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New Delhi-110012

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2018-19

ICAR - Indian Agricultural Research Institute
(Deemed University)
New Delhi-110 012

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PREFACE

The Indian Agricultural Research Institute (IARI) continues its leadership role in basic, strategic and applied agricultural research, education and extension in India. For sustainable food, nutritional and livelihood security, agricultural exports and farm profit, the Institute has developed new crop varieties/hybrids with improved yield, quality and climate resilience. In food crops, three wheat varieties, one rice variety and two maize hybrids were released for commercial cultivation during this year. Wheat variety HD 3226 with inbuilt resistance to all three rusts, Karnal bunt, powdery mildew, flag smut and foot rot diseases with an average yield of 5.75 t/ha was released for commercial cultivation under irrigated timely sown conditions of North Western Plains Zone (NWPZ). It also has high nutritional quality with grain protein content of 13 %. Two bread wheat varieties viz., HD 3237 with an average yield of 4.84 t/ha, and HI 1620 with an average yield of 4.91 t/ha were released for commercial cultivation under restricted irrigation conditions in NWPZ. Pusa Samba 1850, a MAS-derived near isogenic line of a popular slender grain rice variety, BPT 5204 (Samba Mahsuri), possessing *Pi54*, *Pi1* and *Pita* genes for blast resistance was released for the states of Chhattisgarh and Odisha. Sweet corn hybrid, Pusa Super Sweet Corn 1 which matures in 78 days and yields 9.3 and 16.2 t/ha of cobs and green fodder, respectively, was released for Northern Hills Zone (NHZ), North Western Plains Zone (NWPZ), North Eastern Plains Zone (NEPZ) and Peninsular Zone (PZ). Pusa Jawahar Hybrid Maize 1 (PJHM 1) was released for cultivation in Madhya Pradesh.

Eleven varieties/hybrids of different vegetable crops viz., onion (Pusa Sona), garden pea (Pusa Prabal), brinjal (Pusa Safed Baingan 1 & Pusa Hara Baingan 1), long melon (Pusa Utkarsh), round melon (Pusa Raunak), musk melon (Pusa Madhurima), Sarda melon (Pusa Sarda), Chenopodium (Pusa Green), cucumber (Pusa Parthenocarpic Cucumber 6) and okra (Pusa Bhindi 5) and two F_1 hybrids in bitter gourd (Pusa Hybrid 4) and sponge gourd (Pusa Shrestha) have been notified by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Horticultural Crops in 2019. In addition, cabbage F_1 hybrid Central Cabbage Pusa Hybrid 81 and a Kale variety, Central Kale Pusa 64 were also released. In grape, the Delhi State Variety Release Committee notified grape hybrid, Pusa Aditi (Banqui Abyad x Perlette) for Delhi State and NCR region.

The Institute has developed crop and resource management technologies for different farming systems. A horticulture crop-based integrated farming system with a net income of Rs.2.4 lakhs per acre per year has been developed. GreenSeeker and Nutrient Expert® (NE) as decision support systems for precision nitrogen application was developed which saves up to 26 kg nitrogen/ha and thus reducing the cost of cultivation and adverse environmental impact. Conservation agriculture (CA)-based ICM module was developed in pigeon pea with 1.92 t/ha yield and profitability of Rs.82,776/ha. CA based cotton-wheat system was developed which gave 44.1% higher system productivity than conventional tillage with a saving of 25-30% N and emerged as a superior alternative to rice-wheat system. Nitrogen - nanoclay polymer composites (NCPC) was developed and found most efficient in enhancing yield of maize. Rock-phosphate and waste mica treated with phosphate and potash solubulizing bacteria were found as alternate sources of P and K. In farm machineries, gladiolus corm harvester, low cost storage structure for rural areas, spinach-cum-coriander offset rotary cutter were developed. Bio-prospecting rhizospheric and endophytic cyanobacterial diversity led to identification of 25 strains belonging to *Plectonema* sp., *Phormidium* sp., *Nostoc* sp. and *Anabena* sp. Inoculation with osmotolerant bacteria (*Bacillus casamancenis* MKS6 and *Bacillus* sp. MR D17) were found to boost drought tolerance of mustard crop.

Novel methods for diagnostics and integrated pest management were developed. A rapid loop mediated isothermal amplification based protocol was developed for detection of Karnal bunt pathogen in wheat and bakane pathogen of rice. Synthetic compounds active against *Sclerotium rolfsii, Alternaria solani* and root knot nematode (*M. incognita*) were identified. A nano emulsion with significant antifungal activity effective against both *R. solani* and *S. rolfsii* was identified. In addition, five potent antifungal halogen substituted benzylidene aryl amines were identified and synthesized for their formulation development. In nematodes, RNAi silencing was used to discover the roles of *ama-1* and *mad-2* genes of *M. incognita* on infection, development and reproduction of the nematode in tomato. Tomato leaf curl New Delhi virus-derived AC4 protein was found to suppress host RNA silencing mechanism and auxin biosynthesis.

