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Differential sensitivity of insecticides for targeting of multiple pests in grapes (*Vitis vinifera*)

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ABSTRACT

Thrips, leafhoppers, flea beetle and caterpillars cause significant damage to grapes in two pruning-single cropping system of peninsular India and occur simultaneously. Against this pest complex,differential sensitivity of 12 insecticides was evaluated based on their bio-efficacy in laboratory and field. Thiamethoxam 25 WG, lambda cyhalothrin 5 CS, fipronil 80 WG, methomyl 40 SP and spinosad 45 SC recorded 96.45-100 and 89.34-92.98 per cent mortality of *Scelodonta strigicollis* adults in laboratory and field, respectively. Against *Spodoptera litura* 2nd instar larvae,emamectin benzoate 5 SG, fipronil 80 WG and cyantraniliprole 10 OD were able to provide mortality ranging from 79.6-99.0 and 73.65-84.8 percent in laboratory and field, respectively. Spinosad 45 SC, emamectin benzoate 5 SG, fipronil 80 WG and cyantraniliprole 10 OD provided *Scirtothrips dorsalis* mortality from 85.09-98.02 in laboratory and 65.36-91.5 per cent population reduction over control in field. Thiamethoxam 25 WG, clothianidin 50 WDG and fipronil 80 WG recorded *Amrasca biguttula biguttula* mortality from 93.06-100 per cent in laboratory and 80-91.3 per cent population reduction over control in field. The insecticides were classified into four categories, viz. not effective, slightly effective, moderately effective and highly effective; on the basis of their bio-efficacy to various insects. This will help the farmers in selection of right insecticide when multiple pests are present in the vineyard than their conventional practice of tank-mixing separate insecticides for different pests, thus, helping in reducing pesticide load in the environment as well as reduction in cost of cultivation.

Key words: *Amrasca biguttula biguttula,* Insect pest complex, Insecticides, Grapes, *Scelodonta strigicollis, Scirtothrips dorsalis, Spodoptera litura*

The sub-tropical viticulture system of peninsular India differs from rest of the world because the grapevine growth remains active throughout the year as they do not undergo winter dormancy (Chadha and Shikhamany 1999). Thus, the grapevines remain available for the pest development throughout the year leading to high pest infestations. Among insect pests, flea beetle, *Scelodonta strigicollis* Motschulsky; thrips, *Scirtothrips dorsalis* Hood; leafhoppers, *Amrasca biguttula biguttula* Ishida and caterpillar, *Spodoptera litura* (Fab.) are very important and cause considerable damage in two pruning-single yield systems of table grapes in India. An outbreak of leafhopper, *A. biguttula biguttula* was noticed in grapes in Maharashtra state of India (Sharma *et al*. 2013).

Insecticides are the most powerful tools available for use in pest management because they are highly effective, rapid in curative action, adaptable to most situations, flexible in meeting changing agronomic and ecological conditions, and relatively economical (Metcalf 1994). Correct selection of insecticides for application based on their bio-efficacy against pest spectrum can help in reducing the need for application or tank mix of different insecticides for different pests occurring simultaneously. Thus, in the present experiment, we undertook both laboratory and field experiments to identify insecticides for developing a strategy for multi-targeting of insect pest complex of flea beetle, thrips, leafhoppers and caterpillars mostly occurring simultaneously during first 50 days after fruit pruning in table grapes.

MATERIALS AND METHODS

Twelve different chemicals were evaluated for their bio-efficacy against *S. strigicollis*, *S. litura* and *S. dorsalis* and 11 chemicals against *A. biguttula biguttula* under both laboratory and field conditions.

Laboratory bioassays were conducted during July to October 2010 against *S. strigicollis* and *S. litura* and repeated again during July to September 2013. The experiments were laid out in completely randomized design (CRD) with the treatments replicated minimum five times. Leaf dip bioassays were conducted to determine the response of different insecticides against *S. strigicollis* and

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S. litura. Tender leaves of approximately same size were collected from never sprayed grapevine nursery plants (variety Thompson Seedless). The leaves were dipped into the treatment solutions for 10 seconds and hung vertically to air dry for two hours. Control leaves were treated similarly with water. Filter paper was placed inside a glass Petri dish (100 mm ×15 mm) and treated leaves were placed on top of the filter paper. Ten randomly selected *S. strigicollis* adults, collected from never sprayed Dogridge rootstock nursery plants, were released in each Petri dish. In case of bioassay on *S. litura*, laboratory reared 10 second instar larvae were placed in each Petri dish. Observations were taken on live insects at 24, 48 and 72 hr after exposure and moribund insects were considered as dead.

