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Impact Analysis of Biorational Insecticides under Weeded and Non Weeded Habitat on Whitefly, *Bemisia tabaci* Management in Cotton Agroecosystem

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ABSTRACT

Transgenic *Bt* cotton is effective to a high degree of, with respect to target lepidoptran bollworms, however sucking pests especially whitefly posed a serious issues in absence of bollworm in genetically modified (GM) crops. Therefore, to understand the efficacy of various biorational compounds against whitefly under non-weedy as well as weedy field conditions, studies on whitefly carried out during *kharif* 2018, to know the changes in number of whitefly adults as well as nymphs. Transgenic hybrid cotton variety RCH 650 was sown with a spacing of 100×45 cm and replicated four times in both non-weedy and weedy habitat. Although, standard check Dimethoate 30 EC proved it's efficacy after first and second spray in cotton crop against whitefly. Not with standing, after the application of biorational first time as spray in 29th Standard Meteoroloical Week (SMW), Nimbecidine 300 ppm was admitted as most effective in non-weedy (66.76 and 60.65% mean mortality in whitefly adult and nymph, respectively) as well as in weedy habitat that caused 56.77 and 55.54% mean mortality in adult and nymph, respectively over a period of seven days after application. Entomopathogenic fungi *Verticillium lecanii* found better to control whitefly adults (42.06 and 40.63%), while *Metarhizium anisopliae* (42.39 and 36.01%) found more effective for nymphal mortality in non-weedy as well as in weedy habitat. One and same pattern of efficacy of biorational was reconstructed against whitefly again after second application of biorational in all the treatment selected to test against whitefly.

Keywords Biorational, Cotton, Insect-pest, Management, Non-weedy, Weedy, Whitefly.

INTRODUCTION

Cotton (*Gossypium hirsutum*) is one of the principal fiber crops of India known by various names such as "King of Fiber" and or "The White Gold" and major source of raw material for domestic textile industry. It provides sustenance to millions of farmers and the workers involved in the cotton industries, right from processing to trading of cotton (Dahiya *et al.* 2013). Cotton is cultivated in tropical and subtropical regions of more than 80 countries and industrially

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developed as a yearly product in both tropical and temperate areas of the world (Anupam 2010, Ozyigit *et al.* 2007). India is the leading country in terms of area under cotton cultivation with 38% of world cotton area and raw cotton production in the world (Anonymous 2022). However after the release of *Bt* cotton in India, the area under cotton cultivation has gone up to 130.5 lakh ha during the year 2022-23 (Kumari *et al.* 2023), with productivity of 468.87 kg/ha and production of 341 lakh bales during 2022 (Anonymous 2022).

Cotton crop is unable to express its full potential because of biotic and abiotic stresses encountered during its different growth stages. Many and various biotic constraints appear to be very important, of which the ravages caused by insect-pest assume greater importance. About 184 insect-pests have been so far reported on cotton in India which causes upto 80% loss to yield (Patil *et al.* 1998). Although, after the introduction of *Bt* cotton hybrids a substantial change in insect-pest complex has occurred and transgenic cotton played important role in the management of the bollworm population only (Fakrudin *et al.* 2003, Murugan *et al.* 2003), however that led to an exponential rise in population of sucking pests.

Bemisia tabaci (Gennadius) (Hemiptera : Aleyrodidae) is a major threat to the cultivation of *Bt* cotton throughout the country. It is most notorious pest in tropical and subtropical agriculture and is quite devastating on cotton, brinjal, okra, tomato and several ornamental plants (Palaniswami *et al.* 2001). Many biological characteristics that include multivoltinism, wide host range i.e., more than 600 species in the world (Secker *et al.*1998), high fecundity, high temperature tolerance and a propensity to develop resistance to many insecticides makes it a problematic pest and intervene in the way of developing robust and sustainable management system (Ellsworth and Jones 2001, Naranjo 2001). Cotton leaf curl virus (CLCV) transmitted by *B. tabaci* is also very serious problem throughout the cotton belt in India.

Knowledge of effect and nature of relationship between various factors that includes biotic and abiotic factors with pest biology and population dynamics is essential step before developing weather based pest forecasting system.

Among biotic factors viz., natural enemies, pathogens, weeds, alternate host, weeds play an important role in population build-up of whitefly by serving as reservoir and help them to survive in non-crop season (Gerling 1984, Solangi *et al.* 2016). Identification of host particularly weeds and others plants sequences as well as effect on biology and growth rate on various hosts are prerequisite tools in achieving effective whitefly management (Zalom *et al.* 1995). Cotton whitefly is attacked by a number of insect predators and parasitoids including 34 species of *Encarsia*, 12 species of *Eretmocerus*, 2 species of *Amitus* and one species each of *Methycus* and *Signiphora* (Gerling *et al.* 2001), but *Encarsia* and *Eretmocerus* have great importance in terms of their relative abundance (Palaniswami *et al.* 2001). In continuation, entomopathogenic fungi are potentially very important biological control agents due to their wide host range that leads to natural epizootics. The entomopathogenic fungi *Metarhizium* spp., *Beauveria* spp., *Verticillium lecanii* are the most common components in pest control and integrated pest management (IPM) programs as stated by Naglaa and Reyad (2017). In the light of above context, present studies had been planned with special emphasis on eco-friendly management of whitefly, *B. tabaci* by use of biorational insecticides on cotton crop.

