among the cotton growers about the knowledge of novel yield enhancing cotton cultivation technologies. Hence, a study to assess yield gap in cotton between the potential, actual and attainable yields, the knowledge gap among cotton growers and to find out the reasons for the yield and knowledge gap and propose appropriate TOT innovations to reduce the gaps is planned.

During the year 2017-18, the various types of yields *viz.*, potential yield, actual yield and attainable yield and yield gaps were operationalized for the study. The average yield details of the states and the FLDs in the respective states were collected from the available secondary data from the AICRP- FLD reports and CAB from 1997-98 to 2017-18 and yield gap was analyzed. Analysis revealed that the national average seed cotton yield of FLD was 1686 kg/ha as compared to the local farmers' practices 1433 kg/ha (1997-98 to 2017-18). The average yield gap between the seed cotton yield of FLD and farmer's practice over 20 years was 254 kg/ha. To know the potential yield of cotton at station with all recommended technologies of CICR, one acre potential yield trial with cotton variety Suraj (0.5 acre) and Jadoo Bt BG II (0.5 acre) was conducted at ICAR-CICR, Regional Station, Coimbatore. The cotton variety (Suraj) with all recommended technologies of CICR yielded 2721 kg/ha and the Bt cotton hybrid Jadoo Bt BG II gave 2580 kg/ha seed cotton yield.

Socio-technological analysis of drip irrigation in cotton cultivation

Surveys were undertaken in Erode and Namakkal districts of Tamil Nadu to explore the impact and constraints for drip irrigation in cotton cultivation. Adoption of farmers for cotton technologies were significantly at higher rate in the study area. The major varieties cultivated in this area were, ATM Bt (KCH 311 Kavery seeds), Jadoo Bt (KCH 14K59, Kavery Seeds), Jackpot Bt (15K39, Kavery seeds), MRC 6918, RCH 2, and RCH 625 (Bumbag). Major observations on impact made by the drip irrigation are : a) There was a yield increase due to adoption of drip irrigation, b) Drip irrigation made soil into more friable condition and increased root growth, c) Soil compaction was reduced, d) Thrips and other sucking pest population was reduced, e) Water saving was about 30-40%, f) Cotton boll size was higher, g) Seed germination was good and, h) Weed population was reduced in drip irrigated fields. The survey revealed that the major cropping pattern available in this area are, Cotton-Maize-Green gram or Onion-Groundnut-Maize and Green gram or Cotton-Onion–Green gram. Constraint analysis revealed that the major issues for drip irrigation in cotton cultivation are 1. Not exactly 100 percent subsidy by state government, 2. Non-availability of water even for drip irrigation, 3. Damage to drip laterals due to rodents, 4. Crop specific subsidy for drip irrigation for specific year, 5. Getting subsidy documents from Village Administrative Office is cumbersome, 6. Clogging in drippers due to poor quality of water, 7. Accelerated price due to increased tax slab rate of 12-18% in the present GST for drip system, and 8. Standard technical specifications for drip installation does not match with local farm condition.

3.9 : New eco-compatible pest management strategies

Cotton bollworm Management

Nagpur

Push-Pull strategy for management of pink bollworm

The 'push-pull' strategy is an novel ecological pest management strategy to be utilized in integrated pest management programs. This relies on the manipulation of pest behaviour through the use of behaviour modifying stimuli to alter the distribution and abundance of insect pest. For isolation and identification of oviposition deterrent volatiles, field population of pink bollworm from Nagpur (ICAR-CICR farm) was established in the laboratory. The eggs and faecal pellets of pink bollworm were collected in five solvents namely hexane, acetone, methanol, dichloromethane and pentane with difference in polarity. The samples were analysed in GC-MS for identification of volatiles. Results were obtained in methanol as solvent for egg extract and with solvent as acetone, dichloromethane and methanol for faecal pellet extracts. Fatty acids like Palmitic acid, Linoleic acid, Oleic acid, Stearic acid and their methyl esters were identified from eggs (E) and faecal pellet (FP). (Table 3.9.1) These need to be further subjected to lab bioassays evaluation for oviposition deterrent effect.

Table: 3.9.1: Potential oviposition deterrant for Pink bollworm identified

Sr. No.	Volatiles	Area (%)	Recurrence
1.	Hexadecanoic acid and its ester	22-51	Methanol (E), Acetone (FP), DCM (FP), Methanol (FP)
2.	Octadecanoic acid and its ester	27- 78	Methanol (E), Acetone (FP), DCM (FP), Methanol (FP)
3.	Hexacosanol	6-22	Acetone (FP), DCM (FP), Methanol (FP)

Egg parasitoid *Trichogramma bactrae* and *T. brasiliensis* against Pink boll worm

In order to promote the bio control agents for managing pink bollworm, an experiment was conducted at ICAR-CICR, Nagpur to evaluate the efficiency of *Trichogramma bactrae* (T1) and *Trichogramma brasiliensis* (T2) in comparison with chemical sprays (profenophos 50 EC; thidocarb 75 WP; cypermethrin 25 EC). The results indicated that, least number of exit holes were observed in the plots sprayed with chemical insecticides (0.39 exit holes/10 G.B.) and it was at par with *Trichogramma bactrae* (0.50 exit holes). Lowest number of mines on epicarp were noticed in the plots release with *Trichogramma bactrae* (3.25 mines/10 G.B) followed by chemical insecticides (3.39). Mean locule damage (%) was highest in the control plots and lowest in chemical treated plots. (Fig.3.10.1) Amongst the egg parasitoids, plots treated with *T.bactrae* had lower locular damage.

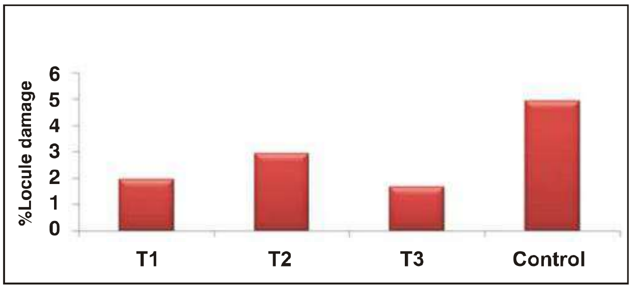


Fig: 3.9.1: Effect of egg parasitoid *Trichogramma bactrae* and *T. brasiliensis* against Pink bollworm (2017-2018)

Coimbatore

Exploring novel dispensers to enhance the trapping efficacy of pheromone traps for Pink bollworm management

Eight new dispensers and ten trap designs were prepared for the pheromone compound gossyplure and evaluated against the cotton pink boll worm under field experiment in RBD with three replications. The dispenser made of polypropylene (11.28 adult/ trap/ week) and silicone (10.93 adult/trap/week) were significantly superior to the standard rubber dispenser (7.36 adult/trap/week) in attracting the pink bollworm moth. The neoprene dispenser recorded highest catch (14.67 adult/trap/week) in first three weeks, but had short persistence (7 weeks) compared to that of standard dispenser (13 weeks). Among the different traps tested, wing trap and LED combo trap provided significantly higher mean trap catch per week compared to the standard funnel trap. The mean moth catch in pheromone trap had significant negative correlation with the boll damage (r = -0.76) and mean larval count (r = -0.81) in field.

A combo trap for pink bollworm targeting both chemo and visual stimuli was developed by combining pheromone compound gossyplure (chemical stimulus) and LED light source (visual stimulus). Solar sensor based automatic on/off switch with rechargeable Le-ion batteries were used to fabricate portable combo traps. Three different colour LED lights *viz.*, red, blue and white with gossyplure pheromone were tried for their efficacy in attracting the male pink boll worm moths and among the combo traps tested, the trap with blue colour light provided significantly higher traps catches.

Nagpur

Identification of oviposition deterrent for ethological management of Cotton Bollworm *Helicoverpa armigera*

Though commercial cultivation of transgenic cotton in India has reduce of bollworm damage, *Helicoverpa armigera,* strategy to manage this pest needs to be in place due to possible development of resistance against Bt toxins. Ethological management of *Helicoverpa* can be developed as a eco-friendly management tactic. Oviposition deterrent is the most promising tool of ethological management as it minimizes the attack of insect at very initial level. In this context collection and identification of volatiles emitted from eggs (E) and faecal pellets (FP) was done from laboratory reared population of *H. armigera* on natural food (cotton square). The volatiles compounds identified from eggs and faecal pellets in different solvents are presented in Fig : 3.10.2 & 3.10.3 respectively. On the basis of area (%) and recurrence of the volatiles in different solvents 5 compounds were identified (Table: 3.9.2), which will be tested as oviposition deterrent against *H. armigera* under

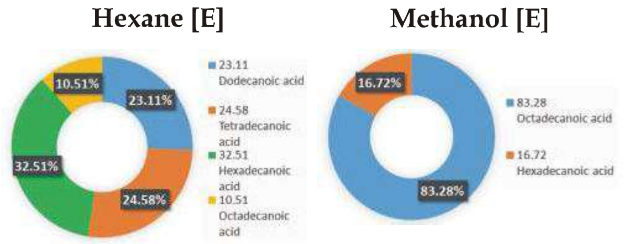


Fig.3.9.2 : Major compounds identified in egg sample

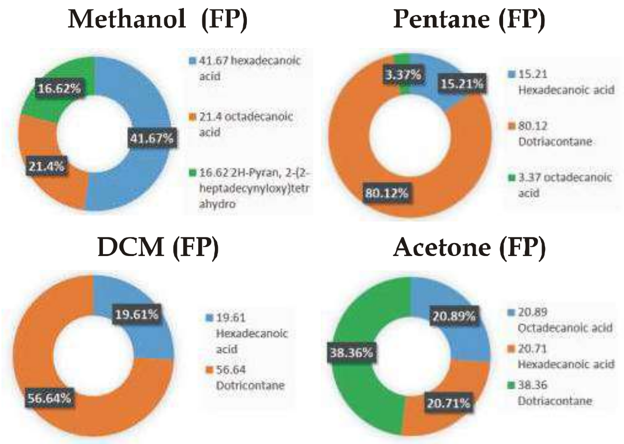


Fig.3.9.3 : Major compounds identified in egg sample

laboratory condition. Hexadecanoic acid fraction was recorded in all the solvents with 15-41% area under GCMS. Other compounds as Octadecanoic acid, Dotriacontane, Dodecanoic acid and Tetradecanoic acid shared 3-83%, 38-80%, 23% and 24% area, respectively No peak was detected in egg sample with acetone, dichloromethane, pentane solvent and in faecal pellets sample with hexane solvent.