For bioassays on *S. dorsalis* and *A. biguttula biguttula*, tender leaves of approximately same size were collected from never sprayed grapevine nursery plants (variety Thompson Seedless). The leaves were dipped into the treatment solutions for 10 seconds and hung vertically to air dry for two hours. Control leaves were treated similarly with water. The treated leaves were cut into 4 cm diameter discs and one leaf disc was placed in each transparent plastic vial of 125 ml volume. Thereafter, *S. dorsalis* and *A. biguttula biguttula*were collected from never sprayed grapevine young shoots. *S. dorsalis* were directly released into the experimental vials in the vineyard by tapping the young shoots on the vials. However, *A. biguttula biguttula* were brought in the laboratory and only 10 nymphal instars were released per vial. The vials were covered with the lid. The lids were pre-cut for providing vent of 2cm × 2cm size and fitted with nylon mesh of 40 micron pore size for leafhoppers and tissue paper for thrips. The numbers of thrips per vial were counted immediately after release. Observations were taken on live insects at 24, 48 and 72 hr after exposure and moribund insects were considered as dead.

Corrected percent mortality was calculated with the help of Abbott's formula (Abbott 1925) as defined by Perry *et al.* (1998). The corrected percentage mortality values were subjected to arc sine transformation and were analyzed using software provided by Statistical Analysis System (SAS 2011). General linear model (GLM) procedures were used to perform the analysis of variance (ANOVA) and means were separated using Tukey's honest significant difference (HSD).

The field experiment was conducted during fruiting seasons of 2010-11, 2011-12 and 2012-13 in a 9-12 years old vineyard with Thompson Seedless variety on Dogridge rootstock. The vines were trained to 'Y' system and the location of the vineyard was at ICAR-National Research Centre for Grapes, Manjri Farm, Pune, India. The experiments were laid out in a Randomized Block Design (RBD) with each treatment replicated thrice. Separate experimental blocks were used for studies on each pest. Spray volume at the rate of 1000 l water/ha was used. The sprayings were done using knapsack sprayer (Inter 16 Green, Goizper S. Coop., Antzuola) fitted with hollow cone nozzle.

S. strigicollis adults and *S. litura* larvae were not evenly distributed in the experimental plots during the trial period during both 2010 and 2011 fruiting seasons, therefore caged experiments were conducted in the vineyard. Single treatment application was made at 20 days after fruit pruning (when 8-10 and 5-7 leaf stages of the vines were reached during 2010 and 2011, respectively) for *S. strigicollis* and at 35 days after fruit pruning (when flowering and 12 inch shoot stages of the vines were reached during 2010 and 2011, respectively) for *S. litura*. The insecticidal treatments were sprayed on respective plants. After an hour of spraying, one healthy shoot which was free of insects was selected randomly from each vine and all damaged leaves, if any, were removed from the shoot. Each shoot was covered with insect breeding net cage (AC-186, Amar Chand and Company, Ambala Cantt., Haryana, India). For *S. strigicollis* experiments, 20 adults, collected from never sprayed Dogridge rootstock nursery plants, were released in each cage. Observations on mortality per shoot were taken after 1, 2 and 3 days after treatment application. For experiments on *S. litura*, laboratory reared 20 second instar larvae of *S. litura* were released on each shoot covered under cage. The test insect chosen for bio-efficacy studies was *S. litura* because of its ubiquity in the vineyards. *S. litura* egg masses were collected from vineyards, reared on fresh grape leaves in the laboratory on grapevine leaves. Observations on number of live *S. litura* per vine were noted on 1st, 2ndand 3rdday after implementation of treatments.

For field experiment on *S. dorsalis*, two treatment applications were made at 40 days (pre-flowering stage) and 45 days (flowering stage) after fruit pruning during 2010-11 and 2011-12. Treatments were evaluated by taking observations on five young shoots per replication before spray (pre-count) and at 1, 3 and 5 days after treatment applications by taping of young shoot on A-4 size white paper and visual counting. For field studies on *A. biguttula biguttula*, two treatment applications were made at 25 days (5-6 leaf stage) and 30 days after (8-10 leaf stage) during 2011-12 and 2012-13 fruiting seasons. The observations on *A. biguttula biguttula* were taken by gently handling the tender shoots and visual counting of leafhoppers per shoot during morning hours and the observations were taken on five young shoots per replication before spray (pre-count) and at 1, 3 and 5 days after treatment applications.

