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ICAR-CENTRAL INSTITUTE FOR COTTON RESEARCH
NAGPUR

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ANNUAL REPORT

2019

भा.कृ.अनु.प.–केन्द्रीय कपास अनुसंधान संस्थान, नागपुर

ICAR- CENTRAL INSTITUTE FOR COTTON RESEARCH, NAGPUR

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PREFACE

Cotton, popularly referred as `white gold', is an economically important natural fibre crop of India. For the past eight years, decline in cotton production and productivity has been observed on account of biotic and abiotic stresses. In 2015-16, cotton growing states of North-India faced an epidemic of whitefly and subsequently, during the period from 2016 to 2018, cotton growing states of Central and South Indian faced challenge of pink bollworm due to breakdown of resistance of BG II cotton. During 2018-19, in the beginning of crop season, the crop was exceptionally good and farmers were expecting bumper yield. However, the terminal moisture stress at critical stage of boll development from mid-October onwards resulted in drastic reduction in production to recent lowest of 33.7 m. bales from an area of 12.6 m. hectares. During 2019-20, the area under cotton was almost static (12.584 m.ha.).

This year, several significant events were organized by the Institute. The foremost important event being a `Brainstorming on Relevance of Cotton Breeding by Public Sector in India' under the Chairmanship of Dr. Trilochan Mohapatra, Hon'ble Secretary (DARE) & Director General (ICAR) on April 3, 2019. The Chairman reemphasized the relevance and role of public institutions and urged to strengthen public-private partnership with more focus on reciprocal sharing of genetic resources, understanding each other's capabilities and strengths collectively so as to break yield plateau and enhance cotton production. On this occasion, the ICAR-CICR Cotton App was launched by the Hon'ble Director General which is serving as a platform to disseminate cotton production and protection technologies. The final report of Quinquennial Review Team of the Institute and ICAR-AICRP on Cotton was also submitted by Dr. S.A.Nimbalkar, Chairman (QRT) to the Hon'ble Director General.

A collaboration between ICAR & CSIR was launched in a joint meeting on `Next Generation Insect Resistance in Cotton' under the chairmanship of Hon'ble Director General, ICAR. This joint collaboration paved way for evaluation of indigenously developed transgenic events (CSIR-NBRI), evaluation of pheromone technology (CSIR-IICT) and initiatives on refinement of cotton picker (CSIR-CMERI). As a follow-up of Cotton Brainstorming, the Institute-Industry Interface Meeting was held under the chairmanship of Dr. A.K. Singh, Hon'ble DDG (CS) seeking broad collaboration in development of parental / inbred lines, widening of genetic base of cotton through pre-breeding and sharing of germplasm / segregating genetic material and quality seed production of public sector varieties / hybrids. An Institute-Industry Interface Germplasm Field Day was also organized to showcase the genetic resources available with the Institute and across the ICAR-AICRP on Cotton centres.

The Institute has made several noteworthy achievements which includes identification of *G. arboreum variety CNA 1028 (Ravi)* for commercial cultivation in rainfed conditions of central zone; a long staple *G. hirsutum* genotype CCH 14-1 (Sunantha) for irrigated conditions of South zone; two medium staple Bt varieties viz. ICAR-CICR 16 Bt and ICAR-CICR 23 Bt for irrigated conditions of central zone and rainfed conditions of south zone, respectively. Two entries viz. CNA 1032 and CCB 51 were promoted to agronomy trial and several cultures are under evaluation across different ICAR-AICRP trials. Cotton production technologies for shallow calcareous soils were validated and demonstrated on farmers fields. Under rainfed conditions, short duration Black gram, Green gram and Soybean were found promising for intercropping. Individual and combined traps with separate or combined lures were found to be more effective than the mixed lures for management of lepidopteran pests. Degree-day based phenology models for predicting the developmental events of pink bollworm was developed which would be handy to predict adult moth

emergence, oviposition and egg hatch, thus in undertaking timely management strategies.

In continuation to the previous year, outreach activities of the Institute further strengthened. '*Mera Gaon Mera Gaurav*' (MGMG), Tribal Sub Plan (TSP), Scheduled Caste Sub-Plan (SCSP) and IRM Pink Bollworm Management Project sponsored by GEAC under National Food Security Mission – Commercial Crops (NFSM-CC) were vigorously implemented by the Institute. *ICAR*-CICR has carried out monitoring of pink bollworm throughout the crop season across all cotton growing states and has through its intense awareness, farmers training activities and dissemination of weekly advisories made its presence felt in the cotton farming community. Under e-Kapas, 68,92,298 voice messages were uploaded.

This season witnessed commercial cultivation of straight Bt varieties developed by the Institute on farmers' fields. A beginning has also been made for collaborative seed production and marketing of Institute's Bt varieties through MSSC, Akola. Linkages were fostered with sister ICAR institutes, SAUs, other public sector institutions, private seed companies, NGOs and farmers to commercialize and upscale varieties and technologies developed by the Institute. Seven MoUs were inked during April to December 2019.

Research apart, progress in implementation of the Official Language (Hindi) has made ICAR-CICR proud by bagging the ICAR's prestigious "Rajarshi Tandon Rajbhasha Puraskar 2018-19" (First) for the best Official language implementation in 'B' Region for successive year. Exemplary skills were shown by the Institute's staff in ICAR Western Zone Tournament-2019 held at Avikanagar and bagged 5 Gold, 1 Silver and 4 Bronze Medals in Athletics.

I owe my gratitude to Dr Trilochan Mohapatra, Hon'ble Secretary, DARE & Director General, ICAR for his constant encouragement and guidance in organizing Brainstorming Session on Cotton Breeding, Joint ICAR-CSIR Collaboration and Institute-Industry Interface which is making a big headway in bringing the Institute to visibility. I am grateful to Dr. A.K. Singh, Hon'ble DDG (CS) and Dr R.K. Singh, ADG (CC) for their constant encouragement, guidance and support throughout. Contribution of Dr A.H. Prakash, PC and Head I/c, Regional Station, Coimbatore; Dr. D. Monga, Head, Regional Station, Sirsa; I/c Heads of Divisions - Dr Blaise D'souza, Dr (Mrs) Sandhya Kranthi, Dr Nandini Gokte Narkhedkar and Dr. S.M.Wasnik, I/c (KVK) in the execution of research programmes and outreach activities is gratefully acknowledged. Dr M.V. Venugopalan, Principal Scientist & I/c PME Cell has immensely contributed in making of this report and needs special acknowledgement. Thanks are also due to the Editorial Committee members for their sincere and dedicated efforts in bringing out this Annual Report-2019. Mrs. Rama Iyer, Sh. Sameer Chalkhure and Dr. Jimmy Vaidya deserve special appreciation for their strenuous effort and commitment in bringing out this Annual Report to a beautiful shape.

(V. N. Waghmare)
Director

CONTENTS

1. EXECUTIVE SUMMARY

CROP IMPROVEMENT

- A *G. arboreum* genotype 'CNA 1028 (Ravi)' was identified for release and commercial cultivation in rainfed conditions of central zone. A long staple *G. hirsutum* genotype 'CCH 14-1 (Sunantha)' was identified for release for irrigated conditions of south zone. Two medium staple Bt genotypes *viz.,* 'ICAR-CICR 16 Bt' and 'ICAR-CICR 23 Bt' were identified for cultivation under irrigated conditions of central zone and rainfed conditions of south zone, respectively.
- Two entries *viz., G. arboreum* genotype CNA1032 (rainfed conditions of central zone) and *G. barbadense* genotype CCB51 (irrigated conditions of south zone) were promoted to agronomy trial.
- Seventeen non-Bt entries were promoted in different trials of ICAR-AICRP on Cotton while, 16 entries were retained in their respective trial for further evaluation.
- Seven Bt entries (CICR 17 Bt in North Zone; CICR 20 Bt, CICR 21Bt, CICR 22 Bt in Central Zone; CICR 24 Bt, CICR 25 Bt, CICR 26 Bt in South Zone) were promoted and three entries were retained for evaluation in Bt varietal trial of ICAR-AICRP on Cotton.
- Breeder seed (207.7kg) of ICAR-CICR released non-Bt varieties [Suraj, Surabhi, LRA 5166, LRK 516, CNA 1003 (Roja)] was produced. TFL seed (20.5q) of ICAR-CICR Bt varieties (Suraj Bt, PKV Rajat Bt, PKV 081 Bt and GJHV 374 Bt) was also produced during the year.
- Exotic accessions (674) were procured and the National Cotton Gene Bank was enriched to 12,335 accessions covering all the cultivated and wild species of *Gossypium* including perennials, landraces and inter-specific derivatives. A total of 3830 germplasm lines of base collection were evaluated and multiplied and 39 germplasm accessions were distributed.
- A new wild species, *G. nelsonii* Fryx was procured from MPKV, Rahuri to enrich the existing wild species collections (24 wild species of *Gossypium*) of ICAR-CICR, Nagpur.
- In order to develop a mini-core, 780 geographically and genetically diverse upland cotton accessions of core collections were phenotyped for DUS traits and genotyped using 52 polymorphic SSR markers.
- The field trial of five RIL mapping populations (two inter-specific populations of *G. arboreum* × *G.hirsutum*, two intra-*hirsutum* and one inter-specific *G. hirsutum* × *G. barbadense* was conducted at ICAR-CICR, Nagpur to phenotype and to develop consensus genetic linkage map of *Gossypium*.
- Fourteen cultures of spinnable *G. arboreum*, 14 high yielding *G. arboreum* genotypes, 4 GMS based *G. arboreum* hybrids were evaluated for traits of economic importance. Twenty two GMS lines were maintained through sib-mating and 18 were submitted to ICAR-NBPGR, New Delhi for long term storage.
- A total of 208 *G. hirsutum* entries were evaluated in eight different trials and promising entries (CNH 1196, CNH 5816, CNH 1246, CNH 2215, CNH 7615, CNH 1015, CNH 6215, CNH 1806, CNH 2616 and CNH 5916) were identified for plant type, boll weight and earliness.
- Six genotypes with comparatively higher colour strength were identified upon lint analysis of 16 naturally brown colour cotton genotypes. Crosses were attempted between cleistogamous MSH-345 and dark brown linted genotype Vaidehi-95 to introduce cleistogamy trait in colour cotton.
- Fifty *G. barbadense* genotypes were evaluated and the identified promising lines for early maturity (CCB 11A), leaf trichome density (ICB 124), gossypol gland density (ICB 46) and epicuticular wax (CCB 25) were utilized in hybridization programme for development of superior *G. hirsutum* × *G. barbadense* hybrids.
- Bio-efficacy of different non-deregulated transgenic events *viz.,* Tg2E13 (*cry1Ac*), UASD78 (*cry1Ac*), CH12 (*cry2Ax1*) was confirmed against American bollworm. Zygosity PCR for Tg2E-13 event was standardized and plants homozygous for Tg2E13 event in BC_2F_2 population of three crosses *viz.,* Suraj × Coker 310 (Tg2E13), NH615 × Coker 310 (Tg2E13) and CISH 3178 × Coker 310 (Tg2E13) were identified for further evaluation and multiplication. Third backcrossing (BC_3) was attempted for introgression of CH12 event and event UASD No. 78 was characterized.
- *Agro-bacterium* mediated transformation of

CICRcry2Ab1Ac::chitinase in *G.hirsutum* Cv. Coker 312 followed by subculture on kanamycin (25mg/L) selection medium resulted in regeneration of 41 putative t

- Three CRISPR/Cas9 gene targeting constructs for the targeted mutagenesis of *GhPHYA1 viz.,* sgRNA1 *GhPHYA1*::CRISPR/Cas9, sgRNA2 *GhPHYA1*:: CRISPR/Cas9 and sgRNA3 *GhPHYA1*:: CRISPR/ Cas9 were generated.
- To elucidate the potential role of Wnt3A like gene in embryogenesis, *Agrobacterium tumefaciens* mediated transformation of pBI121::*Wnt* 3A::*UidA* gene construct in *G. hirsutum* Cv. Suraj was attempted and putative transgenic callus cultures were confirmed for β-glucuronidase activity.
- Freshly harvested seeds were evaluated for storability in different packaging materials and storage conditions. Storing seeds under cold conditions in vacuum containers and modified Argon gas revealed better seed germination.

CROP PRODUCTION

- Field trials at institute as well as in the farmer's field proved that fertilizer recommendation based on Nutrient Expert system was superior in enhancing seed cotton yield as compared to other fertilizer management systems. The Nutrient Expert recorded a seed cotton yield of 3149 kg ha^{-1} (32% increase as compared to farmer practice).
- There found to be no added advantage with application of Sulphate of Potash (SOP) based complex fertilizer over the Muriate of Potash (MOP) based complex fertilizer
- Based on legume compatibility under rainfed conditions, short duration Blackgram, Greengram and Soybean in the ratio of 1:1 cotton intercropping systems were found to perform better even under erratic rainfall conditions. *Desmanthus virgatus* was most amenable for 4:2 cotton intercropping systems under irrigated conditions.
- The total rainfall received during cropping season (2019-20) at ICAR-CICR, Nagpur was 1240.07 mm, out of which, effective rainfall (662.8 mm) was 53.44 % and ineffective rainfall (577.27 mm) was 46.56%. Based on the ineffective rainfall calculation according to USDA Soil Conservation method and soil moisture changes, the runoff estimated during June to December was 57.72 lakh litres from one hectare area.
- Under winter irrigated conditions of Coimbatore, higher values of water use efficiency (WUE) were consistently observed across irrigations scheduled at 1.0, 0.8, 0.6 or 0.4 ETc, where the source was structured water as compared to bore well water. When irrigated at 0.8 ETc the values of WUE were 60.2 and 52.8 kgha^{-1} cm in case of structured water and bore-well water respectively.
- Radish-cotton and Pigeon pea-cotton rotations were found to give lesser inter-row soil penetration resistance as compared to deep sub soiling and shallow sub-soiling. Dhaincha and sunnhemp offered least soil penetration resistance inter-row as well as between row than soybean and sub-soiling every and alternate rows. At Coimbatore, on mixed red and black soils, compared to farmers practice, adoption of Conservation Agriculture system with 100% residue recycling significantly reduced the soil penetration resistance upto 9" soil depth.
- A total of 325 native bacterial strains were tested for their biocontrol potential against pink bollworm, American bollworm and fall army worms through replicated insect diet bioassay. The maximum larval mortality of *Pectinophora gossypiella*, *Helicoverpa armigera,* and *Spodoptera frugiperda* were recorded with the bacterial strains 188 (94%), 219 (85%) and 304 (91%) respectively.
- Among the four cotton spp., *G. arboreum*: (Phule Dhanwantary and PA 255) had more oxalate oxidase enzyme expression. Water stressed leaf samples were observed to possess more oxalate oxidase activity than control. Overall, expression of oxalate oxidase in cotton leaves at gene and protein level confirms the existence of "Alarm photosynthesis" pathway in cotton.
- Tissue specific expression of *ACS* (1-aminocyclopropane-1-carboxylic acid synthase) and *ACO* (1-aminocyclopropane-1-carboxylic acid oxidase) in six medium long to long-linted *Gossypium arboreum* L. genotypes showed their higher expression in ovules as compared to subtending leaves and bolls. Temporal expression analysis of the same revealed their involvement in early fiber elongation stage. A positive correlation was established between the amount of ethylene and fiber length of respective genotypes. Further, role of two candidate genes; *BONZAI* and *PEX1* involved in H_2O_2 and other ROS homeostasis during fibre development was confirmed and re-validated in *G. arboreum.*

- Epigenetic regulating chemicals contributed to drought tolerance in cotton plants, and the effect was inherited till the third generation of seed treated plants. 5 Azacytidine (40 µM) and Epigallocatechin gallate (100 µM) improved the SPAD values, Peroxidase activity, Epicuticular wax content, Proline and relative water contents, while decreased the excised leaf water loss in first generation plants of Suraj and LRA 5166 subjected to drought stress, the stress memory of which was inherited till the third generation. In addition, LRA 5166 plants treated with 5 Azacytidine 10 µM and 40 µM exhibited early flowering (6-7 days) in all three replications, however, it was not evident in Suraj.
- Under e-Communication programme, cotton production technologies were disseminated among farmers through voice message services covering 1.5 lakh farmers of Nagpur, Coimbatore and Sirsa regions. During the reporting period 58,81,315; 3,14,035 and 10773 noise-free voice messages were uploaded from Nagpur, Coimbatore and Sirsa centres, respectively.
- The study on impact of Institutional Credit on Cotton Farming in Maharashtra indicated that the mean of Technical Efficiency at 0.60 for the credit using farmers as against 0.57 for their non-credit using counterparts. Further, agriculture credit itself cannot play any direct role in enhancing the output, rather it indirectly helps through facilitating the purchase of various modern inputs.
- The seed cotton yield of Bt cotton hybrid was significantly superior over SCY of both Bt as well as non-Bt cotton varieties under irrigated cotton-wheat cropping system at Sirsa, but was at par with SCY under non-Bt cotton hybrid-wheat cropping system. Significantly higher SCY was observed with application of NPK (RDF) + Secondary nutrients ($MgSO_4$) + Micro nutrients ($ZnSO_4$ + Borax) + FYM (5 t/ha) once in two years.
- Early sowing of Bt cotton variety (CICR Bt-6) at Sirsa with a plant spacing at 67.5 cm x 45 cm significantly improved the seed cotton yield. Application of Mepiquat chloride 20g a.i./ha at 60 and 75 DAS significantly improved the seed cotton yield.
- The seed cotton yield was significantly higher under Zero tillage - permanent narrow raised bed with residue retention on surface. Amongst the cropping systems, the significantly higher values of seed cotton yield were recorded under Cotton - Chickpea as compared to all other cropping systems.

CROP PROTECTION

- Field efficacy of sex pheromones as individual lures, combinations and as mixtures were tested against the major lepidopterous bollworms and leaf worms of cotton. Trap catch of *Pectinophora gossypiella* and *Spodoptera litura* was found to be at par in Individual traps, combined traps & combined lure, while in the mixed lure experiment a reduction in trap catch was noticed.
- Chemical profiling of ethyl acetate fractions of a new wax degrading fungus, *Aspergillus fumigatus* isolated from striped mealybug, *Ferritia virgata* yielded alkaloids as major component which included 5-Chlorobenzimidazole-2-carboxylic acid (7.06 %), 1,4-Diaza-2, 5-dioxo-3-isobutyl bicyclo [4.3.0] nonane (18.97%), 3,6-Bis (2-methylpropyl) piperazine-2,5-dione (7.13%) and 3-Benzylhexahydropyrrolo [1,2-a]pyrazine-1,4-dione (9.94%).
- The genotype BB-6-1-2 was found to be resistant against Reniform nematode, *Rotylenculus reniformis* among the 29 genotypes of *G. hirsutum* screened.
- Out of nine insecticides tested, cotton leafhopper *A. biguttula biguttula* was most susceptible to thiamethoxam. The level of detoxification enzymes *viz.*, esterase and mixed function oxidases were higher in insecticide exposed leafhoppers.
- Cotton intercropped with marigold recorded lowest population of thrips. Insecticide spinetoram followed by fipronil recorded highest efficacy against thrips.
- A retrospective study on weather parameters triggering whitefly infestation using ICAR-AICRP on Cotton data for the past 15 years for three North Zone locations showed that maximum temperature had more influence in decreasing whitefly infestation while minimum temperature influenced in increasing whitefly infestation. Other weather parameters did not show any pattern or consistency over the years.
- The label claimed insecticides screened under laboratory conditions against leafhopper recorded mortality ranging from 26.67 to 72 percent. The maximum mortality (%) was observed in flonicamid (72), followed by dinotefuran (70), thiacloprid (57.33), acephate (55.33) and imidacloprid (56.67).
- The per cent infestation of pink bollworm in Flowers of BG-II cotton at 60-70 days after sowing was observed at 0 to 22.6% in all cotton growing districts of Maharashtra. Per cent infestation in green bolls at 160-165 days after sowing was observed at 0 to82%.

- Infestation of pink bollworm on BG II cotton in Gujarat was in range of 0 to 8.00 per cent at 80-90 DAS.
- Pink bollworm infestation in North India (Punjab, Haryana and Rajasthan) at 140-150 DAS was recorded nil on BG-II hybrids except in Jind district of Haryana and Bhatinda district of Punjab with 6.90 % and 1.00% of incidence respectively. At 180 DAS PBW incidence at 69.60 % and 28.00 % was observed in Jind district of Haryana and Bhatinda district of Punjab respectively.
- PBW larvae resistant to Cry2Ab toxins have higher alkaline phosphatase activity than the susceptible population collected from infested non-*Bt* cotton bolls.
- *Burkholderia* strains were recorded as endosymbionts in pink bollworm larvae collected from different locations. Other bacteria recorded were *Pluralibacter gergoviae*, *Enterobacter sp.*and *Citrobacter youngae* .
- Laboratory evaluation of six vegetable oils (groundnut, sunflower, safflower, soybean, sesame and ricebran) showed promising results as oviposition deterrant for pink bollworm with respect to avoidance index (Ai) and percent effective deterrence (PED).
- The major putative attractants for pink bollworm identified from squares and bolls were α/β pinene, carene, γ terpinene, α copaene, caryophyllene and humulene.
- Degree-day based phenology model for predicting the developmental events of cotton pink bollworm *Pectinophora gossypiella* in field was developed. Validation of model provided closer estimates across the tested locations.
- The Bio module-1 (2 sprays each of neem+*Isaria javanica* CICR-RSS -0102) followed by existing IPM module (2 sprays each of neem+ flonicamid + spiromecifen), IPM module-3 (2 spray of neem+ Flonicamid @ 1 ml/L + *Metarhizium anisopliae*-1299) and Bio module-2 (2 sprays each of neem+ *Beauveria bassiana*-4511 showed higher nymphal mortality of whitefly than untreated control and other modules.
- PGPR *Bacillus aryabhattai* (CICR-D5) + *B. tequilensis* (CICR-H3) combination followed by strains *B. tequilensis* (CICR-II3) and *B. aryabhattai* (CICR-D5) singly were found most effective against seed and soil borne fungal pathogens (*Macrophomina phaseolina*, *Rhizoctonia solani* and *Fusarium oxysporum* f.sp. *vasinfectum*) and leaf spot diseases of upland cotton Cv. Suraj.
- Cotton endophyte *Nigrospora sphaerica* (CEL 19) effective against *Fusarium solani* and *Corynespora cassiicola* was recorded to produce antimicrobial VOCs namely 1, 3-diethyl benzene, 1, 4-diethyl benzene, cymene-7-ol and m-ethylacetophenone .
- Sap transmission studies with *Tobacco streak virus* showed transmission as evidenced by development of symptoms in greengram, black gram, *Chenopodium amaranticolor, C.quinoa, Nicotiana rustica and N. tabacum* and soybean.

