fruits are rich in vitamins, calcium, potassium and other minerals. The crop is ravaged by a number of insect pests throughout its growth period. Sucking insect pests are on top causing damage from seedling onwards. Amidst the sucking insect pests, whiteflies (*Bemisia tabaci* (Gennadius)) (Hemiptera: Aleyrodidae) and leaf hoppers (*Amrasca biguttula biguttula* (Ishida)) (Hemiptera: Cicadellidae), are predominant (Rai *et al.,* 2014). The incidence of leaf hoppers are dominant almost throughout where the crops like okra and cotton are grown. An enigma, the whitefly, being polyphagous, is cosmopolitan in distribution and occurs almost throughout the country across many agricultural and horticultural crops. It is also accounted for the spread of the dreaded disease okra yellow vein mosaic virus (YVMV) and more recently emerging okra enation leaf curl disease (OELCuD) (Seni and Halder, 2022). To control these nefarious pests Indian farmers are mostly relying on chemical pesticides. Moreover, in spite of repeated sprays, farmers often fail to achieve the desired control measure (Roy *et al*., 2017). During the discussion, it was revealed that they frequently resort to a variety of old generic insecticides to get rid of these sucking pests as advised by the neighborhood pesticide stores and/or other fellow farmers (Roy *et al*., 2017). Many such old insecticides are reported to cause the development of resistance against many sucking pests and often failed to bring the desired pest control measures. To address these issues, a series of new insecticide molecules of different groups were evaluated against the major sucking pests of okra and compared with the widely used neonicotinoid insecticide Imidacloprid 17.8% SL under open field conditions. The present study will certainly help in identifying the effective insecticide molecule(s) for the synthesis/development of effective insect pest management strategies/modules against these sucking pests of okra. The current study will also help to gradual replacement of old generic insecticide molecule(s) with the newer ones for sustainable sucking pest management.

Materials and Methods

Study Area

The field experiments were carried out at the experimental farm of the Indian Council of Agricultural Research-Indian Institute Vegetable Research (ICAR-IIVR), Varanasi (82°52′ E longitude and 25°12′ N latitude), Uttar Pradesh, India during *Kharif* season (July to October) of 2021 and 2022. The experimental site comes under the alluvial zone of Indo-Gangetic plains having soils silt loam in texture and low in organic carbon (0.43%) and available nitrogen (185 kg/ha).

Raising of the Crops

Seeds of okra (*cv.* Kashi Pragati) were sown in the fine-tilth ridge during the first week of July for *Kharif* season. The okra seeds were sown at a spacing of 60×40 cm (row to row and plant to plant) in a plot size of 5×4 m^2. Three replications were maintained for each treatment. The recommended doses of N, P, K fertilizers (100:60:60) and FYM 15-20 t/ha were applied. N, P and K were supplied through urea, di-ammonium phosphate and muriate of potash, respectively. Half of the nitrogen was applied at the time of sowing as basal dose and the rest half was equally split at the branching stage and at the flower initiation stage. The full doses of both phosphorus and potassium were given at the time of final land preparation. Hand weeding and irrigations were provided as required and usual crop husbandry measures were undertaken except plant protection measures for sucking insect pest management.

Test Insecticides

Six newer insecticide molecules based upon their groups and different modes of actions were taken for evaluation and sprayed at the following doses (Table 1) and compared with frequently used neonicotinoid insecticide *i.e.,* Imidacloprid 17.8% SL. In addition, separate untreated control plots were maintained. All the treatments including untreated control plots were replicated thrice. Three rounds of treatment applications were given at 10 days intervals starting with first spray at 25 days after sowing (DAS) when the sucking pest population started gradually increasing. The treatment details along with their respective doses are depicted in Table 1.