The observation values were subjected to arc sine transformation for *S. strigicollis* and *S. litura* per cent

Table 1 Criteria for classification of insecticides based on laboratory and field bio-efficacy studies

Category	Per cent bio-efficacy observed		
	Laboratory studies	Field studies	Symbol
Not effective	<30.0 %	<25.0 %	0
Slightly effective	30.1-75.0%	25.1-50.0%	+
Moderately effective	75.1-95.0%	50.1-80.0%	++
Highly effective	>95.1 %	>80.1 %	+++

Table 2 Bio-efficacy of various insecticides against *S. strigicollis* adults

Insecticide	Dose (ml or g per litre)	Mean per cent corrected mortality									Mean of both seasons at 3 DAT
		Laboratory bioassay			Field cage experiments						
					\2010-11			2011-12			
		1 DAT#	2 DAT	3 DAT	1 DAT	2 DAT	3 DAT	1 DAT	2 DAT	3 DAT	
Buprofezin 25 SC	1.25	0.00 e (0.00)	1.00 fg (3.60)	0.51d e (1.80)	0.00 d (0.00)	2.00 d (5.17)	3.00 e (6.27)	0.00 e (0.00)	2.00 d (5.17)	3.00 d (7.75)	3.00
Thiamethoxam 25 WG	0.25	91.50 a (73.60)	100.00 a (90.00)	100.00 a (90.00)	42.00 ab (40.36)	86.00 a (68.20)	87.74 ab (69.60)	44.00 ab (41.53)	90.00 a (74.04)	91.00 a (74.73)	89.37
Emamectin Benzoate 5 SC	0.22	28.50 d (32.20)	43.50 e (41030)	49.19 c (44.50)	3.00 d (6.27)	27.00 c (31.28)	36.79 d (37.25)	4.00 d (8.86)	29.00 c (32.49)	37.00 c (37.37)	36.90
Lambda cyhalothrin 5 SC	0.50	91.00 a (72.70)	94.50 b (76.70)	96.45 a (80.50)	48.00 a (43.85)	87.00 a (69.30)	89.74 a (73.29)	52.00 a (46.15)	90.00 a (72.03)	92.00 a (77.20)	90.87
Clothianidin 50 WDG	0.12	52.50 c (46.50)	74.50 cd (59.70)	82.22 b (65.50)	38.00 ab (38.02)	53.00 b (46.73)	70.47 bc (57.16)	42.00 ab (40.39)	58.00 b (49.67)	71.00 b (57.46)	70.74
Fipronil 80 WG	0.05	54.50 c (47.60)	89.00 b (70.90)	100.00 a (90.00)	22.00 c (27.94)	77.00 a (61.60)	88.89 a (72.54)	24.00 c (29.20)	80.00 a (63.57)	92.00 a (77.20)	90.45
Methomyl 40 SP	1.00	91.50 a (73.40)	100.00 a (90.00)	100.00 a (90.00)	48.00 a (43.83)	88.00 a (69.82)	91.95 a (75.42)	51.00 a (45.57)	91.00 a (72.67)	94.00 a (78.94)	92.98
Fenpyroximate 5 SC	1.50	1.50 e (4.40)	3.50 f (9.40)	4.04 d (10.00)	1.00 d (2.58)	2.00 d (5.17)	2.00 e (5.17)	2.00 de (5.17)	3.00 d (7.75)	3.00 d (7.75)	2.50
Spinosad 45 SC	0.25	76.00 b (61.00)	85.00 bc (67.70)	100.00 a (90.00)	46.00 a (42.70)	78.00 a (62.24)	87.68 ab (69.81)	48.00 ab (43.85)	82.00 a (65.20)	91.00 a (74.61)	89.34
Sulphur 80 WDG	2.00	0.00 e (0.00)	2.00 fg (6.20)	1.51 de (4.40)	0.00 d (0.00)	1.00 d (2.58)	1.00e (2.58)	0.00 e (0.00)	0.00 d (0.00)	2.00 d (5.17)	1.50
Imidacloprid 17.8 SL	0.30	46.50 c (43.00)	62.00 d (52.00)	82.27 b (65.20)	30.00 bc (33.13)	51.00 b (45.57)	58.16 cd (49.74)	34.00 bc (35.61)	56.00 b (48.47)	61.00 bc (51.37)	59.58
Cyantraniliprole 10 OD	0.70	0.50 e (1.80)	3.50 f (9.60)	3.55 de (8.40)	0.00 d (0.00)	0.00 d (0.00)	1.00 e (2.58)	0.00 e (0.00)	0.00 d (0.00)	2.00 d (5.17)	1.50
Control		0.00 e (0.00)	0.00 g (0.00)	0.00 e (0.00)	0.00 d (0.00)	0.00 d (0.00)	0.00 e (0.00)	0.00 e (0.00)	0.00 d (0.00)	0.00 d (0.00)	
F value		323.35	356.88	382.61	96.25	161.87	91.21	107.41	137.31	69.50	
df (model, error)		12,52	12,52	12,52	16,48	16,48	16,48	16,48	16,48	16,48	
Pr>F		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	