General

- During the period 38 research papers and 37 popular articles were published; 16 training programmes were organized in which 1660 farmers and extension functionaries participated.
- Linkages were fostered with sister ICAR institutes, SAUs, other public sector institutes, private companies, NGO's and farmer producer groups to commercialize and upscale varieties and technologies developed. Seven MoUs were linked during April to December, 2019.

2. INTRODUCTION

2.1 : Brief History

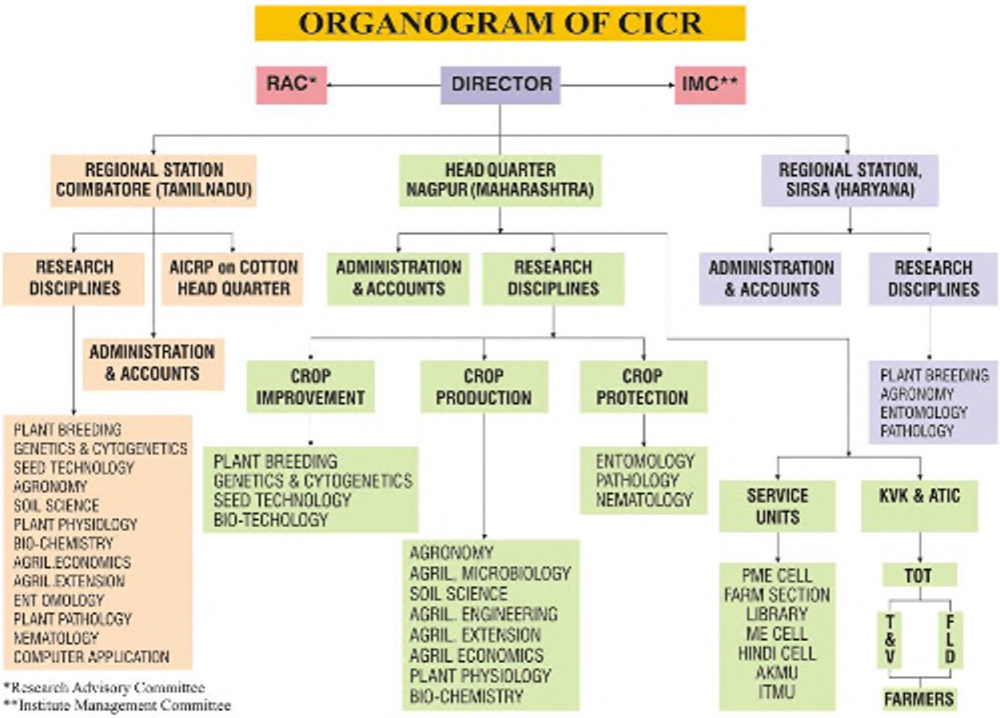
The ICAR-Central Institute for Cotton Research was established at Nagpur, in 1976. The two regional stations of IARI at Sirsa (Haryana) and Coimbatore (Tamil Nadu) were transferred to CICR to cater to the needs of north and south India, respectively.

Location of the of ICAR-CICR Institute

Center	Latitude	Longitude
ICAR-CICR, Head Quarters, Nagpur, Maharashtra	21.037	79.056
ICAR-CICR, Regional Station, Coimbatore, Tamil Nadu	11.014	76.929
ICAR-CICR, Reg ional Station, Sirsa, Haryana	29.543	75.038

2.2 : Mandate

- Basic, strategic and adaptive research on production, protection, fibre quality and by-products of cotton
- Creation of new genetic variability for location-specific adoption in cotton-based cropping systems.
- Coordination and monitoring of applied research on national and regional issues to develop improved varieties and technologies
- Dissemination of technologies and capacity building



2.3 : Staff Position (as on 31st December, 2019)

Name of the Post	Sanctioned Cadre Strength				Post Filled Up			
	NGP	CBE	Sirsa	Total	NGP	CBE	Sirsa	Total
Director (RMP)	1	--	--	**1**	--	--	--	**--**
Scientific	49	22	6	**77**	42	22	6	**70**
Technical	46	16	10	**72**	37	15	9	**61**
Administrative	34	9	5	**48**	20	5	5	**30**
Skilled Support Staff	23	12	9	**44**	23	12	9	**44**
Krishi Vigyan Kendra								
Training Organizer	1	--	--	1	--	--	--	--
Technical	11	--	--	11	9	--	--	9
Administrative	2	--	--	2	1	--	--	1
Skilled Support Staff	2	--	--	2	2	--	--	2

NGP – Nagpur; CBE - Coimbatore

2.4 : Financial Statement

The budget grant and actual expenditure for the year 2019 are furnished below:

(Rs. in Lakhs)

Name of Scheme	2018-19	
	Sanction	Expenditure
Plan Scheme	1505.05	1479.57
Deposit Scheme	2631.51	2284.92
Revolving Fund	21.96	8.06
Govt. Grants (Non-Plan & Plan merged from 2017-18)	3785.08	3608.77
Total (in lakhs)	**7943.6**	**7381.32**
Revenue Generation (Revenue Receipts)	40.52	37.94

3. RESEARCH ACHIEVEMENTS

3.1 Consolidation and characterization of genetic diversity

Cotton germplasm resources

ICAR-CICR, Nagpur maintains one of the largest cotton germplasm collections of the world with 12,335 accessions covering all the cultivated and wild species of *Gossypium* including perennials, landraces and interspecific derivatives (Table 3.1.1).

Species	Base Collection
G. hirsutum	8851
G. barbadense	536
G. arboreum	2053
G. herbaceum	565
Wild species	24
Inter-specific derivatives	40
Perennials and land races	254
Races and derivatives of all 4 species	12
Total Collection	**12335**

Table 3.1.1: Germplasm collections at ICAR-CICR, Nagpur

Quarantine evaluation of imported accessions:

Six hundred seventy-four (674) exotic accessions (346 *G. hirsutum*, 211*G. barbadense* and 117 G. *arboreum*) were procured from USA and evaluated in glass house for quarantine pest, *Xanthomonas campestris* var. *malvacearum*.

Maintenance and evaluation of germplasm:

***G. hirsutum*:** Seeds of 56 exotic accessions and 36 Coker lines including two CLCuD resistant accessions were multiplied. Eight exotic varieties of *G. hirsutum* were evaluated for yield and fibre quality traits.

***G. barbadense*:** Three hundred and twenty-seven (327) accessions and eleven new germplasm lines are being maintained at ICAR-CICR Regional Station, Coimbatore. Eighty-nine accessions have been deposited in MTS at ICAR-CICR, Nagpur.

***G. herbaceum*:** Seeds of 66 accessions received from ICAR-NBPGR, New Delhi are being multiplied and characterized at Main Cotton Research Station (NAU), Surat.

A total of 3830 base collection comprising of 3602 accessions of *G. hirsutum*, registered lines (49), exotic varieties (08), ICAR-NBPGR accessions (67-*G. hirsutum and* 69- *G. arboreum*), West Bengal Culture (32- *G.hirsutum*), and colour cotton accessions (03-*G. arboreum*) were multiplied and evaluated.

In order to develop a mini-core, seeds of 780 geographically and genetically diverse upland cotton accessions of core collections were multiplied and characterized for DUS traits. They were also profiled to assess the DNA polymorphisms using 52 polymorphic SSR markers.

Distribution of cotton germplasm: Thirty-nine (39) germplasm accessions consisting of *G. hirsutum, G. arboreum* and wild species were distributed to breeders/scientists of ICAR-CICR, State Agricultural Universities (SAUs) and private seed companies for utilization.

Exploration of wild species for cotton improvement

Seeds and cuttings of *G. anomalum, G. triphyllum, G. capitis viridis, G. thuberi, G. armourianum, G. davidsonii, G. raimondii, G. trilobum, G. stocksii, G. somalense, G. longicalyx, G.nelsonii* Fryx, and *G. barbasonum* from MPKV, Rahuri were collected. Seeds of *G. nelsonii* Fryx were germinated in MS media in the tissue culture laboratory, hardened and established in a pot while, the cuttings of *G. somalense, G. raimondii* and *G. barbosanum* have been established in pots.

***G. nelsonii* grown on MS medium, hardened in a paper cup and transplanted in pot**

***G. somalense* and *G. raimondii* cuttings from MPKV, Rahuri established in pots**

Six BC_3F_1 cuttings of *G. hirsutum* × *G armourianum* have been established in pots. Progenies of crosses between *G. arboreum* × *G. longicalyx, G. arboreum* race indicum × *G. davidsonii, G. arboreum* × *G. thurberi* and

G. arboreum Cv. AKA 8401 x *G. davidsonii* were advanced from F_4 to F_5 generation. New crosses were attempted using wild species namely *G. australe, G. thurberi, G. raimondii, G. barbosanum, G. anomalum, G. capitis virides, G. triphyllum, G. klotzchianum, G. longicalyx, G. somalense* and *G. mexicanum.*

3.2 Breeding for premium fibre quality and high yield

Genetic improvement of *G. herbaceum*

Nagpur

The F_2 population of five inter-specific crosses *viz.*, IC–371437 × PA-785, Jayadhar × PA-785, Baluchistan-2 × PA-785, IC-371560 × PA-785, IC-371437 × PA-812 and their reciprocals were evaluated. F_4 population of six intra specific crosses (IC-371587×Baluchistan-2, IC-371437×IC-371602, IC-371437×IC-371560, IC-371602×C-371560, Jayadhar×GVHV-655, IC-371136×IC-371437) and five back cross (BC_2) population of inter-specific crosses along with parents were also evaluated.

Genetic improvement of *G. arboreum*

Nagpur

For improvement of fibre quality traits of *G. arboreum*, backcrossing and generation advancement were done for crosses involving long linted genotypes *viz.*, PA255, PA812, PA740, PA785 and KWAN3. Based on morphological and fibre quality trait data, superior progenies were identified and utilized in the backcrossing (BC_3F_1 and BC_2F_2) and generation advancement programme (F_4) (Table 3.2.1.)

Table 3.2.1. Range for fibre quality traits in advance selections of *G. arboreum*

Particulars	Range in *G. arboreum* selections
Fibre length (mm)	16.2-29.5
Fibre strength (g/tex)	21.5-33.1
Micronaire value (µg/in)	4.4-6.8
Uniformity Index (%)	70-81

Promising single plant selections and progenies of *G. arboreum*

Evaluation of introgressed derivatives

500 introgressed derivatives (*G. arboreum* and *G. hirsutum*) were evaluated for fibre and economic traits. Seeds of lines with unique traits and identified high strength introgressed lines *viz.,* CICR 16301 (DB), CICR 16315 (LB), CICR 16337 (LB), CICR 16377 (LB-A) and CICR 16378 (LB-A) sponsored for testing under AICRP on Cotton were multiplied.

Coimbatore

G. arboreum accessions screened for high yield and early maturity were selected for producing F_1's in diallel fashion. The crosses and their parents were evaluated for specific combining ability (SCA) effects and standard heterosis (SH) along with *per se* performance. Seven F_2 populations with white lint *viz.*, AC 3265× PBS1127–SP1, AKA 496 × H 509, AKA 496×AC 3097, PBS 1127-SP1×N 11-54-31-32, AC 3216×AKA 13-SP1, H 503×N 11-54-31-32, H 509×AKA 13-SP1 were selected. A set of 12 F_2 brown linted (coloured) progenies are being evaluated (indicum 12-Sp1×H 480, NA 48×H 483, AC 514×AC 3066, AC 514×Desi 56, H 480× indicum 12-SP1, 30814×AC 3066, 1422×indicum 12-SP1, H 492×30839, Desi 77×Arboreum 12, indicum 12-SP1×H 502, Desi 56×indicum 12-SP, G 725-SP1× indicum 12).

F_2 population of cross from AC 3216 × AKA 13-SP1

F_2 population of cross Desi 56 × indicum 12-SP (brown linted)

Sirsa

Evaluation of spinnable *G. arboreum* cultures: Fourteen cultures were tested in RBD along with two checks CISA 614 (3070 kg/ha) and PA255 (2577 kg/ha). None of the genotypes showed significantly higher yield than the high yielding check (CISA-614). However, two genotypes namely, CISA 6-350 (3171 kg/ha) and CISA 6-295 (3217 kg/ha) recorded numerically higher seed cotton yield than the high yielding check (CISA-614). Three genotypes, namely, CISA 6-350 (3172 kg/ha), CISA 6-295 (3217 kg/ha) and CISA 33-1 (2988 kg/ha) recorded significantly higher yield than the quality check, PA-255 (2577 kg/ha). Genotype CISA 6-295 recorded fiber length of 25.8mm on par to PA 255 (25.5mm) and is also numerically superior to higher yielding check CISA-614. Genotypes CISA-6-350 and CISA-6-295 recorded more than 30q/ha of seed cotton yield and have promise for spinning. Three genotypes CISA-6-295, CISA-33-4 and CISA 33-8 were having UHML >25.0mm and strength >25.0 g/tex in HVI mode during 2019-20.

Evaluation of high yielding *G. arboreum* genotypes: Fourteen genotypes were evaluated in RBD design with two check varieties CISA 614 and CISA 310. Four genotypes CISA 405 (3739 kg/ha), CISA 9 (3531 kg/ha), CISA 294 (3638 kg/ha) and CISA 33-5 (3617 kg/ha) gave significantly higher seed cotton yield than both the check varieties CISA 614 (3102 kg/ha) and CISA 310 (2461 kg/ha).

Evaluation of GMS based *G. arboreum* hybrids: Four GMS based hybrids were evaluated for seed cotton yield with two check hybrids AAH1 and CICR2. Two hybrids CISAA19-1 (3449 kg/ha) and CISAA19-3 (3498 kg/ha) recorded significantly higher seed cotton yield than the highest yielding check hybrid CICR 2 (3106 kg/ha). Fiber quality of CISAA19-1 parameters were also superior (UHML-27.6 mm, strength-27.9 g/tex, mic-5.4 µg/in) to check hybrid (UHML- 21.1 mm, strength-22.3 g/tex, mic-6.3 µg/in). One GMS based hybrid namely CISAA19-2 (3348 kg/ha) recorded numerically higher seed cotton yield than highest yielding check hybrid CICR2.

Maintenance of GMS lines: Four GMS lines (DS5, CISA 2, GAK 413A, CISG-20) and 18 newly identified GMS lines, (CISG-1, CISG-2, CISG-4, CISG-8, CISG-9, CISG-10, CISG-11, CISG-13, CISG-14, CISG-15, CISG-16, CISG-17, CISG-18 (narrow leaf), CISG-18 (broad leaf), CISG-19, CISG-21, CISG-22 (narrow leaf) and CISG-22 (broad leaf)) were maintained through sib-mating. GMS lines CISG 8, CISG-9, CISG-10, CISG-13 and CISG-14 posses red flower colour. The proposal for registration of CISG 20 has been submitted to ICAR-NBPGR, New Delhi.

Genetic improvement of *G. hirsutum*

Nagpur

A total of 440, 850 and 260 single plant selection progenies belonging to F_6, F_5 and F_4 generations respectively are being evaluated. Single plants were selected based on quality traits, early maturity (140-150 days), compact plant type and tolerance to jassids. Eight trials comprising 208 entries were evaluated for seed cotton yield and fibre properties. Promising entries (CNH 1196, CNH 5816, CNH 5916, CNH 1246, CNH 2215, CNH 7615, CNH 1015, CNH 6215, CNH 1806, CNH 2616 and CNH 5916) were identified based on plant type, boll weight and earliness.

From interspecific crosses of *G. hirsutum* × *G. barbadense*, promising introgressed lines were developed using backcrosses, three-way and double crosses. Amongst 73 introgressed lines (F_5) evaluated, CNHB34-53-1, CNHB 34-53-3, CNHB 34-53-4, CNHB 44-50-3, CNHB 44-2-1, CNHB 44-2-2 and CNHB 44-5-1 were promising for fibre length and seed cotton yield. Introgressed lines derived from backcross progenies of cross (Suraj × Suvin) × Suraj recorded significant variation for ginning outturn varying from 29.0% (CNHB 32-3) to 45.9 % (CNHB 33-7). The fibre properties of these lines CNHB 32-3 and CNHB 33-7 had upper half mean length of 28.4 and 27.6 mm and fibre strength of 27.1 and 29.1 g/tex, respectively. These lines possess longer internode distance. Amongst 56 extra long staple lines, 10 lines namely (CNH 1196, CNH 5816, CNH 5916, CNH 1246, CNH 2215, CNH 7615, CNH 1015, CNH 6215, CNH 1806, CNH 2616, CNH 5916) were promising for seed cotton yield.

Colour cotton

Lint samples of 16 naturally brown colour cotton were analyzed for colour parameters and fibre properties at ICAR-CIRCOT, Mumbai. Six samples with comparatively higher colour strength were also the darkest, with L* values (Lightness- darkness scale with 0 being most dark and 90 most light respectively) below 75. Wavelength of maximum absorption (λ_{max}) for all the samples in the visible region was 420 nm. Evaluation of colour fastness of these samples revealed no/least fading. Wash fastness was tested and it was observed that instead of fading, colour became darker after washing indicating stability of colour. Fifty colour cotton entries were evaluated for their fibre traits.

Crosses were attempted between cleistogamous MSH-345 and dark brown linted genotype Vaidehi-95 to introduce cleistogamy trait in colour cotton. Seed multiplication of dark brown linted Vaidehi-95 has been taken up in the institute as well as in Dr PDKV Akola farm under a tripartite agreement signed between ICAR-

CICR, ICAR-CIRCOT and Dr PDKV. Sixty kilograms of delinted seeds of Vaidehi-95 (MSH-53) was supplied to Dr. PDKV Akola for multiplication at Vani Rambhapur, Akola.

Seed production plot at Vani Rambhapur, Akola

Sirsa

Evaluation of advance cultures of *G. hirsutum*

Trial 1: Fourteen *G. hirsutum* cultures were evaluated against the check varieties RS 2013, LH 2076, CSH 3129 and CLCuD susceptible check F1861 in RBD with three replications. The highest seed cotton yield was recorded in the culture CSH 2902 (2103 kg/ha) followed by CSH 2924 (2096 kg/ha) as against the check variety LH 2076 (1832 kg/ha). Maximum ginning outturn of 35.3 per cent was recorded in the culture CSH 2916 as compared to local check varieties CSH 3129 (34.2%) and LH 2076 (34.7%). CSH 1604 recorded fibre length of 28.8 mm whereas CSH 2931 recorded fibre strength of 33.2 g/tex. Six cultures *viz.*, CSH 2932, CSH 1601, CSH 1602, CSH 1604, CSH 1606 and CSH 1607 showed resistant reaction against CLCuD as compared to local check varieties with MS reaction.

Trial 2: Fifteen *G. hirsutum* cultures were evaluated against the check varieties RS 2013, LH 2076, CSH 3129 and CLCuD susceptible check F1861 in RBD with three replications. The culture CSH 1622, CSH 1713 and check variety CSH 3129 recorded the highest length of 29.0 mm whereas CSH 1615 recorded the strength of 31.2 g/tex. Cultures CSH 1615, CSH 1616, CSH 1711, CSH 1712, CSH 1714 and CSH 1604 showed resistant reaction against CLCuD.

Trial 3: Sixteen *G. hirsutum* cultures were evaluated against the check varieties CSH 3075 in RBD with three replications. The highest seed cotton yield was recorded in the culture CSH 49 (2399 kg/ha) followed by CSH 50 (2345 kg/ha) as against the check variety CSH 3075 (1781 kg/ha). Maximum ginning outturn of 35.0 per cent was recorded in the culture CSH 53 as compared to local check variety in CSH 3075 (32.0%). All the advance cultures except CSH 46 and check variety CSH 3075 showed resistant reaction against CLCuD.

Trial 4: Eleven compact cultures of *G. hirsutum* were evaluated against the check CSH 3129 in RBD with three replications. Highest seed cotton yield was recorded in compact culture CSH 92 (2563 kg/ha) followed by CSH 111 (2437 kg/ha) as against the check CSH 3129 (2563 kg/ha). Maximum ginning outturn of 35.3 per cent was recorded in the culture CSH 2916 as compared to local check varieties CSH 3129 (34.2%) Three cultures CSH 109, CSH 114, CSH 116 and the check variety CSH 3129 showed resistant reaction against CLCuD.