The CRISPR-Cas9 genome editing technology was standardized for different crops to enhance stress tolerance and nutritional quality. In rice, CRISPR-Cas9 genome editing was employed to develop mutants of *DST* (*DROUGHT AND SALT TOLERANCE*) gene for improving salt and drought tolerance. To reduce the seed phytate content, CRISPR-Cas9 genome editing was used to mutate *GmIPK1* gene. T0 lines showed about 6-9-fold reduction in phytate content. Overexpressing abscisic acid receptor *OsPYL10* and *Isopentenyltransferase 9* (*IPT9*) genes were found to confer drought and salt stress tolerance to transgenic rice.

Phenomics was used to identify germplasm and breeding lines with high water use efficiency (WUE) and drought tolerance in the major food crops. Genotypes which use significantly less water than that of Nagina 22 in rice and RILs of wheat superior to C 306 in WUE were identified. Elevated CO_2 (EC) mediated decrease in nitrate uptake and assimilation was found to be a cause for reduction in grain quality under EC conditions. Genome-Wide Association Studies (GWAS) and linkage-mapping analyses were used to identify QTLs for stress tolerance and yield in different field and horticultural crops. Marker-assisted breeding approach was used to pyramid genes for all three types of rust resistance in wheat. Marker-assisted backcross breeding was employed to transfer an herbicide tolerance mutant allele of *ALS* gene from Robin, an Imazethapyr tolerant EMS-induced mutant of Nagina 22, into two elite *Basmati* rice varieties viz., Pusa Basmati 1121 and Pusa Basmati 1509. Genome wide association study (GWAS) was employed in rice to map significant QTLs for Fe and Zn for enhancing the endosperm mineral micronutrient density as rice is widely consumed after polishing. In pearl millet, QTLs for grain Fe and Zn content were mapped using 210 RILs (PPMI 683 × PPMI 627). In vegetable crops, doubled haploid production has been standardized in cauliflower, cucumber and onion. QTLs for disease resistance and MAS led to identification of new QTLs and introgression of known QTLs for different quality traits and disease resistance in vegetable crops.

Remote Sensing and GIS approaches have been used to develop methods for crop and resources management. Drone remote sensing method for field phenotyping was developed with multispectral sensor for monitoring nitrogen and drought stress in wheat. In a collaborative study with ISRO and NASA, ground based spectroradiometer and air borne AVIRIS –NG instrument were used to map eight horticultural crops in Sabour, Bhagalpur region of Bihar. Crop residue burning is a major problem in Punjab and Haryana. The Institute has developed method for real-time monitoring of crop residue burning by using thermal image acquired from seven satellites at the IARI satellite ground station.

The School of Social Sciences and Technology Transfer worked in the major areas of Farmer Producer Organization (FPO), Aadhar enabled Fertilizer Distribution System (AeFDS), tariff hike on crude and refined palm oil, tank irrigation system, bioenergy potential of crop residues, Farmer Led Innovations (FLIs), Nutritional Security and Innovative extension models. Under IARI-Post office Linkage Extension Model, seeds of IARI varieties were disseminated to the farmers of different states. Under *Mera Gaon Mera Gaurav*, the flagship programme of Govt. of India, scientists established linkage with more than 600 villages for technology dissemination.

Pusa Krishi Vigyan Mela 2019 with a major theme of "*Krishi Vikas: Innovative Technologies*" was organized by the institute during March 5-7, 2019. The *mela* was inaugurated by Dr. Trilochan Mohapatra, Secretary (DARE) & DG (ICAR) and then Hon'ble Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh, also graced the *mela*. Over one lakh visitors and 170 public and private exhibitors from across the country participated and gained from the *mela*. The Agricultural Technology Information Centre (ATIC) continues to provide products, advisory services, technologies and information to the farmers and other stakeholders through a single window delivery system. The Institute has conducted 1471 demonstrations during this year.

The Institute remained top destination of higher education in agriculture. The 57th Convocation of the Post Graduate School of the IARI was held on February 8, 2019. During this Convocation, 239 candidates (123 M.Sc., 22 M.Tech. and 94 Ph.D.), including 08 international students, were awarded degrees. IARI played key role in establishing Advanced Centre for Agricultural Research and Education (ACARE) at Yezin Agricultural University, Myanmar which was dedicated to people of Myanmar on December12**,** 2018 by the Hon'ble President of India, Shri Ram Nath Kovind.

I congratulate the staff and students of IARI who contributed to the advancement of basic and strategic research, development of technologies, and received prestigious awards/recognitions and brought laurels to the Institute. The Institute's achievements during this year will have significant impact on enhancing farm productivity and income.

I appreciate Dr. Ashok K. Singh, Joint Director (Research) and the multidisciplinary editorial team for compiling and bringing out this report in time.

July 10, 2019
New Delhi-110012

(A.K. Singh)
Director

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IARI : An Introduction

Originally established in 1905 at Pusa (Bihar) with the financial assistance of an American Philanthropist, Mr. Henry Phipps, the Indian Agricultural Research Institute (IARI) started functioning from New Delhi since 1936 when it was shifted to its present site after a major earthquake damaged the Institute's building at Pusa (Bihar). The Institute's popular name 'Pusa Institute' traces its origin to the establishment of the Institute at Pusa.

The Indian Agricultural Research Institute is the country's premier national Institute for agricultural research, education and extension. It has the status of a 'Deemed-to-be-University' under the UGC Act of 1956, and awards M.Sc./ M.Tech. and Ph.D. degrees in various agricultural disciplines.