Data Recording

The populations of sucking pests *viz*., leaf hoppers, and whiteflies were determined by counting the insects (including nymphs and adults for leaf hoppers and only adults for whiteflies) from three leaves (top, middle, and bottom regions) sampled from each plant. As such ten plants were considered from each plot and expressed as the number of sucking pests (leaf hopper/whitefly) per leaf per plant. The observations were recorded at 1 day before each spray and 1, 3, 5, 7 and 10 days after the spray (DAS) in each plot of different treatments including untreated control. As regards to the yield, different pickings of healthy fruits were made separately from entire plot from each treatment. The yield data were converted to a hectare basis and the economics was calculated. Cost-benefit analysis was expressed in terms of ratio using the following formula:

$$\text{Cost-benefit ratio} = \frac{\text{Gross return (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

Statistical Analysis

The data were subjected to to the statistical analysis (analysis of variance) appropriate to the experimental design. The pooled/combined analysis was performed for jassid infestation (per leaf), whitefly infestation (per leaf) and yield of healthy fruits. The post hoc test for treatment means

Table 1: List of test insecticides with their main group, sub-group and primary site of action as per IRAC* and doses

Treatment	*Test insecticide with formulation*	*Dose*	*IRAC Classification*		
			Main Group	*Primary Site of Action*	*Sub-group, class or exemplifying Active Ingredient*
T1	Spiromesifen 22.90% SC	1 ml/L	23 Inhibitors of acetyl CoA carboxylase	Lipid synthesis, growth regulation {Good evidence that action at this protein is responsible for insecticidal effects}	Tetronic and Tetramic acid derivatives
T2	Flupyradifurone 17.09% w/w SL	2.5 ml/L	4 Nicotinic acetylcholine receptor (nAChR) competitive modulators	Nerve action {Strong evidence that action at one or more of this class of protein is responsible for insecticidal effects}	4D Butenolides
T3	Tolfenpyrad 15% EC	2 ml/L	21 Mitochondrial complex I electron transport inhibitors	Energy metabolism {Good evidence that action at this protein complex is responsible for insecticidal effects}	21A METI acaricides and insecticides
T4	Acetamiprid 20% SP	0.15 g/L	4 Nicotinic acetylcholine receptor (nAChR) competitive modulators	Nerve action {Strong evidence that action at one or more of this class of protein is responsible for insecticidal effects}	4A Neonicotinoids
T5	Pyriproxifen 10% EC	1.67 ml/L	7 Juvenile hormone mimics	Growth regulation {Target protein responsible for biological activity is unknown, or uncharacterized}	7C Pyriproxyfen
T6	Dinotefuran 20% SG	0.3 g/L	4 Nicotinic acetylcholine receptor (nAChR) competitive modulators	Nerve action {Strong evidence that action at one or more of this class of protein is responsible for insecticidal effects}	4A Neonicotinoids
T7	Imidacloprid 17.8% SL	0.2 ml/L	4 Nicotinic acetylcholine receptor (nAChR) competitive modulators	Nerve action {Strong evidence that action at one or more of this class of protein is responsible for insecticidal effects}	4A Neonicotinoids
T8	Untreated Control	--	--	--	--

(*IRAC, 2023)

comparison (t-grouping) under each parameter was done on the basis of Tukey's Honest Significant Difference (HSD) at probability P=0.05. The square root data transformation ($\sqrt{(x + 0.5)}$) was applied to jassid infestation (per leaf) and whitefly infestation (per leaf) for holding the normality assumption. All the statistical analysis has been done through SAS (Version 9.3) by using the Procedure Generalized Linear Model (PROC GLM).

Results and Discussion

Different newer insecticide molecules having different mode of action were sprayed and compared with Imidacloprid 17.8% SL, a widely used systemic insecticide in the region, and untreated control plots were presented in Tables 2 and 3. Amongst the tested molecules, the newer molecule Tolfenpyrad 15% EC was the best insecticide in reducing leaf hopper population in okra by having the lowest leaf hopper population (7.91 and 3.31 per leaf) during both the years (2021 and 2022) with 54.30 and 73.46% reduction over control (PROC). The next best molecule among the tested insecticides was flupyradifurone 17.09% SL. Flupyradifurone-treated plots had 7.97 and 3.77 numbers of leaf hoppers population per leaf and thereby registering 53.96 and 69.77 PROC during 2021 and 2022, respectively. Interestingly, Imidacloprid treated plots had the highest leaf hopper population (12.82 and 8.17 per leaf) among all the treatments indicating its low activity against this sucking pest of okra.