Table 3.9.2 : Compounds identified in samples extracted with different solvents

S. No.	Volatiles	Area (%)	Recurrence
1.	Hexadecanoic acid	15-41	All the solvents
2.	Octadecanoic acid	3-83	Hexane (E), Methanol (E), Acetone (FP), Methanol (FP), Pentane (FP)
3.	Dotriacontane	38-80	Acetone, DCM, Pentane (FP)
4.	Dodecanoic acid	23	Hexane (E)
5.	Tetradecanoic acid	24	Hexane (E)

E-eggs, FP-Faecal Pallet

Management of sucking pests

Nagpur

Semio-chemical-based pest management technology

Semio-chemical-based pest management technology is known to serve a major role as rapid advancements are being made to curb the insecticide usage. Within semio-chemicals, pheromones and kairomones are most effective tools in behavioural manipulation; they are species specific and non-toxic to the environment. Isolation and identification of kairomone from the sucking pests was initiated by Solvent method. The sample was subjected to GC-EAD against *Chrysoperla* and *Coccinellids* . Samples were analysed in GC-MS and three probable compounds (1-Dodecanol, Eicosane and Octadecane) have been identified. Behavioural studies will be done in the lab and field after identification and characterization of kairomone.

Enhancing the efficacy of yellow sticky traps

Essentials oils considered to be 'green pesticides', were evaluated for exploring their potential in enhancing efficacy of yellow sticky traps. Different natural essential oils in combination with yellow sticky traps were evaluated against sucking pests of cotton (whitefly, jassids and aphids) at 3 locations *viz.*, ICAR-CICR Nagpur, Coimbatore and Sirsa.

The 6 different natural essential oils *viz.*, Sandal wood, Basil, Clove, Grape fruit, Rose and Mint oils were evaluated. Sandalwood oil and Basil oil in yellow sticky traps attracted maximum number of whiteflies and leaf hoppers among other treatments. For practical utility, being cost effective, Basil oil is potentially the best option to enhance the effectiveness of yellow sticky traps.

Coimbatore

Evaluation of different trap crops for thrips management

To evaluate a suitable trap crop for thrips, Bt cotton was grown with different intercrops such as Marigold, Vegetable cowpea, Onion, French bean and Groundnut. Population dynamics of thrips were recorded at fortnightly interval. Among these, cotton intercropped with Marigold recorded least population of thrips. (Table 3.9.3)

Table 3.9.3: Evaluation of different trap crops for thrips population

Treatments	Thrips population (Nos. /3 leaf/plant)					
	September	October	November	December	January	Mean
T1 – (Bt Cotton) Sole Crop	4.03	4.07	4.17	9.13	8.77	6.03
T2 – (Bt cotton+ Marigold)	1.97	2.36	2.86	7.70	8.20	4.62
T3 – (Bt cotton+ Vegetable cowpea)	2.83	3.00	2.93	8.13	8.03	4.99
T4 – (Bt cotton+ French Bean)	2.33	3.07	2.97	7.90	8.30	4.91
T5 – (Bt cotton+ small Onion)	2.57	3.27	3.16	7.60	8.50	5.02
T6 – (Bt cotton+ Ground Nut)	2.73	2.93	2.53	8.40	7.70	4.86
S. Ed	0.12	0.10	0.08	0.06	0.03	

Evaluation of bacterial endophytes against sucking insect pests

Five bacterial endophytic isolates were evaluated in a field experiment during 2017-18. Three methods *viz.*, seed coating, soil drenching and foliar spray were followed to inoculate the endophytes into cotton plants. Under protected condition, all the treatments recorded reduced population (10-15%) of sucking pests *viz.*, Aphid, Jassid and Whitefly compared to control. Among the isolates, *B. subtilis* and *B. cereus* strain inoculated plants recorded least insect pest population (Table 3.9.4).

Table 3.9.4 : Efficacy of bacterial endophytes against sucking pests under field condition

Treatments	Sucking pests population/3 leaf/plant*		
	Aphids	Jassids	Whitefly
Bacillus sp. E13	24.94	6.28	3.41
B. subtilis	22.54	6.65	3.40
B. cereus B1	25.49	8.60	3.95
B. cereus strain Z2	26.89	7.50	4.87
B. cereus strain S - 11	28.18	8.09	3.82
Control	37.99	10.70	5.29

Sirsa

Morphological and molecular characterization of newly isolated Entomopathogenic fungi (EPF)

A total of 105 EPFs collected from 19 locations from 11 districts of Punjab, Haryana and Rajasthan were morphologically characterized. Out of these, twelve EPFs were selected for molecular characterization. The sequences generated in this study were submitted to NCBI GenBank (Table 3.9.5).

Table 3.9.5 : List of gene sequences of the EPFs isolated from *Bemisia tabaci* cadavers and submitted to NCBI

Sr.No.	Organism	Location	Strain ID	NCBI Gen Bank accession number
1	*Fusarium sudanense*	Punjab	CICR - RSS - 0033	MG976228
2	*Aspergillus versicolor*	Rajasthan	CICR - RSS - 0074	MG976229
3	*Penicillium oxalicum*	Pun jab	CICR - RSS - 0082	MG976230
4	*Fusarium* sp.	Punjab	CICR - RSS - 0083	MG976231
5	*Paecilomyces* sp.	Rajasthan	CICR - RSS - 0089	MG976232
6	*Penicillium oxalicum*	Haryana	CICR - RSS - 0085	MG976233
7	*Isaria javanica*	Punjab	CICR - RSS - 0102	MG976234
8	*Aspergillus oryzae*	Haryana	CICR - RSS - 0015	MG976235
9	*Aspergillus quadrilineatus*	Haryana	CICR - RSS - 0044	MG976236

Sr.No.	Organism	Location	Strain ID	NCBI Gen Bank accession number
10	*Emericella* sp.	Haryana	CICR -RSS -0064	MG976237
11	*Fusarium* sp.	Punjab	CICR -RSS -0035	MG976238
12	*Beauveria bassiana*	Haryana	CICR -RSS -0093	MG976239

Multi-location evaluation of Suction trap against whitefly adults

A trap named as CICR Whitefly Adult Suction Trap, was designed under TMC1.5 project. The trap is power operated, shoulder mounted, portable, adjustable and helps in suction of whitefly adults on the underside of the cotton leaves without any harm to the natural enemies fauna and cotton crop itself. The suction trap was evaluated consecutively for two years under AICRP on Cotton at different locations of the Northern Cotton Growing Zone of India. Based on the data obtained from these locations, the trap reduced whitefly population from 46.6% to 12.7% at different locations and was found to be more efficient in situations with high adult whitefly pressure

Coimbatore

Wax degrading bacteria for management of mealy bug

Eight wax degrading bacteria *viz., Pseudoxanthomonas suwonensis* PSAD1 (KY780940), *Acinetobacter lwoffii* PSAD2 (KY780941), *Klebsiella aerogenes* PSAD3 (KY780942), *Providencia rettgeri* PSAD5 (KY780943), *Enterobacter cloacae* PSAD6 (KY780944), *Acinetobacter beijerinckii* PSAD7 (KY780945), *Klebsiella aerogenes* PSAD8 (MF373207) and *Serratia marcescens* PSAD9 (MF373208) from cotton mealybugs were isolated, screened , characterized and submitted to Gene Bank. Among the isolates *A.lwoffii* PSAD2 and *A.beijerinckii* PSAD7 showed maximum lipase, biosurfactant production and insecticidal activity. Apart from this, *A.lwoffii* PSAD2 and *A.beijerinckii* PSAD7 showed positive plant growth promoting activities. Laboratory bioassay methods to assess the insecticide activity of the isolates against various sucking pests of cotton confirmed the effectiveness of *A.lwoffii* PSAD2 and *A.beijerinckii* PSAD7 as promising biocontrol agents. Based on the results from the above experiments three different formulations of wax degrading bacteria were developed and tested for their effectiveness under field conditions. Different biochemical and growth parameters of cotton analyzed indicated that plant metabolism is favoured due to application of wax degrading bacterial formulation with reduction in sucking pest population including mealybugs.

A new wax degrading entomopathogenic fungus, *Aspergillus fumigatus* Fresenius 1863 was isolated from striped mealybug, *Ferritia virgata* Cockerell. Molecular characterization was carried out and submitted to Gene Bank (Accession No. MF421525). This new fungus is able to produce lipase and degrade waxy coating of mealybug under laboratory condition.

Development of thermal tolerant strain of biocontrol agent, *Acerophagus papayae* for papaya mealybug, *Paracoccus marginatus*

Preliminary screening work has been initiated to identify the thermo tolerant strain of *A. papayae*. The developmental biology of field collected *A. papayae* as well as laboratory populations were compared to bring out the potential strain. The results revealed that the percent parasitization by field collected parasitoid to the second instar mealy bug was high (46.34%) when compared to the lab culture (34.27). In addition, the per cent adult emergence was high (73.43%) in field collected strain.

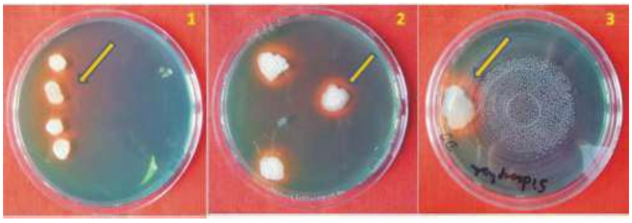
Management of cotton Diseases

Nagpur

Potential of Plant Growth Promoting Rhizobacteria (PGPR) in disease management

Efficient strains of PGPR were polyphasic characterized *in vitro* and nucleotide sequences were submitted to NCBI GenBank accession numbers MG645235-MG645246. Among them, *Bacillus aryabhattai* (CICR-D5), *B. cereus* (CICR-D3) and *B. tequilensis* (CICR-H3) were promising in reducing diseases. Incompatibility study of PGPR with agrochemicals revealed incompatibility of strains *B. altitudinis* CICR-S8, *B. altitudinis* CICR-D2, *B. cereus* CICR-D1, *B. safensis* CICR-4B and *B. safensis* CICR-4A2 with Thiram 75% WS while strains B. *tequilensis* CICR-H3, *B. altitudinis* CICR-D4, *B. safensis* CICR-4B and *B. safensis* CICR-4A2 were incompatible with Mancozeb at recommended dose. Strain *B. tequilensis* CICR-H3 was effective as biocontrol agent followed by *B. cereus* CICR-D3 under dual culture inoculation technique against *Macrophomina phaseolina*. Strains *B. cereus* CICR-D3, *B. tequilensis* CICR-H3 and *B. aryabhattai* CICR-S6 had significant siderophore production. In addition to this, *B. cereus* CICR-D3 and *B. aryabhattai* CICR-D5 were found to produce HCN.