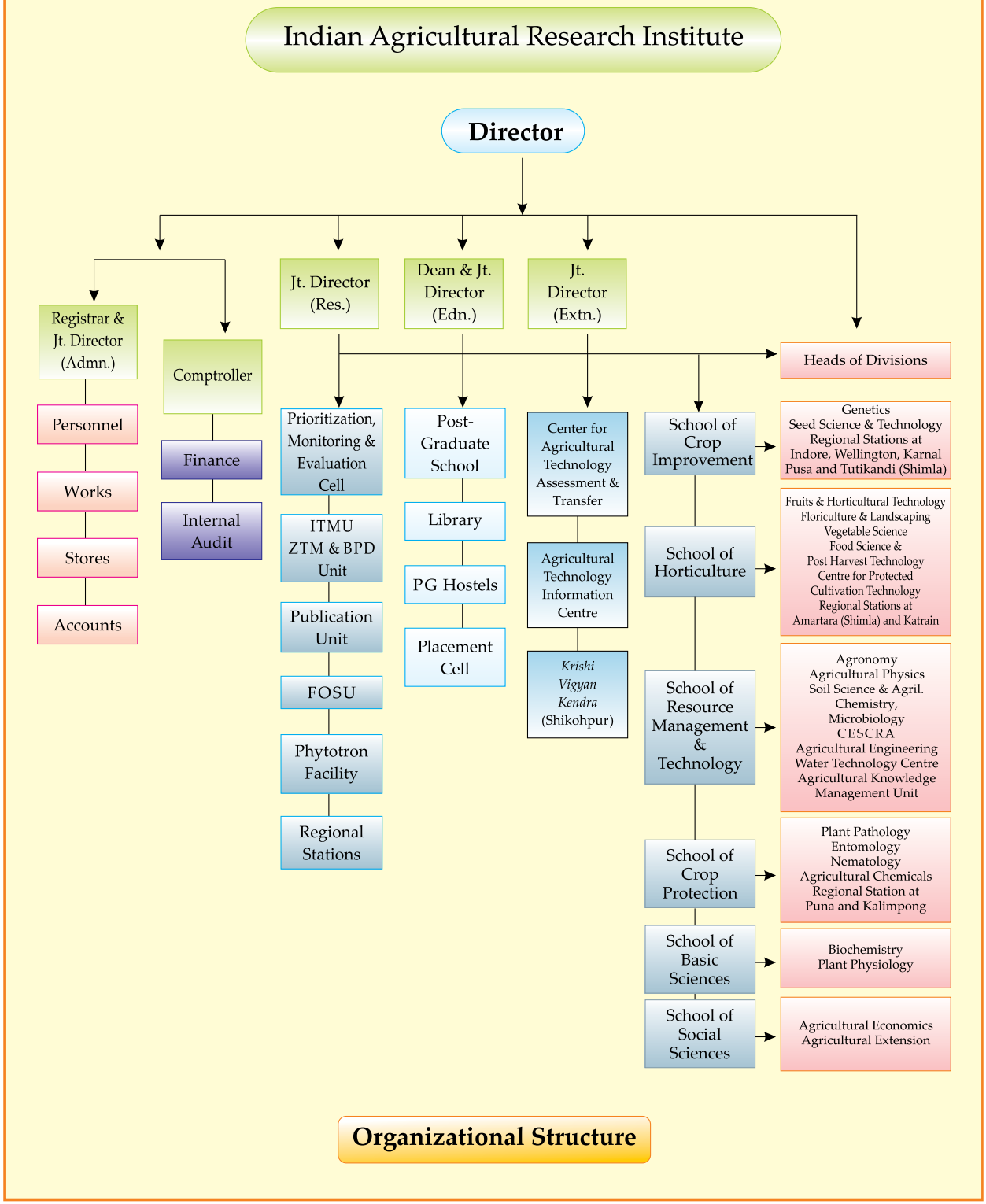
The growth of India's agriculture during the past more than 100 years, is closely linked with the researches done and technologies generated by the Institute. The Green Revolution stemmed from the fields of IARI. Development of high yielding varieties of all major crops which occupy vast areas throughout the country, generation and standardization of their production techniques, integrated pest management and integrated soil-water-nutrient management have been the hallmarks of the Institute's research. The Institute has researched and developed a large number of agrochemicals which have been patented and licensed and are being widely used in the country. Over the years, IARI has excelled as a centre of higher education and training in agricultural sciences at national and international levels.

