RESEARCH ARTICLE

INSECTICIDE RESISTANCE IN COTTON MEALYBUG, *PHENACOCCUS SOLENOPSIS* TINSLEY POPULATION COLLECTED FROM FARMER'S FIELD OF BHARUCH DISTRICT OF GUJARAT

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Abstract: Investigations on cotton mealybug, *Phenacoccus solenopsis* Tinsley" was carried out at Laboratory of Main Cotton Research Station, Navsari Agricultural University, Surat during October 2020 to January 2021 through the IRAC leaf dip bio-assay technique. Mealybug population from the farmers fields' of five locations *viz*., Amod, Bharuch, Jambusar, Netrang and Valia taluka of Bharuch district and as well as Research farm, MCRS, Surat were collected and reared at Main Cotton Research Station, NAU, Surat under field cage cover. Leaf dip bio-assays were carried out for the seven insecticides *viz*., imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, buprofezin 25 SC, lamda cyhalothrin 5 EC, spinosad 45 SC and profenophos 50 EC with eight concentrations including control with three repetitions. The LC_{50} values for imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenophos 50 EC, buprofezin 25 SC, Lamda cyhalothrin 5 EC and spinosad 45 SC ranged from 0.0027 to 0.0032, 0.0015 to 0.0017, 0.005 to 0.007, 0.025 to 0.049, 0.017 to 0.029, 0.004 to 0.011 and 0.009 to 0.022 per cent, respectively. The slope values across locations for specific insecticide were estimated as >1 indicated more near homogeneous population across locations. The LC_{90} values for imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenophos 50 EC, buprofezin 25 SC, lamda cyhalothrin 5 EC and spinosad 45 SC ranged from 0.023 to 0.033, 0.008 to 0.010, 0.048 to 0.058, 0.127 to 0.213, 0.072 to 0.126, 0.050 to 0.099 and 0.078 to 0.204 per cent, respectively. The relative resistance ratio considering lowest LC_{50} value as susceptible population varied from 1.00 to 1.19, 1.00 to 1.13, 1.00 to 1.40, 1.00 to 1.96, 1.00 to 1.71, 1.00 to 2.75 and 1.00 to 2.44 fold for imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenophos 50 EC, buprofezin 25 SC, lamda cyhalothrin 5 EC and spinosad 45 SC, respectively. The comparison between LC_{90} values obtained with the field recommended rate showed the lowest ratio for profenophos (1.27 to 2.13 fold), buprofezin (1.44 to 2.52 fold), acetamiprid (2.00 to 2.50 fold), spinosad (3.94 to 10.30 fold), imidacloprid (4.69 to 6.73 fold) and thiamethoxam (4.80 to 5.80 fold), whereas higher ratio for lamda cyhalothrin (10.00 to 19.80 fold). There was much variation between the LC_{90} and recommended rate in case of lamda cyhalothrin 5 EC at Valia (19.80 fold) followed by Amod (16.80 fold) than other locations (10.0 to 14.0 fold). Similarly, variation in case of spinosad 45 SC showed high at Netrang (10. 30 fold) followed by Bharuch (8.33 fold) than other locations (3.94 to 7.93 fold).

Keywords: Cotton, Farmers, Insecticide, Investigation, Population

INTRODUCTION

Cotton is an important cash crop in India, known as the King of Fibre and commonly known as "White Gold". The cotton fibre is popularly known as "friendly fibre" because it produces approximately 80 percent of the raw material in the textile industry of the country, providing employment for more than 100 million people through production, processing, trading and marketing (Rakesh and Kathane, 1989). It was during 2002 that transgenic *Bt* cotton was first commercialized in India and offered boons to the cotton farmers. The crops were protected from bollworm damage, and losses in yield were minimized. The world produced 113.32 million bales of cotton from 32.20 million hectares of cultivated land with 766 kg/ha productivity while, based on Cotton Advisory Board figures, 37.1 million bales of cotton were produced on 12.95 million hectares of cultivated land in India and the production was 487 kg/ha and India's largest producer of cotton is Gujarat, with more than 9.1 million bales produced from 2.3 million hectares with 677 kg/ha of productivity for 2020-21.