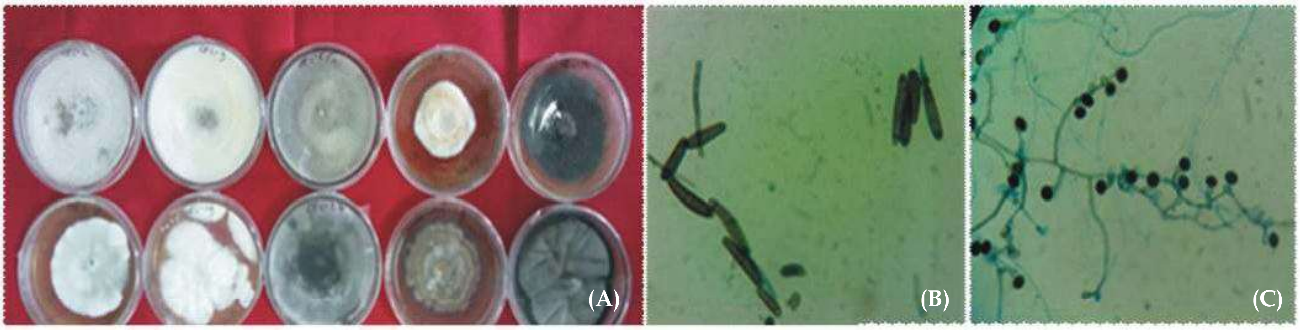
1 & 2 : *Macrophomina phaseolina*+ *B.Cereus* CICR-D3 and 3: *Macrophomina phaseolina* (Control)



Siderophore activity of PGPR strains on Chrome azurol S (CAS) agar medium, 1: ***B. aryabhattai*** **CICR-S6; 2:** ***B. tequilensis*** **CICR-H3 and 3:** ***B. cereus*** **CICR-D3**

Endophytes from cotton with biocontrol activity against major diseases

Studies were initiated to identify endophytes from cotton for biocontrol activity against major diseases. Samples of *Gossypium arboreum* from North India and *G. hirsutum* samples from Gujarat and Maharashtra were collected. About 30 Endophytic fungi from leaf, petiole, stem and root tissues of *G. arboreum* and 45 from *G. hirsutum* from Haryana, Rajasthan, Punjab, Gujarat and Maharashtra states were isolated. Based on the morphological characters some of the endophytic genera identified are *Alternaria*, *Bipolaris*, *Curvularia*, *Fusarium* and *Nigrospora.*



Pure culture of the different fungal endophytes (A), conidia of ***Bipolaris*** **sp. (B) and** ***Nigrospora*** **sp. (C) at 40x magnification**

3.10 : Bio-diversity of pests and natural enemies in cotton ecosystem

Nagpur

Seasonal Dynamics of Insect Pests and Diseases: ***Seasonal dynamics of sucking pests and bollworms***

Seasonal pest population dynamics data was generated under pesticide free conditions by taking weekly sucking insect number counts on DCH 32. Jassid and aphid population crossed ETL while whitefly and thrips were below ETL throughout the season. Jassid were above ETL starting from third week of August till second week of September with a peak population at 36 SMW (07 Sept 2017) (Fig 3.10.1). The highest number of aphids (146 / 3 leaves) were recorded during 33 SMW (17 Aug 2017) (Fig 3.10.2). Negligible population of American bollworm, spotted bollworm, mirid bug and spider populations were recorded over the crop season.

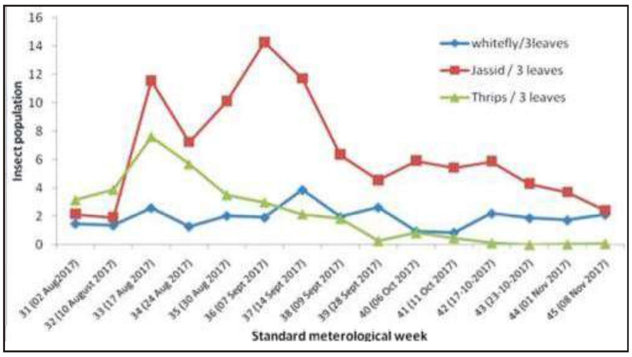


Fig 3.10.1. Population dynamics of sucking pests over the season 2017-18

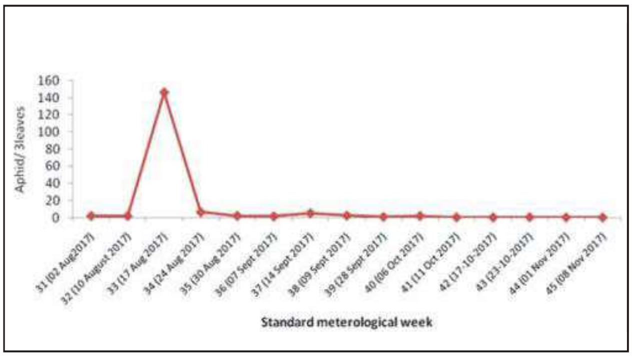


Fig 3.10.2 : Population dynamics of aphid over the season 2017-18

Population dynamics of sucking pests across five genotypes

Pest population dynamics in five genotyes *viz.*, Suraj, Suvin, DCH32, RCH2 & Phule Dhanwantari were compared over the season. Significant variation was observed in population of jassid and whitefly among the genotypes. Population of Jassid and Aphid was significantly high 6.51 jassid/ 3 leaves and aphid 11.46 aphids/ 3 leaves on DCH 32. Thrips, mirids, American bollworm, spotted bollworm and mirid populations were negligible over the crop season in all these genotypes (Fig. 3.10.3).

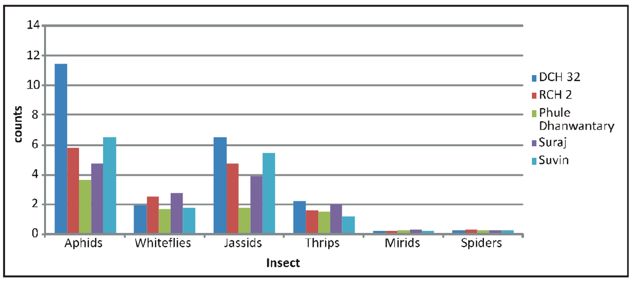
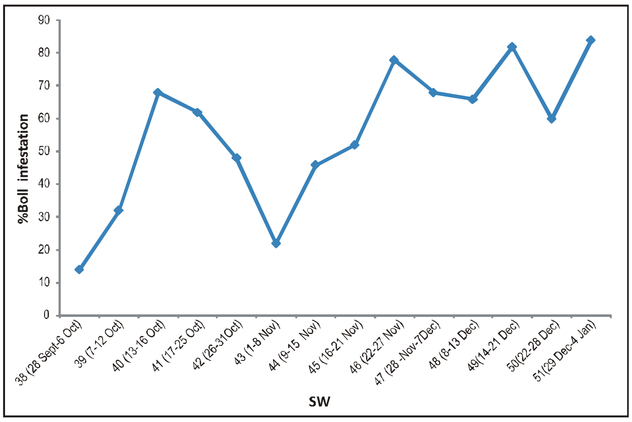


Fig. 3.10.3: Pest population dynamics on five genotypes over the season

Pink bollworm infestation

Pink bollworm infestation was recorded on *G.hirsutum* cv Suraj starting from September end till first week of January. Initially infestation was low but it increased with the progress of the season. During first fortnight of October, 68% boll infestation was recorded. Infestation reduced in first week of November and again it steadily increased to reach up to 84% boll infestation. Infestation in the flowers was high during first week of October thereafter it gradually decreased with the availability of bolls on the cotton plant (Fig 3.10.4).



Standard Meterological Week

Fig. 3.10.4: Pink bollworm infestation on flowers and bolls of Suraj during 2017-18

Pheromone trap catches at Nagpur

During 2017-18 highest moth catches of American bollworm (5.80 moths/trap/week), spotted bollworm (5.33 moths/trap/week), pink bollworm (99 moths/ trap/week) and tobacco caterpillar (26.6moths/trap/ week) were recorded at 50SMW (23-29 Dec.), 50SMW (23-29 Dec.), 47 SMW (26 Nov. -1 Dec.) and 45SMW (12-18 Nov.), respectively (Fig 3.10.5).

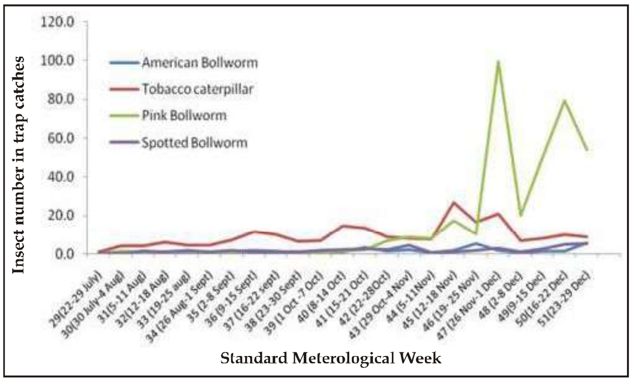
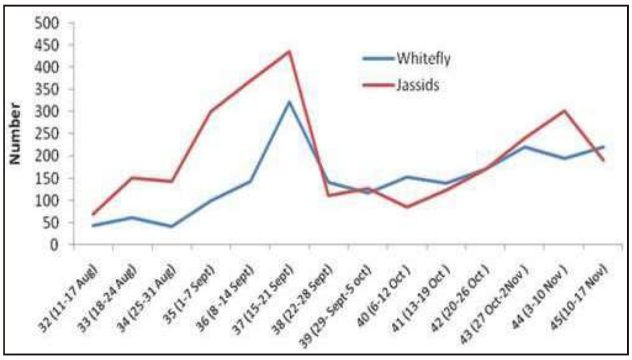


Fig.3.10.5 : Pheromone trap catches at Nagpur (2017-18)

Yellow sticky trap catches

The highest whitefly population (322 whitefly/ trap/week) and jassid population (435 jassid/trap/week) was recorded during 37 SMW (15-21 Sept) (Fig. 3.10.6). Non target insects like lady bird beetle trapped highest (11 LBB/traps/week) during 39 SMW (29- Sept-5 Oct). Similarly dipteran flies also trapped in greater number (29 flies traps /week) during 35 SMW (1-7 Sept) .