The mandates of the Institute are as follows:

- To conduct basic and strategic research with a view to understanding the processes, in all their complexity, and to undertake need based research, that lead to crop improvement and sustained agricultural productivity in harmony with the environment
- To serve as a centre for academic excellence in the area of post-graduate and human resources development in agricultural sciences
- To provide national leadership in agricultural research, extension, and technology assessment and transfer by developing new concepts and approaches and serving as a national referral point for quality and standards
- To develop information systems, add value to information, share the information nationally and internationally, and serve as a national agricultural library and database

The present campus of the Institute is a self-contained sylvan complex spread over an area of about 500 hectares. It is located about 8 km west of New Delhi Railway Station, about 7 km west of Krishi Bhavan, which houses the Indian Council of Agricultural Research (ICAR), and about 16 km east of Indira Gandhi International Airport at Palam. The location stands at 28.08° N and 77.12° E, the height above mean sea level being 228.61m. The climate is sub-temperate and semi-arid. The mean maximum daily temperature during the hot weather (May-October) ranges from 32.2 °C to 40 °C and the mean minimum temperature from 12.2 °C to 27.5 °C. June to September are rainy months during which about 500 mm of rainfall is received. Winter sets in from mid-November and is delightful. The mean maximum temperature during winter (November-March) ranges from 20.1 °C to 29.1 °C and the mean minimum temperature from 5.6 °C to 12.7 °C. During winter, a small amount of rainfall (about 63 mm) is received.

The Institute has 19 divisions, 2 multi-disciplinary centres situated in Delhi, 8 regional stations, 2 off-season nurseries, one krishi vigyan kendra at Shikohpur, 3 all India coordinated research projects with headquarters at IARI, and 21 national centres functioning under the all India coordinated research projects. It has a sanctioned staff strength of 2636 comprising scientific, technical, administrative and supporting personnel. The revised budget estimates of the Institute constituted a total amount of Rs. 60635.42 lakh (Unified Budget) for the year 2018-19.



Organizational Structure

EXECUTIVE SUMMARY

The Indian Agricultural Research Institute (IARI) maintained the status of premier Institute of the Nation in agricultural research, education and extension. Crop improvement programs of the Institute have developed varieties/hybrids of field and horticultural crops with improved yield, quality and adaptability. The basic and strategic research program employed the frontier areas of science for deciphering the mechanisms of nutrient use efficiency and abiotic and biotic stress tolerance mechanisms, and yield. The Institute has developed crop and resource management technologies, and pest and disease management methods, farm machineries, protected cultivation methods and food processing techniques for enhancing the input use, climate resilience, farm profit and environmental sustainability. Extension and training programs focused on enabling farmer and empowering rural women. The salient achievements of IARI in research, extension and education during 2018-19 are summarized here.

By using cutting-edge technologies of genomics, the crop improvement programs developed crop varieties with improved yield, nutritional quality, and resistance to biotic and abiotic stress tolerance with adaptability to different agro-ecological conditions. Wheat variety HD 3226 with an average yield of 5.75 t/ha and potential yield of 7.96 t/ha was released for commercial cultivation under irrigated timely sown conditions in North Western Plains Zone (NWPZ). It is highly resistant to all three rusts (yellow, brown and black), Karnal bunt, powdery mildew, flag smut and foot rot disease. It has high grain protein content (13 %), high wet (30.85 %) and dry gluten (10.10 %) contents and perfect Glu-1 Score (10). The variety is also suitable for early seeding under zero till condition. Two bread wheat varieties viz., HD 3237 with an average yield of 4.84 t/ha, and HI 1620 with an average yield of 4.91 t/ha were released for commercial cultivation under restricted irrigation conditions in NWPZ. Pusa Samba 1850, a MAS-derived near isogenic line of a popular medium slender grain rice variety, BPT 5204 (Samba Mahsuri), possessing three genes for blast resistance (*Pi54*, *Pi1* and *Pita)* was released for the states of Chhattisgarh and Odisha. It produces an average yield of 4.77 t/ha in 140-145 days duration. Sweet corn hybrid, Pusa Super Sweet Corn 1 with an average brix value of 15.9% was released for Northern Hills Zone (NHZ), North Western Plains Zone (NWPZ), North Eastern Plains Zone (NEPZ) and Peninsular Zone (PZ). It matures in 78 days and yields 9.3 and 16.2 t/ha of cobs and green fodder, respectively. A maize hybrid, Pusa Jawahar Hybrid Maize 1 (PJHM 1) was released for cultivation in Madhya Pradesh. This hybrid has average grain yield of 6.5 t/ha with a potential yield of 10.2 t/ha. Besides, a large number of promising genotypes in several crops are under various stages of evaluation in All India Coordinated trials.

The institute has an active programme for collection, maintenance, evaluation and utilization of plant genetic resources in different crops. In wheat about 276 accessions of 38 wild and related species belonging to the genera *Triticum, Aegilops, Secale* and *Agropyron* were maintained. In addition, more than 600 alien introgression lines derived from crosses with species like *T. militinae, T. timopheevi, T. turgidum, T. monococcum, T. spelta, Ae. variabilis, Ae. umbellulata, Ae. speltoides, Ae. markgrafii, Ae. geniculata* and *Secale cereale* were maintained and evaluated for various biotic stresses. Durum wheat line, HI 8774 with multiple disease resistance was registered at ICAR-NBPGR, New Delhi as a genetic stock. In rice, a set of 120 different accessions of wild rice collections of *O. rufipogon, O. nivara, O. longistaminata,* etc. were evaluated for different traits and utilized in wide crossing for introgression of useful traits. A set of 500 rice genotypes, including mega varieties, short grain aromatic rice and NPTs were evaluated for yield component traits during *Kharif* 2018. In pearl millet, 326 germplasm lines have been maintained and evaluated for traits such as early

flowering, tillering, different spike types, grain color, iron and zinc content, heat and drought tolerance. The global chickpea germplasm representing more than 30 countries constituted as Chickpea Global Core germplasm was obtained from Gene Bank, ICRISAT, Patencheru and Telangana. About 1950 core germplasm lines and 8 controls were evaluated for root nodulation. In *Brassica*, a total of 512 germplasm lines including *B. juncea*, *B. carinata*, *B. napus*, *B. rapa*, *B. oleracea* *B. nigra*, *B. tournifortii*, *B. caudatus*, *R. caudatus*, *R. sativa*, *S. alba*, *Eruca sativa*, *Crambe* spp., *Lapidium* spp and *Crambe* spp. were maintained by selfing and utilized in breeding programme. These also included 30 quality accessions with low erucic acid and/or glucosinolates.