Due to the dominance of *Bt* cotton in recent times in India, pest dynamics have changed more often with cropping systems and environmental changes. There are several pests that feed on cotton's leaves, including leaf hoppers, aphids, whiteflies, mealybug, and thrips. The cotton ecosystem in the world is home to 1326 insect species (Hargreaves, 1948). As a result of sucking pests, bollworms, and both sucking pests and bollworms, losses have been recorded as high as 12, 44, and 52 per cent, respectively (Dhawan *et al*., 1988). In recent decades, the exotic mealybug *Phenacoccus solenopsis* Tinsley, previously unknown, has been considered a key pest in Gujarat and India (Nagrare *et al*., 2009). The overall loss (based on 4-grade infested plants) was estimated to be 1.07 percent in 21 surveyed villages of Surat and Bharuch district with the prevalence of the 8.55 percent natural parasitism of *Aenasius bambawalei* Hayat (Bhanderi *et al*., 2020). The mis-use of insecticides, whether they are intended to kill mealybug or other sucking pests, leads to a resurgence and resistance problem. Resistance build up in mealybug was reported in case of organophosphates (acephate, profenophos, chlor-

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pyriphos, monocrotophos and quinalphos), synthetic pyrethroids (bifenthrin, lamda cyhalothrin, deltamethrin and cypermethrin), neonicotinoids (acetamiprid, imidacloprid, thiomethoxam) carbamate (carbosulfan) avermectins (emamectin benzoate) chitin synthesis inhibitor (buprofenzin), tetronic and tetramic acid (spirotetramat) by various workers in India and Pakistan (Afzal *et al*., 2016). Though, little work has been undertaken to assess the level of resistance developed by this pest especially in Gujarat state. It is reported from various locations of Gujarat that the control of this pest through insecticides fails even after frequent applications of recommended dosages of insecticides in various crops like cotton, onion *etc*. It is, therefore, necessary to generate the resistance data of different insecticides against mealybug in various locations of Bharuch district with selected insecticides and find out level of resistance developed by the pest against various insecticides for effective and economical management. Keeping this in view, the present investigation was undertaken to monitor the levels of insecticide resistance in field population of cotton mealybug from different locations of Bharuch district.

MATERIALS AND METHODS

Test Insect

Cotton mealybug, *P. solenopsis* was chosen as the test insect for the experiment. The population of *T. tabaci* was collected from five different location of Bharuch district and as well as Research farm, MCRS, Surat which was not treated with insecticides for more than fifteen days.

Collection and Transport of Mealybug for Bioassay

The sampling for field population of mealybug was carried out during October 2020 to January 2021 when there was sufficient population pressure of mealybug from the farmers fields' of six locations *viz*., Amod, Bharuch, Jambusar, Netrang and Valia taluka of Bharuch district and as well as Research farm, MCRS, Surat. For collecting the samples, infested cotton twigs/shoots with mealybug colonies at rational population pressure were plucked and collected in the special plastic bucket (height-26 cm, diameter-30 cm) having 40 mesh wire net fitted window at the whole central periphery to allow air circulation and the mouth of the bucket covered with muslin cloth and tied with rubber band. From one location, such fifteen buckets were brought to the Main Cotton Research Station, Navsari Agricultural University, Surat for further experimentation.

Multiplication of Collected Mealybug Samples under Caged Condition

The collected mealybug samples of each location were reared separately under field caged condition on hybrid, G.Cot.Hy.8 BG II for three generations at Research Farm, Main Cotton Research Station, Navsari Agricultural University, Surat. For the purpose, untreated seeds of hybrid, G.Cot.Hy.8 BG II were sown in separate plots (Gross plot: 14.40 m x7.65 m) for rearing collected mealybug population of five different locations. One additional plot of similar size was also sown with hybrid, G.Cot.Hy.8 BG II for rearing and maintaining susceptible population under unsprayed condition. All the plots were guarded with one row of pigeon pea and covered with white curtains from all four sides at periphery (3m height). One blanket spray (Azadirachtin 1500 ppm) was given fifteen days prior to collection of the mealybug population from six locations. Then, the collected population of mealybug of respective locations was released from the centre of the intended plot. The established population after three generations of each location was utilized for bioassay studies of seven commonly used insecticides.