MATERIALS AND METHODS

Materials used during the studies

Materials that were utilized for setting up the experiment and for recording the observations includes hand lens (10X), hand mirror, glass vials, petri dish, marking tags, marking pencil, 12-megapixel digital camera, knapsack sprayer, biorational insecticides, compound microscope.

Details of experiments conducted

Experiment was conducted in two set in Randomized Block Design (RBD) with six treatments each in four replications for comparing the efficacy of biorational compounds including standard check as Dimethoate 30 EC (Table 1). Selected biorational were applied as

Table 1. Treatments applied to manage the whitefly population.

	Treatments	Dose
T_1	: Nimbecidine 300 ppm	1.0 L/acre
T_2	: *Beauveria bassiana* (1×10^9 cfu/g)	1.26 kg/acre
T_3	: *Verticillium lecanii* (1×10^9 cfu/g)	1.26 kg/acre
T_4	: *Metarhizium anisopliae* (1×10^8 cfu/g)	1.26 kg/acre
T_5	: Dimethoate 30 EC	300 ml/acre
T_6	: Control	No application

and when whitefly adult population crossed economic threshold (ET) i.e., 6-8 adults/leaf in the field of experimental plots. Each treatment was applied two times during the crop season i.e., 18th of July and 29th of August, 2018 with the help of knapsack sprayer.

Location **:** Biocontrol Laboratory and Research Farm, CCS Haryana Agricultural University, Cotton Research Station, Sirsa, India.

Methodology

Set of field experiments were laid on 13th May, 2018 with a plot size of 6.0×4.95 m with spacing 100×45 cm accommodating a total of 66 plants for each treatment, replicated four times. First experiment was conducted under non-weeded condition, where weeds were not removed during the crop season, hence it served as weedy habitat for whitefly. The second set of experiment was conducted in weeded conditions, where four weedings were carried out during crop season to provide the weed free condition i.e., non-weedy habitat for whitefly. First weeding was carried out on 13th June 2018 (after one month of sowing) in second experiment (weed free condition).

It rained during the crop season in 27th, 29th, 30th, 32th, 33rd, 37th, 38th and 39th SMW (Standard Meteorological Week) and weeding was done after every rain in the respective treatment. First weeding during period of observation was carried out on 13th June, 2018 (24th SMW), second on 10th July 2018 (28th SMW) and third carried out on 1st August 2018 (31st SMW). To maintain the weed free crop environment further, fourth weeding carried out on 23rd August (34th SMW). Last weeding was carried out on 3rd October 2018 (40th SMW) after a spell of rainfall in three consecutive weeks i.e., 37th, 38th and 39th SMW.

Observations recorded

Observations on starting from 40 days after sowing of crop in the 27th SMW (July) at weakly interval. All the obervations were recorded early in the morning as whitefly being sluggish at that time. A hand mirror was placed underside of leaves to count the number of whitefly and nymphal population was counted by using the hand lens of 10X zoom. Number of whitefly adults and nymphs were counted before treatment and at 3, 5 and 7 days after treatment of biorational from five randomly selected plants from each plot.

Statistical analysis

The experimental data were subjected to statistical analysis by using Randomized Block Design (RBD) in Online Agriculture Data Analysis Tool (OPSTAT) for the comparison of treatments in each experiment as per procedures of Sheoran *et al.* (1998). Population reduction (%) over control (mortality % over control) in each treatment of both habitats was calculated and angular transformation of data were carried out by using OPSTAT and each treatment was compared using their arc sine values.

Yield data

The yield of seed cotton was recorded from the plots having different treatments separately at each picking and later converted to kilogram per acre (kg/acre) in all the sets of experiments. Thus data obtained during studies in the above experiments were statistically analyzed by using software OPSTAT (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Present study on impact of biorational and weeding on management aspects of whitefly, *Bemisia tabaci* in cotton was carried out during *kharif* 2018 at Bio-control Laboratory and Research Farm, Cotton Research Station, Sirsa, India. The results of experiment with reference to effect of biorational on whitefly adults and nymphs are presented in this section and data supplemented with different Tables.

Efficacy of biorational compounds against whitefly,

Table 2. Effect of biorational on whitefly, *Bemisia tabaci* population after first application of treatments in non-weedy (weed free) habitat. * Figures in parenthesis are arc sine values, DAS-Days after spray.