The School of Horticulture developed several varieties/hybrids of vegetable, flower and fruit crops. In vegetables, 11 varieties, viz., onion cv. Pusa Sona (Sel. 153-1), garden pea cv. Pusa Prabal (GP 473), brinjal cvs. Pusa Safed Baingan 1 (Sel.195) & Pusa Hara Baingan 1 (G 190), long melon cv. Pusa Utkarsh (DLM 27), round melon cv. Pusa Raunak (DRM 26), musk melon cv. Pusa Madhurima (DM 159-1), Sarda melon cv. Pusa Sarda (DHM 163), Chenopodium cv. Pusa Green (Bathua Sel. 2), cucumber cv. Pusa Parthenocarpic Cucumber 6 (DPaC 6) and okra cv. Pusa Bhindi 5 (DOV 66) and two F_1 hybrids, viz., bitter gourd cv. Pusa Hybrid 4 (DBGH 12), sponge gourd cv. Pusa Shrestha (DSGH 9) have been notified by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Horticultural Crops in 2019. Two varieties, viz., a cabbage F_1 hybrid Central Cabbage Pusa Hybrid 81 (KTCBH 81) and a Kale variety Central Kale Pusa 64 (KTK 64) were released. Four varieties, viz., cucumber cv. Pusa Long Green (DC 83), brinjal cv. DBL 175, cowpea cv. CP 55 and dolichos bean cv. DB 10 were identified by ICAR-AICRP (VC).

In early group cauliflower, most promising (>24.0 t/ha) hybrids ,namely, DCEH 312367, DCEH 310471, DCEH 7571, DECH 7523 and DCEH 31523 were identified. A purple cauliflower (PC 1) was derived through recurrent selection from exotic cv. Sicilian Purple, besides, Pusa Purple Broccoli was also isolated. Introgression of *Trachystoma ballii* and *Diplotaxis catholica* male sterile cytoplasm, β-carotene rich *'Or'* and anthocyanin rich *'Pr'* genes into the nuclear background of cauliflower was attempted. In bitter gourd, inter-specific hybridization between *Mormordica charantia* variety Pusa Aushadhi (female) and *M. balsamina* (male), resulted in one F_1 plant, which was selfed and backcrossed with Pusa Aushadhi and *M. balsmina*. Inheritance studies for fruit tubercle (*Tb*), discontinuous ridges (*Cr*) and green colour of fruit (*WW*) were found to be governed by single dominant gene, whereas seed coat colour was governed by semi-dominant gene, while gynoecy by single recessive gene (*gy1*). In cucumber, DC 22 and DC 43 were identified promising with respect to fruit size and quality. Gynoecy based hybrids DGCH 31 and DGCH 40 yielded higher (25.9 and 26.2 t/ha, respectively). In luffa, lines DSG 7 (DSGVRL 13) and DSG 5 (DSGVRL 4) were found to be most promising for *Tomato Leaf Curl New Delhi Virus* (TLCNDV) resistance. In pumpkin, DPU 14, DPU 41, DPU 45 and DPU 58 were found as promising lines. Three promising F_1 hybrids were DPU 41 × DPU 45 (av. fruit wt. 2.4 kg), Narendra Agrim × DPU 63 (av. fruit wt. 2.6 kg) and DPU 46 × DPU 45 (av. fruit wt. 1.75 kg). In summer squash, DS 17 and in muskmelon DM 154 were most promising lines for open field cultivation. In bottle gourd, EC 800998 was most tolerant against *Cercospora leaf spot.*

In brinjal, DBHR 2019 (dark purple round, 69.32 t/ha), was the most promising compared to check Navina (50.63 t/ha), and Pusa Hybrid 6 (41.87 t/ha). In tomato, 12 promising F_1s were sent to ICAR-IIVR and three to ICAR-IIHR for TOLCV resistance station trial. Two hybrids, promising for *ToLCD* resistance and yield were included in AICRP (VC) trials. In chilli, inter-specific crosses between *C. annuum*, *C. frutescens* and *C. chinense* were attempted and eight heat tolerance selections were identified, which fruited during May to July. In garden pea, genotypes GP 916, GP 473, GP 912-II, VP 438-2, and Bonneville were found promising for pod set at high temperature. *Pisum fulvum*, *P. elatius*, and *P. sativum* var. *elatius* were identified to be tolerant to *Fusarium* wilt. In okra, DOH 2, DOH 3 and DOH 4 were found superior in pod yields and quality along with resistance to YVMV and ELCV. In carrot, IPC 13 red, IPC 98 and IPC Ht-1 were advanced to AVT-II of AICRP (VC) trial. In onion, AKON 82, SWSL, AKON 79, JRO 4 and AKON 69 less than 10% bolting were identified as inbred lines for bolting tolerance. For *Kharif* season, three best lines KP-M1 (25.66 t/ha), KP 36 (24.77 t/ha) and KP 41(24.24 t/ha) were most promising.