Trial 5: Eighteen *G. hirsutum* cultures were evaluated against the check variety CSH 3075 in RBD with three replications. The highest seed cotton yield was recorded in culture CSH 89 (3143 kg/ha) followed by CSH 90 (2926 kg/ha) as against the check variety CSH 3075 (2416 kg/ha). Maximum ginning outturn of 34.5 per cent was recorded in the culture CSH 95. Three cultures CSH 107, CSH 115 and CSH 117 showed resistant reaction against CLCuD.

Population improvement

Nagpur

Evaluation of single plant selection: A total of 1508 superior single plants selected from random mating population (897 of *G. arboreum* and 611 of *G. hirsutum*) were evaluated as plant to row progenies. These were monitored for segregation, if any, and also evaluated for uniformity, economic and fibre quality traits.

Evaluation of advance cultures: *G. arboreum* 111 cultures and 72 of *G. hirsutum* were evaluated in 7 replicated trials (4 rows in 2 replications). In all, 4 trials of *G. arboreum* and 3 of *G. hirsutum* were conducted following spacing of 60 x 45 cm.

Evaluation of sterile plants: A total of 3269 single sterile plants from random mating population (1244 of *G. arboreum* and 2054 of *G. hirsutum*) were evaluated as plant to row progenies to access its superiority for specific trait. All the single plant progenies were monitored for segregation and sterile and fertile plants were tagged. Fertile plants shall be evaluated for economic and quality traits to identify progenies for specific superior traits.

Sirsa

GMS based random mating population

Individual plants in the population were monitored for sterility/fertility at anthesis and sterile plants were

tagged. Out-crossed bolls from the sterile plants in the population were bulk harvested and ginned to constitute the next cycle of GMS based random mating population. After 8th cycle of random mating, 75 fertile plants having high yield potential and tolerance against CLCuV were selected for evaluation in progeny row trial.

Evaluation of advance cultures selected through random mating of *G. hirsutum*

Trial 1: 24 cultures were evaluated against the check varieties CSH 3129 and CSH 3075 in RBD with 3 replications. Highest seed cotton yield was recorded for culture CSH 70-15 (2238 kg/ha) followed by CSH 71-16 (2210 kg/ha) as against the check variety CSH 3129 (2050 kg/ha).

Trial 2: Thirty-two cultures were evaluated against the check varieties CSH 3129 and CSH 3075 in RBD with 2 replications. The highest seed cotton yield was recorded for culture CSH 223-10 (2859kg/ha) followed by CSH 99-02 (2734 kg/ha) as against the check variety CSH 3129 (2050 kg/ha).

Genetic improvement of *G. barbadense*

Coimbatore

Cleistogamy in *G. barbadense* : A stable complete cleistogamous progeny was obtained in the segregating population from an intra *barbadense* cross (Giza -45 × Suvin- 3-7-2). This cleistogamous trait is highly useful in seed production and pure line breeding. Fifty grams of cleistogamous plant seeds was sent to ICAR-CICR, Nagpur and MPKV, Rahuri for multilocation evaluation. Mass multiplication of seed was done for sending to ICAR-NBPGR, New Delhi for registration.

Seed multiplication of the promising genotypes : Seed multiplication of advance cultures for the station as well as ICAR-AICRP trials was taken up. These include advance cultures (CCB-141, CCB-142 and CCB-64b for the initial evaluation trial) and eight cultures (CCB-26, CCB-28, CCB-29, CCB-51, CCB-51-2, CCB-64, CCB-129, CCB-143B) entered in three breeding trials (Br.12a, Br13a and Br.14a) of AICRP-2019-20.

3.3. Breeding for climate resilience and biotic stress tolerance

Drought tolerance

Three sets of experiments were conducted. In the first set, advance generation of thirteen crosses were tested in replicated trial with LRA 5166, Rajat and Suraj as checks. In second set, 15 crosses in advance generation along with parents and checks were tested. The same material was tested for drought tolerance under rainfed and irrigated condition. The third set of experiment comprising of F_3 and F_4 generation of three-way and single crosses are being tested for developing compact genotypes for high density planting.

Single plant progenies (672) evaluated for seed cotton yield and fibre quality. Sixteen inter-cross lines with zero monopodia, seed cotton yield and fibre quality and 129 single plant progenies of 281 × Suvin were raised for developing genotypes with compact plant type, high yield and good fibre quality.

Single plant progenies (2972) were raised for ten parental cross for developing MAGIC RILs. Out of these, 250 MAGIC lines were subjected for proline estimation and Polyethylene glycol (PEG) treatment. The leaf discs of drought tolerant plants were subjected to stress in half MS media with different PEG concentration gradient at 0.2, 0.4, 0.6 and 0.8 MPa for 15 days which showed higher proline accumulation. Another set of 3031 single plant progenies have been raised from eight parental cross for developing MAGIC RILs. These are being evaluated for yield and other economic traits.

Breeding for early maturity, compact plant type and jassid tolerance

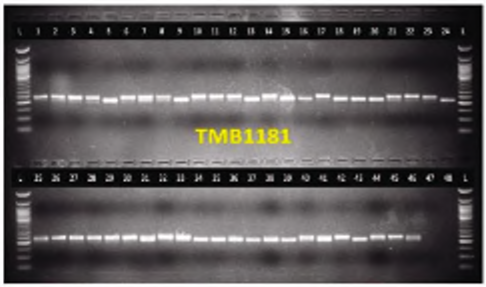
Single plant progenies and selections promising for earliness, jassid tolerance, compact plant architecture, yield and fibre quality were identified from the segregating populations (Table 3.3.1). Crop duration and plant architecture were severely impacted by the incessant rains resulting in heavy infestation of sucking pests. Taking advantage of pest pressure, material was thoroughly screened for jassid tolerance and promising lines/progenies were identified.

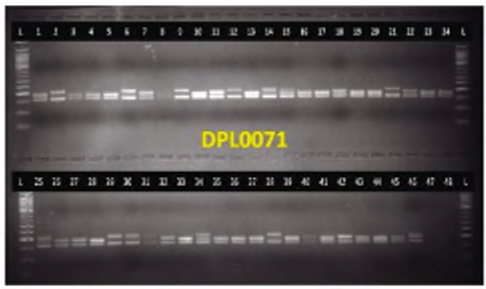
Table 3.3.1. Single Plant Selections having early maturity, jassid tolerance, compact plant architecture along with better yield and fibre quality

Single Plant Selection	Plant Height (cm)	Width at Mid height (cm)	Monopodia	Sympodia	Percent boll bursting at 150 DAS	Av. boll weight (g)	Plant yield (g)	UHML (mm)	Mic (µg/in)	Str. (g/tex)
SPS18-08	112	51	1	12	100	4.50	127	27.6	4.4	29.3
SPS18-10	98	42	0	13	100	3.83	81	28.1	3.5	27.4

Single Plant Selection	Plant Height (cm)	Width at Mid height (cm)	Monopodia	Sympodia	Percent boll bursting at 150 DAS	Av. boll weight (g)	Plant yield (g)	UHML (mm)	Mic (µg/in)	Str. (g/tex)
SPS18-11	100	38	0	16	100	3.83	120.5	27.9	4.4	29.0
SPS18-18	84	38	2	16	100	3.50	124	26.9	4.4	28.4
SPS18-25	86	37	1	18	100	2.50	96.5	28.0	4.1	29.0
SPS18-27	78	28	1	11	100	4.17	89	27.1	4.7	28.4
SPS18-32	88	38	1	14	100	3.83	97.5	26.7	4.2	27.7
SPS18-34	82	32	0	14	100	3.83	88	26.6	3.8	26.5
SPS18-35	108	52	1	12	100	4.00	106.5	26.8	4.1	27.9
SPS18-36	88	38	0	11	100	4.00	80.5	26.3	4.3	27.1
SPS18-40	84	40	0	12	100	5.17	85	26.5	4.8	27.0
SPS18-42	92	30	0	15	100	3.50	78.5	26.5	4.6	28.4

In order to assess the molecular divergence among jassid tolerant (16) and susceptible (30) entries, 50 polymorphic markers were identified and utilized for molecular characterization. Out of 50 polymorphic SSR markers screened, 18 of them have been reported to be associated with QTL for jassid tolerant traits as per the information available from Cotton QTL database (www.cottonqtldb.org)



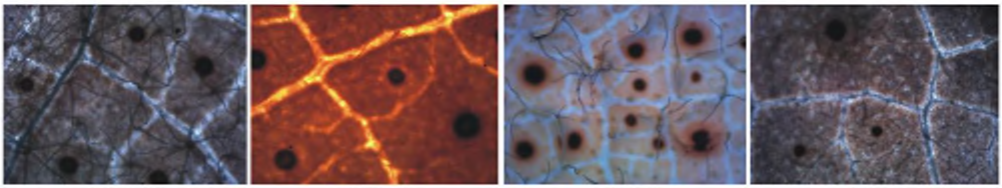


SN. Genotype	SN. Genotype	SN. Genotype	SN. Genotype	SN. Genotype	SN. Genotype
1 G-COT16	9 EC343591	17 CNH2035	25 AKH8828	33 NISC44	41 CNH2034
2 Narasimha	10 AKH081	18 RS875	26 CNHO7-34	34 N170	42 Phule688
3 RCH Non-Bt	11 EC344804(S)	19 IIS6	27 NISC-40	35 GCot12	43 NISC-43
4 CNH2026	12 CNH2025	20 SurbhiXMM2-4BK	28 NH545	36 IC359478	44 CSH3178
5 Anjali	13 SurbhiXM532-4-2	21 IC357857	29 Khandwa-2	37 IC359691	45 NH615
6 CINHTI-1	14 LRA5166	22 CNH09-7	30 Supriya	38 Sahara	46 MCU12
7 Arogya	15 F1378	23 RS2013	31 DSC99	39 Suraj	47 NTC
8 EC344092	16 CNHO12	24 Sumangala	32 KC-3	40 Sikandar Ageti	48 NTC

Molecular diversity analysis for jassid tolerance in cotton

***G. hirsutum* × *G. barbadense* hybrids**

Fifty *G. barbadense* genotypes comprising of 40 germplasms and 10 advance cultures were sown in two replications along with four *G. hirsutum* lines namely Suraj, Surabhi, MCU5 VT, CCH 15-1 during Kharif 2019. The *barbadense* lines were evaluated for various morphological characters to select diverse parents for further crossing programme. ICB 28 and CCB 141 were found to be early in flowering and boll bursting. The genotype ICB 124 had higher leaf trichome density (135 no./sq. cm), ICB 264 had maximum gossypol glands per sq. cm (126/sq.cm) and the genotype ICB 1 showed higher epicuticular wax (29.63 µg/sq.cm). The genotypes ICB 264, CCB 26 and ICB 73 showed lesser sucking pest incidence. About 28 crosses were attempted with seven *barbadense* lines namely ICB 161 (Compact type), CCB 11 A (early maturing), CCB 29 (advance culture for yield), Suvin (Quality), ICB 124 (hairs), CCB 25 (Epicuticular waxy lines), ICB 46 (high gossypol glands) with four *hirsutum* genotypes.



ICB 124 (135 trichomes/sq.cm) | **CCB 64** (10 trichomes /sq.cm) | **ICB 264** (126 gossypol glands/sq.cm) | **CCB 64** (6 gossypol glands /sq.cm

Genotypes with maximum and minimum trichome density and gossypol glands

Development of Bt cotton varieties using deregulated transgenic event (Mon531)

Nagpur

Two Bt genotypes *viz.*, ICAR-CICR 16 Bt and ICAR - CICR 23 Bt were identified for release in irrigated conditions of central zone and rainfed conditions of south zone, respectively by Variety Identification Committee, ICAR-AICRP on Cotton under the Chairmanship of Dr. A.K. Singh, DDG (Hort. & CS), ICAR.

Seven Bt entries are in second year of testing while four entries are in first year of testing in ICAR-AICRP Bt trial. Work on development of Bt hybrids was initiated and 109 Bt hybrids are being tested in institute common trial. Few hybrids were identified which showed reasonable promise during flowering and boll development stage. Promising hybrids will be carried forward for seed production and further testing in AICRP multilocation trial. New crosses were attempted between Bt varieties (Suraj Bt, Rajat Bt, PKV 081 Bt and GJHV 374 Bt) and GMS lines and introgressed derivatives for development of Bt hybrids. Promising single plant selections and progenies carrying *cry1Ac* gene (Mon531 event) were evaluated for early maturity, compact plant architecture, jassid tolerance, yield and fibre quality traits.

Coimbatore

cry1Ac positive plants in different BC_1F_1 populations (in background of Suraj, Surabhi, Supriya, Anjali, Sumangala, MCU 5-VT, LRA 5166, CCH 2623, Subiksha, Sunantha, CCH 15-1, BB 6 and BB 7) were backcrossed with recurrent parent. F_2 population from different crosses were raised, Cry1Ac positive plants were identified and selfed to produce F_3 population. H×B crosses were attempted between four Bt varieties and 7 *barbadense* lines.

Development of Bt cotton varieties using non-deregulated transgenic events

Nagpur

Effectiveness of different non-deregulated transgenic events against bollworms : Different non-deregulated transgenic events *viz.*, Tg2E13 (*cry1Ac*), UASD78 (*cry1Ac*), CH12 (*cry2Ax1*) were assessed for their bio-efficacy against pink bollworm and American bollworm along with checks BGII hybrid (*cry1Ac–cry2Ab*), Suraj Bt variety (Mon531), Non-Bt (Coker 310). For pink bollworm Tg2E13 was found to be comparable to single and dual Bt checks. The event Tg2E13 has good bio-efficacy against American bollworm as assessed in previous two years. Event UASD No. 78 and CH12 tested for their bio-efficacy against American bollworm showed good response.

Introgression of non-deregulated events into elite cotton varieties: In order to introgress Tg2E13 event, BC_2F_1 populations of three crosses *viz.*, Suraj × Coker310 (Tg2E13), NH615 × Coker310 (Tg2E13) and CISH3178×Coker310 (Tg2E13) were raised in seedling trays. ELISA was conducted at 20-30 DAS and non-Bt plants from the segregating backcross populations were roughed out. Event (Tg2E13) positive plants were transplanted to bigger pots on which ELISA was conducted at 60DAS and event positive plants having high toxin expression were identified and selfed. Generation was advanced using embryo culture technique. BC_4F_2 populations thus derived were evaluated for cry toxin expression at 30 days and non-Bt plants were roughed out. Event positive plants (BC_4F_2) were transplanted and using standardized zygosity PCR, plants homozygous for Tg2E13 event (*cry1Ac* gene) in BC_4F_2 population of three crosses were identified for further evaluation and multiplication. CISH3178 based BC_4F_1 plants having Tg2E13 and Mon531, alone and in combination have been identified. Characterization of UASD No. 78 event has been completed. Third backcross (BC_3) for introgression of CH12 event (*cry2Ax1* gene) into elite cotton genotypes (Suraj, NH615 and CISH3178) was successfully attempted (Fig.3.3.1). The presence of gene was confirmed by using *cry2Ax1* and Actin primers.

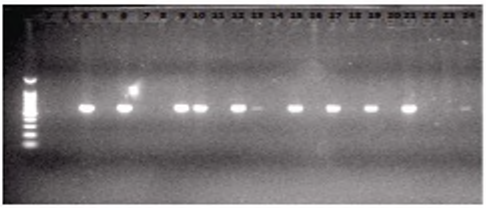


Fig. 3.3.1.: Foreground selection for CH12 event using *cry2Ax1* gene specific primer (Lane 1-100bp Ladder, 2-23 CH12 samples, 24- Positive control)

Evaluation trials for varietal identification and release

Institute Common Trial of *G hirsutum and G. arboreum*

G. hirsutum (18 entries) and *G. arboreum* (10 entries) were evaluated for seed cotton yield and fibre properties to identify promising entries for sponsoring in coordinated trials.

State Multi Varietal Trial (SMVT) at ICAR-CICR, Nagpur

An SMVT trial of *G. arboreum* (16 entries and 7 checks) and *G. hirsutum* 19 entries and 4 checks) was conducted with three replications following recommended package of practices at ICAR-CICR, Nagpur. The crop duration was prolonged due to intermittent rains during the crop season.

ICAR – AICRP on Cotton trials

The entries of ICAR-CICR, Nagpur sponsored, promoted and retained for different trials of ICAR – AICRP on Cotton trials during 2019-20 are summarized in as follows :

Table 3.3.2. : Entries sponsored in ICAR-AICRP on Cotton trials 2019-20

Trial	AICRP trial code	Name of Entry
National trials		
IET of *G. hirsutum*	Br 02 (a)	CCH 19-1, CCH 19-2
IET of *G. hirsutum*	Br 02 (b)	CNH 17393, CNDTS 283, CNH 2077, CNH 09-119, CNH 1134, CCH 19-2, CCH 19-3
IET of *G. hirsutum* -Colour cotton trial	Br 02 (a/b) CC	CNH 18528, CNH 18529, CCHC 19-1, CCHC 19-2
IET of *G. arboreum*	Br 22 (a/b)	CNA 1042, CNA 2035, CNA 2036, CNA 2037
IET of *G. arboreum* Long linted	Br 22 (a/b)LL	CNA1067, CNA 1068, CNA 1069, CISA 6-256, CISA 6-295
IET of *G. arboretum* -Colour cotton	Br 22 (a/b) CC	CNA18562, CNA18563
PHT - Desi Hybrid	Br 25 (a/b)	CISA 18-3, CISA 18-4
IET of compact *G. hirsutum*	Br 06 (a)	CCH 15-1, CCH 19-2, CCH 19-4
IET of compact *G. hirsutum*	Br 06 (b)	CNH 1132, CNH 1133, CNDTS 44, CNH 09-77, CNH 09-45, CNH 2046, CCH 15-1, CCH 19-4, CCH 19-5
IET of *G. barbadense*	Br 12(a)	CCB 141, CCB 142, CCB 64B

Table 3.3.3. : Entries promoted and retained in ICAR-AICRP on Cotton during 2019-20

AICRP trial	Entries promoted	Entries retained
North Zone		
Br-03 a	CSH 1721, CSH 3012	
Br 25 (a/b)	CISA-18-1	
Br 06 (a)	CSH 3158	
Br 24 (a)	CISA 10	
Central Zone		
Br 04 (b)		CNH11-11
Br 13 (a)	CCB 26	CCB 143b, CCB 51-2
Br-24 (b) CVT – *G. arboreum*		CNA1031, CNA1054

AICRP trial	Entries promoted	Entries retained
Br-24 (b) LL: CVT – *G. arboreum*	CNA 1065	
Colour cotton-*hirsutum*	CNH 17395	
Colour cotton - *arboreum*	CNA1091, CNA17522	
South Zone		
Br 13 a	CCB 26, CCB 28	CCB64, CCB 51, CCB 29
Br 14 (a)	CCB 143B, CCB 129, CCB 51-2	
Br06 h	-	CNH 1128
Br-24 b: CVT – *G. arboreum*		CNA 1054, CNA1031
Br-24 (b) LL: CVT – *G. arboreum*	CNA 1065	
Coloured Cotton Trial *G. hirsutum*	CNH 17395	16315 LB, 16301 DB, 16337 LB
Coloured Cotton Trial *G. arboreum*	CNA 1091, CNA 17522	CNA 407 SLP, CNA 405, CNA 407, 16377 LB-A

Table 3.3.4. : Entries sponsored, promoted and retained in ICAR-AICRP Bt varietal trials 2019-20

Name of the Zone	Entries sponsored	Entries promoted	Entries retained
North zone			
Irrigated	CICR 86 Bt, CICR 902 Bt	CICR 17 Bt	-
Central zone			
Irrigated	-	CICR 20 Bt, CICR 21Bt, CICR 22 Bt	-
Rainfed	CICR Bt.19-32, CICR Bt.19-33	CICR 20 Bt, CICR 21Bt, CICR 22 Bt	Bt 183059-4, Bt 183059-5
South zone			
Irrigated	-	CICR 24 Bt, CICR 25 Bt, CICR 26 Bt	-
Rainfed	CICR Bt.19-31	CICR 24 Bt, CICR 25 Bt, CICR 26 Bt	Bt 183059-2

Entries for agronomy trial		
G. *arboreum* (Variety, Rainfed)	CNA1032	Central zone
G. *barbadense* (Variety, Irrigated)	CCB 51	South zone

Varieties identified for release

CNA 1028 (RAVI) : A *G. arboreum* variety CNA 1028 tested in 18 AICRP trials for three years, 2015-18 and in agronomy trial in 2018-19 was identified for release and commercial cultivation in central zone rainfed conditions. It recorded an overall mean seed cotton yield of 1325 kg/ha with an yield advantage of 15.32 percent and 6.05 percent over the zonal check AKA 7 and local checks. It topped in 9 out of 18 AICRP trials and is identified as Jassid tolerant entry. The variety recorded ginning outturn of 34.23 per cent and lint yield of 452 kg/ha. In the agronomy trial conducted at Nagpur it recorded seed cotton yield (4633 kg/ha) at 125% RDF and 60 x 15 spacing despite terminal stress situation during the end of the crop season. The fibre quality characteristics of the variety are - 2.5% span length (25.5 – 29.6mm), micronaire (4.0-6.0 ug/inch), fibre strength (24.7 - 31.5 g/tex) with strength/length ratio of 1.154. The full-scale spinning test data from ICAR-CIRCOT indicates that the variety spun well at 30.6s counts with CSP of 2220 and at 40.7s counts with CSP of 1929.