DAS	Whitefly adult/ leaf					Population reduction (%) over control in whitefly adults			
Treatment	Pre-treatment	3	5	7	Mean	3	5	7	Mean
Nimbecidine 300 ppm	7.33	3.00	1.78	1.77	2.18	46.96 (43.23)*	76.47 (61.01)	76.85 (61.76)	66.76 (58.14)
Beauveria bassiana	7.11	4.56	3.67	3.22	3.82	15.46 (22.96)	48.28 (43.97)	56.51 (48.75)	40.08 (38.62)
Verticillium lecanii	7.89	4.67	4.22	3.44	4.11	21.33 (27.10)	46.93 (43.18)	57.93 (49.62)	42.06 (40.08)
Metarhizium anisopliae	8.33	5.11	4.89	4.42	4.81	17.56 (24.41)	41.68 (40.06)	48.59 (44.16)	35.94 (36.38)
Dimethoate 30 EC	8.44	2.22	1.22	1.00	1.48	66.02 (54.36)	85.61 (67.79)	88.72 (70.47)	80.12 (64.11)
Control	8.22	6.11	8.26	8.50	7.62	-	-	-	-
CD (p=0.05)	NS	0.72	0.91	0.43	-	(7.14)	(5.74)	(4.57)	-

Table 2. Continued.

DAS	Whitefly nymphs/ leaf					Population reduction (%) over control in whitefly nymphs			
Treatment	Pre-treatment	3	5	7	Mean	3	5	7	Mean
Nimbecidine 300 ppm	8.22	2.44	1.44	1.11	1.66	41.51 (40.02) *	68.66 (56.17)	71.79 (58.02)	60.65 (51.31)
Beauveria bassiana	10.22	4.00	3.44	2.33	3.26	23.59 (28.65)	40.29 (39.31)	51.57 (45.90)	38.49 (38.11)
Verticillium lecanii	9.89	4.20	4.11	3.00	3.77	16.89 (24.10)	27.13 (30.80)	35.26 (34.98)	26.43 (30.68)
Metarhizium anisopliae	8.33	3.00	2.89	1.56	2.48	29.65 (32.86)	38.39 (37.99)	59.13 (50.46)	42.39 (40.50)
Dimethoate 30 EC	9.56	1.44	1.00	1.00	1.15	69.76 (56.83)	82.11 (64.96)	78.75 (62.62)	76.88 (61.15)
Control	9.22	4.78	5.22	4.44	4.81	-	-	-	-
CD (p=0.05)	NS	0.91	0.62	0.40	-	(7.59)	(7.78)	(10.54)	-

Bemisia tabaci

After first application of biorational in non-weedy habitat

First application of treatments was carried out at ET in 29th SMW to know the effect of biorational at different days after spray i.e., 3, 5 and 7 days. Pre-treatment population of whitefly adults and nymphs were statistically similar in all experimental plots throughout the course of investigation. Standard check, Dimethoate 30 EC proved it's caliber to reduce number of nymphs and adults of whitefly that reflected in terms of reduction in population throughout the period of experimentation. Biorational treatments were compared to control during the investigations in terms of efficacy. Three days after application of biorational, the maximum population reduction (46.96%) of adult whitefly was observed in Nimbecidine 300 ppm. Followerd by *V. lecanii* which was found next most effective to reduce numbers of whitefly (21.33%) and at par (Table 2) with *M. anisopliae* (17.56%) and *B. bassiana* (15.46%). Further reduction in whitefly adults was observed after five days of treatments as it decreased from 3.0 to 1.78 adults per leaf in Nimbecidine 300 ppm treated plots that depict the population reduction (76.47%). Population reduction (48.28 %) due to treatment of entomopathogenic *B. bassiana* was at par with *V. lecanii* (46.93%) and least reduction (41.68 %) in adult whitefly after five days of treatment was observed in *M. anisopliae* i.e., from 5.11 to 4.89 adults per leaf. Mean maximum population reduction (%) was carried out by Nimbecidine 300 ppm (76.85%), while entomopathogenic

Table 3. Effect of biorational on whitefly, *Bemisia tabaci* population after first application of treatments in weedy (having weeds) habitat. * Figures in parenthesis are arc sine values, DAS-Days after spray.