In mango, hybrid H 11-2 (281.8 g) was the most promising. Hybrid NH 7-2 had bright yellow-apricot peal with bright orange pulp and high TSS (22.37°Brix). Polymorphism studies using 245 Novel Hyper Variable SSRs in mango for Amrapali and Sensation identified 109 polymorphic HMSSRs. In citrus, cross Mosambi × tangerine recorded the highest fruit set (10.87%), while in acid fruited type it was in Konkan Seedless × Pusa Udit (52.23%). In rootstock breeding, 29 citrus rootstock hybrids were screened as resistant to *Phytophthora nicotianae*. In sweet orange, clones MS 3, MS 7, MS 9 and MS 21, in acid lime ALC 103, ALC 90, ALC 5 and ALC 4 and in lemon LS 1 were found promising. In Kinnow mandarin, the heaviest fruit (258.0 g) was recorded in the mutant M 15-2, with high juice recovery (64.93%) and TSS (12.2°Brix). In pummelo, application for registration of 5 clones were submitted with NBPGR, New Delhi.

In grape, the Delhi State Variety Release Committee notified grape hybrid Pusa Aditi (Banqui Abyad × Perlette) for Delhi State and NCR region. Genotype, Flame Seedless performed better in terms of yield and quality traits. Three promising hybrids, namely, ER-R_2P_{36} (Higher TSS > 23°Brix), R_1P_9 (early maturing, bold berry, seeded, loose bunch, golden-yellow berry) and Hy. 16/2A-R_1P_{14} (early maturing, bold berry, seeded, loose bunch, colored) were extra-early in maturity. In guava breeding, two hybrids, Trichy × Punjab Pink-having the red peel and pulp and G 1-15(Hisar Safeda × Lalit - white pulped with red peel) were identified. In papaya, *Vascocellea cauliflora* and *V. cundianamarcensis* were found tolerant to papaya ring spot virus (PRSV). Amongst *Carica papaya* genotypes, Pune Sel. 3 and Pune Sel. 1 had maximum viral tolerance. *Prunus persica* Japan was found as most compatible dwarfing rootstock for most of the temperate fruits. *Prunus japonica* rootstock induced bigger sized fruit in Japanese plum cultivars.

In rose, phylogenetic relationships were studied in 28 species of genus *Rosa* based on nuclear and chloroplast markers. A total of 101 novel nucleotide sequences of genus *Rosa* (*ITS*-16, *matK*-17, *rbcL*-23, *trnH-psbA*-21 & *ycf*-1b-24) were submitted to Genbank database of NCBI, USA. RS 1-2018, an open-pollinated seedling of cv. Jantar Mantar and RM 1-2018 - a natural bud sport of cv. Folklore were isolated. Eight pre-breeding powdery mildew resistant lines were developed for initiating resistance breeding. In chrysanthemum, Pusa Aditya and Basanti were identified as salinity tolerant genotypes. In marigold, an efficient protocol was developed for *in vitro* mass multiplication of doubled haploid line of African marigold (*Tagetes erecta* L.) var. Local Orange. In gladiolus, three hybrids, namely, Melody Open Seedling, Chandni × Snow Princess and P-16-1 × Eurovision showed earliness in flowering, while Hybrid Salmon Queen Open Seedling, Yellow Stone × Melody and Bindiya × Creamy Green had recorded maximum plant height and stalk length. In turf grass, turf species crow foot grass, St. Augustine and Zoysia performed well in shady conditions (shade level 75%). In *Lilium*, interspecific hybrids, namely, (KILH 13 × Navona) × Brunello, KILH 13 × Topeka and KILH 13 were found promising.

The Crop and Natural Resource Management research at the Institute has developed technologies for enhancing agricultural productivity and farmers' income. A horticulture crop-based integrated farming system, targeted towards marginal farmers was developed that gave net income of 2.4 lakh/year by integrating polyhouse crops cultures, mushroom cultivation, and horticulture enterprises. Use of GreenSeeker (GS) and Nutrient Expert® (NE) as decision support systems for precision nitrogen application reduced the N requirements by 26 kg/ha and resulted in higher maize yield over state recommendation. The system productivity (12.5 t/ha) under maize-wheat system was highest when nutrient management was made through NE and GS. Soybean planted with conventional tillage (CT)-furrow irrigated raised beds system and irrigated at 25% depletion of available soil moisture resulted in significantly higher yield over CT-flat and irrigated at 50 or 75% DASM. Application of 30 kg N/ha by calcium cyanamide in combination with additional 30 kg N/ha alone as NCU or DAP or in combination with both, saved N by 25 to 50% without affecting grain yield in wheat. A CA-based ICM module [ZT-PRB + CRR @ 3 t ha^{-1} + 100% recommended dose of fertilizers (RDF) + (glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1 HW-mulch) + 2 irrigations + need based IDM/IPM] led to significantly higher pigeon pea seed yield (1.92 t/ha) and profitability (Rs.82,776 /ha). Overall, this CA based ICM modules showed an edge over CT based ICM modules on growth, LAI, PAR interception, root