Test Insecticides and Preparation of Insecticidal Solution

The commonly used seven insecticides *viz*., imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenophos 50 EC, buprofezin 25 SC, Lamda cyhalothrin 5 EC and spinosad 45 SC were procured and used for bioassay against mealybug; the details of seven insecticides used are given in Table 1. Bioassay was carried out for each of the seven insecticides with eight concentrations in distilled water with three repetitions. The concentrations for each test insecticide rendering mortality between 20 to 80 per cent mortality considered for bio-assays based on pilot scale testing. Insecticide solutions with graded concentration/doses especially in geometrical progression with three lower and three higher field recommended doses to get better responses along with no exposure were prepared by serial dilution technique in the glass jars with wide mouth (height-15cm, diameter-13cm) after washing thoroughly with distilled water just prior to experimentation and such jars with eight graded concentrations of single insecticide were properly labeled.

Bio-assay for *P. solenopsis* to Insecticides

Samples of mealybug were collected from cotton grown under cage condition in field and exposed to graded concentrations of each test insecticide following leaf dip method recommended by Insecticide Resistance Action Committee (IRAC No. 14). In order to treat substrate, upper leaves with long petioles were selected from 75 to 90 day old plants, and slanting cuts were made using sterilized knife. Immediately after the petioles were cut, they were wrapped with a cotton swab moistened with a ten percent sucrose solution and parafilm was applied. Such 175 leaves (with petiole) were selected and prepared for conducting tests. Three leaves were dipped for 30 seconds in insecticidal solutions of each concentration for each insecticide. A control was run which were dipped with distilled water.

After dipping, each leaf was allowed to naturally shade dry for fifteen minutes under a fan before it was placed individually in Petri dishes (9 cm diameter). The established population of mealybug on G.Cot.Hy.8 BG II hybrid was brought to the laboratory by plucking infested leaves/twigs in the plastic buckets from the intended plot. Uniform size 100 young nymphs of cotton mealybug were released per leaf of cotton with pointed camel hair brush in Petri dish. Such 24 petri dishes, each containing 100 mealybug were used for bioassay for eight different concentrations with three repetitions for single insecticide. A total of 168 sets comprising of seven insecticides were kept for observations. The mortality of mealybug was observed under laboratory at 24 hour interval up to 72 hours after exposure to different test concentrations. Counts of dead mealybug were made every 24 hours during observation in the petri dish. Those mealybug, which were unable to move themselves within ten seconds on slight touch with camel hair brush or unable to turn on their back once disturbed, were considered dead. The suspected individuals were gently touched with a fine camel hair brush and their mortality recorded when in doubt. For each concentration, including control, the number of live and dead mealybug was counted at the end of 72 hours and the data so obtained were subjected to LDP analysis through Polo Leora software provided. The mortality data of each treatment were corrected with respect to control mortality as per Abbott's formula (1925) for mealybug bioassay.

$$\text{Corrected mortality (\%)} : \frac{X - Y}{100 - Y} \times 100$$

Where, X= % mortality in the treated sample
Y= % mortality in the control

Estimation of LC_{50} for Susceptibility of Insecticide to Mealybug

The value of median lethal concentration (LC_{50}) for each insecticide was worked out using probit analysis by Finney (1971) and by computer software Polo Leora software (2003) provided earlier under TMC project by ICAR-CICR, Nagpur. Similarly, LC_{50} values of these insecticides against the collected population of cotton mealybug were calculated. The LC_{50} and LC_{90} values of each insecticide so obtained through bioassay studies on mealybug population collected for different locations were compared.