DAS		Whitefly adults/leaf				Population reduction (%) over control in whitefly adults			
Treatment	Pre-treatment	3	5	7	Mean	3	5	7	Mean
Nimbecidine 300 ppm	8.44	3.56	3.44	3.43	3.48	52.08	56.46	61.78	56.77
						(46.19)*	(48.83)	(51.90)	(48.87)
Beauveria bassiana	8.56	6.39	4.50	4.06	4.98	19.63	41.32	51.05	37.33
						(25.65)	(39.44)	(45.64)	(37.91)
Verticillium lecanii	9.00	6.54	4.52	4.33	5.13	20.65	46.50	54.73	40.63
						(25.98)	(42.78)	(47.77)	(41.18)
Metarhizium anisopliae	8.78	7.02	5.22	4.88	5.71	14.19	38.78	48.61	33.86
						(21.79)	(38.19)	(44.16)	(36.57)
Dimethoate 30 EC	8.78	2.78	2.22	2.67	2.56	64.61	73.70	71.55	69.96
					`	(53.58)	(59.51)	(57.91)	(56.78)
Control	8.89	7.95	8.56	9.56	8.69	-	-	-	-
CD (p=0.05)	NS	1.76	0.86	0.38	-	(6.93)	(8.86)	(7.49)	-

Table 3. Continued.

DAS		Whitefly nymphs / leaf				Population reduction (%) over control in whitefly nymphs			
Treatment	Pre-treatment	3	5	7	Mean	3	5	7	Mean
Nimbecidine 300 ppm	9.44	3.44	2.33	1.89	2.55	40.88	60.41	65.33	55.54
						(39.54)*	(51.20)	(54.08)	(48.21)
Beauveria bassiana	9.22	5.44	4.17	3.00	4.78	7.16	30.54	44.64	19.51
						(15.40)	(32.40)	(41.78)	(24.15)
Verticillium lecanii	10.67	6.00	4.89	3.89	4.93	10.96	30.24	38.30	26.50
						(18.98)	(32.86)	(38.09)	(30.30)
Metarhizium anisopliae	9.67	5.11	3.56	2.78	3.82	16.28	41.17	50.60	36.01
						(23.68)	(39.29)	(45.35)	(36.34)
Dimethoate 30 EC	8.56	2.00	1.56	1.44	1.67	62.91	70.27	70.78	67.99
						(52.50)	(57.33)	(57.46)	(55.55)
Control	9.33	5.89	6.28	5.56	5.91	-	-	-	-
CD (p=0.05)	NS	0.90	0.95	0.34	-	(7.12)	(5.99)	(6.11)	-

fungi's; *V. lecanii* (57.93%), *B. bassiana* (56.51%) and *M. anisopliae* (48.59%) being a par in power to bring desired effect in whitefly adults population (Table 2) at seven days.

Nimbecidine 300 ppm caused 41.51% reduction in whitefly nymph after three days of appication. Among three entomopathogenic fungal biopesticides, *M. anisopliae* effectively controlled nymphs (29.65%) was at par with *B. bassiana* (23.59%) while, *V. lecanii* caused least reduction of 16.89%. After five days of application of Nimbecidine 300 ppm, nymphal population of whitefly drop down from 2.44 to 1.44 nymphs per leaf causing 68.66% reduction. A similar trend in the edge of biorational was observed after seven days of treatment. In order of reduction per cent in number of whitefly nymph as Nimbecidine 300 ppm (71.79%) succeeded by *M. anisopliae* (59.13%), *B. bassiana* (51.57%) and *V. lecanii* (35.26%) in treated plots.

After first application of treatments in weedy habitat

Pathogenicity of entomopathogenic fungi were found at par with each other (Table 3) and reduction in whitefly adults was observed in order of *V. lecanii* (20.65%) followed by *B. bassiana* (19.63%) and *M. anisopliae* (14. 19%), however plant product Nimbecidine 300 ppm claimed highest reduction in number (52.08%) at 3rd day after treatment. Again at 5 DAS, Nimbecidine 300 ppm superseded in reduction of adults i.e., 56.46% compared to allied treatments. At 7 DAS, the maximum reduction in whitefly adults

Table 4. Effect of biorational on whitefly, *Bemisia tabaci* population after second application of treatments in non-weedy (weed free) habitat. * Figures in parenthesis are arc sine values, DAS-Days after spray.

DAS Treatment	Pre-treatment	Whitefly adults/leaf 3	5	7	Mean	Population reduction (%) over control in whitefly adults 3	5	7	Mean
Nimbecidine 300 ppm	8.44	4.11	1.56	1.33	2.33	49.55 (44.74)*	70.82 (57.29)	65.97 (54.41)	62.11 (55.10)
Beauveria bassiana	9.33	7.00	3.11	2.11	4.07	22.67 (28.15)	47.01 (43.26)	51.37 (45.77)	40.35 (39.15)
Verticillium lecanii	9.33	6.67	2.56	2.00	3.74	27.12 (30.92)	55.26 (48.04)	53.61 (47.08)	45.33 (42.14)
Metarhizium anisopliae	9.67	7.45	4.22	3.11	4.93	21.51 (27.54)	30.71 (33.48)	31.35 (33.99)	27.86 (31.77)
Dimethoate 30 EC	8.22	3.11	1.11	0.89	1.70	59.72 (49.87)	78.69 (62.51)	76.92 (61.44)	72.07 (58.28)
Control	9.89	9.56	6.22	4.67	6.82	-	-	-	-
CD (p=0.05)	NS	1.31	0.67	0.77	-	(8.69)	(6.60)	(5.60)	-

Table 4. Continued.