biomass, yield, net returns and B:C ratio. Conservation agriculture emerged as a promising option for mitigation and adaptation of climate change through effectively tackling problems related to water, nutrient, weeds, energy and GHGs emissions. The triple ZT rice-wheat-mungbean system gave 13% higher wheat yield and 40% higher system productivity, with a saving of 60 kg N/ha than conventional system. CA based cotton-wheat system gave 44.1% higher system productivity than CT with a saving of 25-30% N and emerged as a superior alternative to rice-wheat system. A diversified baby corn – *palak* - okra cropping system resulted in highest system productivity in terms of okra pod equivalent yield (OPEY) (24.2 t/ha), net returns (Rs. 238300/ha) and B:C ratio (1.85).

Soil management studied showed that long term application of 50% fertilizer N by FYM or green manure along with 50% NPK in rice/maize-wheat cropping system could enhance the stability of soil organic carbon (SOC). The effect of long-term fertilization on humic acid highlighted that 150% NPK and 100% NPK+FYM showed the least degree of acidity, and in turn, lowered the degree of humification. Based on E4/E6 ratio, it was found that these systems might have the potential for effective nutrient supply to crop. The total PLFA concentrations (nmol/g soil) in surface soil of PBB+R plots were 79.9 and 82.3% higher compared to that of CT plots in pigeon pea-wheat and maize-wheat systems, respectively. Soil quality indices (SQI) worked out to assess the relative order of performance CA management practices revealed that the relative order of SQI were : (mungbean residue + zero-till direct seeded rice - rice residue+ zero-till mustard –zero-till mungbean) > (zero-till direct seeded rice-zero-till mustard–zero-till mungbean)> (zero-till direct seeded rice - zero-till mustard) > (transplanted rice - zero-till mustard) > TPR-CTM (transplanted rice–conventional tillage mustard). Nitrogen applied through nanoclay polymer composites (NCPC) was most efficient in enhancing yield of maize. There was an indication that 25-50% of applied P could be curtailed using polymer-based phosphatic fertilizer loaded NCBPC. The application of rock-phosphate (RP) and waste mica treated with PSB and KSB could increase yield and uptake of P and K by wheat.

Establishment of low-cost wastewater treatment facility in Mathura, UP emerged as a ground-breaking step towards water management. The treated wastewater had low bacterial load (1.6×10^3 MPN/100ml) with 82% reduction in BOD and 100% reduction in turbidity. The IFSHED Decision Support System was developed for irrigation and fertigation scheduling in vegetable crops based on climate parameters, soil properties and crop requirement to reduce water wastage and ensure maximum efficiency. For the benefits of small and marginal farmers, a naturally ventilated polyhouse was designed with different types of cladding materials. Polyhouse with C4 type of cladding material showed maximum yield in winter, while polyhouse with cladding material C1 showed maximum yield in summer crop, thus establishing two materials for efficient use in different seasons and temperatures.

A harvester for gladiolus corms was developed, which registered less losses (3.6% conveyor loss) and higher digging and separation efficiency (98.5% and 92.7%, respectively). For accurate monitoring of ecological parameters for low cost storage structure in rural areas, a data logger was designed. By providing real time data, this device would be highly useful in reducing grain losses due to storage and reduce man power. A novel spinach-cum-coriander offset rotary cutter, powered by battery was developed for the use of small farmers. The cutter gave an impressive output of 172 m^2/h at 0.8 km/h and bundled up the harvest at the rate of 80-82 m^2/h. A solar powered evaporatively cooled storage structure was designed and developed for storage of 500 kg fresh fruits and vegetables to increase their shelf life. Cooling pads of CELdek showed highest efficiency of 78.7% and maintained 5-10 degree lower internal temperature than ambient conditions. This helped to increase the shelf life of fruits and vegetables by 1-5 days.

Pre-harvest fruit bagging of litchi, preparation of osmo-vac dehydrated guava slices, formulation of black carrot lactic drink were all carried out to enhance nutritional value of foods and increase storage time. The use of citrus peel phenolics as a nano-emulsion revealed that more potent anti-oxidants were released this way, when compared to non-encapsulated ones and showed good retardation of mustard oil rancidity. This would have great implications to prolong shelf

life of oils and decrease the use of synthetic rancidity controllers. Micronutrient-rich low fat gluten free buckwheat biscuits were formulated, replacing up to 40% fat with Psyllium husk and mucilage from okra and basil seeds. With a high fibre content of 10%, buckwheat biscuits emerged as a low calorie nutrition alternative.