The whitefly (*Bemisia tabaci*) population on okra was also monitored after different treatments. Amongst the tested molecules flupyradifurone 17.09% SL was the most

Table 2: Bio-efficacy of different newer molecules against jassid infestation (per leaf) in okra during 2021 and 2022

Treatments	*2021*			*2022*			*Pooled*		
	Before spray	*After spray**	*PROC#*	*Before spray*	*After spray**	*PROC#*	*Before spray*	*After spray**	*PROC#*
Spiromesifen 22.90% SC	16.57	3.06^{c} (8.86)	48.82	13.69	2.47^{d} (5.62)	54.93	15.13	2.77^{cd} (7.17)	51.52
Flupyradifurone 17.09% w/w SL	15.59	2.91^{e} (7.97)	53.96	10.68	2.07^{ef} (3.77)	69.77	13.14	2.49^{cd} (5.70)	61.46
Tolfenpyrad 15% EC	17.08	2.90^{e} (7.91)	54.30	11.07	1.95^{f} (3.31)	73.46	14.08	2.43^{d} (5.40)	63.49
Acetamiprid 20% SP	16.89	2.96^{de} (8.26)	52.28	11.14	2.13^{e} (4.05)	67.52	14.02	2.55^{cd} (6.00)	59.43
Pyriproxifen 10% EC	15.44	3.17^{c} (9.55)	44.83	12.98	2.70^{c} (6.81)	45.39	14.21	2.94^{bc} (8.14)	44.96
Dinotefuran 20% SG	16.71	3.15^{c} (9.42)	45.58	11.82	2.59^{cd} (6.19)	50.36	14.27	2.87^{bcd} (7.74)	47.67
Imidacloprid 17.8% SL	17.83	3.65^{b} (12.82)	25.94	12.46	2.94^{b} (8.17)	34.48	15.15	3.30^{b} (10.39)	29.75
Untreated Control	17.49	4.22^{a} (17.31)	--	13.69	3.60^{a} (12.47)	--	15.59	3.91^{a} (14.79)	--

#PROC= Per cent reduction over control; Means followed by same letters in a column are not significantly different at P=0.05 based on Tukey's Honest Significant Difference; *Data were subjected to square root transformation √ (x + 0.5), values in parentheses represent original values.

Table 3: Bio-efficacy of different newer molecules against whitefly infestation (per leaf) in okra during 2021 and 2022

Treatments	*2021*			*2022*			*Pooled*		
	Before spray	*After spray**	*PROC#*	*Before spray*	*After spray**	*PROC#*	*Before spray*	*After spray**	*PROC#*
Spiromesifen 22.90% SC	14.12	2.42^{cd} (5.36)	60.47	18.69	2.42^{e} (5.36)	65.79	16.41	2.42^{c} (5.36)	63.16
Flupyradifurone 17.09% w/w SL	14.60	2.36^{d} (5.07)	62.61	20.89	2.06^{g} (3.76)	76.01	17.75	2.21^{c} (4.38)	69.90
Tolfenpyrad 15% EC	13.76	2.38^{d} (5.16)	61.95	19.63	2.23^{f} (4.47)	71.47	16.7	2.30^{c} (4.79)	67.08
Acetamiprid 20% SP	12.98	2.49^{cd} (5.70)	57.96	20.07	2.61^{d} (6.31)	59.73	16.53	2.55^{c} (6.00)	58.76
Pyriproxifen 10% EC	14.39	2.54^{c} (5.95)	56.12	17.96	2.79^{c} (7.30)	53.41	16.18	2.67^{bc} (6.63)	54.43
Dinotefuran 20% SG	13.08	2.48^{cd} (5.65)	58.33	19.67	2.56^{d} (6.04)	61.46	16.38	2.52^{c} (5.85)	59.79
Imidacloprid 17.8% SL	13.57	3.08^{b} (8.99)	33.70	18.61	3.25^{b} (10.09)	35.61	16.09	3.17^{b} (9.55)	34.36
Untreated Control	14.69	3.75^{a} (13.56)	--	17.37	4.02^{a} (15.67)	--	16.03	3.88^{a} (14.55)	--