DAS Treatment	Pre-treatment	Whitefly nymphs/leaf 3	5	7	Mean	Population reduction (%) over control in whitefly nymphs 3	5	7	Mean
Nimbecidine 300 ppm	11.22	4.44	3.22	2.00	3.22	58.25 (49.73)*	74.20 (59.56)	72.84 (58.63)	68.43 (55.91)
Beauveria bassiana	11.78	9.44	7.22	3.89	6.85	18.67 (25.05)	47.83 (43.70)	51.95 (46.11)	39.48 (38.47)
Verticillium lecanii	12.33	9.22	8.56	4.22	7.34	19.38 (25.80)	35.08 (35.15)	44.60 (41.48)	33.02 (34.76)
Metarhizium anisopliae	12.00	8.11	6.78	3.56	6.15	26.00 (29.35)	48.13 (43.92)	52.00 (46.19)	42.05 (40.22)
Dimethoate 30 EC	11.22	3.11	2.44	1.81	2.45	70.79 (57.31)	80.51 (63.95)	74.88 (60.20)	75.39 (60.31)
Control	13.89	13.22	15.89	9.22	12.78	-	-	-	-
CD (p=0.05)	NS	1.17	0.99	0.66	-	(9.25)	(9.03)	(7.91)	-

was observed in Nimbecidine 300 ppm (52.08 %). Entomopathogenic fungi were found at par with each other, *V. lecanii* caused maximum reduction (54.73%) followed by *B. bassiana* (51.05%) and *M. anisopliae* (48.61%) in adult whitefly counts. Maximum drop in mean nymphal population of whitefly was observed in Nimbecidine 300 ppm and found to be most effective (55.54%) compared to all other treatment. In entomopathogenic fungi, maximum reduction were observed in *M. anisopliae* (36.01%) followed by *V. lecanii* (26.50%) and *B.bassiana* (19.51%) in weedy habitat.

Effect of weeding

After first application of biorational, mean reduction of whitefly population in a particular treatment in non-weedy habitat was higher than that of their respective plots in weedy habitat over a period of week (Tables 2–3). Plant product Nimbecidine 300 ppm proved potent and caused 66.76 and 60.65% mean reduction in non-weedy habitat and 56.77 and 55.54% mean reduction in whitefly adult and nymphal population, respectively in weedy habitat (Tables 2–3). It is quite conspicuous that Nimbecidine 300 ppm was found most effective in non-weedy habitat compared to entomopathogenic fungi application that leads to more control of pest than weedy habitat. *B. bassiana, V. lecanii* and *M. anisopliae* caused 40.08, 42.06 and 35.95% of population reduction in whitefly adults in non-weedy habitat were apparent while, the per cent reduction in weedy habitat was 37.33% in

B. bassiana, 40.63% in *V. lecanii* and 33.86% in *M. anisopliae* treated plots.

After second application of treatments in non-weedy habitat

At 3rd day after second application of biorational in non-weedy habitat, again Nimbecidine 300 ppm again caused maximum (49.55 %) reduction in adult whitefly population. *V. lecanii* was found most effective and *M. anisopliae* was least effective against whitefly adult that bring down population 27.12 and 21.51% respectively. A further reduction in whitefly adults was observed after five and seven days of treatments of biorational in the field (Table 4) as Nimbecidine 300 ppm caused adult whitefly to reduce from 4.11 to 1.56 adults per leaf (70.82 and 65.97%). Reduction due to treatments of entomopathogenic was maximum in treatment with *V. lecanii* (55.26 and 53.61%) at par with *B. bassiana* that induced 47.01 and 51.37% of whitefly. *M. anisopliae* caused least reduction (30.71 and 31.35%) from 7.45 to 4.22 then 3.11 adults per leaf at 5 and 7 days after use of.

Three days after application of Nimbecidine 300 ppm (58.25 %) was found most effective to cut down whitefly nymph among biorational (Table 4), reduction in whitefly nymphs observed in treatment as of in order *M. anisopliae* (26.0%) followed by *V. lecanii* (19.38%) and *B. bassiana* (18. 67%). Although, five days after treatment of entomopathogenic fungus exhibited significantly less nymphal mortality than Nimbecidine 300 ppm, however in entomopathogenic fungi the highest mortality (48.13%) in nymphal population caused due to *M. anisopliae* was at par with *B. bassiana* and *V. lecanii* causing 47.83 and 35.08% mortality, respectively. A similar trend of efficacy even after seven days after biorational application reverberated equally, Nimcidine 300 ppm found to be most promising (72.84%) and *M. anisopliae* registered as most effective among treatment of entomopathogenic fungi with a mortality of 52.00% of nymphal whitefly.