CCH 14-1 (Sunantha): The good quality long staple variety of *G. hirsutum* CCH 14-1 (Sunantha) has been released for commercial cultivation in South Zone States of Karnataka, Andhra Pradesh, Telengana and Tamil Nadu under irrigated conditions. The variety recorded a mean seed cotton yield of 1688 kg/ha under irrigated condition in AICRP multi location trial and has an yield potential of 3675 kg/ha. The variety registered ginning outturn of 34.2 per cent and posses excellent fibre quality parameters *viz*., Upper Half Mean length of 32.0 mm, micronaire of 3.7 µg/in and tenacity of 32.7 g/tex in HVI mode, 2.5 % Span length of 32.8 mm, micronaire of 3.6 µg/in and tenacity of 24.1 g/tex in ICC Mode matching the CIRCOT norm for 50s count yarn. The variety recorded a mean boll weight of 4.5 g/boll. It is resistant to bacterial leaf blight, grey mildew and

tobacco streak virus and immune to root rot. The variety is tolerant / resistant to jassids, white fly, thrips, aphids and stem weevil.

ICAR-CICR 16 Bt: The medium staple Bt genotype 'ICAR-CICR 16 Bt' was identified for cultivation under irrigated condition of central zone. It recorded seed cotton yield of 1221 and 1471 kg/ha during the year 2017-18 and 2018-19 in central zone comprising states of Maharashtra, Gujarat and Madhya Pradesh respectively while the local BG II hybrid recorded seed cotton yield of 980 and 1264 kg/ha, respectively. It showed overall yield superiority of

15.23% over local check. It recorded lint index of 4.45 (g), GOT of 34.5%, UHML of 25.3 mm, micronaire of 4.3 µg/in, bundle strength of 26.1g/tex and uniformity index 81.5% which is at par to the local and zonal checks. ICAR-CICR 16 Bt recorded Cry protein expression of 6.79 ppm in leaves at 60 days crop duration during 2018-19. Mortality of 97% was recorded for *Helicoverpa armigera* in leaf bioassay at 90 days stage.

ICAR-CICR 23 Bt: The medium staple Bt genotype 'ICAR-CICR 23 Bt' was identified for cultivation under rainfed condition of south zone. It recorded average (over five locations in two years) seed cotton yield of 1459 kg/ha during its testing in ICAR-AICRP on Cotton in south zone comprising states of Tamil Nadu, Karnataka, Telangana and Andhra Pradesh respectively and ranked first in both the years. The zonal non-Bt check and local check recorded mean seed cotton yield of 1302 kg/ha and 1307 kg/ha, respectively. It recorded increase seed cotton yield of 26.39, 20.21 and 6.61% in 2017-18 and 0.76, 4.26 and 8.59% in 2018-19, respectively over zonal non-Bt check, local check and qualifying variety 1. ICAR-CICR 23 Bt recorded lint index of 4.35 (g), GOT of 35.0%, lint yield of 497.52 kg/ha, UHML of 27.6 mm, micronaire of 3.7 µg/in, bundle strength of 26.8 g/tex and uniformity index 83.0% which is at par to the local and zonal checks. ICAR-CICR 23 Bt recorded Cry protein expression of 4.7 ppm in leaves at 120 days crop duration and 4.46 ppm in boll at 90 and 120 days of crop during 2018-19. Mortality of 100% was recorded for *Helicoverpa armigera* on leaves upto 120 days.

3.4 Gene discovery, genomics and trait improvement

Nagpur

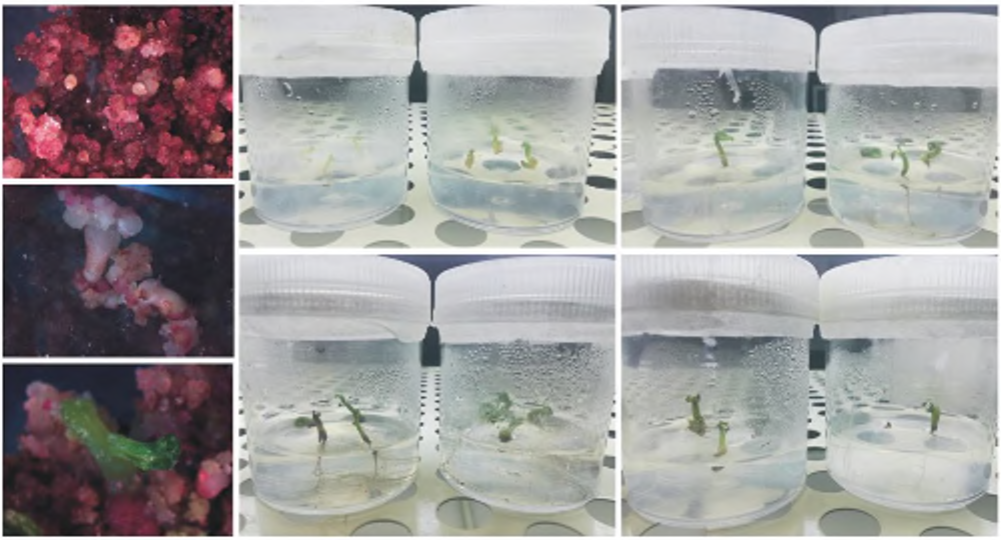
Development of consensus genetic linkage map of *Gossypium*

The field trial of five RIL mapping populations (two inter specific populations of *G. arboreum* × *G. hirsutum*, two intra-*hirsutum* and one interspecific *G. hirsutum* × *G. barbadense*) in two replications conducted to phenotype for morphological, yield and fibre quality traits at ICAR-CICR Nagpur. Phenotyping for economic

traits continued beyond December 2019 due to prolonged crop duration.

Transformation studies with *CICRcry2Ab1Ac*::chitinase:

Hypocotyl and cotyledanary explants derived from seven to ten days old seedlings were either (A) incubated in Pre Induction Medium (PIM) for 30 minutes with *A. tumefaciens* suspension containing gene cassettes CICR- *cry2Ab1Ac::chitinase* (OD600 0.3-1.0) or (B) applied with pre-induced *Agrobacterium* suspension (OD600 0.3-1.0) of 5 & 10 µl to the cut side of the cotyledonary and hypocotyl explants followed by co-cultivation and subculture in to MS medium supplemented with 2,4-D (0.1mg/l) and kinetin (0.5mg/l), and selection on kanamycin 25mg/L. Total 41 putative transformants comprising 21 and 20 from method A and B respectively, were regenerated through somatic embryogenesis. Eleven out of the 21 putative transformants regenerated from method A produced good rooting but only 3 out of 20 are showing proper rooting in matured embryos regenerated from method B.



Construction of CRISPR/Cas9 gene targeting vectors for the targeted mutagenesis of *GhPHYA1*:

Four sgRNAs have been designed to target *GhPHYA1* gene using CRISPR/Cas9. Construction of gene targeting vector sgRNA1*GhPHYA1*::CRISPR/Cas9, sgRNA2*GhPHYA1*::CRISPR/Cas9 and sgRNA3*GhPHYA1*::CRISPR/Cas9 has been completed and confirmed. Putative recombinant colonies were analyzed for the presence of these gene targeting vector constructs through plasmid PCR. Presently, preparation of sgRNA4*GhPHYA1*::CRISPR/Cas9 gene targeting vector is in progress (Fig.3.4.1).

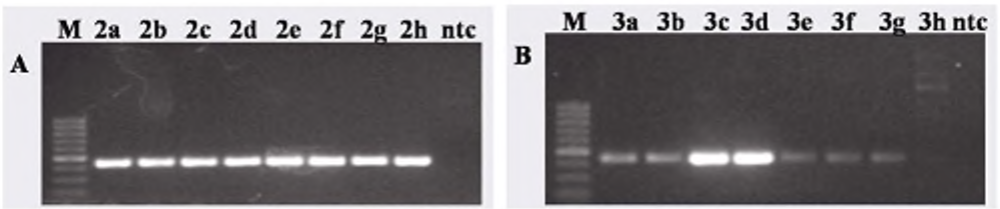


Fig.3.4.1: Plasmid PCR confirmation of sgRNA2*GhPHYA1*::CRISPR/Cas9 (A) and sgRNA3*GhPHYA1*::CRISPR/Cas9 gene targeting vectors (B)

Confirmatory GUS assay of putative transgenic callus cultures for the presence of pBI121::*Wnt 3A* gene construct:

The pBI121::*Wnt 3A* gene construct was utilized for *Agrobacterium tumefaciens* mediated transformation of non responsive cotton genotype for somatic embryogenetic (suraj variety) using hypocotyls as an explants. Pure cultures of hypocotyl explants specific calli have been maintained and after six sub cultures of the putative callus cultures with pBI121::*Wnt 3A* gene construct. GUS assays have been performed and it has been confirmed that many of the calli derived from specific hypocotyls were found to be positive for β-glucuronidase activity (Fig.3.4.2). All the GUS positive callus cultures along with controls are being maintained on appropriate tissue culture media from time to time for evaluating potential role of Wnt 3A like gene.

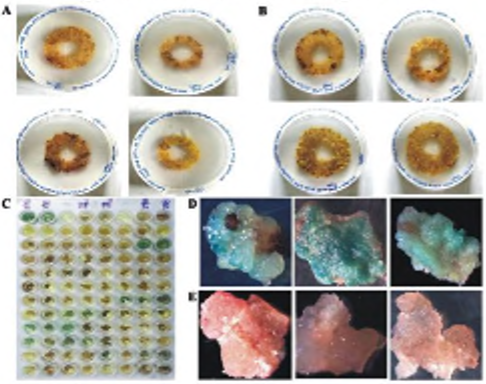


Fig.3.4.2 : Confirmatory GUS assay of putative transgenic callus cultures. A) GUS-positive callus cultures B) GUS-negative callus cultures C) GUS assay of putative calli with pBI121::*Wnt 3A* gene construct D) Microscopic photographs of GUS positive calli E) Microscopic photographs of GUS negative calli

Standardization of Zygosity PCR for Tg2E-13 event

Genomic sequence information of the T-DNA Right border junction sequence of the Tg2E-13 event was utilized for In-silico genome walking and identified the upstream cotton genomic sequences of T-DNA Left border of the transgenic event. Primers for detection of homozygous and hemizygous transgenic plants were designed, synthesized and PCR conditions was standardized (Fig. 3.4.3). The standardized PCR method is being utilized for identification of homozygous and hemizygous transgenic plants in BC4F2 progenies of three cross viz., Coker310Tg2E-13 × Suraj, Coker310Tg2E-13 × NH615, and Coker310Tg2E-13 × CISII3178.

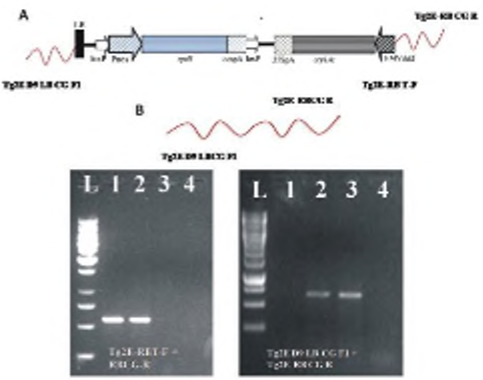


Fig. 3.4.3: Zygosity PCR for detection of homozygous and hemizygous plants of Tg2E13 event. L=1kb ladder; 1= Tg2E13 Homozygous sample; 2= Tg2E13 Hemizygous sample; 3= Azygous non-transgenic sample; 4= No template Control.

3.5 Seed Production and Quality improvement

Nagpur

Storability of cotton seed

Freshly harvested seeds in *kharif* 2018 were stored in different packaging materials, under different storage conditions. The seeds stored under cold conditions in vacuum containers and modified Argon gas indicated encouraging results in terms of higher germination.

Seed protein characterization

Quantification as well as profiling of seed storage protein was undertaken in varieties of four cultivated species as well as F_1 hybrids and their parents. The total seed protein content determined by Bradford method in 22 *G. hirsutum* cultivars of varying seed index ranged from 28µg/g (Supriya) to 51µg/g (Suraj). No correlation was observed between seed index and soluble seed protein content. The SDS PAGE profiling of varieties as well as 4 CICR hybrids along with their parents did not show major variations. The four cultivated species (*G. hirsutum; G. arboreum; G. barbadense and G. herbaceum*) were characterized for seed storage protein profiling by SDS PAGE. Unique polypeptide fragments with high intensity were distinct for *G. hirsutum* compared to other three.

The seed protein content was highest in *G. hirsutum* (50µg/g of seed tissue) and lowest in *G. barbadense*

(22µg/g seed tissue). The seeds of ten *G. hirsutum* varieties were artificially aged/deteriorated in a desiccator placed at 40°C and 100% RH. The total protein content was found to be higher in fresh seeds with good germination compared to deteriorated seeds with poor germination as observed in 10 different varieties. The SDS PAGE profile of total seed proteins in aged and fresh seed lots of three varieties showed distinct 2 polypeptide fragments in fresh seeds compared to deteriorated seeds (Fig.3.5.1).

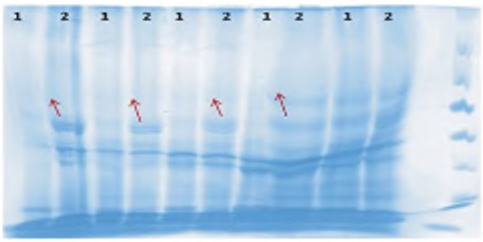


Fig.3.5.1: SDS PAGE profile of deteriorated low viable seed (1) and fresh viable seed (2)

Distinctiveness Uniformity and Stability (DUS) testing

Nagpur:

Five trials were laid out for DUS testing which includes New/First Year Trial (1 genotype); Varieties under Common Knowledge (1genotype); Essentially Derived Varieties and Initial Variety (1 each); Second Year Trial (3 genotypes) and reference variety trial (15 genotypes). The monitoring of trial was held at Nagpur on 28th November 2019 under the chairmanship of Dr. S.A. Patil, former Director, IARI, New Delhi.

Coimbatore

Data base on extant cotton varieties and notified cotton varieties has been updated. Data base of registered tetraploid and diploid cotton varieties was acquired from PPV&FRA, New Delhi. Maintenance breeding and characterization of 185 extant cotton varieties were carried out *viz.*, 140 in *G. hirsutum*, 35 in *G. arboreum*, 5 in *G.herbaceum* and 5 in *G. barbadense*.

Field trials of new candidate varieties for the establishment of DUS have been conducted. This trial consists of 7 new candidate varieties for second year of testing, 4 candidate varieties for first year of testing along with 10 reference varieties. Germination count at 12 DAS. Morphological characters were recorded on 10 plants of all varieties. The data received from participating centers were compiled and submitted to PPV & FRA for issue of registration certificate. Monitoring of DUS trials at the participating centres was done under the chairmanship of Dr. S.A. Patil, former Director, IARI, New Delhi.

Seed Production

Breeder seed production was taken up for non Bt varieties [Suraj, Surabhi, LRA 5166, LRK 516, MCU5VT, Subiksha, Suvin, CNA 1028, CNA 1003 (Roja)] and TFL seed for Bt varieties (Suraj Bt, PKV Rajat Bt, PKV 081 Bt, GJHV 374 Bt & Bt 6 in all three centres of ICAR-CICR (Table 3.5.1).

Stock seed production of 75 varieties (*G. hirsutum, G. arboreum, G. barbadense)*, parents of 18 hybrids, variable traits (12) of *G. arboreum* race cernuum was taken up. In Farmers Participatory mode, 7 tribal farmers had taken up TFL seed production of 4 Non-Bt varieties in 20 acres and one farmer taken up seed production of 4 Bt varieties in 4 acres. Certified seed production of red gram Cv. BSMR-736 was taken up in 32 acres, gram Cv. Jaki 9218 in 8 acres and foundation seed production of linseed Cv. NL 260 in 1.0 acre at the Institute farm.

Table 3.5.1. Quantity of Bt and non-Bt cotton seeds produced in 2019

S. No	Variety	Quantity (Kg)
Cotton Bt varieties		
1	Suraj Bt	714.4
2	Rajat Bt	901.1
3	GJHV 374 Bt	156.7
4	PKV 081 Bt	277.9
	Grand Total	**2050.2**
Non-Bt varieties		
1	Suraj (BS)	70.9
2	Surabhi (BS)	27.0
3	LRK 516 (BS)	12.0
4	LRA-5166 (BS)	15.3
5	NH 615(TFL)	46.7

S. No	Variety	Quantity (Kg)
6	Roja (BS)	82.5
7	Phule Dhanwantri(TFL)	10.5
	Grand Total	**264.9**

Coimbatore

Nucleus and Breeder Seed Production

Nucleus and Breeder seed production was undertaken for Suvin, Suraj, Subiksha, Surabhi and MCU 5-VT. During the year 2019, a total of 8 kg of breeder seed of Suvin was distributed to various seed producers.

Under AICRP-NSP (Crops), an experiment was laid out for redefining isolation distance of IMSCS 2013 for foundation and certified seed production of cotton. One male fertile (HD1-10-151) and one male sterile (GAK 433) received from PDKV, Akola was used for the experiment. To assess the efficiency of molecular markers in hybrid purity testing in comparison to the grow-out test (GOT) in various field crops. PDKV Akola, AAU Anand, NAU Navsari and UAS Dharwad were identified for cotton. Accordingly, ICAR-CICR had supplied the seeds of male and female parents of 5 hybrids CSHG 1862, CSH 198, CSH 243, CSH 238 and CICR-2 to all the four centres. All parents were grown for sufficient seed production for further testing.

To validate the validity period of certified seeds of field crops (as per the IMSCS regulations) at ICAR-CICR Regional Station, Coimbatore, seeds of NH 615 (*G. hirsutum*), Roja (CNA1003 *G. arboreum*) about 2.5 kg seeds of each variety were supplied to ICAR-CICR Regional Station, Coimbatore, PDKV, Akola, PJTSAU, Hyderabad and UAS, Dharwad for providing observations on 10 seed quality parameters on bi-monthly basis.

In another experiment on physiology studies and development of priming technologies for enhancing planting value of seed in field crops under optimal and sub-optimal conditions. Two seed lots i.e. seed lot I (2017-18) and seed lot II (2018-19) of varieties Surabhi and LRA-5166, were taken for the experimentation. Seeds were subjected to 12 treatments and 2 controls (untreated & Imidacloprid treatment). Observations are being recorded on 10 seed quality parameters. Field performance and productivity of Surabhi of 2017-18 (low vigor) and 2018-19 (high vigor) lots were taken for the study.

At Coimbatore, freshly harvested seed lot of cotton variety NH 615 and Roja (CNA1003) received from ICAR-CICR, Nagpur was used. Seed lots were assessed for initial viability and moisture content and stored in polythene and gunny bag under ambient condition. Bimonthly observations on seed moisture content (ISTA), germination % (ISTA), Vigour index-I and II (Abdul Baki and Anderson, 1973) and dry matter production of seedlings revealed that the performance of seed lots are well above the minimum seed certification standards. Two cotton varieties Surabhi (V1) with two seed lots produced during 2017-18 (L1) and 2018-19 (L2) and LRA 5166 (V2) with two lots of 2016-17 produced (L1) and 2018-19 (L2) were subjected to 14 treatments under laboratory conditions. The following parameters were estimated at laboratory moisture content (ISTA) before and after treatment i.e. before sowing, germination % (ISTA), vigour index-I and II in field, emergence (%) and final plant stand establishment (%). The positive response of seed treatments was observed in low vigour cotton seeds.

3.6 : Enhancing Resource Use Efficiency through climate smart agro-techniques

Nagpur:

Exploring the productivity potential of long-linted *G. arboreum* cotton

Six potential long linted genotypes (PA 812, PA 760, PA 528, PA 402, DLSa 17,CNA 1041) and a short staple check- Phule Dhanwantary were evaluated under HDPS and normal spacing on 2 dates of sowing (normal and 15 days delay) on an Inceptisol and a Vertisol under rainfed conditions at Nagpur and under winter irrigated conditions at Coimbatore.

Across sowing dates, year of experimentation, within row spacings and soil types -

- the date for the appearance of first square and first flower was the earliest in genotype DLSa 17 and farthest in the genotype Phule Dhanwantary
- the duration from flowering to boll opening was least in Phule Dhanwantary and hence it was the earliest in maturity
- the fibre quality parameters of PA 812 and PA 760 were distinctly superior to the rest

Role of the enzymes involved in ethylene biosynthesis pathway in *G. arboreum* genotypes in fibre elongation

An attempt was made to correlate the fibre length with ethylene in six varieties of long linted *arboreum* cotton and short staple check (Phule Dhanwantary). Relative quantification of ethylene (gaseous form) was done in young cotton bolls of approximately uniform size using ethylene monitor/sensor. The maximum ethylene release was observed in PA812 followed by PA 528, whereas minimum ethylene was registered in Phule Dhanwantary followed by PA402 (Table 3.6.1).

Table 3.6.1: Estimation of ethylene in young cotton bolls

Genotype	Ethylene (ppm)
DLSA-17	0.95
PA-528	1.12
PA-402	0.58
PA-812	1.27
PA-760	1.03
CNA1041	0.97
Phule Dhanwantari	0.55

Expression analysis of two genes of ethylene biosynthesis pathway, coding for key enzymes ACCS (1-aminocyclopropane-1-carboxylic acid synthase) and ACCO (1-aminocyclopropane-1-carboxylic acid oxidase) was performed in seven *arboreum* cotton genotypes to correlate their expression with fibre length. The expression of *ACCS* was maximum in PA812 followed by PA528, where as PA402 had minimum expression of *ACCS* among all seven genotypes when compared (Fig 3.6.1). In continuation, there was also significant difference for *ACCO* transcript level among the seven genotypes where PA812 showed maximum expression followed by PA760 while minimum ACCO level was observed in PA 402 among all desi genotypes (Fig 3.6.2).