Standard Meterological Week

Fig 3.10.6: Jassid and whitefly population trapped in yellow sticky traps

Advancement in whitefly peak occurrence – need change in strategies

The analysis of historical data (2004-05 to 2016-17) was carried out to assess if there is any change in seasonal dynamics and severity of white fly population in north zone. Data presented for representative locations in Haryana (Hisar), Rajasthan (Sriganganagar) and Punjab (Faridkot) indicate that between 2004-05 to 2016-17, the peak occurrence advanced by 7-9 weeks and the average infestation increased by about 3.4 fold in Hisar and faridkot and by about 1.25 fold in Shriganganagar (Fig. 3.10.7).

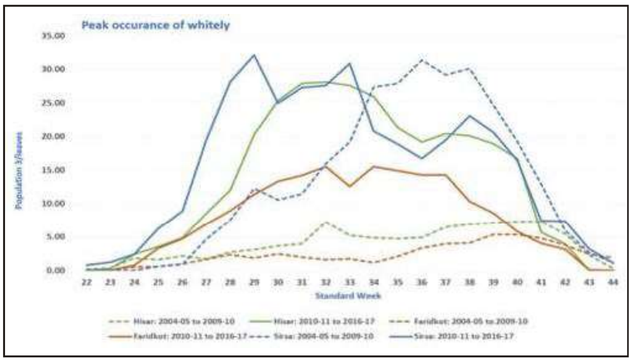


Fig.3.10.7 : Seasonal Dynamic whitefly population for the period 2004-05 to 2016-17

Sirsa

Seasonal Dynamics of Insect Pests:

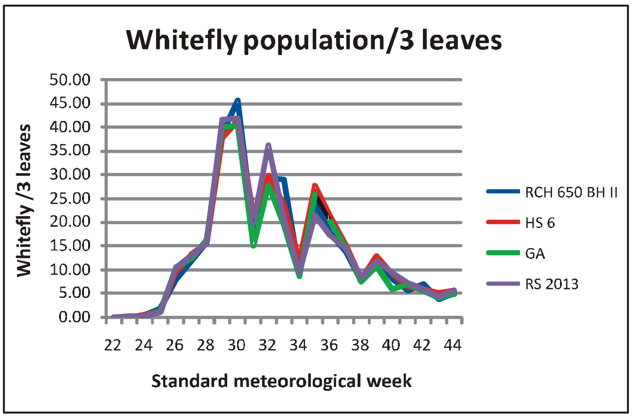
In RCH-650 BGII hybrid, leafhopper population ranged from 0.00 to 6.30 leafhoppers/ 3 leaves. Peak activity of leafhopper was observed in 30th SMW. Population of whitefly was initially observed in 22nd SMW (0.00 whitefly/3 leaves) & peak activity occurred in 30th SMW (45.70 whitefly/3 leaves). Thrips population ranged from 0.00 to 81.20 thrips/3 leaves which were first noted in 25th SMW. Peak activity of thrips was observed in 30th SMW.

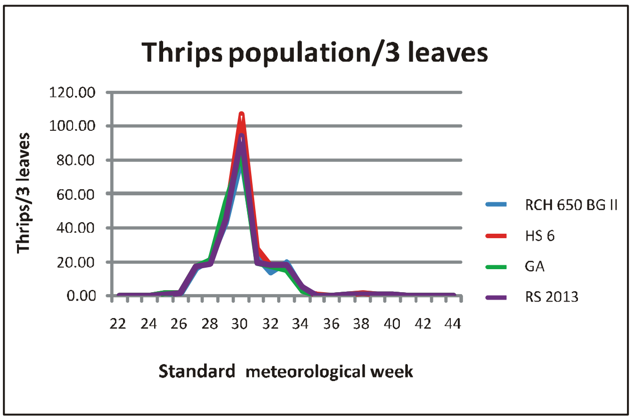
In HS-6, leafhopper population ranged from 0.00 to 6.30/ 3 leaves. Peak activity of leafhopper was observed in 31st SMW. Population of whitefly was initially observed in 22nd SMW (0.00 whitefly/ 3 leaves) & peak activity occurred in 30th SMW (41.30 whitefly/ 3 leaves). Thrips population ranged from 0.00 to 106.80 thrips/ 3 leaves and peak activity of thrips was observed in 30th SMW.

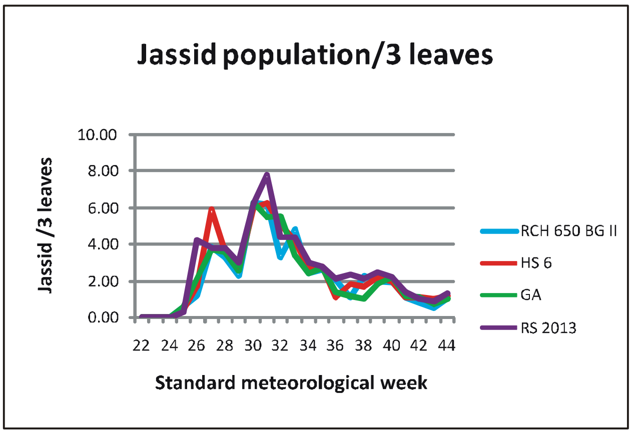
In Ganganagar Ageti, the leafhopper population ranged between 0.00 to 6.30 leafhoppers/ 3 leaves. Peak activity of leafhopper was observed in 30th SMW. Peak activity of whitefly occurred in 30th SMW (40.20 whitefly/ 3 leaves). Thrips population ranged from 0.00 to 84.40 thrips/ 3 leaves and peak was observed in 30th SMW.

In RS-2013, leafhopper population ranged from 0.00 to 7.80 leafhoppers/3 leaves. Peak activity of leafhopper was observed in 31st SMW. Population of whitefly was initially observed in 22nd SMW (0.00 whitefly/ 3 leaves) & peak activity occurred in 30th SMW (41.80 whitefly/ 3 leaves). Thrips population ranged from 0.00 to 94.20 thrips/ 3 leaves and peak was observed in 30th SMW.

Bollworm infestation was not observed on RCH-650 BG II. In non Bt varieties HS-6, GA & RS-2013 first incidence of bollworm was observed in the 37th SMW which ranged from 0.1 to 0.5, 0.30 to 0.90 & 0.23 to 1.20% fruiting bodies damage, respectively.







Within plant distribution of whitefly

Whitefly prefers to feed on lower canopy of the plant as compared to middle and upper canopy. Mean whitefly adults population/leaf recorded during the entire season of 2017-18 on upper, middle and lower strata was 4.77 (2.99-6.63), 12.07 (7.63-21.79) and 15.15 (7.50-33.06), respectively during different time of the day in RCH650 BG-II. Similar trend was recorded cv Ganganagar Ageti and RS2013. Though whitefly prefers to lay eggs on the fresh leaves but the nymphal pattern indicated the equal preference both for middle and lower strata leaves as compared to upper strata leaves.

The life table analysis of whitefly starting from 34-41SMW on its nymphal stage indicated maximum natural mortality due to fungal/bacterial infection (17.93-23.71%) followed by dislodgement (9.33-19.59%) and parasitism (4.77-18.60%). The total natural mortality obtained was 36.81-53.59 percent

Seasonal Dynamics of Diseases

To ascertain the extent of incidence and severity of the CLCuV, a survey was conducted in 8 cotton growing districts namely Sirsa, Fatehabad and Hisar of Haryana, Hanumangarh, Sriganganagar of Rajasthan, Fazilka, Bathinda and Mansa districts of Punjab in North India during the month of August. Disease grading (0-6 scale) technique developed by AICRP on cotton was used to record the per cent disease incidence. Associated Symptoms *viz.*, vein thickening, upward and downward curling (cupping), and cup shape outgrowths or enations on the lower side of the infected leaves were also recorded

CLCV Infected leaf showing vein thickening and enation

The incidence was highest in Fatehabad District followed by Hisar in Haryana. (Table.3.10.1)

Table 3.10.1 : Survey and surveillance of Cotton leaf curl infected field in North India (0 to 6 Grade)

State	District	ClCuV incidence (0-6 scale)
Haryana	Sirsa	2.04
	Fatehabad	2.32
	Hisar	2.06
	Hansi	1.30
Rajasthan	Hanumangarh	2.03
	Sriganagnagar	1.93
Punjab	Fazilka	1.20
	Bhatinda	1.72
	Muktaar	0.70

Biological Diversity of Insect Pests, Pathogens and Natural Enemies

Whiteflies

Whitefly populations from all the three cotton growing zones were taken up to study the genetic diversity of *Bemisia tabaci*. Collected whiteflies were subjected to molecular characterization by mitochondrial COI gene primer. After obtaining sequences from sanger sequencing, the sequence were trimmed in Bioedit software and submitted to NCBI to generate accession number (MG448545 - MG448602). The 58 sequences obtained were used for phylogenetic analysis using Mega 7 software. The phylogenetic tree for 58 Mt COI sequences of *B. tabaci* containing 425 nucleotides each was constructed by using *Trialeurodes vaporariorum* as an outgroup. The analysis involved total of 70 nucleotide sequences including reference sequences. The phylogenetic tree was constructed based on the Jukes-Cantor model. A discrete Gamma distribution was used to model evolutionary rate differences among sites (5 categories (+G, parameter = 0.3485)). The rate variation model allowed for some sites to be evolutionarily invariable ([+I], 29.88% sites). The maximum likelihood phylogenetic tree showed two monophyletic clades with Asia-I belonging to south and central India and Asia-II representing north India whitefly populations. The tree construct supported moderately to strong with bootstrap value range from 50 to 93%.