Insecticides resistances build up of the tested insecticide

The relative resistance ratio between cotton mealybug population collected from six different locations was determined for each insecticide using the formula as under whereas, insecticide resistance levels were described using RFs (Lai *et al*., 2011) as follows: susceptibility (RF=1), decreased susceptibility (RF= between 3-5), low resistance (RF= between 5-10), moderate resistance (RF= between 10-40), high resistance (RF= between 40-160) and very high resistance (RF>160).

$$\text{Relative Resistance Ratio} : \frac{LC_{50} \text{ of particular location mealybug population}}{LC_{50} \text{ of relatively susceptible location mealybug population}}$$

RESULTS AND DISCUSSION

Resistance ratios are useful to monitor the evaluation of insecticide resistance in a given field population. Resistance ratio usually estimated by dividing the LC_{50} of field population by the LC_{50} of a susceptible strain. In the absence of baseline susceptible data of tested insecticides against mealybug infesting cotton, resistance ratios were estimated from the variability in LC_{50} of respective insecticides in the field population collected from five locations of Bharuch district in Gujarat and as well as Research farm, MCRS, Surat.

Relative Resistance Ratio across Locations

The data on the LC_{50} of seven different insecticides *viz.*, imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenophos 50 EC, buprofezin 25 SC, Lamda cyhalothrin 5 EC and spinosad 45 SC against mealybug population of five different locations *viz*., Amod, Bharuch, Jambusar, Netrang and Valia taluka of Bharuch district and as well as Research farm, MCRS, Surat are presented and the population of specific location for each insecticide showing lowest LC_{50} was considered susceptible population and used for comparing and working out the relative resistance ratio across locations for respective insecticides (Table 1).

The data on the relative resistance ratio of imidacloprid to six different populations of *P. solenopsis* are presented in the Table 2. The results determined that relative resistance ratio with susceptible population of Jambusar and Surat showed 1.03 fold (Netrang), 1.07 fold (Valia and Bharuch) and 1.19 fold (Amod) increased in LC_{50} against mealybug population. For acetamiprid, the mealybug population of Netrang and Surat location showed lowest LC_{50} (0.0015%) and the relative resistance ratio with susceptible population showed 1.07 fold to Jambusar and 1.13fold to Amod, Bharuch and Valia population against mealybug. Similarly, the mealybug population of each of the locations *viz.*, Valia and Jambusar showed 1.20 fold whereas Bharuch showed 1.40 fold increase in LC_{50} value of thiamethoxam against susceptible population of Amod, Netrang and Surat (LC_{50}=0.005%). The LC_{50} of profenofos for six different population of *P. soleopsis* revealed that there was a lowest LC_{50} (0.025%) in mealybug population of Valia and the relative resistance ratio at LC_{50} calculated against susceptible population was found to be increase by 1.40 fold in Amod, 1.44 fold in Bharuch, 1.36 fold in Jambusar, 1.76 fold in Netrang and 1.96 fold in Surat mealybug population. For buprofezin, mealybug population of Jambusar location showed lowest LC_{50} (0.017%) and the relative resistance ratio with

susceptible population of Jambusar showed 1.12, 1.06, 1.71, 1.41 and 1.41 fold increases in LC_{50} in Amod, Bharuch, Netrang, Valia and Surat populations, respectively. For lamda cyhalothrin, mealybug population of Jambusar and Surat location showed lowest LC_{50} (0.004%) and the relative resistance ratio with susceptible population of Jambusar and Surat showed 1.25 fold (Bharuch), 1.50 fold (Netrang), 1.75 fold (Amod) and 2.75 fold (Valia) increased in LC_{50} against mealybug population. For spinosad, the mealybug population of Jambusar location showed lowest LC_{50} (0.009%) and the relative resistance ratio with susceptible population showed 1.67 fold to Amod and Surat, 2.00 fold to Bharuch, 2.33 fold Valia and 2.44 fold to Netrang population against mealybug. The present study revealed that the relative resistance ratio for imidacloprid, acetamiprid, thiamethoxam, profenofos, buprofezin, lamda cyhalothrin and spinosad varied from 1.03 (Netrang) to 1.19 (Amod); 1.07 (Jambusar) to 1.13 (Amod, Bharuch and Valia); 1.20 (Jambusar and Valia) to 1.40 (Bharuch); 1.36 (Jambusar) to 1.96 (Surat); 1.06 (Bharuch) to 1.71 (Netrang); 1.25 (Bharuch) to 2.75 (2.75) and 1.67 (Amod and Surat) to 2.44 (Netrang) respectively. Thus, in the present study, moderate level of resistance was found in field population of cotton mealybug against spinosad 45 SC, lamda cyhalothrin 5 EC and low level to profenofos 50 EC and buprofezin 25 SC.