#DAT, Days after treatment; The figures with same letter (s) do not differ significantly and are separated using Tukey's honest significant difference (HSD); The figures presented in the table are mean actual values and figures in parenthesis are their Arc Sine transformed values

Table 3 Bio-efficacy of various insecticides against *S. litura* third instar larva

Insecticide	Dose (ml or g per litre)	Mean per cent corrected mortality									Mean of both seasons at 3 DAT
		Laboratory bioassay			Field cage experiments						
					2010-11			2011-12			
		1 DAT#	2 DAT	3 DAT	1 DAT	2 DAT	3 DAT	1 DAT	2 DAT	3 DAT	
Buprofezin 25 SC	1.25	0.00 e	0.00f	1.60 g	0.00 f	2.00d	3.00d	0.00d	2.00 d	3.00 d	3
		(0.00)	(0.00)	(4.49)	(0.00)	(5.17)	(6.27)	(0.00)	(5.17)	(7.75)	
Thiamethoxam 25 WG	0.25	16.50 c	24.50 d	32.80 e	9.00 bcd	20.00 c	33.50 c	13.00 bc	23.00 c	36.00 c	34.75
		(23.75)	(29.53)	(34.91)	(16.75)	(26.50)	(35.24)	(18.69)	(28.51)	(36.82)	
Emamectin Benzoate 5 SC	0.22	17.50 bc	70.00 ab	99.00 a	3.00 def	27.00bc	82.60 a	19.00 ab	29.00c	87.00 a	84.8
		24.69	(56.91)	(47.42)	(6.27)	(31.28)	(66.00)	(23.2)	(32.49)	(69.48)	
Lambda cyhalothrin 5 SC	0.50	32.00 a	52.00 c	67.60 d	25.00	46.00 a	55.20 b	38.00 a	46.00 ab	69.00 ab	62.1
		(34.38)	(46.17)	(87.42)	(29.88)	(42.68)	(47.98)	(37.95)	(42.67)	(56.35)	
Clothianidin 50 WDG	0.12	7.50 d	7.50 e	13.60 f	12.00 abc	17.00 c	28.50 c	13.00 bc	19.00 c	24.00 c	26.25
		(15.41)	(15.41)	(55.38)	20.06	(24.30)	(32.12)	(18.8)	(25.51)	(29.27)	
Fipronil 80 WG	0.05	6.00 d	60.50 bc	79.60 cd	8.00 cde	46.00 a	73.30 a	19.00 ab	49.00 a	74.00 ab	73.65
		(11.01)	(51.11)	(21.51)	(14.52)	(42.66)	(59.55)	(25.14)	(44.41)	(59.88)	
Methomyl 40 SP	1.00	28.00 abc	75.00 a	89.70 bc	18.00	50.00 a	68.40 ab	29.00 ab	52.00 a	65.00 b	66.7
		(31.85)	(60.11)	(63.30)	(24.98)	(44.98)	(55.82)	(32.23)	(46.15)	(53.93)	
Fenpyroximate 5 SC	1.50	0.00 e	0.00 f	2.10 g	1.00 ef	2.00 d	2.00 d	2.00 cd	3.00 d	4.00 d	3
		(0.00)	(0.00)	(71.77)	(2.58)	(5.17)	(5.17)	(5.17)	(7.75)	(8.86)	
Spinosad 45 SC	0.25	20.00 abc	58.00 bc	76.60 d	8.00 cdef	48.00 a	72.40 ab	13.00 bc	50.00 a	67.00 b	69.7
		(26.55)	(49.61)	(6.37)	(12.80)	(43.83)	(58.37)	(18.69)	(45)	(55.15)	
Sulphur 80 WDG	2.00	0.00 e	0.00 f	0.50 g	0.00 f	1.00 d	0.00d	0.00 d	0.00 d	2.00 d	1.5
		(0.00)	(0.00)	(61.21)	(0.00)	(2.58)	(2.58)	(0.00)	(0.00)	(5.17)	
Imidacloprid 17.8 SL	0.30	0.00 e	1.50 f	2.60 g	0.00 f	0.00 d	1.00d	0.00 d	0.00 d	2.0 d	1.5
		(0.00)	(4.40)	(1.82)	(0.00)	(0.00)	(2.58)	(0.00)	(0.00)	(5.17)	
Cyantraniliprole 10 OD	0.70	28.50 ab	56.50 c	94.80 ab	22.00 ab	41.00 ab	75.40 a	34.00 ab	45.00 ab	72.0 ab	73.7
		(32.22)	(48.77)	(8.16)	(27.76)	(39.79)	(60.36)	(35.61)	(42.1)	(58.34)	
Control		0.00 e	0.00 f	0.00 g	0.00 f	0.00 d	0.00 d	0.00 d	0.00 d	0.00 d	
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
F value		71.53	242.44	247.84	13.83	60.71	98.36	12.08	62.38	64.80	
df (model, error)		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
Pr>F		12, 52	12, 52	12, 52	16,48	16,48	16,48	16,48	16,48	16,48	