After second application of treatments in weedy habitat

Second application of biorational in weedy habitat was carried out in 35th SMW. Whitefly adults per leaf decreased in all the treatments at three DAS (Table 5) as evident that Nimbecidine 300 ppm caused 43.10% reduction, in fungus the maximum reduction of whitefly adults observed in *V. lecanii* (23.18%) followed by *B. bassiana* (18.99%) and *M. anisopliae* (14.79%). At five and seven DAS, the maximum reduction in whitefly adults was observed in Nimbecidine 300 ppm (64.38 and 66.83 %) at par with standard check Dimethoate 30 EC (74.63 and 72.37%). *V. lecanii* caused 53.79 and 49.63% reduction in whitefly adults, *B. bassiana* earned 43.51 and 37.61% reduction at par with treatment of *M. anisopliae* (35.69 and 31.18%).

Whitefly nymphs per leaf decreased in biorational treatments, treatment of Nimbecidine 300 ppm found most effective and caused 62.05% mean reduction. Elevated reduction in nymphal population (42.82%) after the treatment of *M. anisopliae* was spotted followed by *B. bassiana* (35.24%) and *V. lecanii* (25.52%) in line. Utmost nymphal reduction at 5 DAS was observed in treatment of Nimbecidine 300 ppm i.e., 64.02 % (Table 5) and treatment of *B. bassiana* and *M. anisopliae* were at par. At 7 DAS, maximum reduction in whitefly nymphs was observed in Nimbecidine 300 ppm (67.49%). Furthermore, *M. anisopliae* caused more reduction of 53.26% compared to *B. bassiana* (46.90%) and *V. lecanii* (37.94 %).

Effect of weeding

After second application of biorational in weedy and non-weedy habitats, mean reduction of whitefly population in each treatment in non-weedy habitat was higher than their respective plots in weedy habitat over a period of week (Tables 4–5). Nimbecidine 300 ppm established as most effective as caused 62.11 and 68.43% mean reduction in adults and nymphs of whitefly in non-weedy than 58.10 and 62.05% mean reduction in weedy habitat (Tables 4–5). Likewise entomopathogenic fungi treated plots in non-weedy habitat led to more control than weedy habitat as indicated *B. bassiana*, *V. lecanii* and *M. anisopliae* caused 40.35, 45.33 and 27.86% in whitefly adults, while in nymph 39.48, 33.02 and 42.05% reduction, respectively (Table 4), while in weedy habitat whitefly adult and nymph were at lowerside as most i.e.,

Table 5. Effect of biorational on whitefly, *Bemisia tabaci* population after second application of treatments in weedy (having weeds) habitat. * Figures in parenthesis are arc sine value, DAS-Days after spray.

DAS Treatment	Pre-treatment	Whitefly adults/leaf 3	5	7	Mean	Population reduction (%) over control in whitefly adults 3	5	7	Mean
Nimbecidine 300 ppm	9.00	5.22	3.78	1.44	3.48	43.10 (40.96)*	64.38 (53.39)	66.83 (54.84)	58.10 (49.72)
Beauveria bassiana	11.33	9.39	7.44	3.11	6.65	18.99 (25.47)	43.51 (41.14)	37.61 (37.49)	33.37 (34.96)
Verticillium lecanii	11.56	9.00	6.22	2.78	6.00	23.18 (27.98)	53.79 (47.24)	49.63 (44.78)	42.20 (40.23)
Metarhizium anisopliae	10.44	9.11	7.89	3.44	6.81	14.79 (22.58)	35.69 (36.46)	31.18 (33.89)	27.22 (31.07)
Dimethoate 30 EC	10.22	5.85	2.89	1.33	3.36	43.81 (41.39)	74.63 (59.18)	72.37 (58.42)	63.61 (53.14)
Control	12.33	12.56	14.56	5.89	11.00	-	-	-	-
CD (p=0.05)	NS	0.93	0.73	0.30	-	(7.25)	(6.10)	(6.47)	-

Table 5. Continued.

DAS Treatment	Pre-treatment	Whitefly nymphs/leaf 3	5	7	Mean	Population reduction (%) over control in whitefly nymphs 3	5	7	Mean
Nimbecidine 300 ppm	13.11	5.22	3.22	2.33	3.59	54.65 (47.47)*	64.02 (53.25)	67.49 (55.27)	62.05 (52.00)
Beauveria bassiana	15.33	10.44	7.22	4.44	7.37	24.05 (29.30)	31.76 (34.22)	46.90 (43.20)	34.24 (35.61)
Verticillium lecanii	14.44	10.00	8.33	4.89	7.74	22.45 (28.07)	16.17 (22.73)	37.94 (37.93)	25.52 (30.00)
Metarhizium anisopliae	14.33	8.56	5.89	3.67	6.04	34.30 (35.81)	40.91 (39.74)	53.26 (46.85)	42.82 (40.81)
Dimethoate 30 EC	15.22	4.22	2.56	2.11	2.96	69.16 (56.28)	75.72 (60.51)	74.39 (59.74)	73.09 (58.75)
Control	16.11	14.56	11.22	8.89	11.56	-	-	-	-
CD (p=0.05)	NS	1.79	0.98	0.66	-	(5.46)	(8.13)	(6.25)	-

33.37 and 34.24% in treatment of *B. bassiana*, 42.20 and 25.52 in *V. lecanii* and 27.22 and 42.82% in *M. anisopliae*, respectively as recorded (Table 5).