Nagpur

Biodiversity of natural enemies

To record the abundance and diversity of natural enemies in cotton ecosystem in central, south and north India a study was conducted. Yellow pan trap was used for recording parasitoids and visual count method was adopted to record predators. In central India the study was conducted on Phule Dhanwantari, Suraj, Suvin, RCH-2 and DCH-32. More than 30 different kinds of natural enemies were recorded. Diversity indices such as Shannon Index (H), Shannon evenness Index (E), Simpson Index (D), Sorenson's Coefficient (CC) and Species richness (S) were calculated for above mentioned varieties of cotton. It was observed that species richness and abundance was highest in Phule Dhanwantari (H=1.94, S=20) followed by Suvin (H=2.09 , S=15) and Suraj (S=15) than compared to the RCH-2 and DCH-32. Unprotected cotton varieties carry more species richness than protected ones.


Healthy Whitefly nymph


Parasitized Whitefly pupa


Eretmocerus sp. exit hole on Whitefly pupa


Adult *Eretmocerus sp.*


Cheilomenes sexmaculata grubs and pupa


Rivellia sp.


Rivellia sp.

Monitoring of Pink bollworm field incidence in India

Two bollworms viz., American (*Helicoverpa armigera*, spotted bollworm (*Earias vitttela & E. Insulana)* were recorded in negligible number while, pink bollworm (*Pectinophora gossypiella)* was seen to damage cotton to a greater extent. Pink bollworm infestation varied from place to place and ranged from 40-95% in central and south India.

The per cent infestation of pink bollworm in green bolls of BG-II at 140-180 days after sowing was observed in all cotton growing districts of Maharashtra *Viz.*, Yavatmal (56.63%), Akola (80%), Amaravati (70.67%), Nandurbar (86.7%), Dhule (99%), Jalgaon (92%), Aurangabad (91%), Jalna (79%), Nanded (81%), Parbhani (82%), Hingoli (80%) and Buldhana (99%). Infestation on BG II cotton in Madhya Pradesh was recorded at 68 per cent.

Similarly, infestation on BG II cotton fields of Gujarat were in the range of 20 to 90 per cent, the highest infestation was observed in Amreli (90%) and in the fields of Bharuch (25%) infestation was lower as compared to other districts in Gujarat. However, no pink bollworm infestation was observed in North India (Punjab, Haryana and Rajasthan) on BG-II hybrids. Infestation of pink bollworm in South India was same as in central India. In Andhra Pradesh the infestation ranged from 72 to 84 per cent and in Telangana 69 to 91.2 per cent with highest observed in Adilabad (91.2%). Raichur (28%) district of Karnataka had less infestation as compared to Dharwad (92%). Incidence of pink bollworm on non Bt cotton fields of central India (Maharashtra, Madhya Pradesh and Gujarat) was observed in the range between 36 to 100 per cent, whereas, in North India, it was 7 to 42 per cent. The non Bt bolls from Nandiyal and Dharwad recorded 68 and 100 per cent infestation respectively.

Widespread infestation of the pink bollworm, Pectinophora gossypiella (Saunders) on Bt cotton in Maharashtra

The pink bollworm *Pectinophora gossypiella* (Saundars) has recently re-emerged as a serious menace on Bt cotton in India. An extensive roving surveys were conducted in 71 locations spread across 15 major cotton growing districts of Maharashtra to assess the level of pink bollworm infestation in Bt cotton. The dynamics and severity of pink bollworm damage during the different stages of boll development (90-130 days of crop age) was assessed based on random sampling of green bolls, opened bolls and picked bolls per plant and number of locules damaged per boll. The survey results revealed that there was a widespread infestation of pink bollworm on Bt cotton throughout the surveyed sites in the range of 40 – 95 % (Fig 3.10.8). Yield losses of 20-30% are expected with observed level of infestation. A typical pattern of progressive increase in the level of pink bollworm infestation and intensification of locular damage with the advancement of the crop season was observed. The pink bollworm hitherto supposed to be under control since the introduction of Bt cotton in India, now appears to be widespread, especially on Bt cotton throughout the cotton growing areas of Maharashtra State which accounts for approximately 25 % of country's cotton production.

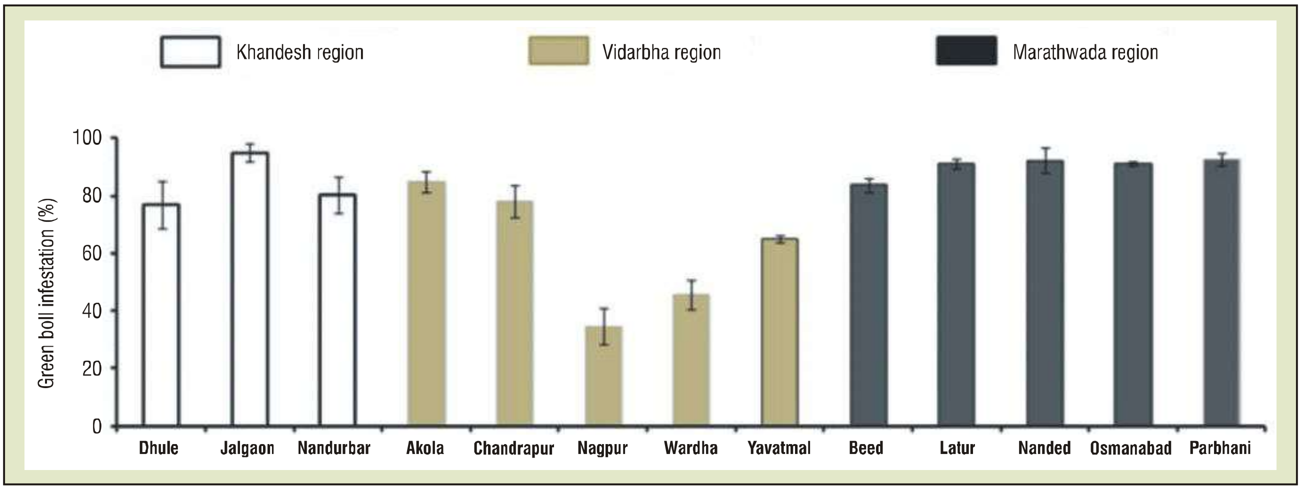


Fig. 3.10.8: Pink bollworm infestation in Bt-cotton in Maharashtra (2017 -18)

Genetic Diversity of pink bollworm

Pink bollworm population from flower and green bolls were collected from Maharashtra and Adilabad. The collected samples were used for diversity studies. In BLAST analysis sequences have shown 99 percent identity with NCBI Accession No.MF044026.1

Emerging fungal pathogens

Marathwada, Khandesh and Vidarbha region of Maharashtra were surveyed to record shifting trend, if any of leaf spot pathogens. Various types of leaf spots were recorded (fig. 3.10.9) and diverse fungal pathogens viz., *Corynespora cassiicola* (15), *Colletotrichum gloeosporioides* (06), *Colletotrichum siamense* (02), *Alternaria spp*. (02) and *Myrothecium roridum* (20) were isolated. Of these, *Corynespora cassicola* and *Colletotrichum siamense* were observed as potential new emerging diseases of cotton. Widespread infestation of *C.cassicola* was recorded from 15 locations from cotton growing regions of Vidarbha, Khandesh and Marathwada of Maharashtra. Identity of fungal species was confirmed by morphological and molecular characters including mycelia growth on media. (fig. 3.10.10)

Fig. 3.10.9 : Various types of fungal leaf spots observed during survey

Fig. 3.10.10 : Mycelial growth of a) *Corynespora cassiicola* b) *Colletotrichum gloeosporioides* c) *Myrothecium roridum* on Sabouraud Dextrose Agar (SDA) medium

Occurrence and distribution of *Tobacco Streak Virus* (TSV) in Cotton

Symptoms expression in *Gossypium barbadense* : The cotton fields at CICR Regional Station Coimbatore were surveyed during 2017 for the presence of TSV infected cotton plants. The presence of disease affected plants in the germplasm of *Gossypium barbadense* were observed at 90 Days after sowing (DAS). The per cent disease incidence ranged between 1.61% (CCB 140) to 26.60% (ICB 71) (Table 3.10.2). The expression of TSV symptoms were also observed in *Gossypium barbadense*. The symptoms were very distinct with necrotic spots dark purple in colour and also drying of squares. The symptom expression in the germplasm of ICB 71, CCB 129, CCB 51 and CCB 141 were given in the Fig.3.10.11.

Table 3.10.2: Per cent disease incidence of TSV in the germplasm of *Gossypium barbadense*

Sr. No	Germplasm	Per cent disease incidence (90 DAS)*
1.	ICB 71	26.6 %
2.	CCB 129	20.5 %
3.	CCB 51	13.9 %
4.	ICB 72 & ICB 73	12.6 %
5.	CCB 141	12.3 %
6.	CCB 29	6.8 %
7.	Suvin	6.7 %
8.	CCB 143b, TCB 49, NDGB 12, NDGB 21, C1, DB 3 & Rhc01R1	6.6 %
9.	ICB 60, ICB 61, ICB 65, ICB 67, ICB 70, ICB 74, ICB 75, ICB 94, ICB 145, ICB 163, ICB 180, ICB 182, ICB 245, ICB 260 & C 7	5.7 %
10.	CCB 11, CCB 11a, CCB 30 & CCB 64	3.6%
11.	CCB 64a, H8, H9R2, H3, H8, TCB 4, DB, GSB 41, C9, ICB 17, ICB 17R2, ICB 25, ICB 183, ICB 209, ICB 210, ICB 222, ICB 224, ICB 238, ICB 241, ICB 248, ICB 263, ICB 271, ICB 275, ICB 276, ICB 290, NDGB 1, NDGB 23, NBGB 31, NDGB 41, NDGB 62, NDGB 63 & NDGB 64	3.3%
12.	CCB 26, CCB 51- 2, CCB 67 & CCB 143	2.9%
13.	CCB 25, CCB 140, HP & SP	1.6 %

*Per cent disease incidence= No. of infected plants / Total no. of plants assessed x 100

Fig 3.10.11: Typical symptoms of TSV showing necrotic spots with purple colour and drying of squares on *G. barbadense* genotypes

Symptoms expression in *Gossypium hirsutum* : The presence of disease affected plants in the varieties and hybrids of *Gossypium hirsutum* were observed at 60 to 70 DAS. The per cent disease incidence varied from 5.0% (Suraj) to 16.6% (Surabhi and RCH659 BG-II) (Table 3.10.3). Typical symptoms observed in *G. hirsutum* were chlorotic with necrotic spots in young leaves and marginal necrotic streaks with leaf deformation while in mature plants veinal necrosis, drying of squares and terminal shoots was observed (Fig. 3.10.12). Yellowing, leaf malformation and necrotic spots were also observed in *G. arboreum* (Fig. 3.10.13).