#DAT, Days after treatment; The figures with same letter (s) do not differ significantly and are separated using Tukey's honest significant difference (HSD); The figures presented in the table are mean actual values and figures in parenthesis are their Arc Sine transformed values,

Table 4 Bio-efficacy of various insecticides against thrips

Insecticide	Mean per cent corrected mortality (Laboratory bioassay)				Mean number of trhips per shoot (Field experiment)							
					210-11				2011-12			
	1 DAT#	2 DAT	3 DAT	Precount	1 DAT	3 DAT	5 DAT	Precount	1 DAT	3 DAT	5 DAT	PRC$
Buprofezin 25 SC	1.39 f	1.27 fg	2.76 ef	3.93 a	3.80 ab	3.60 abc	2.47 abc	6.00 a	6.53 a	5.80 a	5.60abcd	20.92
	(5.19)	(4.11)	(8.55)	(1.97)	(1.95)	(1.86)	(1.54)	(2.43)	(2.55)	(2.41)	(2.36)	
Thiamethoxam 25 WG	58.48 b	66.64 bcd	70.50 bc	4.67 a	3.40 abcd	2.80 abcd	2.60 ab	6.53 a	4.67 ab	3.40 bc	3.33bcde	41.83
	(49.93)	(54.76)	(57.15)	(2.16)	(1.84)	(1.67)	(1.61)	(2.53)	(2.16)	(1.84)	(1.82)	
Emamectin Benzoate 5 SC	53.65 b	81.33 ab	87.78 ab	4.07 a	2.33 de	0.87 de	0.87 cde	5.87 a	4.80 ab	1.73 cd	2.07 ef	71.24
	(47.18)	(67.52)	(74.23)	(2.02)	(1.52)	(0.91)	(0.9)	(2.41)	(2.18)	(1.32)	(1.43)	
Lambda cyhalothrin 5 SC	58.45 b	64.18 bcd	77.88 abc	4.40 a	2.47 cde	2.07 abcd	2.00 abcd	5.33 a	3.27 b	2.80 cd	2.27 ef	58.17
	(49.9)	(53.5)	(64.82)	(2.09)	(1.57)	(1.44)	(1.41)	(2.31)	(1.8)	(1.67)	(1.5)	
Clothianidin 50 WDG	17.05	34.57 de	59.07 bcd	2.67 a	3.67 abc	2.87 abcd	2.53 abc	5.47 a	4.40 ab	3.40 cd	3.20 cde	43.79
	(23.81)	(35.82)	(50.34)	(1.61)	(1.91)	(1.69)	(1.59)	(2.29)	(2.08)	(1.84)	(1.79)	
Fipronil 80 WG	9.18	45.76 cde	85.09 ab	4.33 a	2.60 bcde	1.00 de	1.07 bcde	6.53 a	4.07 ab	1.80 cd	2.47 ef	65.36
	(15.88)	(42.42)	(75.01)	(2.06)	(1.61)	(1.00)	(1.03)	(2.55)	(2.01)	(1.34)	(1.57)	
Methomyl 40 SP	48.21 bc	71.35 bc	81.47 abc	2.93 a	2.27 de	1.40 cde	1.60 bcd	5.87 a	4.80 ab	2.40 cd	3.00 def	54.90
	(43.92)	(58.55)	(67.69)	(1.71)	(1.49)	(1.18)	(1.26)	(2.41)	(2.18)	(1.54)	(1.73)	
Fenpyroximate 5 SC	29.82 bcd	44.51 cde	59.94 bcd	4.40 a	4.40 a	3.53 abc	4.07 a	5.80 a	6.33 a	5.73 ab	6.73 a	0.00
	(33.02)	(41.78)	(50.95)	(2.1)	(2.09)	(1.85)	(2.00)	(2.41)	(2.51)	(2.39)	(2.59)	
Spinosad 45 SC	83.32 a	95.45 a	98.02 a	3.40 a	3.07 abcd	0.27 e	0.33 e	6.00 a	3.60 ab	0.40 e	0.53 g	91.50
	(68.33)	(82.13)	(86.33)	(1.83)	(1.75)	(0.51)	(0.56)	(2.44)	(1.9)	(0.6)	(0.71)	
Sulphur 80 WDG	10.02 def	17.76 ef	21.69 de	2.73 a	3.80 ab	4.13 ab	4.27 a	7.47 a	6.80 a	6.00 a	6.07 ab	0.00
	(16.12)	(24.42)	(27.18)	(1.65)	(1.95)	(2.03)	(2.06)	(2.73)	(2.59)	(2.43)	(2.45)	
Imidacloprid 17.8 SL	9.85 ef	24.92 e	47.44 cd	3.80 a	2.40 cde	1.73 bcde	1.47 bcde	7.33 a	4.47 ab	3.07 cd	3.73bcde	49.02
	(13.78)	(26.63)	(43.1)	(1.95)	(1.55)	(1.31)	(1.17)	(2.7)	(2.11)	(1.75)	(1.93)	
Cyantraniliprole 10 OD	23.94 cde	60.80 bcd	88.38 ab	3.20 a	1.87 e	1.40 cde	0.60 de	6.87 a	4.80 ab	1.53 d	1.27bcde	81.70
	(27.65)	(51.68)	(74.55)	(1.76)	(1.36)	(1.07)	(0.77)	(2.62)	(2.19)	(1.23)	(1.11)	
Control	0.00 f	0.00 g	0.00 f	2.53 a	4.20 a	4.73 a	4.20 a	5.67 a	6.33 a	6.20 a	6.00 abc	
	(0.00)	(0.00)	(0.00)	(1.57)	(2.05)	(2.17)	(2.04)	(2.37)	(2.51)	(2.48)	(2.43)	
F value	29.76	27.44	24.70	1.90	9.60	8.20	11.38	0.94	3.03	23.58	17.24	
df (model, error)	<0.0001	<0.0001	<0.0001	0.0799	<0.0001	<0.0001	<0.0001	0.5360	0.0083	<0.0001	<0.0001	
Pr>F	12,52	12,52	12,52	14,24	14,24	14,24	14,24	14,24	14,24	14,24	14,24	