Biorational are widely used to manage cotton whitefly through application of insecticides and biorational (Lal and Jat 2015) at lowest of whitefly adults on cotton plants with seed treatment of Dimethoate 30 EC then in NSKE 5% spray, furthermore seed treatment with Imidacloprid 20 SL and spray of NSKE (5%) spray aids in management of pest menace.

After three days of first application of biorational i.e., Nimbecidine 300 ppm was found most effective to reduce whitefly adults (46.96 and 52.08%) and nymphs (41.51 and 40.88 %) in both habitats, respectively (Tables 2–3). Nimbecidine (2%) caused 69.6% mortality in whitefly population in cotton (Udaiyan and Ramarathinan 1994). Three DAS, *V. lecanii* caused maximum adult mortality (%) than *B. bassiana* and *M. anisopliae* in both non-weedy as well as weedy habitat, whereas higher potency of *M. anisopliae* was apparent in terms of nymphal mortality (%) of whitefly than *B. bassiana* and *V. lecanii* in both habitats. An entomopathogenic fungus, *V. lecanii* (52.0 to 100.0% reduction) was more virulent than *B. bassiana* and *M. anisopliae* (52.0 to 89.0% reduction) against *B. tabaci* adults on cotton in the field (Abdel-Raheem and Al-Keridis 2017).

On 5th day, application of Nimbecidine 300 ppm most effective with 76.47 and 56.46% mortality of whitefly adults, mortality of nymphs was 68.66 and 60.41% in non-weedy and weedy habitats, respectively (Tables 2–3). A decrease of 69.9% in adult whitefly population was apparent on cotton crop after the application of Econeem plus® (blend of Azadirachtin 1% and neem oil) @3 ml/ L (Manu *et al.* 2018). Efficacy of plant product Nimbecidine 300 ppm on whitefly adults in non-weedy habitat was followed by *B. bassiana* (48.28% reduction), *V. lecanii* (46.93% reduction) and *M. anisopliae* (41.68% reduction). What is more, *B. bassiana* (66.11% reduction over control) established more effectively than *V. lecanii* (64.33% reduction over control), while *M. anisopliae* (52.15% reduction over control) was least effective against whitefly population on cotton (Ghosal 2018). It is already evident that moratlity of whitefly adults in weedy habitat of cotton field treated with *V. lecanii* (46.50% reduction), *B. bassiana* (41.32% reduction) and *M. anisopliae* (38.78% reduction) at the least. Biorational i.e., *V. lecanii* was more effective than *B. bassiana* and *M. anisopliae* against whitefly on tomato crop in field experiment (Naglaa and Reyad 2017).

At 7 DAS Nimbecidine 300 ppm caused highest population reduction (%) in whitefly adults (76.85% in non-weedy and 61.78% in weedy habitat) as well as in nymphs (71.79% in non-weedy and 65.33% in weedy habitat). Use of Nimbecidine was validated effective in minimizing the leaf curl incidence by controlling whitefly (Singh *et al.* 2009), *B. tabaci* population in tomato crop. Amidst entomopathogenic fungi, *V. lecanii* did not allow whitefly to spur and exhibited minimum population (6.64 adults/leaf) along with highest bio-efficacy (32.93% population reduction) followed by *B. bassiana* (30.12%) and *M. anisopliae* (28.50%) (Singh and Singh 2018). On nymphal population of whitefly, the application of *M. anisopliae* was found more suppressive than *V. lecanii* and *B. bassiana* in weedy as well as non-weedy habitats. *M. anisopliae* was more effective (upto 79.99% reduction over control) than *B. bassiana* (12.26 to 77.20% reduction over control) in controlling the number of whitefly nymphs (Khangura 2017) under field natural condition.

Mean reduction (%) in whitefly adults after a period of seven days indicated that among the biorational treatments used to manage, the order of effectiveness against whitefly adults in weedy and non-weedy habitat as Nimbecidine 300 ppm at first, subsequently *V. lecanii* then *B. bassiana* and next *M. anisopliae* placed. Similarly, use of nimbecidine (2%) caused 69.6% mortality in whitefly population (Udaiyan and Ramarathinan 1994), furthermore application of Nimbecidine 300 ppm controlled the whitefly population on *Bt* cotton effectively (Mehra *et al.* 2018). The magnitude of effectiveness against cotton whitefly nymph in current study in order exists as Nimbecidine 300 ppm > *M. anisopliae* > *B. bassiana* > *V. lecanii*. Neem based insecticide was tracked more effective than entomopathogenic fungi to contain whitefly population on cotton crop and *M. anisopliae* was more effective than *V. lecanii* and *B. bassiana* (Khangura 2017). *M. anisopliae* was significantly more effective against egg, nymphs and pupae (Flores *et al.* 2012), whereas *B. bassiana* caused more harm to the adult population with higher mortality rate.