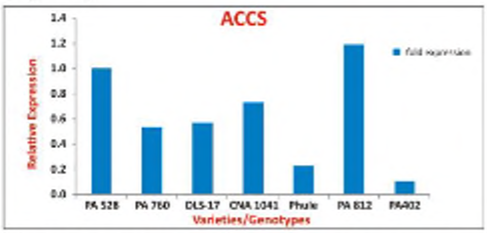


Fig 3.6.1: Expression of ACCS gene in subtending leaf of cotton boll

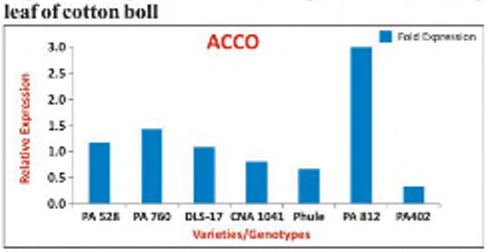


Fig 3.6.2: Expression of ACCO gene in subtending leaf of cotton boll

To relate the ethylene release and expression of genes involved in ethylene biosynthesis with fibre length, a correlation analysis was done and a positive correlation was observed between ethylene and fibre length of different long linted *arboreum* cotton genotypes.

In an effort to establish a correlation between few already known genes involved in cell elongation (*Bonzai*, *Myb25* and *Pex1*) and ethylene expression, transcript level of these selected genes were measured in 0, 7 & 14 DPA ovules of PA812 and Phule. At all stages, PA812 had more expression of all these genes compared to Phule Dhanwantary. *Myb 25* was found to be involved specifically in fibre elongation (7DPA), whereas *Bonzai* and *Pex1* were more at fibre initiation stage (0DPA).

On-station water foot print estimation of cotton production system

Cotton being a rainfed crop in India, a major emphasis needs to be given to improve its water productivity. Priority needs to be given for the development of indices those indicate appropriation of fresh water resources from a particular management system. In this regard water footprint estimation of cotton can be used to indicate both direct and indirect appropriation of fresh water resources.

On-station experiment was conducted at ICAR-CICR, Nagpur to estimate water footprint of cotton production under three water management practices (T_1: Rainfed condition with runoff collection, T_2: Furrow irrigated, T_3: Drip irrigated). The total rainfall received during cropping season 2019-2020 is 1240.07 mm, out of which effective rainfall (662.8 mm) is 53.44 % and ineffective rainfall (577.27 mm) is 46.56%. Considering ineffective rainfall according to USDA Soil Conservation method and soil moisture changes, the runoff estimated during June to December was 49.46 lakh litres from one hectare area. (Fig 3.6.3).

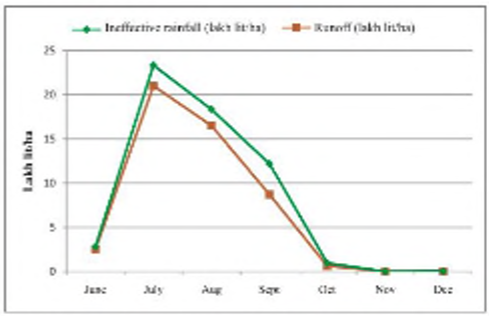


Fig 3.6.3 : **Ineffective rainfall (lakh lit/ha) and runoff (lakh lit/ha) during cotton growing season**

New complex fertilizer for Bt hybrid cotton

Replicated field experiments with Bt hybrid cotton were conducted using the complex fertilizers (Muriate of Potash (MOP) and Sulphate of Potash (SOP) supplied by Smartchem Technologies, along with MOP and SOP based complex fertilizers. Equivalent to recommended dose of fertilizer, 10% more, 10% less, which were compared with the ICAR-CICR recommended dose of fertilizers (RDF) and farmers practice under rainfed conditions. The results showed that all the treatments showed significant increased in the cotton yield as compared to farmers practice. Seed cotton yield was the highest with the 10% more MOP based complex grade fertilizer treatment. There was no additional advantage with SOP based complex fertilizer over the MOP based complex fertilizer.

Coimbatore

Use of structured water for Irrigation

A field experiment was conducted in a split plot design during summer 2018-19 and 2019-20 to study the benefits of irrigation under drip system using structured water.The results revealed that water saving due to drip ranged from 390.7 mm to 633.3 mm over conventional irrigation. The structured water irrigation recorded higher water use efficiency ranging from 23.5 to 62.6 kg/ha cm as against 20.2 to 55.2 kg/ha cm with bore well irrigation. The structured water irrigation resulted in enhanced water use efficiency of 5.7 kg/ha cm across irrigation scheduling over two years of experimentation. The structured water irrigation and moisture regimes significantly influenced the seed cotton yield of BG II hybrid. Among the irrigation scheduling, 0.8 ETc recorded the highest seed cotton yield and was on par with 1.0 ETc but significantly different from rest of the treatments. Water use efficiency was the highest in drip irrigation given at 0.4 ETc irrespective of the source of water (Fig 3.6.4).

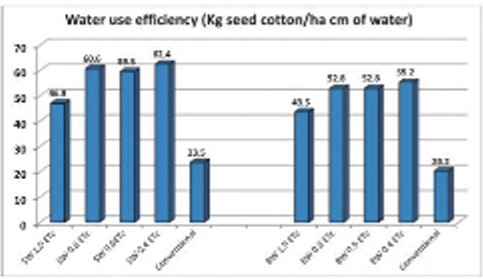


Fig 3.6.4: **Water use efficiency (kg/ha cm) of BG II cotton irrigated with structured water (SW) and borewell water (BW) irrigation pooled mean of 2018-19 and 2019-20**

Sirsa

Long Term Fertilizer Experiment

- A long term fertilizer experiment involving 5 cropping systems and five nutrient regimes is being conducted. During 2019-20 cropping season:-
- Among the cropping systems, seed cotton yield was in the order; Bt cotton hybrid – fallow > Bt cotton hybrid – wheat > non-Bt cotton hybrid – wheat > Bt cotton variety – wheat > non Bt cotton variety – wheat.
- Among the nutrient regimes, recommended dose of NPK + secondary nutrients ($MgSO_4$) + Micronutrients ($ZnSO_4$ + Borax) and FYM @ 5 t/ha once in two years out yielded other nutrient regimes with respect to seed cotton yield.
- Interaction between nutrient regimes and cropping systems was not significant for seed cotton yield

Enhancement in productivity of cotton through improvement in agrotechniques under North-Western Indian conditions:

(a) Bt cotton variety (CICR Bt-6) and non-Bt cotton variety (CSH 3075):

- Early sowing of Bt cotton variety (CICR Bt-6) and non-Bt cotton variety (CSH 3075) during [2nd week of May] gave significantly higher seed cotton yield than sowing at later dates.
- Spacing of 67.5 cm x 45 cm was superior to closer spacing at 67.5 cm x 10 cm.
- Response to the application of growth regulator (Mepiquat chloride) was significant.
- Spraying of Mepiquat chloride twice @ 20 g ai / ha at 60 and 75 DAS was superior to a single spray at the same rate at 60 DAS.
- Interaction between sowing date and spacing was significant indicating when sowing was delayed till first week of June, closer spacing (67.5 cm X 10 cm) gave higher yield than wider spacing (67.5 cm x 10/30 cm).

(b) Bt cotton hybrid (SP-7172):

- Early sowing of Bt cotton hybrid (SP-7172) during [2nd week of May] gave significantly higher seed cotton yield than sowing at later dates.
- The optimum spacing was 67.5 cm x 60 cm.
- Application of Mepiquat chloride @ 20 g ai / ha at 60 and 75 DAS significantly improved the seed cotton yield.
- Spacing x sowing date effect was significant. When sowing was delayed to the first week of June, planting

at closer spacing (67.5 cm X 30 cm) gave higher yields than planting at wider spacings (67.5 cm x 60 cm or 67.5 cm x 45 cm).

Nutrient expert system for hybrid cotton

The "Nutrient Expert" a decision support system for site specific nutrient management (SSNM) was developed and evaluated in hybrid cotton. The system was validated at ICAR-CICR farm as well as in ten farmers' fields. During 2018-19, the seed cotton yield (SCY) was found to be highest in "Nutrient Expert" as compared to other treatments in both institute as well as the farmers' field trials. The results reinforce the need for balanced fertilizer application based on site specific nutrient management especially for rainfed cotton.

3.7. Sustainable farming systems through conservation agriculture and precision techniques

Alleviating soil compaction – a production constraint in cotton

Replicated trials were laid out to study the effect of different sub soiling, crop rotations and deep rooted crops on soil penetration resistance in order to devise a suitable plan for ameliorating soil compaction. Radish-cotton (1450 KPa) and Pigeon pea-cotton (1333 KPa) rotations were found to give lesser inter-row soil penetration resistance as compared to deep sub soiling (2067 KPa) and shallow sub soiling (2000 KPa). Dhaincha (1000 KPa) and sunhemp (1033 KPa) offered least soil penetration resistance inter-row as well as between row than soybean (1233 KPa) and sub soiling every (2800 KPa) and alternate rows (2433 KPa).

Identification of suitable nitrogen fixing legumes for cotton intercropping under rainfed cultivation

Higher N was recorded in initial soils samples of short duration legumes. During kharif 2019 characterized by high rainfall, intercropping cotton with black gram, green gram and soybean were better than intercropping with groundnut. Cowpea and cluster bean. Post-harvest analysis shows enhancement in soil nitrogen in Cotton + Soybean, Cotton + Cowpea and Cotton + blackgram intercropping system.

Evaluation of PGPR and microbial inoculants to alleviate drought stress in cotton (*G.hirsutum*)

Nine bacterial strains (*Solibacillius isronenesis, Acinetobacter pitti I, Acinetobacter pitti II, Acinetobacter pitti III, Pseudomona sp., Sphingomonas sp.I, Sphingomonas sp.II, Acinotobacter pitti, Acinotobacter sp.*) isolated from *G.hirsutum* and *G. arboreum* rhizosphere were shortlisted for drought stress studies. Talcum based formulation of these isolates were inoculated to variety Suraj as seed treatment, and evaluated for its plant growth promotion attributes. In general, the microbial treated seedlings showed increased leaf chlorophyll content (SPAD value in the range of 35 to 45) and leaf temperature 24-26 ℃.

Microbial interventions for potassium nutrition in cotton

Native Potassium Solubilizing Microbes (KSM) were isolated from different cotton growing regions and forest areas of Vidarbha using Alexandrov medium. The efficient K solubilizing microbes were screened qualitatively using bromothymol blue @ 0.5% in the Alexandrow medium (Fig 3.7.1). The shortlisted KSM were evaluated for potassium solubilization quantitatively (Flame photometry) through soil incubation studies. Significant difference was observed between the isolates on solubilization of potassium. The available potassium in the treatments ranged from 0.92-1.20 ppm and 0.98-1.35 ppm on 7 DAI and 14 DAI, respectively (Fig 3.7.2).

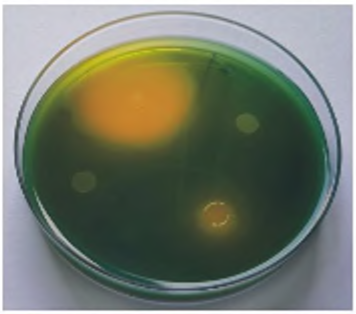


Fig 3.7.1. Rapid screening of K solubilizing microbes using bromothymol blue

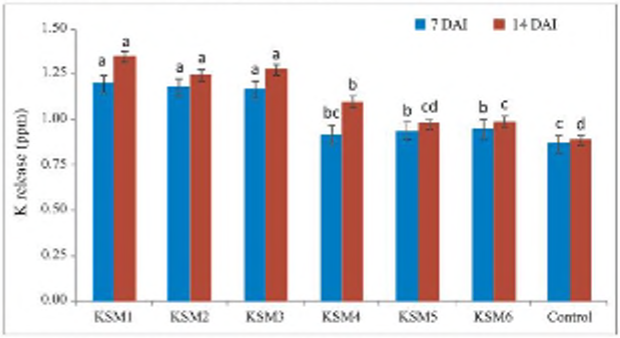


Fig 3.7. 2: Potassium release by KSM's at 7 and 14 DAI

Remunerative cotton based cropping systems using conservation agriculture principles under irrigated condition

Coimbatore

Field experiments based on conservation agriculture principles were conducted by combining land shaping with residue retention coupled with location specific remunerative cropping systems from 2015 to 2019 for enhancing system productivity and soil quality under irrigated condition. The salient findings are as follows :

- Cotton - Black gram - Maize (for grain purpose) is identified as a candidate cropping system to implement conservation agricultural practices under irrigated conditions as it produced significantly higher Cotton Equivalent Yield (CEY) of 4577, 4174, 4247 and 4408 kg ha^{-1}, respectively during first (2015-16), second (2016-17), third (2017-18) and fourth (2018-19) cropping sequences than the conventional Cotton - Fallow system (CEY of 3400, 1223, 1996 and 2609 kg ha^{-1}, respectively).

Cotton - Black gram - Maize cropping system

- Beds and furrows system is found suitable for raising cotton and other component crops under conservation agricultural practices *viz*., minimum tillage and residue recycling
- CA system with 100% residue recycling significantly reduced the soil penetration resistance upto 9" soil depth vis-à-vis Farmer's practice

Field demonstration of remunerative cotton based cropping systems using conservation agriculture principles under irrigated condition to the farmers

Sirsa

The seed cotton yield was significantly higher under M_6 (Zero tillage - permanent narrow raised bed with residue retention on surface) amongst the all other treatments. The lowest seed cotton yield was obtained under M_1 (Conventional Tillage - Flat Bed without residue incorporation) i.e. farmers' practice. However, it was at par with M_2 (Zero Tillage - Flat Bed without residue retention on surface). Amongst the cropping systems, the significantly higher seed cotton yield were recorded under (S_3) [Cotton - Chickpea (Bengal gram)] as compared to all other cropping systems. Second best cropping system with respect to the seed cotton yield was (S_5) [Cotton - Mustard (Raya)] which was at par with (S_2) [Cotton - Berseem (Fodder)] and (S_1) Cotton - Wheat cropping system. Seed cotton yields under (S_1) Cotton - Wheat and (S_4) Cotton - Barley cropping systems were at par with each other. Lowest seed cotton yield were obtained under (S_6) [Cotton - Winter Maize (Spring Maize)] cropping system.

Exploiting the epigenetic transgenerational inheritance of stress responsive traits for imparting abiotic stress tolerance in cotton

The epigenetic regulating chemicals (ERC) treated Suraj and LRA 5166 cotton plants is being screened for drought tolerance in the third generation. The plants were subjected to drought stress during pin head stage of squaring by withholding irrigation for 10 days. Control plants were maintained for each treatment. Chlorophyll content was numerically higher (23.1) in plants treated with epigallocatechin gallate 100µM in suraj (29.0) and in LRA 5166 it was numerically higher in plants treated with 5 Azacytidine 40µM. Relative water content is numerically higher in plants treated with Nicotinamide 35 µM and control (73%) in LRA 5166 and it was numerically higher in plants treated with 5 Azacytidine 40µM (77.8 % in Suraj). In LRA 5166 plants that received seed treatment of 5 Azacytidine 10µM, the epicuticular wax content was higher (104.9 µg/cm^2) when compared to control (17 µg/cm^2). However in Suraj, plants treated with epigallocatechin gallate (100 µM) recorded higher epicuticular wax content(105.8 µg/cm^2) followed by 5 Azacytidine 40µM (105.6 µg/cm^2) as against control (51.3 µg/cm^2). Among the treatments, 5 Azacytidine 40µM was found to be effective in imparting drought tolerance to cotton plants.

Metabolite exploration of drought stress in cotton

A new metabolic pathway "Alarm photosynthesis" has been explored in some of the model plants, which support them in sustaining under drought stress conditions. To explore this pathway in cotton, all the four cultivated *Gossypium* spp. (*G hirsutum*: DTS-44, DTS-155 and DTS-108 as drought tolerant and IC-357637, IC-359834 and IC-357055 as drought susceptible; *G. arboreum*: Phule Dhanwantary and PA 255; *G. barbadense*: Suvin; *G. herbaceum*: G-cot 25) were subjected to drought stress. Expression analysis (qPCR) of GLP1/oxalate oxidase gene in leaves of all the four cultivated cotton spp. as well as in different tissue [leaves, cotyledon, 10DPA (Days Post-anthesis) and 25 DPA ovule] confirmed its presence at gene level. Significant day night variation in oxalate content and oxalate oxidase (OxO) activity was also observed in cotton leaves. Further, to confirm at protein level, In-gel activity of oxalate oxidase was performed in cotton leaves. A combination of different extraction and staining buffers were tested and the method was standardized with some modifications. Proteins extracted in PBST (Phosphate Buffered Saline with Tween 20) buffer showed only the bands of oxalate oxidase (Fig 3.7.3) in the gel. Among the four cotton spp., desi cotton had more oxalate oxidase expression, where in water stressed leaf samples were observed to possess more oxalate oxidase activity than control (Fig 3.7.4). Overall, expression of oxalate oxidase in cotton leaves at gene and protein level confirms the existence of "Alarm photosynthesis" pathway in cotton.

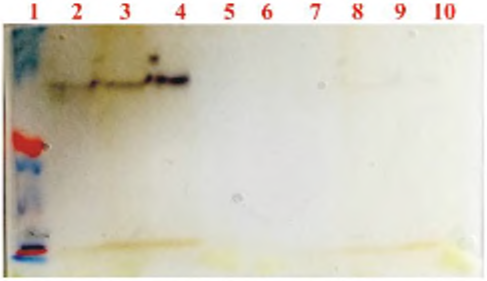


Fig 3.7.3: *In-gel* activity of OxO in cotton leaves, in different buffers. 1. Protein ladder(10-180 KDa), 2-4. PBST buffer, 5-7. Phosphate buffer, pH 7.2 + EDTA, 8-10. Tris buffer, pH 8.0

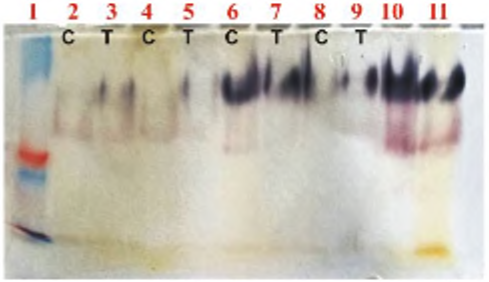


Fig 3.7.4: *In-gel* activity of OxO in cotton leaves. C: Control; T: Water stressed. 1. Protein ladder (10-180 KDa), 2-5: *G. hirsutum*, 6-7: *G. arboreum*, 8-9: *G. herbaceum*, 10-11: *G. arboreum* infested with Grey mildew

3.8. Economics and extension research and e- communication tools

e-Communication: dissemination of cotton production technology

The ICAR-Central Institute for Cotton Research, Nagpur has continued its efforts on strengthening *e-Kapas* as a model to disseminate cotton production technologies among farmers through voice message services covering 1.5 lakh farmers of Nagpur, Coimbatore and Sirsa regions. During the period, IT Tube light Communications Ltd, Mumbai served as a service provider. During this period, 16884 new farmers from Nagpur centre were registered. At Nagpur, 58,81,315 noise free voice messages uploaded on to 1,24481 farmers mobile numbers. From Coimbatore centre, 3,14,035 were uploaded voice messages on to 10773 farmers mobile. From Sirsa, 191008 messages were uploaded on to 21301 registered farmers' mobile numbers. The overall successful delivery of messages was only 42.40 percent.

Success stories of e-Kapas beneficiary farmers were documented. Few farmers shared their experiences and benefits of timely receipt of messages during the Kapas Mela organized at ICAR-CICR Nagpur on November 29 2019. Advisory services are, therefore, playing a crucial role in promoting cotton production, protection technologies, increasing productivity and improving rural livelihoods. During the period, farmers belong to Schedule Caste were also motivated under SCSP towards adoption of cotton production/protection technologies. An integrated ICAR-CICR Cotton App provides information about the latest cotton production, protection and improvement technologies, farmers outreach programmes, weekly advisories, etc. The App can be downloaded from Google Play Store for targeted end users including farmers, students, researchers, state department, agriculture officials, KVK officials, policy makers, etc

Impact of Institutional Credit on Cotton Farming in Maharashtra

Indian Society of Agricultural Economics (2015) and Parliamentary Committee on Agriculture has recently emphasized requirement of concrete evidence of efficacy of credit on farm profitability and productivity. Based on the above recommendations, a study was conducted to investigate the impact of institutional credit on technical efficiency of cotton production in Vidarbha region of Maharashtra, and to suggest policy measures to enhance and improve the efficiency of rural financial sector using primary data and purposive random sampling (720 cotton farmers) covering both credit users (Borrowers) and non-users of credit (Non-Borrowers). Sampling was done from 18 talukas two each from Amaravati, Wardha, Nagpur, Yavatmal, Aurangabad, Beed, Buldhana, Jalna and Jalgoan. Based on the stochastic frontier analysis, it was found that the credit use cotton farmers are more efficient than non credit user farmers except in Buldhana and Jalgaon. The ranges of technical efficiency were 0.30 to 0.91 with mean 0.60 for the credit user farmers and 0.25 to 0.89 with mean 0.57 for their non-credit user counterparts (Table 3.8.1). Further, the Maximum likelihood estimation results of the stochastic frontier production function shows a positive and significant coefficient of irrigation, bullock labour and credit dummy variables that indicate the overall cotton production can be enhanced by exploiting irrigation, bullock labour and expansion of credit (Table 3.8.2).