The data on the LC_{90} values of seven different insecticides obtained with field recommended rate of *viz.*, imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenofos 50 EC, buprofezin 25 SC, lamda cyhalothrin 5 EC and spinosad 45 SC against mealybug population of six different locations *viz*., Amod, Bharuch, Jambusar, Netrang, Valia and Surat as well as relative resistance ration across locations for respective insecticides are presented in Table 3. In general, resistance ratio based on LC_{90} for imidacloprid (4.69 to 6.73 fold), acetamiprid (2.00 to 2.50 fold), thiamethoxam (4.80 to 5.80 fold), profenofos (1.27 to 2.52 fold), buprofezin (1.44 to 2.52 fold), lamda cyhalothrin (10.00 to 19.80 fold) and spinosad (3.94 to 10.30 fold). There was large difference between the LC_{90} and recommended rate showing evolving of resistance in mealybug populations.

Thus, in present study, the relative resistance ratio considering lowest LC_{50} value as susceptible population varied from 1.00 (Jambusar and Surat) to 1.19 (Amod), 1.00 (Netrang and Surat) to 1.13 (Valia, Amod and Bharuch), 1.00 (Amod, Netrang and Surat) to 1.40 (Bharuch), 1.00 (Valia) to 1.96 (Surat), 1.00 (Jambusar) to 1.71 (Netrang), 1.00 (Jambusar and Surat) to 2.75 (Valia) and 1.00 (Jambusar) to 2.44 (Netrang) fold for imidacloprid 70 WG, acetamiprid 20 SP, thiamethoxam 25 WG, profenofos 50 EC, buprofezin 25 SC, lamda cyhalothrin 5 EC and spinosad 45 SC, respectively. In present study, the resistance ratio differed across locations to tested insecticides and depended on the practices followed in the different locations. Earlier, Venkatesan *et al*. (2016) reviewed the insecticide resistance and its management in mealybug and opined that efforts should be required to determine insecticide resistance across the geographical populations of different species of mealybug for effective management at regional level. Afzal and Shad (2017) found 282.45 fold resistance to spinosad 24 SC after seven rounds of selection and spinosad 24 SC selected population showed low cross-resistance to spinetoram 120 SC (16.21 fold), very low cross-resistance to profenofos 500 EC (3.16 fold) and very high cross-resistance to deltamethrin 10 EC (137.69 fold) in with respect to unselected population. Ismail *et al*. (2017) found that cholr-SEL strain of *P. solenopsis* had increased resistance ratio from 123 to 15292 fold and also increased LC_{50} values from 75.30 to 9328.24 µg a.i./ml after 23 generation compared to susceptible strain. Afzal *et al*. (2019) found 25623.17 fold resistance in indoxacarb in lab selected strains of 27 generations which showed very high cross-resistance to spinosad and very low cross-resistance to bifenthrin and chlorpyrifos. Banazeer *et al*. (2019) found increased in LC_{50} value of spinosad 24 EC from 100.61 to 54,274.19 mg/l (G_2 to G_{28}) and also increased resistance ratio from 1.0 fold to 539.5 fold compared with field population and 28.2 fold to 15,233.8 fold compared with laboratory population whereas cross-resistance to spinetoram 120 SC, profenofos 500 EC, and deltamethrin 10 EC was 24.58, 0.74 and 74.46 fold, respectively. Nagrare *et al*. (2019) found very high level 378.29 fold resistance against thiadiazines (buprofezin 25 SC) in mealybug population collected from Amravati, whereas resistance was found negligible at other locations while low to very low level of resistance was recorded against organophosphates (monocrotophos 36 SL, chlorpyrifos 20 EC, quinalphos 25 EC and acephate 75 SP) and thiourea derivatives (diafenthiuron 50 WP) from all the locations with respect to susceptible strain.