Findings also revealed reduction in mean population of whitefly adults and nymphs after seven days' period in each treatment was higher in non-weedy than their respective treatments in weedy habitat e.g., Nimbecidine 300 ppm caused 66.76% reduction over control in whitefly adults on non-weedy habitat, but reduction in weedy habitat was restricted to 56.77%. Present experimentation construed that weeds can play an important role in manipulating the activity of whitefly, weeding combined with use of biorational compounds ensued maximum reduction in whitefly population in the cotton field. Weeds enhanced the activity of whitefly and the highest reduction in population counts of *B. tabaci* was recorded with use of insecticide in weed free plots (Solangi *et al.* 2016). On the contrary, weeds also favored the presence of parasitoids and helped in reduction of whitefly population in many field crops (Medina-Balderas *et al.* 2002). It may be due to presence and or attributes of such weeds which preferentially favor the parasitoid population by increasing their activities more than that of the whitefly.

After 2nd application of biorational, treatments were more or less as of similar to findings after first application as the maximum population reduction (%)

of whitefly adults and nymphs over control in non-weedy and weedy habitats. Order of effectiveness of biorational treatments in reducing the whitefly adult's population was followed in fashion as first Nimbecidine 300 ppm (62.11 and 58.10%) subsequently *V. lecanii* (45.33 and 42.20%), *B. bassiana* (40.35 and 33.37%) and lastly *M. anisopliae* (27.86 and 27.22%) in non-weedy and weedy habitats, respectively. Reduction of whitefly nymph were more in *M. anisopliae* (42.05 and 42.82%) compared to *V. lecanii* (33.02 and 25.52%), *B. bassiana* (39.48 and 34.24%) in non-weedy and weedy habitats, respectively. Effectiveness of neem based insecticides over EPF's was also compared in terms of it's usefuless as Neem oil caused more reduction in number of whitefly than *B. bassiana*, *V. lecanii* and *M. anisopliae* (Khangura 2017). *V. lecanii* managed minimum population of whitefly (6.64 adult/leaf) and highest bio-efficacy (32.93% population reduction) compared to *B. bassiana* (30.12%) and *M. anisopliae* (28.50%) in field experiments (Singh and Singh 2018). Application of biorational compared to control except *V. lecanii* caused more reduction of whitefly adults population in non-weedy than weedy habitat. It can be attributed to ability of weeds to act as alternate and or collateral host of whitefly that can enhance it's population providing ambient conditions to get thrive and flourish more. Presence of weeds enhanced the activity of whitefly (Solangi *et al*. 2016) likewise and the highest reduction in population counts of *B. tabaci* was recorded with use of insecticide in weed free plots.

CONCLUSION

It has been brought to a conclusion from the present course of experimentation that after the first application of biorational in 29th SMW, Nimbecidine 300 ppm and entomopathogenic fungi *Beauveria bassiana*, *Metarhizium anisopliae* and *Verticillium lecanii* could not make a mark compared to as standard check i.e., Dimethoate 30 EC in weedy as well as non-weedy habitat. However, it is quite interesting; Nimbecidine 300 ppm found most effective in non-weedy (66.76 and 60.65% mean mortality in adult and nymphal population, respectively) as well as weedy habitat that caused 56.77 and 55.54% mean mortality in adult and nymphal whitefly, respectively over a seven days period after application. After that, *V. lecanii* found to be better to control whitefly in cotton field and in line *B. bassiana*. Altough, among entomopathogenic fungi, *M. anisopliae* caused lowest mortality in adult whitefly, however it is worth to mention that *M. anisopliae* found more effective than *V. lecanii* and *B. bassiana* for nymphal mortality in non-weedy as well as in weedy habitat.

After the second application of biorational in 35th SMW, Nimbecidine 300 ppm was most effective in non-weedy (62.11 and 68.43% of mean mortality in adult and nymphal whitefly population, respectively) as well as weedy habitat with 58.10 and 62.05% mean mortality in adult and nymphal population, respectively. Similarly as ealier at first application of biorational, Nimbecidine 300 ppm again acted as superior to *V. lecanii* preceded by *B. bassiana* that fall behind. Not with standing, with least mortality of whitefly adults in *M. anisopliae*, in context of nymphal mortality *M. anisopliae* was effective than *V. lecanii* and *B. bassiana* as much.

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