#DAT, Days after treatment; The figures presented in the table are actual mean values and figures in parenthesis are Arc Sine (bioassay) and square root (field) transformed values. The figures with same letter (s) do not differ significantly and are separated using Tukey's honest significant difference (HSD), $PRC= Per cent Reduction over Control (mean of both seasons at 5 DAT),

Table 5 Bio-efficacy of various insecticides against *A. biguttula biguttula*

Insecticide	Mean per cent corrected mortality (Laboratory bioassay)				Mean number of trhips per shoot (Field experiment)							
					210-11				2011-12			
	1 DAT#	2 DAT	3 DAT	Precount	1 DAT	3 DAT	5 DAT	Precount	1 DAT	3 DAT	5 DAT	PRC$
Buprofezin 25 SC	16.00 d	48.72 bcd	81.56 bc	4.33 a	2.80 ab	1.60 bcd	1.07 bcde	3.27 a	1.80 ab	1.13 bcde	0.93 cd	73.91
	(20.96)	(43.77)	(70.06)	(2.07)	(1.66)	(1.26)	(1.03)	(1.8)	(1.31)	(1.04)	(0.94)	
Thiamethoxam 25 WG	65.56 ab	98.00 a	100.00 a	4.60 a	0.60 cd	0.53 de	0.13 e	2.40 a	0.93 b	0.80 cde	0.60 d	90.43
	(54.42)	(86.31)	(90)	(2.11)	(0.77)	(0.72)	(0.3)	(1.55)	(0.9)	(0.83)	(0.62)	
Emamectin benzoate 5 SC	17.78 d	25.89 cd	44.39 e	4.33 a	2.80 ab	2.40 abc	2.87 ab	3.40 a	2.33 ab	2.27 abcd	2.13 abc	34.78
	(23.91)	(30.23)	(41.76)	(2.06)	(1.67)	(1.55)	(1.68)	(1.84)	(1.47)	(1.5)	(1.46)	
Lambda cyhalothrin 5 SC	55.33 abc	64.89 bc	82.28 bc	4.33 a	1.07 bcd	0.80 de	0.80 cde	2.80 a	1.07 b	1.20 bcde	1.07 bcd	75.65
	(48.15)	(54.01)	(68.22)	(2.07)	(1.02)	(0.84)	(0.87)	(1.67)	(0.99)	(1.08)	(1)	
Clothianidin 50 WDG	71.56 a	93.33 a	100.00 a	3.53 a	0.27 d	0.40 de	0.40 de	3.20 a	0.80 b	0.47 e	0.27 d	91.30
	(58.4)	(80.48)	(90)	(1.88)	(0.51)	(0.62)	(0.62)	(1.78)	(0.89)	(0.67)	(0.51)	
Fipronil 80 WG	53.11 abc	74.61 ab	93.06 ab	3.20 a	0.80 cd	0.47 e	0.60 de	2.27 a	1.07 b	0.73 de	0.93 bcd	80.00
	(46.79)	(65.88)	(80.23)	(1.77)	(0.86)	(0.56)	(0.62)	(1.5)	(1.03)	(0.81)	(0.96)	
Methomyl 40 SP	53.33 abc	62.67 bc	68.56 cd	3.00 a	1.27 bcd	1.13 cde	1.47 abcd	2.13 a	2.07 ab	1.47 bcde	1.20 bcd	65.22
	(46.95)	(52.41)	(55.99)	(1.69)	(1.12)	(1.05)	(1.21)	(1.39)	(1.42)	(1.18)	(1.09)	