Table 1. Insecticides used for cotton mealybug, *P. solenopsis* for bio-assay

S. N.	Common name	Chemical name (IUPAC name)	Field dose (Dose/ha) in 500 l water			Test concentrations (C_1 to C_8)	Manufacturer
			(g) *a.i.*/ha	Formulation (g or ml per ha)	Field conc.		
1	Imidacloprid 70 WG	N-{1-[(6-Chloro-3-pyridyl)methyl]-4,5 dihydroimidazol-2-yl}nitramide	24.5	35	0.0049	0.00, 0.0006125, .001225, 0.00245, 0.0049, 0.0098, 0.0196, 0.0392	Bayer Crop Science Ltd., Mumbai
2	Acetamiprid 20 SP	N-[(6-chloro-3pyridyl)methyl]-N'-cyano-Nmethyl-acetamidine	20	100	0.0040	0.00, 0.0005, 0.001, 0.002, 0.004, 0.008, 0.016, 0.032	Rallis India Pvt. Ltd., Mumbai
3	Thiamethoxam 25 WG	3-[(2-Chloro-1,3-thiazol-5yl)methyl]-5-methyl-N-nitro1,3,5-oxadiazinan-4-imine	50	200	0.0100	0.00, 0.00125, 0.0025, 0.005, 0.01, 0.02, 0.04, 0.08	Syngenta (India) Pvt. Ltd., Mumbai
4	Profenofos 50 EC	4-bromo-2-chloro 1[ethoxy(propylsulfanyl)phos phoryl]oxybenzene	500	1000	0.1000	0.00, 0.0125, 0.025, 0.05, 0.1, 0.2, 0.4, 0.8	Excel Crop Care Ltd., Mumbai
5	Buprofezin 25 SC	(2Z)-3-Isopropyl-2-[(2-methyl-2-propanyl)imino]-5-phenyl-1,3,5-thiadiazinam-4-one	250	1000	0.0500	0.00, 0.00625, 0.0125, 0.025, 0.05, 0.1, 0.2, 0.4	Rallis India Pvt. Ltd., Mumbai
6	Lamda cyhalothrin 5 EC	(R)-α-cyano-3-phenoxybenzyl(1S)-cis-3-[(Z)-2-chloro-3,3,3-trifluoropropenyl]-2,2-dimethylcyclopropanecarboxylate and (S)-a-cyano-3-phenoxybenzyl(1R)-cis-3-[(Z)-2-chloro-3,3,3-trifluoropropenyl]-2,2-dimethylcyclopropanecarboxylate	25	500	0.0050	0.00, 0.000625, 0.00125, 0.0025, 0.005, 0.01, 0.02, 0.04	Syngenta (India) Pvt. Ltd., Mumbai
7	Spinosad 45 SC	(1S,2R,5S,7R,9R,10S,14R,19S)-15-[(2R,5S,6R)-5-(dimethylamino)-6-methyloxan-2-yl]oxy-19-ethyl-14-methyl-7-[(2R,3R,4R,5S,6S)-3,4,5-trymethoxy-6-methyloxan-2-yl]oxy-20-oxatetracyclo[10.10.0.02,10.05,9]docosa-3,11-diene-13,21-dione	100	220	0.0198	0.00, 0.002475, 0.00495, 0.0099, 0.0198, 0.0396, 0.0792, 0.1584	Bayer Crop Science Ltd., Mumbai

Table 2. Relative resistance ratio based on LC_{50} of insecticides at recommended concentration against mealybug populations at different locations

Sr. No.	Locations	Imidacloprid 70 WG		Acetamiprid 20 SP		Thiamethoxam 25 WG		Profenofos 50 EC		Buprofezin 25 SC		Lamda cyhalothrin 5 EC		Spinosad 45 SC	
		LC_{50}	RR	LC_{50}	RR	LC_{50}	RR	LC_{50}	RR	LC_{50}	RR	LC_{50}	RR	LC_{50}	RR
1	**Amod**	0.0032	1.19	0.0017	1.13	0.005	1.00	0.035	1.40	0.019	1.12	0.007	1.75	0.015	1.67
2	**Bharuch**	0.0029	1.07	0.0017	1.13	0.007	1.40	0.036	1.44	0.018	1.06	0.005	1.25	0.018	2.00
3	**Jambusar**	0.0027	1.00	0.0016	1.07	0.006	1.20	0.034	1.36	0.017	1.00	0.004	1.00	0.009	1.00