Table 3.10.3 : Per cent disease incidence of TSV in *Gossypium hirsutum*

S. No	Variety/ Hybrid	Per cent disease incidence (60 to 70 DAS)
1.	Suraj	5.0 %
2.	Surabhi	16.6%
3.	RCH 659 BG-II	16.6 %
4.	Suraj Bt	7.6 %

Fig. 3.10.12 : Typical symptoms of marginal necrosis and necrotic leaves in young plants

Fig. 3.10.13 : Symptoms expression in *Gossypium arboreum*

For the first time symptoms resembling Tobacco Streak Virus (TSV) on *G. hirsutum* was also recorded in some fields of Fatehabad and Sirsa Districts of Haryana during survey. Further work is underway for confirmation of presence of TSV.

a) Team Conducting survey

b) Symptoms resembling TSV infection on *G. hirsutum*.

Nematode mapping of Vidarbha districts

Soil sampling was done for mapping of 9 districts of Vidarbha and total of 667 samples were collected. The samples were washed by Cobb's sieving and decanting technique and nematode population was estimated qualitative and quantitatively. Initial results show that reniform *nematode Rotylenchulus reniformis* was most frequent and dominant species followed by *Meloidogyne incognita* (Table 3.10.4)

Table 3.10.4: Important nematode species of Vidarbha region of Maharashtra

S. No.	Nematode species	Dominance %
1.	*Rotylenchulus reniformis*	100
2.	*Meloidogyne incognita*	71
3.	*Tylenchorhynchus dubius*	88
4.	*Helicotylenhus dihystera*	63
5.	*Hoplolaimus columbus*	58
6.	*Paratylenchus minutus*	26
7.	*Pratylenchus goodeyi*	85
8.	*Hirschmanniella mucronata*	51
9.	*Hemicycliophora arenaria*	45

Coimbatore

First record of Tea mosquito bug, *Helopeltis theivora* Waterhouse was documented on cotton variety, Suraj under hydroponic nutritional studies conducted with various levels of nutrients at Central Institute for Cotton Research, Regional Station, Coimbatore. Both nymphs and adults suck the sap from leaves, young shoots, squares and bolls which causes black lesions and the leaves get rolled at the edge with brown central black lesions near the main veins. Scars with papery layer appear on the leaves. Retarded growth with shortening of inter nodal length and gradual drying of the shoots were also observed.

3.11: Integrated Pest Management

Nagpur

Phytotoxicity and growth stimulating effect on plants and crop yield

The experiment was conducted to understand phytotoxicity and growth stimulating effect of insecticides on cotton plants and crop yield. Four insecticides viz., Clothianidin 50%WDG, Spiromesifen 22.9%SC, Dinotefuran 20% SG and Flonicamid 50% WG along with control were taken as main plots in split plot design. The dosages of insecticides taken were at x, 2x and 4x. The treatments were imposed at 60, 75 & 90 DAS. There was no noticeable phytotoxicity and growth stimulating effect with the imposed insecticidal treatments. Yields did not vary significantly among the treatments. Jassid population was significantly different in all the insecticides tested at given dosage and was lower in all the treatments as compared control. Among the insecticides tested Dinotefuran 20% SG and Flonicamid 50% WG registered lowest population of jassid. Among the dosage, highest dose (4x) resulted in lowest jassid population (Fig 3.11.1). Whitefly population was lowest in Spiromesifen 22.9%SC and Flonicamid 50% WG. Significantly lower population of thrips was recorded in all the designated insecticides over control. However, not much difference was recorded between different dosages. Mirid population was not impacted much with different insecticides sprayed at different dosages.

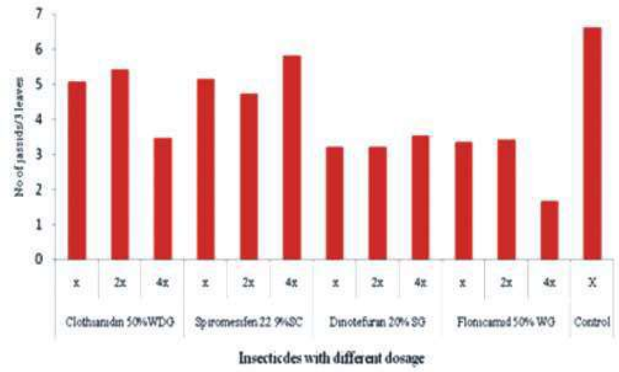


Fig 3.11.1 : Jassid population as a result of insecticidal treatments at different dosages of insecticides

Insecticides:

The field experiment was conducted at ICAR-CICR, Nagpur to study the effectiveness of Quinolphos 25EC, Profenophos 50 EC, Thiodicarb 75 SP, Clorantraniliprole 18.5 SC, Spinosad 45SC, Neem Oil, Cypermethrin 25EC, Deck (Cypermethrin + Profenophos), Spark (Deltamethrin + Triazophos), Traizophos 40EC and Deltamethrin 2.8 EC against Pink bollworm of cotton under High density Planting system (HDPS). The data on exit holes, mines on epicarp, number of larvae and per cent locule damge was observed in 10 green bolls (GB). Data indicated that, lower number of exit holes was noticed in the treatment cypermethrin + profenophos (0.44/10 GB) and it was at par with cypermethrin 25 EC. All other insecticides tested were equally effective and number of exit holes recorded were in the range of 1.11 to 2.33 with 4.56 in untreated control. Similarly, lowest number of larvae per 10 green bolls was observed in the plots sprayed with cypermethrin + profenophos (1.33 larvae) and it was followed by (deltamethrin+triazophos) and cypermethrin 25 EC with 1.67 and 1.78 larvae, respectively. Cypermethrin + profenophos was also highly effective in reducing locule damage (8.62%) while cypermethrin 25 EC (13.60%) was not so effective. Treatment with neem oil was effective in reducing locule damage (17.86%) in comparison with untreated control (38.88). (Fig 3.11.2)

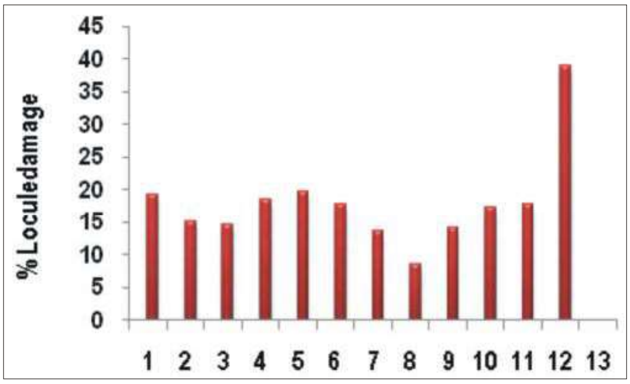


Fig: 3.11.2: Effect of different newer molecules against Pink bollworm (2017-2018)

Sirsa

Compatibility study of entomopathogens with insecticides

The *in vitro* compatibility of 12 pesticides with top ten Entomopathogenic fungi (EPFs) was assessed using their full and half of the recommended dose following poison food technique on Sabouraud Dextrose Agar (SDA) amended with 0.2% yeast. The redial growth of mycelium (per plate), conidial production (5 mm disc) was recorded in all treatments seven days after inoculation, separately. The toxicity of chemicals and botanicals against EPFs was calculated using the formula of Alves *et al.*, (1998): T= [20 (VG) + 80 (ESP)]/100. In this formula, values for vegetative growth (VG) and sporulation (ESP) were given in relation to control (100%). Where toxicity grades were considered as follow: T = 0 to 30 (very toxic); 31 to 45 (toxic); 46 to 60 (moderately toxic); >60 (compatible). Among botanicals, neem oil and pongamia oil were found to be compatible to moderately toxic with all the EPFs except *Beauveria bassiana*-6097, *Beauveria bassiana* -409, *Beauveria bassiana*-4543. The castor oil was found to be toxic to with all EPF's except EPF strain *Paecilomyces javanicus*-89, *Beauveria bassiana*-4565 and *Fusarium monoliformae*-83. Among chemicals flonicamid and diafenthiuron, the insect growth regulators (spiromesifen, pyriproxifen, buprofezin), were found to range between compatible to moderately toxic while organophosphate group of pesticides and fipronil ranged between compatible to very toxic. Overall, EPF strain namely, *Paecilomyces javanicus*- 89, *Paecilomyces javanicus*-102, *Metarhizium anisopliae* -1299, *Beauveria bassiana*-4511 were found to be the most compatible with full and half dose of the chemical and botanicals tested.

Comparative field study of selected entomopathogens

The field trial conducted during 2017-18 revealed that the entomopathogenic fungal strain and chemical treatments were significantly superior over control in terms of nymphal mortality. The highest nymphal mortality seven days post spray was recorded with *B. bassiana* 4511 (83.65%) followed by *P. javanicus* CICRRSS 0102 (81.78%) which were significantly superior to Diafenthiuron 50% WP (1. g/L), Neem oil (300 ppm) and commercial formulation of *L. lecanii* (0.1% WP) (Fig.3.11.3.).

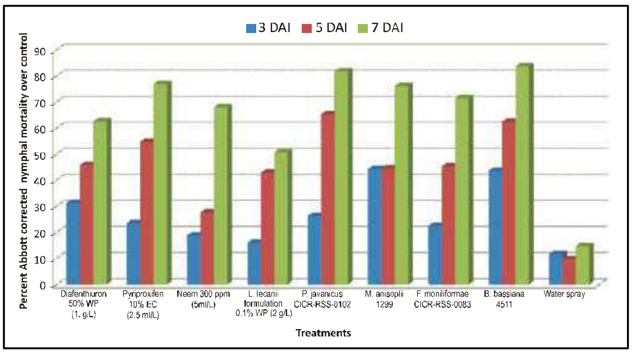


Fig. 3.11.3 : Effect of selected entomopathogenic fungal strains and pesticides on whitefly nymphal mortality under field conditions (*Average, maximum and minimum % RH during the experiment 76.7 (50-87) and 58.5 (40-72) during last week of July and first week of August 2017)

Bioefficacy of insecticides and biorationals against thrips

The efficacy of twelve label claim insecticides and five biorational interventions (castor oil, pongamia oil, sesame oil, 2 neem based formulation) were tested under laboratory conditions against thrips at ICAR-CICR, Regional Station, Sirsa at three dosages during 2017-18. Among the insecticides Spinosad (78% mortality), Fipronil (72% mortality), Spinoteram 11.7 % SC(68%mortality) and Diafenthiuron and Profenphos (66% mortality) gave mortality. Among the biorational approaches, sesame oil (58 & 66 % mortality @10& 15 ml/litre), castor oil (50 & 58% mortality @ 10 & 20ml/liter), pongamia oil (40% mortality @ 10ml/liter) recorded moderately good mortality against thrips.