#PROC= Per cent reduction over control; Means followed by same letters in a column are not significantly different at P=0.05 based on Tukey's Honest Significant Difference; *Data were subjected to square root transformation √ (x + 0.5), values in parentheses represent original values.

promising during both the years. The percent whitefly population reductions were 62.61 and 76.01 over control during 2021 and 2022, respectively with mean of 69.90 PROC. The next best treatment in the list was Tolfenpyrad 15% EC with 61.95 and 71.47 per cent whitefly population reductions over control during 2021 and 2022, respectively. Here also Imidacloprid 17.8% SL treated plots had the highest whitefly population than the other chemical treated plots. Flupyradifurone is the first member of the butenolide class of insecticides. Its mode of action is similar to neonicotinoid

Table 4: Yield and Economics of different chemical treatments in okra

Treatment	*Yield of healthy fruits (q/ha)*	*Cost of cultivation (₹/ha)*	*Cost of plant protection treatments # (₹/ha)*	*Total cost (₹/ha)*	*Gross return (₹/ha)*	*Net return (₹/ha)*	*Cost benefit ratio*
Spiromesifen 22.90% SC	139[bc]	95000	8099	103099	208500	105401	1:2.02
Flupyradifurone 17.09% w/w SL	143[ab]	95000	14900	109900	214500	104600	1:1.95
Tolfenpyrad 15% EC	152[a]	95000	9270	104270	228000	123730	1:2.19
Acetamiprid 20% SP	137[bc]	95000	392	95392	205500	110108	1:2.15
Pyriproxifen 10% EC	131[cd]	95000	4418	99418	196500	100082	1:1.98
Dinotefuran 20% SG	140[bc]	95000	2227	97227	210000	112773	1:2.16
Imidacloprid 17.8% SL	126[d]	95000	994	95994	189000	93006	1:1.97
Untreated Control	104[e]	95000	--	95000	156000	61000	1:1.64

Means followed by same letters in a column are not significantly different at P=0.05 based on Tukey's Honest Significant Difference; *Cost of okra was ₹15/kg; # For three rounds of sprays; Spray volume = 500 lit of water

insecticides that act on the central nervous system of target insect pests as an agonist of the nicotinic acetylcholine receptor (nAChR) (IRAC, 2023). Similarly, tolfenpyrad is another newer molecule that inhibits the mitochondrial electron transport inhibitor and thereby affects the energy metabolism of insects. Recently, Garg *et al*., 2018 documented that flupyradifurone 200 SL @ 125, 150, 175 g. a.i./ha were effective for managing jassid and whitefly populations on brinjal and the dose of flupyradifurone 200 SL @ 150 and 175 g. a.i./ha gave a higher yield of brinjal fruits (73.17 and 75.07 q/ha) respectively than the rest of the treatment. Patil *et al*. (2013) reported that residual toxicity of Flupyradifurone 200 SL was up to 15th days found best for control of mulberry thrips without deleterious effects on silkworm growth. Rao *et al*. (2014) identify novel chemistries of flupyradifurone 20 SC @ 200 g. a.i./ha as effective alternatives to neonicotinoid insecticides in a cotton ecosystem. Tolfenpyrad 15% EC @ 125 and 150 g a.i./ha showed better performance against the sucking pest complex of okra and they also concluded that Tolfenpyrad 15% EC @ 125 and 150 g a.i./ha might be recommended for okra and it is also safer to natural enemies (Mallick *et al*., 2016). In another field study, Shivaleela and Chowdary (2020) revealed that tolfenpyrad 15% EC @ 150 g a.i./ha provided cross-spectrum and superior in managing the leafhoppers, thrips and red pumpkin beetles infesting cucumber with the highest fruit yield (5.85 t/ha). Imidacloprid is the first compound launched under the neonicotinoid group, it mimics nicotine in its mode of action and the biochemical target site is the nicotinic acetylcholine receptor (nAChR) of the insect nervous system (Elbert, 2007; Banik and Hader, 2013). Due to extensive use as systemic insecticide in the region might be responsible for its lower activity amongst the test insecticides.