The study concludes that agriculture credit itself cannot play any direct role in enhancing the output rather indirectly helps through buying various modern inputs. Hence agriculture credit should be enhanced to large proportion of rural population. The financial institutions provided credit to the marginal and small farmers in limited quantity based on the size of holding, this study recommends subsidized credit should be given more to the farmers of small size holdings. Imparting training to borrower regarding procedural formalities of financial institutions could be helpful on increasing their access to institutional credit. The sample respondents opined that up to five lakh rupees crop loan limit must be with no interest and repayment of crop loan amount should be based on the price received for their produce. Increase in irrigation facilities such as drip, sprinkler tube well and tractor plays important role in enhancing the productivity, therefore special loans should be given directly to farmers on easy installments.

Table 3.8.1. Distribution of Technical Efficiency of Borrowers and non-Borrowers (Stochastic Frontier Analysis)

Efficiency Class	Amaravati		Aurangabad		Beed		Buldhana		Jalgoan		Jalna		Nagpur		Wardha		Yavatmal		All	
	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
<0.60	4	7	-	-		-	20	24	-	-	6	4	5	10	5	-	-	6	22	35
0.61-0.80	5	10	24	42	18	29	34	28	48	47	52	72	64	59	11	20	21	13	56	50
0.80-1.00	91	83	76	58	82	71	46	48	52	53	42	24	31	30	84	80	79	81	22	15
Maximum (TE)	0.99	0.98	0.97	0.90	0.98	0.91	1	0.99	0.98	0.94	0.96	0.92	0.99	0.96	0.99	0.97	0.85	0.87	0.30	0.25
Minimum (TE)	0.51	0.46	0.65	0.63	0.89	0.66	0.41	0.49	0.60	0.72	0.34	0.33	041	0.39	0.35	0.65	0.29	0.31	0.91	0.89

C= Credit; NC= Non Credit

Table 3.8.2: Maximum Likelihood Estimates of the Cobb Douglas Stochastic Frontier Function

Variables	Coefficients	t- statistics
Constant	4.244***	3.86
Seeds	0.276	0.18
No. of. Irrigations	0.198**	2.48
Fertilizers	0.093	1.8
Pesticides	-0.033	-1.24
Human labour	-0.211	-1.23
Animal labour	0.262**	2.25
Machine labour	-0.035	-1.87
Dummy of credit	0.163*	2.40
Sigma-squared	0.129***	3.61
Gamma	0.746***	6.80

*** Significant at 1%, ** significant at 5%. * significant 10%

Socio-technological analysis of drip irrigation in cotton cultivation

Field survey was conducted in two districts viz., Sabarkantha and Rajkot of Gujarat state. Major research observations made about drip irrigation from the study area are; a) In Gujarat state adoption rate for drip irrigation in cotton cultivation was estimated at 18.60 %. Hence, there is a lot of scope for drip irrigation in cotton cultivation. b) Major cropping system followed in the area is Cotton – Wheat / Cotton-Potato / Cotton-Groundnut / Groundnut-Wheat-Groundnut / Maize-Wheat-Green gram. c) Majority of the farmers are cultivating cotton crop and where ever water is available farmers are going for second crop wheat or other crops. d) Most of the lands are unfragmented and it suits for drip irrigation well. e) drippers spacing mostly adopted by 1.5 and 2.0 feet. f) last three years the area was affected by Pink bollworm, hence there is a significant shift in area under cotton to other crops like groundnut. g). Average self-life of drip system is 6-7 years. Further. Constraint analysis revealed that lesser amount of subsidy by state government, rat menace, crop specific subsidy for drip irrigation for the specific year, clogging and increased price in the GST regime were some of the constraints reported by respondents.

Further analysis revealed that in the cotton based intercrop yielded additional profit. Shri. Bhurubheri Samjibheri Oobuniya, a farmer of Haripur village, Jetpur (Taluk), Rajkot district of Gujarat state cultivated Bt cotton in row spacing of 4.5 feet to 5 feet. He adopted Sesame and maize as intercrops for the season. He adopted drip fertigation for entire 5 acres of land. Maize was ready for harvest within two months and it was mainly used for fodder purposes. intercropped sesame was harvested at third month. The intercrop sesame realised the significant yield. He sold the sesame at the rate of Rs. 8500 / Q. He reported that the net profit was Rs One Lakh from Sesame cultivation from the five acres of land. The farmer realised Rs.1.5 Lakh as net profit from his five acres of cotton. In the duration of six months his net income from cotton based intercropping system was 2.5 lakhs. He reported that he was happy with the adoption of the technology "Cotton based intercropping system with Sesame and maize under drip fertigation". Thus, this case reveals that the present Central Government's Vision of "More Crop Per Drop" and "Doubling the Farmers Income" are not a distant *dream* but achievable one.

Field Survey in Gujarat Districts

Cotton marketing in Maharashtra

The study aims to assess the existing market mechanism for cotton in Maharashtra for its sustainability and profitability to study the price quality relations, harvesting and post harvesting practices and to examine the utilization pattern of cotton by-products. Data was collected from farmers and various market functionaries of four cotton growing districts Aurangabad, Amravati, Jalgaon and Yavatmal. Preliminary analysis revealed that the cotton farmers are incurring an amount of Rs. 77000 per ha towards production costs and producing about 18 q/ha of seed cotton. Five marketing channels were identified through which farmers are selling cotton in the study area. Cotton farmers most preferred point of sale is village merchants followed by traders and ginners. Highest price is realized by the cotton farmers when they sold their produce to ginners directly and the lowest price when they sold in the village to the merchants. Transport cost, delays in payment, waiting period, fear of rejection due to low quality and complicated price procedures deter the farmers to take their produce to the ginners or CCI. Procurement by CCI is observed whenever the prices are below MSP. Immediate cash payment, no transportation cost and small quantity of the produce make the farmers to prefer sale in the village itself. The practice of quality wise separate storage as well as selling is not practiced. All the cotton is stored at a single place and sold as per the requirement of the farmer. Harvesting of cotton is done in three or four pickings. Quality of the cotton harvested in first two /three pickings is superior when compared with that of last picking. As per the farmers price difference between different qualities of cotton is nominal. Hence they do not separate and sell each quality separately. Moisture content, trash and colour are the major factors considered by the traders while fixing price.

There is no commercial utilization of the cotton stalks in the study area. About 70-80 percent of the stalks are burned in the field and 10-15 percent are used as household fuel, while, very few farmers incorporate the cotton stalks in the field with the help of rotavator.



3.9 : New eco-compatible pest management strategies

3.9.1 : Bollworms

Nagpur

Push-Pull strategy for management of pink bollworm *Pectinophora gossypiella* (Saunders) in cotton

The 'push-pull' approach is an ecological based novel pest management tool that relies on the manipulation of pest behavior by utilizing attractant and repellent (deterrent) components in combination.

Identification and evaluation of vegetable oils as oviposition deterrents:

In this study, oils containing fatty acids that have proven role as oviposition deterrent in previous years were evaluated both under lab and field conditions. The crude vegetable oil samples - groundnut, sunflower, safflower, soybean, sesame and rice bran were subjected to GC-MS analysis for presence of deterrent components. Bioassays were carried out under laboratory conditions (65 ± 5% relative humidity; 14L:10 D photoperiod; 27 ± 1°C temperature) in insectary using individual oils. Moths were allowed to mate for two days and allowed to lay eggs on treated cotton twigs. Cotton twigs were dipped in eppendroff tubes provided with water and covered with parafilm to keep twigs fresh for long time. Bioassays were performed for each oil using six different concentrations (0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0%) prepared in methanol. Field evaluation of crude vegetable oils under field conditions at three different concentrations (1.0%, 2.0% and 4.0%) is continued beyond December 2019.

Identification and evaluation of plant based volatiles:

Identification of relative proportion of various components and evaluation of their role as attractants was initiated. The major compounds identified were α/β

pinene, carene, γ terpinene, α copaene, caryophyllene and humulene. The evaluation of these compounds as attractant towards pink bollworm is in progress.

Identification of oviposition deterrent for ethological management of Cotton Boll worm (*Helicoverpa armigera*)

Semiochemicals are the acceptable alternative for the management of insects as it alter the behavior of insect particularly as oviposition deterrent. Analysis of feacal pellets of cotton boll worm showed the presence of four major fatty acids *viz.,* linoleic acid (9,12-octadecadienoic acid), palmitic acid (hexadecanoic acid), myristic (Tetradecanoic acid) and stearic acid (Octadecanoic acid) and were found promising (in pure form) with a significant reduction in egg laying over control under laboratory condition. In all the compounds, deterrence was higher than 68 per cent. For this study eight oils namely, palm, groundnut, sunflower, safflower, soybean, sesame, rice bran, and shea butter were selected based on the compounds identified in previous year through GC-MS and evaluated both under lab and field conditions (on cotton and chick pea). Laboratory and field evaluation of oils is in progress.

Development of microbial biofilm formulations for cotton pest management

Screening of native bacterial isolates for biofilm preparation was continued and 325 native bacterial strains were tested on major pests such as *Pectinophora gossypiella, Helicoverpa armigera,* and *Spodoptera frugiperda* of cotton through diet based insect bioassay. Out of 325 native bacterial isolates, best 20 isolates, which have shown maximum mortality on *Pectinophora gossypiella* (>80% mortality), *Helicoverpa armigera* (>70% mortality), and *Spodoptera frugiperda* (>70 mortality) were selected for further biochemical studies (Table 3.9.1.1). The best performing and unidentified bacterial isolates were submitted for identification through 16S rRNA sequencing.

Table 3.9.1.1: Top ranking isolates based on mortality of target pest

S.N.	Pink bollworm			American bollworm			Fall army worm		
	B*	S*	M*	B*	S*	M*	B*	S*	M*
1	Not identified	188	94	Not identified	219	85	Not identified	304	91
2	*Delftia acidovorans*	148	89	*Bacillus subtilis*	3	80	Not identified	276	86
3	Not identified	313	89	*Pseudomonas spp*	174	75	Not identified	Bt 25	81
4	*Ralstonia spp*	80	89	*Pseudomonas spp*	155	75	Not identified	Bt 27	81
5	Not identified	Bt 11	83	*Pseudomonas*	165	75	Not identified	29	81
6	Not identified	Bt 20	83	*Enterobacter cloacae*	116	75	*Enterobacter spp*	23	76
7	Not identified	68	83	Not identified	261	75	Not identified	310	76
8	Not identified	198	83	Not identified	Bt 2	70	Not identified	Bt 16	71
9	Not identified	275	83	Extensimonas	150	70	Not identified	167	71
10	Not identified	315	83	Not identified	157	70	*Pseudomonas spp*	12	71

*** B=Bacteria, *S=Strain code, *M=Mortality %,**

Strain 188- *Pectinophora gossypiella* mortality rate 94%

Strain 219- *Helicoverpa armiger* mortality rate 84%

Strain 304- *Spodoptera frugiperda* mortality rate 91%

Coimbatore

Field evaluation on the efficacy of the combination lures and mixed lures against major lepidopterous pests in cotton

Field efficacy of sex pheromones *viz.*,7,11-hexadecadienyl acetate (Pink bollworm, *Pectinophora gossypiella*); (Z,E)- 9,11- tetradecadienyl acetate (Cotton leaf worm, *Spodoptera litura*); (Z)-9 - hexadecenal (American bollworm, *Helicoverpa armigera*) and (E, E) - 10, 12- hexadecadienyl (Spotted bollworm, *Earias vitella*) as individual lures, combinations and as mixtures were tested against the major lepidopterous bollworms and leaf worms of cotton. Trap catch of *Pectinophora gossypiella* and *Spodoptera litura* was found to be identical in Individual traps, combined traps & combined lure, while in the mixed lure experiment a reduction in trap catch was noticed.

Chemical profiling of a wax degrading fungus

Chemical profiling of ethyl acetate fractions of a new wax degrading fungus, *Aspergillus* fumigatus isolated from striped mealybug, *Ferritiavirgata* Cockerell was carried out. From the GC/MS analysis of extract, 43.1 % of the composition of compounds are identified and rest of them are unidentified (56.9%). The mass spectrum of each compound was compared with the NIST 05 library. All the identified major constituents are alkaloids which includes 5-Chlorobenzimidazole-2-carboxylic acid (7.06%), 1,4-Diaza-2,5-dioxo-3-isobutyl bicyclo[4.3.0]nonane (18.97%), 3,6-Bis(2-methylpropyl) piperazine-2,5-dione (7.13%), 3-Benzylhexahydropyrrolo[1,2-a]pyrazine-1,4-dione (9.94 %) (Table 3.9.1.2.) It was found that this fraction is rich in secondary metabolites.

Table 3.9.1.2 : Composition of major compounds analyzed through GC-MS

Compounds	RT	Molecular Formula	Molecular Weight	% Peak Area
5-Chlorobenzimidazole-2-carboxylic acid	20.18	$C_8H_5ClN_2O_2$	196	7.06
1,4-Diaza-2,5-dioxo-3-isobutyl bicyclo[4.3.0]nonane	22.09	$C_{11}H_{18}N_2O_2$	210	7.14
1,4-Diaza-2,5-dioxo-3-isobutyl bicyclo[4.3.0]nonane	22.46	$C_{11}H_{18}N_2O_2$	210	11.83
3,6-Bis(2-methylpropyl)piperazine-2,5-dione	27.14	$C_{12}H_{22}N_2O_2$	226	7.13
3-Benzylhexahydropyrrolo[1,2-a]pyrazine-1,4-dione	30.12	$C_{14}H_{16}N_2O_2$	244	9.94

3.9.2 : Sucking pests

Nagpur

Studies on chemical cues mediating natural enemy and sucking pest interaction in cotton

This study explores identification of volatiles emitting from the sucking pests that attract natural enemies and evaluation of their effect in enhancing natural enemies and reduction in sucking pests load.

Sucking pests (jassids and whitefly) were collected from the cotton field. For isolation of kairomones compounds whole body wash of insect was performed using methanol, with solvent volume of 5 µl whitefly and 25 µl of solvent/jassids. The compounds reconfirmed as observed in previous year with 9-Octadecenoic acid esters were major compounds in both sucking pests followed by 9,12-Octadecadienoic acid (Z,Z)-, methyl ester, hexadecanoic acid, methyl ester and methyl stearate. As the vegetable oils like groundnut, sunflower, safflower, soybean, sesame and ricebran contain these components, the field application of these oils in three different concentrations, 1.0%, 2.0% and 4.0% was taken up and observations on occurrence of natural enemies like coccinellids, *Cheilomenes sexmaculata* was recorded.

Coimbatore

Different intercrops in cotton against thrips

Summer Cotton grown with different intercrops *viz.*, marigold, vegetable cowpea, onion, french bean and groundnut was evaluated against thrips. Among these, cotton intercropped with marigold recorded reduced population of thrips. Cotton + vegetable cowpea system registered the significantly higher nitrogen (150.3 kg/ha) and phosphorus uptake (29.5 kg/ha). Cotton + marigold intercropping showed higher potassium uptake (136.5kg/ha).

Different group of insecticides against thrips in cotton

Efficacy of 10 different insecticides was evaluated against thrips in summer cotton. Among insecticides, Spinetoram followed by fipronil showed highest efficacy against thrips. The similar trend was observed in 2018-19 trial.

3.9.3 : Diseases

Nagpur

Evaluation of cotton PGPR for broad spectrum disease resistance

PGPR *Bacillus aryabhattai* (CICR-D5) + *B. tequilensis* (CICR-H3) combination followed by strains *B.*

tequilensis (CICR-H3) and *B. aryabhattai* (CICR-D5) singly were found most effective at 10^8 CFU/ml against seed and soil borne fungal pathogens (*Macrophomina phaseolina*, *Rhizoctonia solani* and *Fusarium oxysporum* f.sp. *vasinfectum*) and leaf spot diseases of cotton Cv. Suraj (*G. hirsutum*) as compared to control plots. No wilt and root rot incidence was noticed in *B. aryabhattai* (CICR-D5) + *B. tequilensis* (CICR-H3) treated plots. Minimum PDI (1.67) was recorded for *Myrothecium* leaf spot, *Corynespora* leaf spot and bacterial leaf blight in PGPR treated plots as compared to control at 60 DAS. Least PDI was recorded 120 DAS for grey mildew, *Corynespora* leaf spot and bacterial leaf blight diseases in PGPR formulation applied plots. Similarly, *B. tequilensis* (CICR-H3) strain was also found effective under *in vitro* bioassay against root knot nematode, *Melidogyne incognita*.

a) Field application of PGPR strains, b) Effect of PGPR strains treated plots Antifungal, nematicidal and insect repellent VOC's from CICR-H3 and CICR-D5 stains

Identification, characterization and antagonistic activity of cotton endophytes

About 48 endophytic fungi have been identified through ITS sequence analysis and the sequences were submitted to NCBI GenBank (Acc No. MN180847-MN180857 and MN173112-MN173148). Based on the mycelium inhibition percentage (>50 to 66%) in dual culture against *Fusarium solani* and *Corynespora cassiicola*, nine promising endophytes were selected for *in vivo* evaluation and is being carried out in pots by using different inoculation methods

An endophyte *Nigrospora sphaerica* (CEL 19) was tested for production of antimicrobial VOCs through GC/MS using methanol as solvent wherein, four compounds namely 1, 3-diethyl benzene, 1, 4-diethyl benzene, cymene-7-ol and m-ethyl acetophenone were identified, further confirming the previous results when DCM was used as a solvent (Fig.3.9.3.1.a&b) Table No. 3.9.3.1.

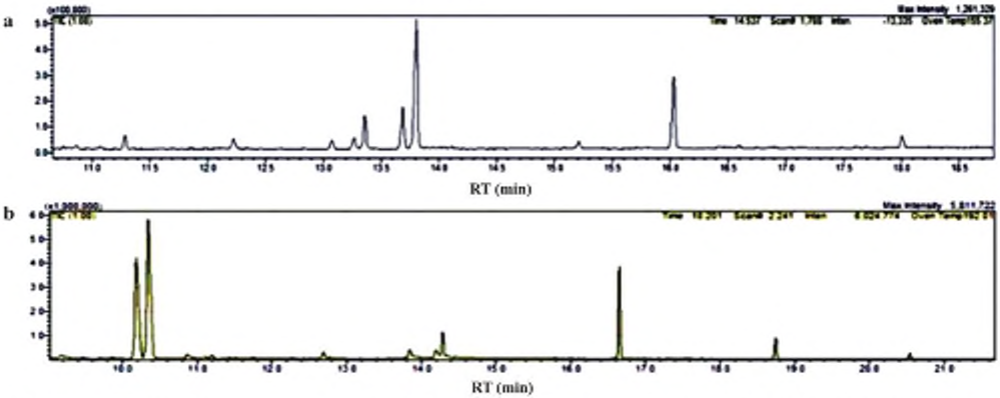


Fig.3.9.3.1 a & b: Total ion chromatogram (TIC) of endophytic Nigrospora sphaerica (CEL-19) for VOCs identification through GC-MS using DCM (a) and Methanol (b) as solvents

Table No. 3.9.3.1: List of VOCs of endophytic Nigrospora sphaerica (CEL-19) identified through GC-MS using DCM (a) and Methanol (b) as solvents

S.No.	Name of Compound	Relative abundance in DCM (%)	Relative abundance in Methanol (%)
1.	Benzene 1,3 diethyl	39.8	38.8
2.	Benzene 1,4 diethyl	46.4	51.5
3.	Naphthalene	1.37	1.62
4.	p-cymen-7-ol	2.51	---
5.	m- Ethyl acetophenone	4.16	5.1
6.	Ethanone, 1-(4-ethylphenyl) or p- ethyl acetophenone	5.69	---
7.	Nonanal	---	1.02
8.	Benzene 1,2,3 trimethyl	---	0.77

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

Seasonal Dynamics of Insect Pests and Diseases and their natural enemies

3.10.1: Sucking pests

Nagpur

Sucking pests *viz.*, jassid (*Amrasca biguttula biguttula* Ishida), aphids (*Aphis gossypii* Glover), mirid bug (*Campylomma livida Reuter)*, thrips (*Thrips spp.*), whitefly (*Bemisia tabaci* Genn.), mealybug (*Phenacoccus solenopsis* Tinsley*)*, red cotton bug (*Dysdercus cingulatus* Fab) and dusky cotton bug (*Oxycarenus hyalinipennis* Costa) were recorded on cotton in central India. Infestation of *mealybugs (Phenacoccus solenopsis* Tinsley, *Paracoccus marginatus* Williams and Granara de Willink) was in traces.

Population dynamics of sucking pests

All the sucking pests were higher in number with onset of growing season and later decreased in late season. Jassid was the most prominent pest. (Fig. 3.10.1.1). All the sucking pests were least during third week of October coinciding with heavy rain. Natural enemies *viz.*, spider and Coccinellids were recorded in good number during the season.