The efficacy of biorationals against whitefly was studied during 2017-18. Castor oil, pongamia oil and sesame oil reduced whitefly population 42.81, 39.20 and 36.86 percent respectively. The maximum reduction was obtained in standard check Difenthiauron (55.24%) treatment.

Coimbatore

Evaluation of selectivity of insecticides against different mealy bug species and their major natural enemies associated with cotton, tomato, brinjal and papaya

1. Out of eight insecticides tested, Clothinidin was

found to be more toxic to *P. solenopsis*. The descending order of toxicity Clothionidin > Cypermethrin > Pyriproxyfen + Fenpropathrin > Lambdacyhalothrin > Spiromesifen > Flonicamid > Diafenthiuron. The relative resistance (RR) was calculated by keeping the most toxic insecticide as unity (1.00). The study observed that the clothionidin was highly toxic to the mealybug. Based on the RR value it was observed that the insecticides Cypermethrin, Pyriproxyfen + Fenpropathrin, Lambdacyhalothrin, Spiromesifen, Flonicamid, Diafenthiuron were 8.33, 32.70, 60.69,255.05, 555.13 and 625.48 times less toxic respectively as compared to Clothionidin (Table 1).

2. Safety evaluation study of thirteen different insecticides against larvae of *Chrysoperla zastrowii sillamii* revealed that the Thiamethoxam (LC_{50}=7.010mg ai/ L) was found to be more harmful to the larvae of Chrysoperla, whereas Thiodicarb (LC_{50}= 307.75 mg ai/L) was found to be safer to the larvae by this method.
3. Safety evaluation study of fourteen different insecticides against the grubs of *Cryptolaemus montrouzieri* by diet contamination method revealed that the imidacloprid (LC_{50} = 3.70 mg ai/L) was found to be more harmful to the grubs of *Cryptolaemus*, whereas thiodicarb (LC_{50} = 286.51 mg ai/L) was found to be safer to the grubs.

Table 3.11.1: Toxicity of different insecticides against, *Phenacoccus solenopsis* by leaf dip method

Name of the insecticide	No	Slope	LC_{50}mg ai/L	Fiducial limit		RR*	LC_{90}	Fiducial limit	
				Min	Max			Min	Max
Clothionidin	169	1.291	4.84	3.17	6.96	1.00	47.65	27.35	121.54
Cypermethrin	190	3.771	40.34	33.22	45.72	8.33	88.22	73.12	128.07
Diafenthiuron	180	2.072	3027.34	2310.39	3792.32	625.48	1883	8970.8	22123.0
Flonicamid	196	1.838	2686.82	1584.00	3840.05	555.13	13380.0	8072.0	44062.0
Lambdacyhalothrin	182	3.075	293.75	230.76	343.57	60.69	766.98	613.49	1177.33
Pyriproxyfen + Fenpropathrin	210	1.815	158.26	114.08	202.58	32.70	804.68	523.95	1917.48
Pyriproxyfen	210	2.204	5025.08	2608.17	7580.87	1038.24	19164.0	11004.0	0.001947
Spiromesifen	210	1.943	1234.45	848.14	1580.80	255.05	5637.0	3958.0	11044.0

*Relative Resistance = LC_{50} of test insecticide / LC_{50} of reference insecticide

Effect of thermal stress on fitness traits of two mealybug pests, *Phenacoccus solenopsis* and *Paracoccus marginatus* and their parasitoids *Aenasius bambawalei* and *Acerophagus papaya*

The studies on developmental biology of *Phenacoccus solenopsis* under laboratory condition (30 ± 5°C and RH 60-70 %) showed that the mean developmental period of male individuals were higher than that of their female counterpart. The mean developmental period of Punjab population of *P. solenopsis* was 15.0 days for male and 11.0 days for female, which was found to the lowest as compared to Tamil Nadu and Maharashtra population.

Pink bollworm Resistance in India

The resistance development of pink bollworm on BG-II and non Bt cotton fields was monitored across India. In North India, 9 districts from three states (Hisar, Fatehabad and Sirsa of Haryana, Mansa, Abohar, Bathinda and Faridkot of Punjab, Sriganganagar and Hanumangarh of Rajasthan), in Central India 24 districts namely Wardha, Yavatmal, Washim, Hingoli, Nanded, Parbhani, Aurangabad, Buldana, Akola, Amravati, Rahuri, Jalgaon districts of Maharashtra; Khandwa and Pandhurna districts of Madhya Pradesh, Surat, Bharuch, Vadodara, Anand, Ahmedabad, Bhavnagar, Amreli, Junagadh, Rajkot and Surendranagar districts of Gujarat and 13 districts namely Guntur, Kaddapa, Anantpur, Kurnool and Krishna in Andhra Pradesh; Karimnagar, Adilabad, Warangal and Khammam in Telangana, Srivelliputtur and Coimbatore in Tamil Nadu and Dharwad and Raichur in Karnataka were monitored .

The Pink bollworm populations collected from North India recorded susceptibility to Bt toxins. Pink bollworm populations from Prakasam, Bharuch, Rajkot, Kurnool and Surendrangar recorded 172, 278, 372, 391 and 674 fold resistance to Cry1Ac toxin compared to susceptible check. Populations from Surendranagar, Guntur, Warngal, Yavatmal, Jalna, Buldana, Jalgaon, Anand, Vadodara, Bharuch, Aurangabad, Dhule, Rajkot and Khammam recorded 141, 182, 182, 220, 287, 315, 436, 436, 444, 518, 671, 671, 4214 and 5947 fold resistance over the susceptible check to Cry2Ab.

Insecticide resistance monitoring against jassid

Resistance monitoring against jassid was carried out for 4 locations of Vidarbha region by taking 9 insecticides which are commonly used by the farmers. The LC_{50} ranges of these insecticides were, Flonicamid 50%WG 0.0002 - 0.0009 mg/L, Monocrotophos 36%SL 0.0001-0.185 mg/L, Acephate 75%SP 0.0015-0.1837 mg/L, Imidacloprid 17.8%SL 0.0008 - 0.0074 mg/L, Acetamiprid 20%SP 0.0027 - 0.0307 mg/L, Thiamethoxam 25%WG0.0012 - 0.0034 mg/L, Clothianidin 50%WDG 0.0002 - 0.0043 mg/L, Dinotefuran 20%SG 0.0001 - 0.0004 mg/L, Spiromecifen 22.9%SC 0.0069-0.0488 mg/L. Nagpur populations were more susceptible to Flonicamid while susceptibility of populations from Amravati were more to Clothianidin and Dinotefuran as compared to other populations.

Monitoring of resistance development in sucking pests against newer insecticides *viz.*, Acetamiprid, Clothianidin, Dinotefuran, Flonicamid, Imidacloprid, Monocrotophos, Spiromesifen, Thiamethoxam was taken up with population of Nagpur, Wardha, Amravati and Yavatmal. It was observed that jassid populations of these districts were susceptible to these designated insecticides.

Resistance monitoring against cotton whitefly (*Bemisia tabaci*) for Nagpur population

Resistance monitoring against cotton whitefly (*Bemisai tabaci*) was initiated from 2015-16 for Nagpur population. Twenty one insecticides from 10 groups (Biorationals, Neonicotinoid, Phenylpyrazole, Carbamates, Pyridine, Carboxamide, Insect Growth Regulators, Organophosphate, Tetronic acids, Synthetic pyrethroid) were taken for resistance monitoring during 2015-16, 2016-17 and 2017-18. Over the three years, it was observed that resistance ratio did not exceed > 20 fold. In the current year, resistance was negligible against all the insecticides indicating that susceptibility of whitefly was intact.

Sirsa

Whitefly resistance to insecticides in North zone.

Organophosphate: The Resistance ratio obtained in case of Ethion (2.62-7.38 & 1.84-11.04), Chlorpyriphos (3.64-11.26 & 7.56-10.46) and Triazophos (28.94-43.15 & 11.84-54.56) during 2016-17 and 2017-18 was attributed to the pesticide use pattern on cotton as well as on other alternate hosts crops.

Neonicotinoid : The high resistance to Thiamethoxam (12.8 - 58.96 & 10.34 - 51.48 fold resistance ratio during 2016-17 & 2017-18) was recorded at different locations of the north zone but resistance was low for Acetamiprid, and Imidacloprid and this may be due to insecticide use pattern. Low resistance ratio was recorded against Dinotefuran (0.96-17.80 & 1.46-9.80 during 2016-17 and 2017-18), Thiacloprid and Clothianidin .

Synthetic Pyrethroid : Low to moderate resistances to Cypermethrin were reported in the *B. tabaci* populations, very low or minimal resistance to Fenpropathrin was observed which is again a result of insecticide use pattern in cotton and other crops.

Insect Growth Regulators : Younger stages of insects are generally more sensitive to insecticides as compared to older stages. Among the newer insecticides, Diafenthiuron recorded highest resistance with 70.67-163.30 & 33.33-128 fold resistance during 2016-17 & 2017-18) .

Nematode Management

Nagpur

Induction of Systemic Acquired Resistance against phyto nematode.

Bio formulations (Curcumin water soluble and alcohol soluble extracts, neem oil and cow urine in different combinations) were evaluated for confirmation of induction of systemic acquired resistance against reniform nematode under field conditions. Effect of bio formulations on nematode population in field and on final cotton yield was evaluated. Alcohol soluble curcumin was more effective in suppression of plant parasitic nematodes as compared to water soluble curcumin. In 2017-18, application of bio-formulation with curcumin, cow urine and neem oil on PKV081 reduced nematode population and increased yield by 29%. The spray treatments were better than the corresponding treatments applied to soil in reducing nematode population and increasing seed cotton yield.

Evaluation of bacteria for efficacy against nematodes

Bacterial species isolated as endosymbiont from nematodes were evaluated for efficacy against reniform nematode (Table 3.11.2). *Lysinibacillus sphaericus* used as seed treatment was found to reduce nematode population and also induce resistance against nematodes as evidenced by split root experiment.