Fenpyroximate 5 SC	34.44 bcd	41.06 cd	43.89 de	4.00 a	3.07 ab	2.93 abc	3.13 ab	2.67 a	3.00 ab	2.40 abc	2.53 abc	26.09
	(35.76)	(39.81)	(41.47)	(1.99)	(1.68)	(1.7)	(1.77)	(1.63)	(1.73)	(1.54)	(1.59)	
Spinosad 45 SC	30.22 cd	31.89 cd	48.61 de	3.87 a	3.00 ab	2.87 abc	2.33 abc	3.20 a	2.47 ab	2.87 ab	2.60 abc	35.65
	(32.87)	(33.79)	(44.19)	(1.95)	(1.73)	(1.69)	(1.53)	(1.78)	(1.57)	(1.69)	(1.61)	
Sulphur 80 WDG	12.22 d	16.44 de	21.22 e	4.13 a	3.93 a	3.67 ab	3.13 ab	3.13 a	3.07 ab	2.73 ab	2.67 ab	24.35
	(20.27)	(18.91)	(26.66)	(2.03)	(1.97)	(1.91)	(1.77)	(1.77)	(1.75)	(1.65)	(1.63)	
Imidacloprid 17.8 SL	34.22 bcd	39.28 cd	64.61 cd	4.20 a	2.20 abc	1.47 cde	1.60 abcd	3.00 a	1.73 ab	1.20 bcde	1.00 bcd	66.09
	(35.18)	(38.73)	(53.6)	(2.03)	(1.48)	(1.19)	(1.26)	(1.72)	(1.28)	(1.09)	(0.99)	
Control	0.00 e	0.00 e	0.00 f	3.87 a	4.93 a	4.07 a	3.73 a	3.53 a	4.07 a	3.80 a	3.93 a	
	(0.00)	(0.00)	(0.00)	(1.95)	(2.22)	(2.02)	(1.91)	(1.88)	(2.02)	(1.95)	(1.98)	
F value	17.91	22.90	44.13	0.79	11.10	12.18	10.94	1.15	3.76	7.15	10.00	
df (model, error)	11,48	11,48	11,48	0.6638	<0.0001	<0.0001	<0.0001	0.3713	0.0031	<0.0001	<0.0001	
Pr>F	<.0001	<.0001	<.0001	13, 22	13, 22	13, 22	13, 22	13, 22	13, 22	13, 22	13, 22	

#DAT= days after treatment; The figures presented in the table are actual, mean values and figures in parenthesis are Arc Sine (bioassay) and square root (field) transformed values. The figures with same letter (s) do not differ significantly and are separated using Tukey's honest significant difference (HSD); $PRC= Per cent reduction over control (mean of both seasons at 5 DAT) mortality data and square root transformation for *S. dorsalis* and *A. biguttula biguttula* count data and were analyzed using software provided by Statistical Analysis System 9.3 (SAS Institute 2011). General linear model (GLM) procedures were used to perform the analysis of variance (ANOVA) and means were separated using Tukey's honest significant difference (HSD). Based on results of both laboratory and field studies, the insecticides were categorized into four categories by method as modified from Sterk *et al*. (1999) (Table 1).