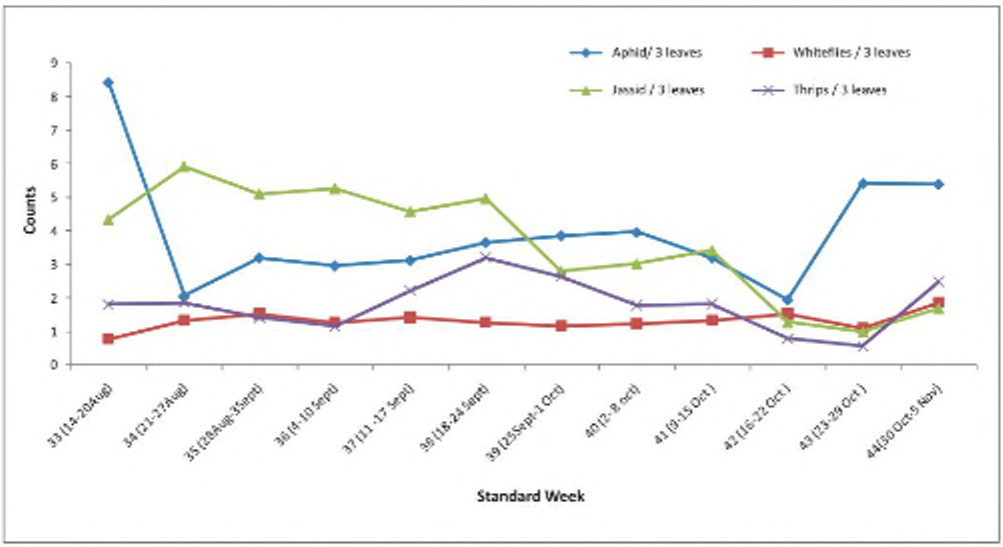


Fig.3.10.1.1: Population dynamics of cotton pests over the season in RCH 2 during 2019-20

Yellow sticky trap catches

Under protected conditions maximum jassid population 578 jassid/trap/week was trapped during 34 SMW (21-27Aug), whereas, under unprotected conditions, maximum trapped were 718 jassid/ trap/week during 35 SMW (28Aug-3Sept). Over the season, average trap catches recorded were 237 and 287 jassid/trap/week under protected and unprotected conditions, respectively. Maximum whitefly populations 225 whitefly/ trap/week and 381 were trapped during 48 (27 Nov - 3 Dec) and 35 SMW (28 Aug - 3 Sept), under protected and unprotected conditions respectively. The overall average population recorded 125 and 156 whitefly/ trap/week under protected and unprotected condition, respectively (Fig.3.10.1.2).

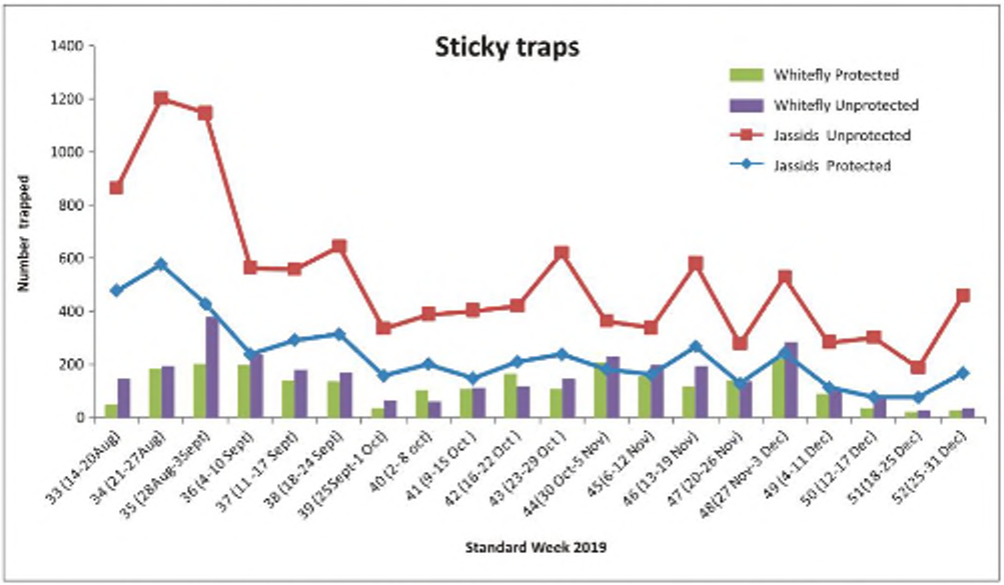


Fig.3.10.1.2: Jassid and whitefly population in yellow sticky traps during 2019-20

Sirsa

In RCH-650 BG-II hybrid leafhopper population ranged from 0.00-6.20/3 leaves peak with in 32nd SMW. Population of whitefly was initially observed in 22nd SMW (1.44 / 3 leaves) and peak activity occurred in 31st SMW (18.40 / 3 leaves). Thrips population ranged from 0.00-35.20 / 3 leaves which were first noted in 22nd SMW and peak activity observed in 27th SMW (Fig..3.10.1.3 & Fig.3.10.1.4)

In HS-6, leafhopper population ranged from 0.00-5.80/ 3 leaves, peak activity was observed in 32nd SMW. Population of whitefly was initially observed in 22nd SMW (0.60/ 3 leaves) & peak activity occurred in 30th SMW (29.50 / 3 leaves). Thrips population ranged from 0.00-31.20 / 3 leaves and peak activity in 28th SMW.

In Ganganagar Ageti (GA), the leafhopper population ranged between 0.40-6.60/3 leaves and peak activities of leafhopper was observed in 33rd SMW. Population of whitefly was initially observed in 22nd SMW (0.40/ 3 leaves) and peak activity in 30th SMW (23.40 / 3 leaves). Thrips population ranged from 0.00-31.70 / 3 leaves and peak activity observed in 27th SMW.

In RS-2013, leafhopper population ranged from 0.10-5.60 /3 leaves peak activity observed in 33rdSMW. Population of whitefly was initially observed in 22nd SMW (1.30/ 3 leaves) and peak activity occurred in 33rd SMW (18.50 / 3 leaves).Thrips population ranged from 0.00-30.80 / 3 leaves and peak activity of thrips was observed in 27th SMW.

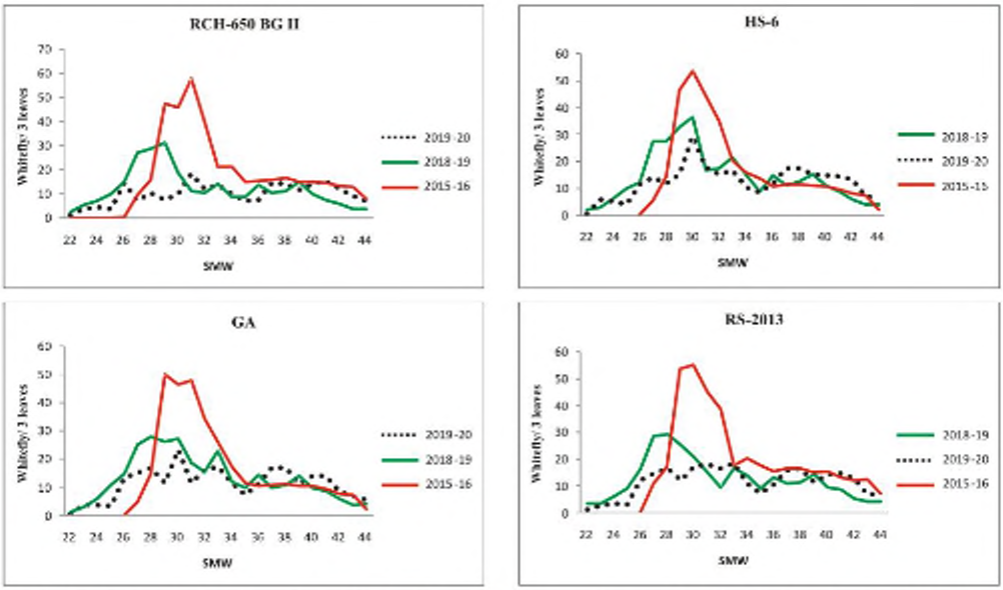


Fig.3.10.1.3: Population dynamics of Whitefly on cotton in north zone (2015-16-Epidemic year, 2018-19 & 2019-20)

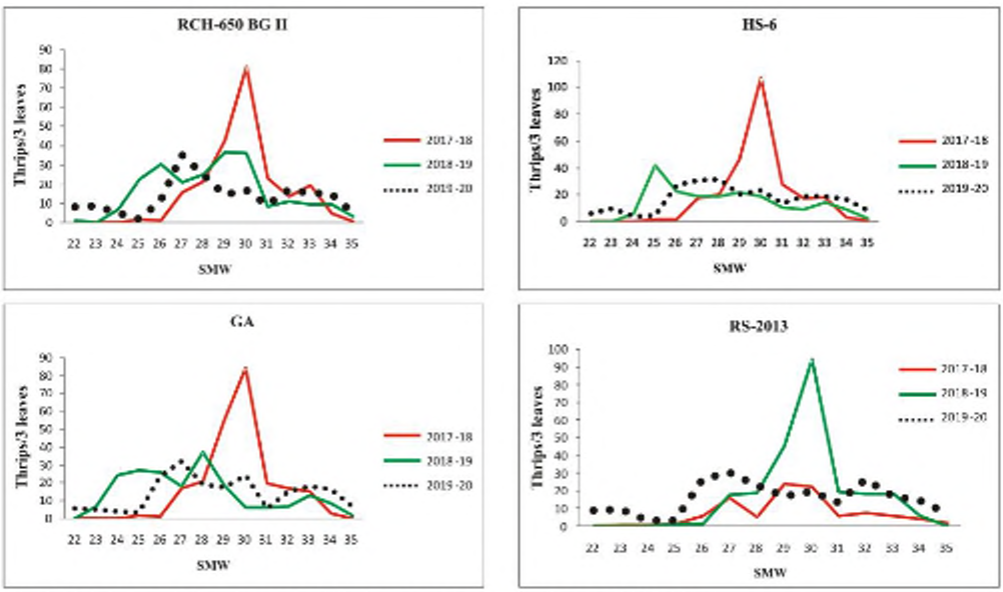


Fig. 3.10.1.4: Population dynamics (Thrips) on cotton in north zone (2017-20)

3.10.2: *Bollworms*

Nagpur

Pink bollworm (*Pectinophora gossypiella)* infestation ranged between 0-100% after 2-4 pickings in central and south India, while American bollworm (*Helicoverpa armigera)* and spotted bollworm (*Earias vitttela*) were in negligible number.

Evaluation of early (flower) and late (boll) populations of pink bollworm (PBW)

PBW in India appears in two stages, during the early flowering crop season at 60 to 80 DAS and in late season during boll development. Pink bollworm larvae collected from damaged rosette flowers and infested bolls were taken up for sequence analysis of COI region. The comparison of 36 early populations of Pink Bollworm collected from infested flowers was made with the same size of populations collected from infested bolls. The values of pairwise genetic distance between early and late populations was 0.08438 indicating moderate genetic differentiation. Significantly negative departures from zero for neutrality tests values also support population expansions. Genetic data shows that the two populations of pink bollworm, those occurring early in the season is genetically close to the late season populations with respect to their COI region (Fig. 3.10.2.1).

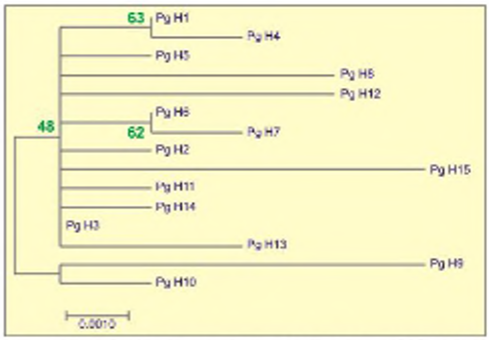


Fig. 3.10.2.1 : Phylogenetic tree of the 15mt COI DNA haplotypes in the early and late populations of *Pectinophora gossypiella*

Parasitoid infestation of Pink bollworm Larvae

Pink bollworm larvae were recovered from infested green bolls collected from different cotton growing districts of India. Dead larvae were kept for the emergence of parasitoids. Parasitization by *Apanteles angaleti* in Maharashtra was found to be in the range of 4.76% (Parbhani) to 13.04% (Yavatmal). In Gujarat, highest parasitization was recorded in Rajkot population (44.59 %) and lowest in Surendranagar (27%). In south India, the Kurnool population recorded highest parasitisation (12.50%) followed by Mehbubnagar (1.96%) population.

Endosymbionts from different geographical populations of Pink bollworm

Endosymbiotic microbiota in Pink Bollworm populations collected from 12 different districts of India was investigated. *Burkholderia* strains were isolated from most of the locations as endosymbionts. *Pluralibacter gergoviae*, *Enterobacter sp.* and *Citrobacter youngae* strain were also recorded.

Sirsa

American bollworm infestation was not observed on RCH-650 BG II. In Non Bt varieties HS-6, Ganganagar Ageti and RS-2013 first incidence of bollworm was observed in the 35th SMW which ranged from 0.34 to 7.80, 0.90-6.18, and 0.23 to 5.57 based on percent

fruiting body damage respectively in Non Bt genotypes.

PBW scenario in North india

Green boll infestations due to Pink Bollworm were studied through destructive boll sampling from Hisar, Sirsa, Bathinda, Faridkot and Sriganganagar at 90,120, 135 and 150 DAS. At these locations 4-31% pink bollworm larval recovery was observed in Non-Bt cotton at 150DAS. Though no larval recovery was recorded in BG-II cotton in three IRM adopted villages (ShamshabdPati, Panjuana, Kishanpura) and one Non-IRM Village (Kharian) in Sirsa district of Haryana. But in Jind (Haryana) under IRM project from two IRM villages (Palwan and Kirsindhu) 4.5-46.67% infestation of Pink Bollworm was recorded.

Similarly in villages namely Jodhpur Romana, Gurusar Sainewala and Sangat Mandi (Bathinda) Punjab during the months of October and November, the incidence of Pink Bollworm were observed in the fields of cotton growers in BG-II cotton fields. The damage was mainly confined to 20-25 acres of cotton crop near to Krishna Cotton Mill in Jodhpur Romana village. During the month of October, PBW incidence was below 5%, but during second fortnight of November about 30-38 % damage noticed in their fields where 2 pickings were already done from cotton crop.

Other pests

Migratory population of Fall armyworm *Spodoptera frugiperda* (Smith) (Lepidoptera:Noctuidae) was recorded to infest cotton crop cultivated adjacent to maize crop in Ahmednagar, Parbhani and Jalgaon districts of Maharashtra state. Flower chafer beetle (*Oxycetonia versicolor*) a minor pest of cotton was seen to infest cotton crop in central India.

Pheromone trap catches at Nagpur

During 2019-20, highest moth catches of American bollworm (4.6 moths/ trap/ week), Spotted bollworm (4.0 moths/trap/week) and Pink Bollworm (22.2 moths/ trap/ week) were recorded at 48SW (3 -9 Dec), 39 (1-7 Oct), 48SW (3-9 Dec) and 36SW (8-14 Sept), respectively (Fig. 3.10.2.2).

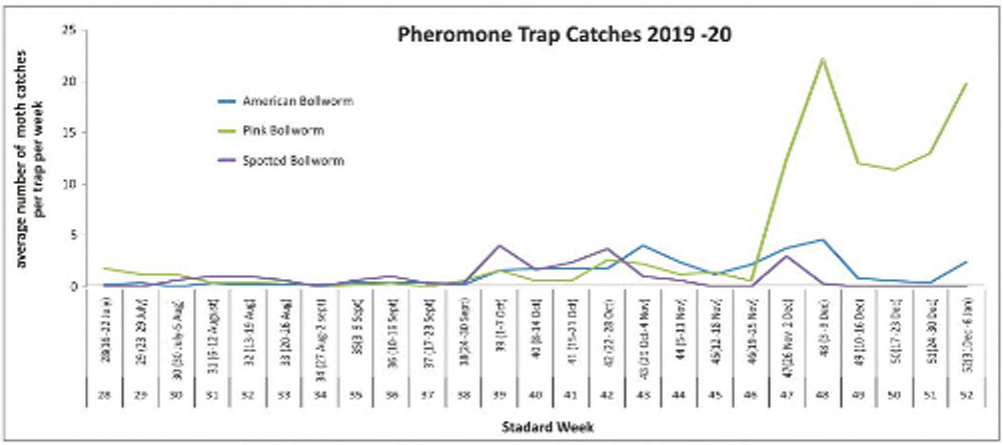


Fig. 3.10.2.2: Pheromone trap catches at Nagpur (2019-20)

Pink bollworm infestation at station trial in non-Bt and Bt cotton

Pink bollworm infestation was negligible till October end, however started increasing with the progress of season. Both Bt and non Bt cotton were found to be infested by pink bollworm however, higher infestation was recorded in non-Bt cotton. In non Bt cotton pink bollworm infestation was recorded starting from second week of November while in Bt cotton, it was started in fourth week of November (Fig. 3.10.2.3).

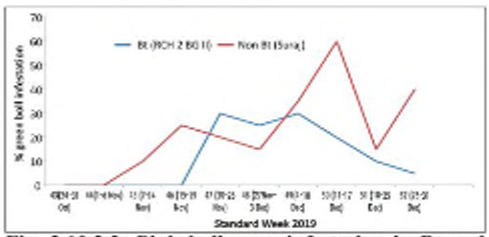


Fig. 3.10.2.3: Pink bollworm infestation in Bt and non-Bt cotton during 2019-20

Pink Bollworm infestation scenario

The per cent infestation of pink bollworm in flowers of BG-II at 60-70 days after sowing was observed in cotton growing districts of Maharashtra *viz.*, Yavatmal (10.57%), Nanded (8.00%), Parbhani (22.55 %), Akola (15.04%), Amarvati (5.77%) and Buldhana (1.38) while in Hingoli and Jalna no flower infestation was observed. Similarly the per cent infestation of pink bollworm in green bolls of BG-II at 160-165 days after sowing was observed in all cotton growing districts of Maharashtra *Viz.*, Parbhani (82 %), Yavatmal (72%), Hingoli (69%), Jalna (66.7%), Akola (62.67%), Nanded (60 %), Wardha (44 %), Aurangabad (42 %), Buldhana (37.33 %) while in Amravati nil incidence was recorded. Infestation on BG II cotton in Gujarat was in range of 0 to 8.00 per cent with highest in Vadodara district (8.00 %) at 80-90 DAS. In Telangana at 140-150 DAS the incidence of PBW was observed in Adilabad at 10.90% while in Kommaram bheem and Nirmal district infestation was below ETL. At 160-170 DAS in Ananthapur and Kurnool district of Andhra Pradesh, Raichur, Bellary and Yadgiri district of Karnataka and Mahaboobnagar district of Telangana infestation above ETL was observed. However, the pink bollworm infestation in North India (Punjab, Haryana and Rajasthan) at 140-150 DAS was recorded nil on BG-II hybrids except in Jind district of Haryana and Bhatinda district of Punjab with 6.90 % and 1.00% of incidence respectively. Similarly at 180 DAS PBW incidence of 69.60 % and 28.00 % was observed in Jind district of Haryana and Bhatinda district of Punjab respectively.

Seventeen teams consisting of Scientists and technical personnel conducted random surveys in 56 districts of 7 cotton growing states of India during October to December 2019. Till October infestation of pink bollworm (PBW) was negligible in central and south India. The survey teams visited 14 districts of Maharashtra (Yavatmal, Wardha, Nagpur, Amravati, Akola, Buldana, Jalgaon, Dhule, Nandurbar, Nanded, Hingoli, Parbhani, Beed and Ahemednagar), 13 districts of Gujarat (Bharuch, Ahmadabad, Vadodara, Surendranagar, Rajkot, Junagadh, Amreli, Bhavnagar, Mehsana, Banaskantha, Sabarkantha, Patan, Chhota Udaipur), 9 districts of Telangana (Adilabad, Mahabubabad, Warangal rural, Warangal urban, Karimnagar, Peddapalli, Narayanpet, Nirmal, Kumuram Bheem), 5 district of Madhya Pradesh (Khandwa, Khargone, Dhar, Barwani, Chhindwada), 5 districts of Karnataka (Dharward, Haveri, Raichur, Bellari, Yadgiri), 3 districts of Andhra Pradesh (Guntur, Prakasam, Kurnool) and 2 districts of Tamil Nadu (Coimbatore, Erode) covering 425 locations. State wise average percent infestation recorded as Madhya Pradesh- 33.4, Gujarat -30.42, Maharashtra -25.85, Andhra Padesh-17.46, Karnataka- 9.00. Telangana- 8.09 and Tamil Nadu- 7.23. During the survey 2-4 pickings were over at several locations (**Fig. 3.10.2.4**).

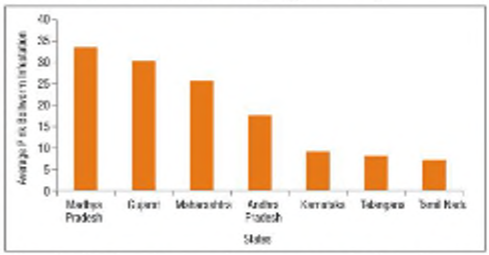


Fig. 3.10.2.4 : **State wise average pink bollworm infestation during 2019-20**

3.10.3: Disease Prevalance

Prevalance of *Xanthomonas citri* pv. *malvacearum* races of Cotton

Bacterial blight of cotton (BLB) caused by *Xanthomonas citri* pv. *malvaceulum* is an important disease of cotton. Bacterial blight infected cotton leaf samples (12) were collected from different cotton growing areas of Maharashtra (6 no.), Gujarat (3 no.) and North India(3 no.). Pathogenicity of all 12 isolates was confirmed on one month old seedling by syringe infiltration technique. The artificially inoculated leaf showing symptoms of BLB were again re-isolated to confirm the pathogenicity of original isolates. Biochemical and Molecular characterization of these isolates is progress.