4	**Netrang**	0.0028	1.03	0.0015	1.00	0.005	1.00	0.044	1.76	0.029	1.71	0.006	1.50	0.022	2.44
5	**Valia**	0.0029	1.07	0.0017	1.13	0.006	1.20	0.025	1.00	0.024	1.41	0.011	2.75	0.021	2.33
6	**Surat**	0.0027	1.00	0.0015	1.00	0.005	1.00	0.049	1.96	0.024	1.41	0.004	1.00	0.015	1.67

RR: Resistance Ratio and **LC**: Lethal Concentration
Note: Relative resistance ratio was estimated considering LC_{50} values of respective locations with recommended conc. of insecticides

Table 3. Relative resistance ratio based on LC_{90} of insecticides at recommended concentration against mealybug populations at different locations

S. N.	Locations	Imidacloprid 70 WG			Acetamiprid 20 SP			Thiamethoxam 25 WG			Profenofos 50 EC			Buprofezin 25 SC			Lamda cyhalothrin 5 EC			Spinosad 45 SC		
		RC	LC_{90}	RR	RC	LC_{90}	RR	RC	LC_{90}	RR	RC	LC_{90}	RR	RC	LC_{90}	RR	RC	LC_{90}	RR	RC	LC_{90}	RR
1	**Amod**	0.0049	0.033	6.73	0.004	0.010	2.50	0.01	0.058	5.80	0.1	0.182	1.82	0.05	0.095	1.90	0.005	0.084	16.80	0.0198	0.144	7.27
2	**Bharuch**	0.0049	0.032	6.53	0.004	0.009	2.25	0.01	0.053	5.30	0.1	0.195	1.95	0.05	0.083	1.66	0.005	0.057	11.40	0.0198	0.165	8.33
3	**Jambusar**	0.0049	0.023	4.69	0.004	0.009	2.25	0.01	0.051	5.10	0.1	0.193	1.93	0.05	0.072	1.44	0.005	0.061	12.20	0.0198	0.078	3.94
4	**Netrang**	0.0049	0.028	5.71	0.004	0.008	2.00	0.01	0.049	4.90	0.1	0.213	2.13	0.05	0.126	2.52	0.005	0.050	10.00	0.0198	0.204	10.30
5	**Valia**	0.0049	0.032	6.53	0.004	0.010	2.50	0.01	0.053	5.30	0.1	0.127	1.27	0.05	0.112	2.24	0.005	0.099	19.80	0.0198	0.135	6.81
6	**Surat**	0.0049	0.026	5.31	0.004	0.008	2.00	0.01	0.048	4.80	0.1	0.252	2.52	0.05	0.104	2.08	0.005	0.070	14.00	0.0198	0.157	7.93

RR: Resistance Ratio and **LC**: Median Lethal Concentration
Note: Relative resistance ratio was estimated considering LC_{90} values of respective locations with recommended conc. of insecticides

CONCLUSION

From the results of research experiment, the uses of buprofezin since last 5 years against sucking pests including mealybug and against younger larval stages in the desi cotton may lead to the low level evaluation of resistance in buprofezin 25 SC against mealybug as used as higher dose than recommended dose especially at Netrang, Valia and Surat locations. Similarly, the low level resistance in mealybug for profenophos at Surat and Netrang may be due to regular and frequent use against mealybug populations having some water logging conditions and uses at higher doses at shorter intervals. The synthetic pyrethroids especially lamda cyhalothrin was most preferred against pink bollworm control (which is major problem in Bt cotton owing to development of resistance) and farmers resorted frequent sprays at shorter interval in initial window as well as use of combination product containing lamda cyhalothrin against pink bollworm and mealybug lead to the development of moderate level of resistance especially at Valia and Amod locations. The spinosyns specifically spinosad 45 SC were also used frequently at shorter interval for the control of thrips and was also recommended against pink bollworm and the farmers of Netrang and Valia having more irrigation facilities and regular high incidence of thrips and pink bollworm due to monocropping tendency which lead to development of moderate level of resistance across locations.

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