RESULTS AND DISCUSSION

When exposed to *S. strigicollis* adults under laboratory bioassays, all the treatments except buprofezin 25 SC, sulphur 80 WDG and cyantraniliprole 10 OD were capable to cause significant mortality as compared to the control on third day after treatment (Table 2).Thiamethoxam 25 WG, fipronil 80 WG, spinosad 45 SC and methomyl 40 SP caused 100 per cent mortality and lambda cyhalothrin 5 CS resulted in 96.45 per cent, however, these were statistically at par with each other. Similarly, during field cage studies in both seasons during 2010 and 2011 (Table 2), thiamethoxam 25 WG (87.74 and 91 per cent), lambda cyhalothrin 5 CS (89.74 and 92 per cent), fipronil 80 WG (88.89 and 92 per cent), methomyl 40 SP (91.95 and 94 per cent) and spinosad 45 SC (87.68 and 91 per cent) were able to provide maximum mortality, respectively. The present study conforms to the reports where cyantraniliprole 10 OD did not cause significant mortality in *S. strigicollis* adults and thiamethoxam 25 WG and spinosad 45 SC were found effective (Yadav *et al*. 2012a).

When tested against *S. litura* 2^{nd} instar larvae under laboratory bioassays, all the treatments except buprofezin 25 SC, fenpyroximate 5 SC, sulphur 80 WDG and imidacloprid 17.8 SL were capable of causing significant mortality as compared to the control at three days after treatment (Table 3), but emamectin benzoate 5 SG (99 per cent) and cyantraniliprole 10 OD (94.8 per cent) provided best results. During field cage studies in both seasons during 2010 and 2011, emamectin benzoate 5 SG (82.6 and 87 per cent), fipronil 80 WG (73.3 and 74 per cent) and cyantraniliprole 10 OD (75.4 and 72 per cent) were able to provide maximum mortality, respectively (Table 3).These findings are in confirmation with reports of Ahmad *et al*. (2005) for emamectin benzoate and spinosad, and Yadav *et al.*(2012a) for cyantraniliprole against *S. litura*.

When exposed to *S. dorsalis* under laboratory bioassays, spinosad (98.02 %) resulted the highest per cent corrected mortality and was at par with emamectin benzoate 5 SG (87.78), lambda cyhalothrin (77.88 %), fipronil 80 WG (85.09 %), methomyl (81.47 %) and cyantraniliprole 10 OD (88.38 %) at 3 days after treatment (Table 4). In field studies, for both seasons 2010-11 and 2011-12 spinosad 45 SC (91.5 per cent), emamectin benzoate 5 SG (71.24%), fipronil 80 WG (65.36 %) and cyantraniliprole 10 OD (81.7 %) provided effective per cent reduction over untreated control at five days after treatment (Table 4).The findings from the present study conforms to Kulkarni and Patil (2012) and Yadav *et al.* (2012b) for thiamethoxam 25 WG and cyantraniliprole 10 OD, respectively.

Table 6 Summary of differential sensitivity of insecticides based ontheir bio-efficacy to pest complexin grapes

Chemical	Dose (ml/L)	Flea beetle	Cater-pillar	Thrips	Leaf-hopper
Buprofezin 25 SC	1.25	0	0	0	++
Thiamethoxam 25 WG	0.25	+++	+	+	+++
Emamectin Benzoate 5 SG	0.22	+	+++	++	+
Lambda Cyhalothrin 5 CS	0.5	+++	++	++	++
Clothianidin 50 WDG	0.12	++	+	+	+++
Fipronil 80 WG	0.05	+++	++	++	++
Methomyl 40 SP	1.0	+++	++	++	++
Fenpyroximate 5 SC	1.5	0	0	0	+
Spinosad 45 SC	0.25	+++	++	+++	+
Sulphur 80% WDG	2.0	0	0	0	0
Imidacloprid 17.8SL	0.3	++	0	+	++
Cyantraniliprole 10 OD	0.7	0	++	+++	NA

When tested against *A. biguttula biguttula* nymphs under laboratory bioassays, thiamethoxam and clothianidin provided 100 per cent corrected mortality and were at par with fipronil (93.06 %) (Table 5). Similarly, in field studies for both seasons 2011-12 and 2012-13, thiamethoxam 25 WG (90.43 %), clothianidin 50 WDG (91.3 %) and fipronil 80 WG (80 %) were found superior at 5 days after treatment (Table 5).Thiamethoxam and clothianidin by Gupta *et al.*(2009) and fipronil by Patnaik and Mishra (2014) were found effective against leafhoppers supporting present findings.

This identification of differential sensitivity of insecticides on the basis of their bio-efficacy can help in right selection of insecticide during times when multiple pests; out of pest complex of flea beetle, caterpillars, thrips and jassids; are present in the vineyard. It will help in reducing pesticide load in the environment and reduction in cost of cultivation by avoiding tank-mixing separate insecticides for different pests.

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