The economics of each treatment was computed. The harvestable healthy fruits were collected at periodical intervals. Similarly, the cost of cultivation and plant protection measures, gross return and net return for each treatment was also worked out (Table 4). The highest healthy green fruit yields (152 q/ha) were obtained from treatment 3 *i.e.,* spraying of tolfenpyrad 15% EC. A maximum cost-benefit (CB) ratio of 1:2.19 was also recorded from the plots treated with tolfenpyrad 15% EC followed by dinotefuran 20% SG (1:2.16) and Acetamiprid 20% SP (1:2.15). Although the other newer molecule flupyradifurone 17.09% SL gave good result in controlling whiteflies and jassids but due to its relatively higher cost and dose/rate per litre leading to lower net return and thereby registered a lower (1:1.95) CB ratio.

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सारांश

भिण्डी में रस चूसने वाले कीट लीफ हॉपर या जैसिड (अमरस्का बिगुटुला बिगुटुला (ईशिडा)) और वाहक-सफेद मक्खी (बेमिसिया टैबसी (गेनाडियस)) को भारत में प्रमुख जैविक तनावों में से एक माना जाता है। पौधों के सीधे रस को चूसने और फसल को उनके विशेष रूप से अनुकूलित मुखभागों को नष्ट करने के अलावा, उनमें से कई महत्वपूर्ण पौधों की बीमारियों जैस- भिण्डी का पित्त शिरा विषाणु और भिंडी एनेशन लीफ कर्ल रोग के लिए वाहक के रूप में भी कार्य करते हैं। इन चूसने वाले कीटों और वाहक को नियंत्रित करने के लिए, वर्ष 2021 और 2022 के खरीफ मौसम के दौरान मुक्त दशा में कई नये कीटनाशक अणुओं का परीक्षण किया गया। दो वर्ष के एकत्रित आंकड़ों के आधार पर, परीक्षण किए गए कीटनाशकों में से, टॉल्फ़ेनपाइराड 15% ईसी @ 2 मिली/लीटर अनुपचारित नियंत्रण पर 63.49 प्रतिशत कमी के साथ भिंडी में लीफ हॉपर की संख्या (5.40 प्रति पत्ती) कम करने में सबसे अच्छा कीटनाशक पाया गया। इसके अलावा सबसे अच्छा कीटनाशक फ्लुपाइराडिफ्यूरोन 17.09% एसएल (अनुपचारित नियंत्रण पर 61.46 प्रतिशत की कमी के साथ प्रति पत्ती 5.70 जैसिड्स) था। सफेद मक्खी के मामले में, फ्लुपाइराडिफ्यूरोन 17.09% एसएल दोनों वर्षों के दौरान सबसे अधिक आशाजनक परिणाम प्राप्त हुआ और कीटसंख्या नियंत्रण में 69.90 प्रतिशत की कमी पायी गयी। सूची में अगला सबसे अच्छा कीटनाशक अनुपचारित नियंत्रण पर 67.08 प्रतिशत की कमी के साथ टॉल्फ़ेनपाइराड 15% ईसी का स्थान रहा। आश्चर्यजनक बात यह है कि इमिडाक्लोप्रिड उपचारित भूखंडों में सभी उपचारों के बीच पत्ती हॉपर (10.39 प्रति पत्ती) और सफेद मक्खी (9.55 प्रति पत्ती) की संख्या सबसे अधिक थी जो भिंडी के चूसने वाले कीटों के विरूध्द इसकी कम गतिविधि को दर्शाता है। उच्चतम स्वस्थ हरे फल की पैदावार (152 कुंतल/हेक्टेयर) टॉल्फ़ेनपाइराड 15% ईसी से उपचारित भूखंडों से प्राप्त हुई, जिसमें अधिकतम लागत लाभ अनुपात 1:2.19 था। इसके बाद डिनोटफ्यूरान 20% एसजी (1:2.16) और एसिटामिप्रिड 20% एसपी (1: 2.15) पाया गया।