1 Leaves showing the typical symptoms leaf blight

Oily spots observed on green bolls of cotton

Coimbatore

Symptom expression, host range, transmission studies with *Tobacco streak virus* (TSV) infecting cotton

Serological detection of *Tobacco Streak Virus* in the different plant parts of advance generations of *Gossypium barbadense* were carried out by DAS-ELISA. The different plant parts used for detection include root, stem, petiole, leaf, squares and pollen grains. It was observed that the absorbance value was more in leaf followed by petiole and squares **(Table 3.10.3.1).**

Table 3.10.3.1:Serological detection of TSV in the different plant parts of *Gossypium barbadense*

S. No	Advance generations	Root	Stem	Petiole	Leaf	Squares	Pollen grains
1.	CCB 129	1.236 (0.08)	1.789 (0.08)	2.287 (0.08)	3.237 (0.09)	2.220 (0.03)	1.119 (0.03)
2.	CCB 143	1.114 (0.05)	1.685 (0.05)	2.145 (0.05)	2.156 (0.05)	2.113 (0.09)	1.112 (0.02)
3.	CCB 64	1.115 (0.06)	1.520 (0.06)	2.210 (0.02)	3.193 (0.04)	2.118 (0.05)	0.998 (0.06)
4.	CCB 11	1.113 (0.04)	1.452 (0.08)	2.145 (0.06)	2.552 (0.03)	2.119 (0.08)	0.875 (0.05)
5.	CCB 11a	1.118 (0.06)	1.326 (0.09)	2.365 (0.08)	2.112 (0.07)	2.002 (0.02)	0.897 (0.06)
6.	CCB 26	1.119 (0.09)	1.258 (0.06)	2.114 (0.07)	2.345 (0.09)	2.006 (0.04)	0.568 (0.04)
7.	CCB 28	1.201 (0.08)	1.652 (0.06)	2.213 (0.07)	2.356 (0.09)	2.007 (0.05)	0.789 (0.05)
8.	CCB 29	1.203 (0.07)	1.456 (0.07)	2.140 (0.08)	2.564 (0.08)	2.008 (0.06)	0.226 (0.06)
9.	CCB 51	1.206 (0.05)	1.325 (0.08)	2.012 (0.05)	2.542 (0.06)	2.006 (0.07)	1.025 (0.05)
10.	CCB 51-2	1.205 (0.08)	1.234 (0.09)	2.031 (0.08)	2.411 (0.05)	2.003 (0.09)	1.042 (0.04)
11.	CCB 141	1.238 (0.06)	1.785 (0.05)	2.270 (0.05)	2.879 (0.07)	2.114 (0.08)	1.115 (0.05)
12.	CCB 142	1.115 (0.07)	1.256 (0.06)	2.014 (0.08)	2.213 (0.03)	2.115 (0.07)	1.032 (0.07)
13.	S X P	1.113 (0.04)	1.236 (0.04)	2.112 (0.08)	2.102 (0.04)	2.114 (0.06)	1.045 (0.05)
14.	Suvin (Control)	1.238 (0.05)	1.880 (0.05)	2.285 (0.08)	3.865 (0.09)	2.221 (0.04)	1.118 (0.08)

Molecular detection was achieved through RT-PCR which resulted in the amplification of coat protein gene of ~929 bp in all the TSV infected samples of *Gossypium barbadense*. Typical leaf symptoms from CCB 29, ICB 25 and Suvin were used for sap transmission studies on cowpea (CvCO7) seedlings. Symptoms like chlorotic lesions, necrotic lesions, necrotic spots, veinal necrosis, systemic symptoms, necrosis on petioles, stem necrosis and total necrosis were observed on cowpea seedlings at 3 to 7 days after inoculation. Viral inoculum was maintained artificially in different hosts under insect-proof net house conditions. Necrotic lesions were observed in greengram, black gram and soybean. Necrotic lesions and chlorotic lesions were observed on

mechanical inoculation on *Gossypium barbadense* (Suvin, ICB 25, CCB 11, CCB 29 and MRC 7918) and *Gossypium hirsutum* (Suraj and Mallika Bt) after 5 to 8 days of inoculation. Mosaic symptom and necrotic lesions were observed on Cucurbitaceae family hosts after 5 to 8 days of inoculation. Chlorotic lesions were observed on *Chenopodium amaranticolor* and *C.quinoa* 3 to 5 days after inoculation. Curling and necrotic lesions were observed on Nicotiana rustica and Nicotiana tabacum after 8- 17 days of inoculation.

3.11: Integrated Pest Management

Field evaluation of egg parasitoid *Trichogramma species* against pink bollworm

A field trial was conducted for evaluation of egg parasitoid *Trichogramma bactrae*, *Trichogramma brasiliensis* and *Trichogramma chilonis* through inundative release. Two weekly interval releases at flowering (40-55 DAS) and boll formation (60-75 DAS) stage along with a botanical, a microbial and two insecticides at 60-70 DAS, 70-80 DAS and 80-90 DAS were carried out. The observation were taken at ten days interval from 100DAS.

In all the treatments, in green bolls, number of exit holes, number of mines on the epicarp, number of larvae and per cent locule damage were recorded at ten days interval. From the seven treatments, Cypermethrin 4%EC+Profenophos 40% treatment was most promising with 13.49 per cent locule damage. The *T.bactrae* with 14.69 per cent locule damage was most effective among three parasitoids tested (Fig 3.11.1).

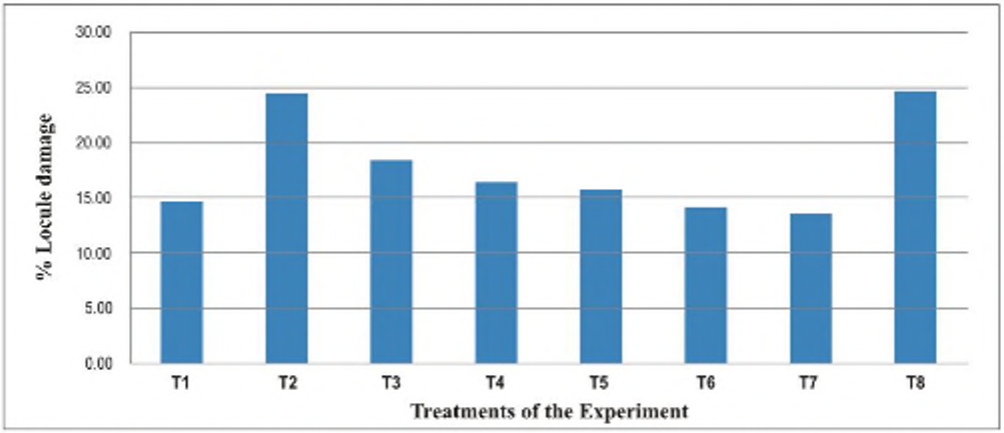


Fig 3.11.1:Evaluation of egg parasitoid *Trichogramma species* for management of pink bollworm *Pectinophora gossypiella* (Saunders) in field conditions. T1- T. bactrae, T2-T. brasiliensis, T3-T. chilonis, T4-Beauveria bassiana, T5-Neem oil, T6-Profenophos 50EC, T7-Cypermethrin 4% EC + profenophos 40% EC, T8- Control (water spray)

Resistance Monitoring

The resistance development in 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 23 districts namely Wardha, Yavatmal Washim, Hingoli, Nanded, Parbhani, Aurangabad, Buldana, Akola, Amravati, Rahuri, Jalgaon districts of Maharashtra; Surat, Bharuch, Vadodara, Anand, Ahmedabad, Bhavnagar, Amreli, Junagadh, Rajkot and Surendranagar districts of Gujarat, in South India 10 districts namely Ananthapur and Kurnool district of Andhra Pradesh; Adilabad, Komaram bheem, Nirmal and Mahaboobnagar district of Telangana, Raichur, Bellary, Yadgiri district of Karnataka were surveyed and monitored for pink bollworm infestation.

The populations were collected from the damaged green bolls of Bt and Non Bt cotton across India for conducting the resistance monitoring studies against Cry1Ac and Cry2Ab. The collected populations were reared on the semi-synthetic diet up to F_1 generation and later subjected to Cry toxin bioassay. Resistance monitoring was carried out with twenty nine populations collected, of these five population were from North India, nineteen from Central India and five populations were from South

India. The populations were subjected to Cry1Ac and Cry2Ab log doses assays. All populations of North India were susceptible to Bt toxins except population of Jind district of Haryana.




Leaf hoppers

In order to determine the resistance of leaf hopper to different insecticides, the leaf hopper populations were collected from Chandrapur, Wardha and Nagpur districts of Maharashtra and subjected to eight insecticide bioassay *viz*., Flonicamid, Monocrotophos, Acephate, Acetamiprid, Thiamethoxam, Imidacloprid, Acephate, Spiromesifen and Clothianidin at ICAR-CICR, Nagpur. The results indicated that, LC_{50} value to Flonicamid ranged from 0.004 mg/L (Chandrapur) to 0.284 mg/L (Wardha). Monocrotophos from 0.012 mg/L (Chandrapur) to 0.113 m g/L (Nagpur). Acephate from 0.013 mg/L (Chandrapur) to 0.052 mg/L (Nagpur). Imidacloprid from 0.012 mg/L (Chandrapur) to 0.048 mg/L (Wardha). Acetamiprid from 0.014 mg/L (Chandrapur) to 0.309 mg/L (Nagpur), Thiamethoxam from 0.005 mg/L (Chandrapur) to 0.24 mg/L (Wardha). Spiromecifen from 0.013 mg/L (Chandrapur) to 0.027 mg/L (Nagpur). Clothianidin from 0.012 mg/L (Chandrapur) to 0.028 mg/L (Wardha). Populations from Chandrapur were more susceptible to Flonicamid, Thiomethoxon, Acetamiprid, Imidaclopride, Acephate, Spiromesifen, Monocrotophos and Clothianidin.

Coimbatore

Identification of resistant genetic sources for Reniform nematode and mechanism of resistance

Screening of 29 *G.hirsutum* genotypes for identification of resistance to Reniform nematode was carried out. Elevated level of P peroxidase, G peroxidase, phenol and reducing sugar were recorded at 11 days post infection in all genotypes. Time taken to reach different developmental stage varies with the germplasm tested. There was significant difference in root and soil nematode population in different germplasm with BB-6-1-2 recording significantly low population. A positive correlation between nematode resistance and P peroxidase, G peroxidise and phenol was observed.

Investigation on the susceptibility status and possible detoxification mechanism for neonicotinoids and newer molecules against cotton leafhopper

Out of nine insecticides tested (Chlorpyrifos, Thiodicarb, Flonicamid, Spiromesifen, Thiamethoxam, Imidacloprid, Thiacloprid, Diafenthiuron and Clothianidin), cotton leafhopper *A. biguttula biguttula*

was highly susceptible to thiamethoxam. The level of detoxification enzymes viz., esterase and mixed function oxidases were higher in insecticide exposed leafhoppers. The esterase activity was higher (21.614 uM napthol / min / mg protein) in thiamethoxam exposed insects. The activity of mixed function oxidase (MFOs) was higher in spiromesifen (118.17 nM cyto/min/mg protein) followed by thiamethoxam (117.30 nM cyto/min/mg protein) exposed leafhopper. As compared to control the activity of MFOs was reduced in clothionidin, flonicamid and diafenthiuron exposed leafhoppers.

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

The level of antioxidant enzymes present in the thermal stress exposed mealybugs and their enemies were studied. Irrespective of the population, the enzyme activities *in P. solenopsis* were significantly affected by increase in treatment temperatures. The activity of catalase (CAT), peroxidase (POD) and super oxide dismutase (SOD) in *P. solenopsis* were significantly increased as compared to control. The activity of SOD in *P. marginatus* was increased at higher temperature whereas there were no significant differences in POD level. The activity of CAT was higher in *P. solenopsis* parasitized by A. *arizonensis* at 34°C. However, no significant difference was observed in the level of peroxidise.

Sirsa

Field study of IPM and biocontrol modules against whitefly

A field trial was conducted at ICAR- CICR Regional Station, Sirsa during 2018-19 and 2019-20 to evaluate the existing IPM module with three new IPM modules and three biocontrol modules along with commercial formulation of *Lecanicillium lecanii* and untreated control. The area under whitefly reduction curve (AUWRC) of pooled data revealed that the Bio module-1 (2 sprays each of neem+*Isaria javanica* CICR-RSS-0102) followed by existing IPM module (2 sprays each of neem+ flonicamid + spiromecifen), IPM module-3 (2 spray of neem+Flonicamid @ 1ml/L+ *Metarhiziumanisopliae* -1299) and Bio module-2 (2 sprays each of neem + *Beauveria bassiana*-4511 showed higher nymphal mortality than untreated control and other modules (Fig 3.11.2). The lowest CLCuD PDI was recorded in new IPM module-3, followed by IPM module-1, -2 and Bio module-3. However the highest seed cotton yield was recorded in IPM module-3 (25.4Q/ha) followed by Bio module-3 (25.3Q/ha). The new IPM module and Bio modules were at par with respect to the nymphal mortality, seed cotton yield, and CLCuD PDI. Based on economics of the four-spray applications, the Bio modules and new IPM modules can save up to Rs. 2250/- and Rs. 1500/- per ha over existing IPM module, respectively. Also, the entomopathogenic fungi used in bio and IPM modules are compatible with the recommended chemical insecticides for whitefly management.

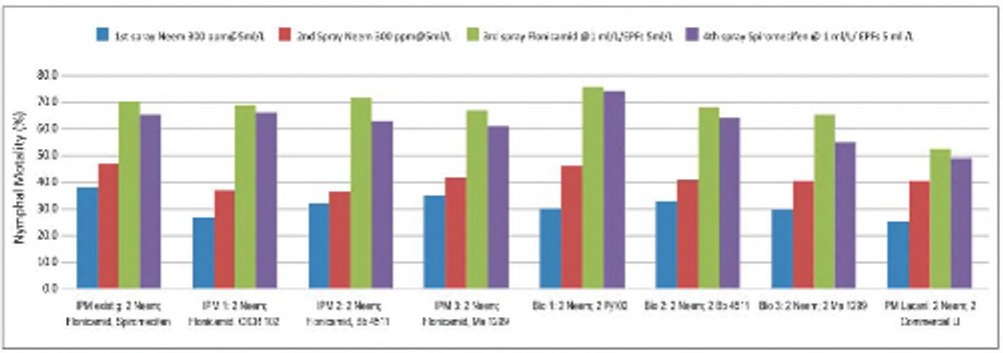


Fig 3.11.2: **Pooled Corrected mortality at 7 DAI 2018-19 & 2019-20**

IPM Strategies to combat whitefly infestation

A retrospective study on weather parameter triggering whitefly infestation studied using past data AICRP on Cotton for three North Zone locations at Faridkot, Hisar and Sriganganagar. Infestation level of whitefly shows significant change over different time periods (Table 3.11.1). There was also significant change in the peak occurrences of whitefly in all three locations (Fig 3.11.3)

Table 3.11.1: Average whitefly infestation per three leaves

	2005-06 to 2009-10 (Period 1)	2010-11 to 2018-19 (Period 2)	Increase (%) from period 1 to period 2	Peak Occurrence
Faridkot	2.99	8.2	174%	21.84 (2015-16)
Hisar	5.37	23.34	334%	66.40 (2017-18)
Sriganganagar	17.36	19.56	13%	50.92 (2014-15)

Faridkot | Hisar | Sriganganagar

Fig 3.11.3: Average whitefly infestation per three leaves

Statistical Regression (log-linear) Model: Statistical Model (log-Linear) was developed for the whitefly population (dependent variable) against the weather parameters (independent Variables) *viz*., Maximum Temperature, Minimum Temperature, Rain Fall, Morning Relative Humidity, Evening Relative Humidity etc. The model attempted for three different scenarios - whitefly scenario based on the same week, previous week and week before previous week climatic factor.

The model estimates that Maximum temperature had high influence in decreasing whitefly infestations in all three locations especially after 2015-16. In contrary, Minimum temperature had high influence in increasing whitefly infestations in all three locations. Other weather parameter did not show any pattern or consistency over the years on whitefly infestation.

Bioefficacy of insecticides and biorationals against thrips and leafhoppers

Under the common trials conducted for GEAC approved genotypes and testing of agrochemicals during 2019-20, the efficacy of label claim insecticides studied under laboratory conditions against leafhopper recorded mortality (%) ranging from 26.67 to 72 percent. The maximum mortality (%) was observed in flonicamid (72), followed by dinotefuran (70), thiacloprid (57.33), acephate (55.33) and imidacloprid (56.67). Similarly for thrips also label claimed insecticides were screened under laboratory conditions and recorded mortality (%) ranging from 16.33 to 76.33 percent. The maximum mortality (%) was observed in Spinosad (76.33), followed by dinotefuran (70), thiacloprid (57.33), acephate (55.33) and imidacloprid (56.67).

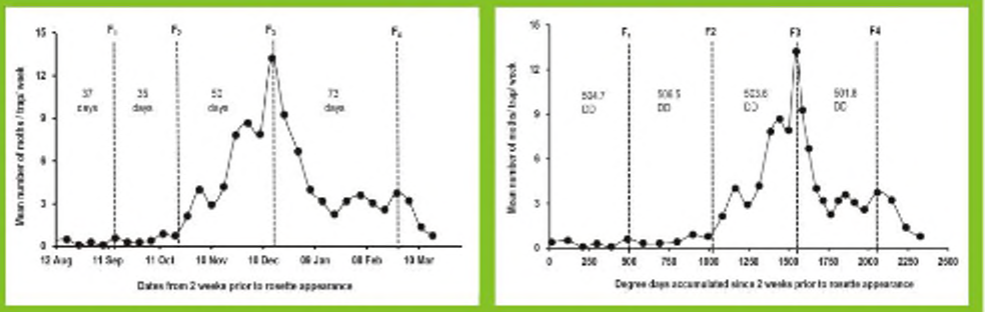
3.12: Development of new detection methods, tools and protocols

Degree-day based phenology model for cotton pink bollworm (*Pectinophora gossypiella*)

Development of degree-day based phenology model for predicting the developmental events of cotton pink bollworm (Saunders) in field was taken up. Lower and upper developmental temperature thresholds of 13.0 and 34.0 °C were determined for PBW, using a coefficient of variation (CV) technique of degree-day (DD) accumulations. Eight years (2009, 2012-2018) field data on pheromone trap catches of male moths recorded at Nagpur (Maharashtra) were used for DD accumulation between the consecutive moth peaks starting from beginning of the emergence, employing a sine wave method with horizontal upper cut-off. The combination of lower and upper developmental thresholds with the lowest CV of DD between events was accepted. The estimated thresholds and DD were validated at different locations across the North (Faridkot, Haryana), Central (Surat and Junagadh, Gujarat) and South (Dharwad, Karnataka) cotton growing zones of India. Two weeks prior to rosette appearance was used as starting point for DD accumulation assuming peak in-field infestation. Using 13.0/34.0 °C thresholds, the mean heat units (HU) accumulated between the consecutive moth peaks (one in field generation, adult to adult) were estimated at

504.05 ± 4.84 DD. Asynchronous moth peaks of eight years fairly coincided when plotted on HU scale. Seven generations were determined for PBW in a cropping season, the length of which varied between 35 - 73 days in response to temperature. Validation of model provided closer estimates across the tested locations. In the context of climate change, the present findings are crucial in predicting the dates of moth emergence, oviposition and egg hatch in PBW, which will aid in undertaking timely management strategies.

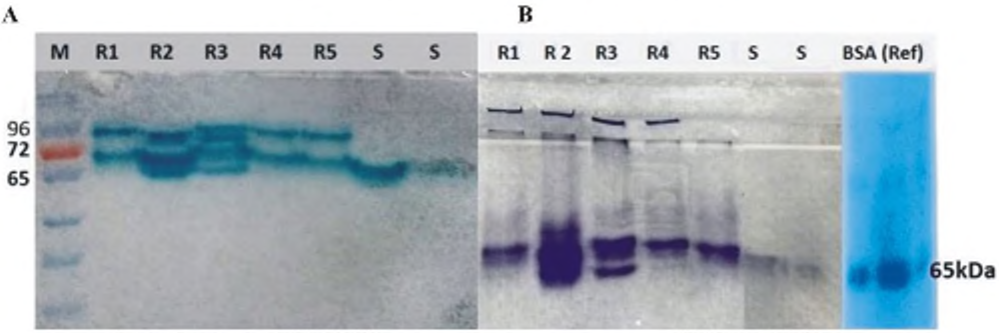
Prediction of in-field generation events



✓Field data on rosette flowers, green boll damage & moth trap catches for the cotton season 2018-19 at experimental field (C-19) of ICAR-CICR, Nagpur

Characterization of midgut alkaline phosphatase activity associated with Cry2Ab resistance in Pink Bollworm populations

Alkaline Phosphatase is one of the receptor which adheres to brush border membrane of midgut of PBW larvae. PBW larvae resistant to Cry2Ab toxins have shown higher alkaline phosphatase activity than the susceptible population (Fig.3.12.1). PBW larvae resistant to higher concentration to Cry2Ab have also shown protein bands in the range of 72kDa to 95kDa while susceptible population showed isozymes in the range of 55kDa to 65kDa with lower enzymatic expression. Midgut alkaline phosphatase is probably a key biomarker associated with Cry2Ab resistance in Pink Bollworm populations.



A] non-denaturing SDS PAGE B] Native PAGE]

Fig.3.12.1:Gel electrophoresis for enzymatic activity of alkaline phosphatase in resistant and susceptible PBW protein samples [M- marker, R- Resistant population, S- Susceptible population. A] non-denaturing SDS PAGE B] Native PAGE]