Table 3.11.2: Bacterial species evaluated for efficacy against reniform nematode *Rotylenchulus reniformis*.

Bacterial species	NCBI Acc. No.	Bacterial species	NCBI Acc. No.
Aeromonas veronii	KU507539	*Alcaligenes faecalis*	KX808583
Aeromonas veronii	KU507540	*Alcaligenes faecalis*	KX808584
Aeromonas veronii	KU554699	*Ochrobactrum pseudogrignonense*	KC342237
Aeromonas veronii	KU564079	*Bacillus nealsonii*	JQ319066
Enterobacter cloacae	KU738572	*Ochrobactrum pseudogrignonense*	KF312237
Brevundimonas aurantiaca	KU744945	*Alcaligenes faecalis*	KX808583
Brevundimonas aurantiaca	KU755452	*Alcaligenes faecalis*	KX808584
Enterobacter hormaechei isolate CICR-XA	KC759141	*Ochrobactrum pseudogrignonense*	KC342237
Lysinibacillus sphaericus isolate CICR-X12	KC759142	*Brevundimonas aurantiaca* strain CICR-EMA4	KU744945

3.12 : Development of new Detection Methods, Tools and Protocols

Nagpur

Validation of CLCuV LAMP Detection Technique

Development of diagnostic tools which are rapid, specific and sensitive have immense role to play in detection and management of economically important viruses. The protocol for rapid diagnosis of CLCV infected samples by using Loop Mediated Isothermal Amplification (LAMP) has been standardized. Primer synthesized using conserved regions selected by multiple sequence alignment for standardization of LAMP protocol was validated. The temperature and time essential for LAMP assay was standardized at isothermal conditions of 61 ^{0}C for 60 min for set of four primers (F3, B3 and FIP, BIP). The colorimetric detection for diagnostic simplicity of amplified LAMP product by using SYBR safe DNA gel stain has enhanced applicability of this technique. During survey the leaf samples were collected from 8 different cotton growing districts of North zone. The DNA was isolated by using DNeasy plant mini kit and tested for CLCuV infection by using LAMP techniques (Fig. 3.12.1).

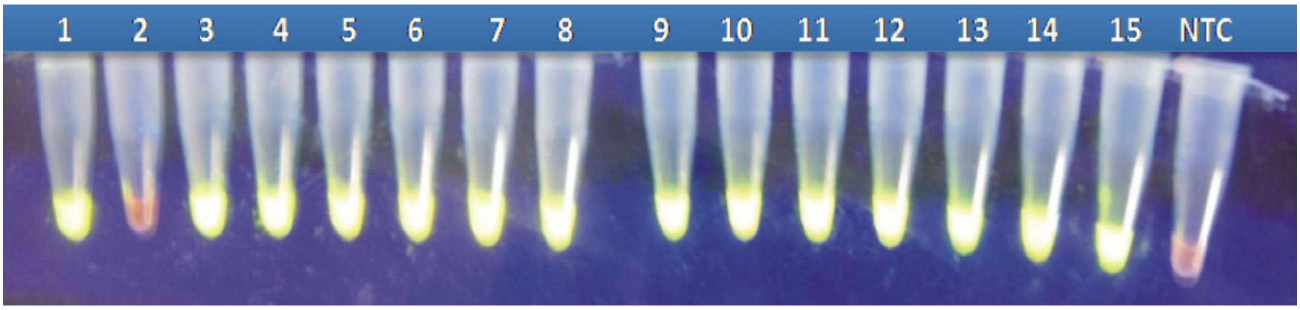


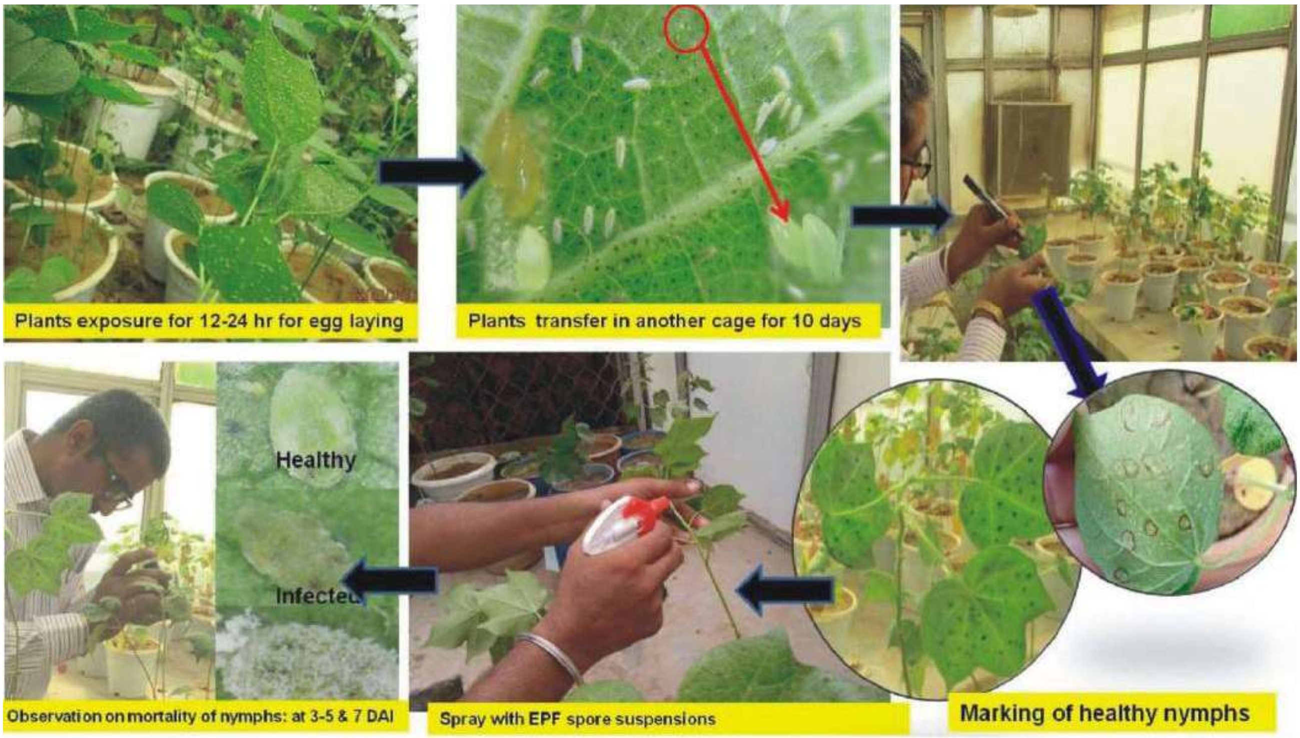
Figure 3.12.1 : Colorimetric detection of CLCV by LAMP technique in samples collected from different locations

Sirsa

Development of new modified poly house bioassay method against whitefly nymphs

Fungal isolates were evaluated against white nymphs through six different methods including leaf disc method-A , detached leaf method using 0.2% agar plate (detached leaf method-B), detached leaf supported with 0.2% sucrose solution (5 ml vial) (detached leaf method-C), detached leaf supported with 0.2% sucrose solution (15 ml) in plastic cups (detached leaf method-D), detached leaf supported with 0.2% sucrose +0.1% NPK and placed on aluminum mesh to support the leaf in plastic tray (detached leaf method-E) and the new modified polyhouse bioassay method (F). The percent mortality of the whitefly nymphs by all the fungal isolates were consistent under new modified poly house screening method, while in the other method the mortality trend was uneven due to reduced turgidity of the leaves. Hence, the new modified poly house bioassay method was found to be the most suitable method for evaluating entomopathogenic fungi in large numbers.

In the new bioassay method, one month old potted plants were kept inside the whitefly rearing poly house for egg laying (50-60 whitefly per leaf) (Fig.4.10.2). Twenty four hour post egg-laying, whitefly adults were gently removed from the plants and the plants were transferred to an another nethouse aseptically for next 10 days. Subsequently, the number of nymphs (40-50 nymphs per leaf) was recorded and marked on abaxial surface of the leaf with water proof marker. Freshly prepared conidial suspension (1×10^7 ml^1) of EPFs was applied to abaxial surface of leaves at 10 ml per plant (~2 ml per leaf) in the poly house having relative humidity of around 75% and temperature 30 ± 2°C. In control treatment, potted plant leaves were sprayed with 0.01% Tween 80 solution only. The mortality was recorded using 20X hand magnifying lens at 3, 5 and 7 days post treatment. Corrected Abbott's formula was used to correct for control mortality (Abbott, 1925) before subjecting mortality data for analysis of variance.



Entomopathogenic virulence screening method against whitefly nymphs- New modified polyhouse bioassay method

Coimbatore

Optimization of critical medium component for enhanced efficacy of Entomopathogenic fungi

Seven carbon sources at two doses, four surfactants, three salts and four pH were tested to optimize critical medium component for maximum biomass, lipase and metabolite production by three entomopathogenic fungi *viz., Lecanicillium lecanii, Metarhizium anisopliae* and *Aspergillus fumigatus*. Maximum biomass and lipase production in *A. fumigatus* was observed at Coconut oil (2%), Tween 80, $FeSO_4$ and at pH 7.0. Maximum biomass and metabolite production of *L. lecanii* was recorded in media containing Castor oil (2%) as carbon source and Tween 80, $FeSO_4$ and at pH-7.0 whereas Coconut oil (2%), Tween 80, $MgSO_4$ and at pH-7.0 supported maximum biomass and metabolite production by *M. anisopliae*. Crude metabolites produced by *L. lecanii* and *M. anisopliae* were screened for their insecticidal activity against Aphids under laboratory condition. Both were found to be effective and caused 100 per cent mortality at higher concentration. Crude metabolites of *Paecilomyces lilacinus* were screened for nematicidal activity against reniform nematode under *in vitro* condition. Nematode mortality was found to increase with increase in concentration of metabolite. Ovicidal activity of metabolite was also observed.

Screening for biotic stress tolerance

Among the 53 genotypes tested for leafhopper resistance, 22 genotypes recorded Jassid Injury Grade of <1 under field conditions. Nymphal emergence studies conducted under laboratory conditions also confirmed the field observations and minimum number of nymphs (1.5 No./3 leaves) that emerged from the above genotypes indicated the level of leafhopper tolerance.