Bio-prospecting rhizospheric and endophytic cyanobacterial diversity led to identification of twenty five strains belonging to *Plectonema* sp., *Phormidium* sp., *Nostoc* sp. and *Anabena* sp. Inoculation with osmotolerant bacteria (*Bacillus casamancenis* MKS6 and *Bacillus* sp. MR D17) helped sustain the plant growth under drought stress in mustard. Bacterial inoculation with *Azospirillum* improved shoot and root biomass and number of crown roots in pearl millet with a grain yield increase by 2-27% in inoculated treatments. Fungal inoculants, namely, *Coprinopsis cinerea* LA2 and C*yathus stercoreus* ITCC emerged as suitable options for *in situ* paddy straw management. On farm evaluation of microbial inoculants in different crops revealed that BGA, *Rhizobium, Azotobacter, Azospirillum*, PSB, AM fungi and *Azolla* could substantially improve soil and crop conditions and curtail the need for synthetic fertilizers.

Quantification of GHGs emissions in different rice-based systems indicated that the rice - fallow system in Sunderbans resulted in highest GWP (4619 kg CO_2 eq ha^{-1}) in rice, while the rice –wheat system in Varanasi resulted in lowest GWP (888 kg CO_2 eq ha^{-1}) in rice. In order to reduce reactive nitrogen losses in rice, different treatments were evaluated, and the lowest ammonia emission was recorded in integrated organic and inorganic treatment. The impact of crop diversification and irrigation methods on GHGs emissions was studied and drip irrigation was found to reduce both methane and N_2O emissions by 2.62 kg ha^{-1} and 0.49 kg ha^{-1}, respectively. Studies on plant growth promoting *Rhizobacteria* (PGPR) and elevated carbon dioxide under elevated tropospheric ozone in black gram showed increased seed yield by 22.8% under the elevated CO_2 and PGPR-treated seeds. Microbial bio-sorbent (*Brevibacillus laterosporus)* was assessed for bioremediation of heavy metals contaminated wastewater, which showed 84% lead removal and emerged as an efficient eco friendly procedure with low cleanup costs.

In crop protection, studies on diagnostics, diversity analysis, identification of resistant sources and integrated management of important pests and pathogens of national importance were undertaken. A rapid diagnostic loop mediated isothermal amplification based protocol was developed for detection of wheat Karnal bunt pathogen, *Tilletia indica* and bakane disease of rice caused by *Fusarium fujikuroi*. Whole genome sequencing and host-pathogen interaction of *Bipolaris sorokiniana* and pearl millet infecting blast fungus of *Magnaporthe* isolates was accomplished. Phytoplasma associated with flat stem disease of Manilkara zapota caused by *Canditatus Phytoplasma asteris* and *Candidatus Phytoplasma aurantifolia* associated with flower virescence disease of *Anacardium occidentale* have been characterized from West Tripura. Multiplex RT-PCR assays were developed for simultaneous detection of different viruses in different crops. CRISPR-Cas9 based genome editing approach has been applied for the precise degradation of Chilli leaf curl virus genome. Out of five *Rhizoctonia solani* isolates belonging to different anastomosis groups (AG) evaluated for the sheath blight disease of rice AG1, AG2, AG3, AG4 could produce infection cushions after 24 hrs of inoculation in rice variety Pusa Basmati 1. A carrier based bio control consortium was developed to induce *Fusarium* wilt resistance in tomato. Treatment with *B. subtilis* DTBS-5 formulation significantly reduced bacterial leaf blight disease severity in rice and powdery mildew in wheat as compared to other treatments. Resistant sources have been identified in different crops for important diseases by evaluating under artificially inoculated conditions.

Resistant sources to different insect-pests were identified in various crops and efficacy of different chemicals / biopesticides was tested against various pests in different crops. Monitoring of adult population of chickpea pod borer revealed that the activity of *Heliothis armigera* was highest during 8^{th} to 16^{th} SMW during the crop season. Spatial distribution of mixed population of the aphids and predatory coccinellid beetles was analyzed using variance-mean ratio and regression models. Fitness consequences of delayed

mating on reproductive performance of *Chilo partellus* have been investigated. Studies on virus vector dyanamics showed significant differences in the rate of transmission between *B. tabaci* genetic groups, Asia I and Asia II-1. High incidence of pink boll worm in central and south cotton growing zone of India in concurrence with high LC_{50} values to Cry1Ac, Cry2Ab and BGII (Cry1A+Cry2Ab) in most of the cotton growing regions of Central and South India *vis a vis* susceptible population provided the evidence of field evolved resistance in the pink bollworm to BGII cotton.

Silencing effects of the two genes, *ama-1* and *mad-2* of *M. incognita*, on infection, development and reproduction of the nematode in tomato using *in vitro* RNAi approach was studied. A fast protocol was developed for *Agrobacterium* mediated *in-planta* transformation for tuberose, *Polianthes tuberosa*. Evidence for the functional role of a sterol regulatory element binding protein (Mi-SBP-1) in development, reproduction and parasitism of an obligate root parasite of plants, *M. incognita* was studied first time. Four chemosensory genes, namely, *Mi-odr-1*, *Mi-odr-3*, *Mi-tax-2* and *Mi-tax-4* were cloned, sequenced, analyzed and functionally characterized from *M. incognita*, which provides crucial advances towards understanding of plant-nematode interactions in rhizosphere. A model was developed indicating *Mi-tax-2* and *Mi-tax-4* function downstream of *Mi-odr-1* and *Mi-odr-3* in chemotaxis pathway of *M. incognita*. The recombinant protein characterized from *P. luminescens* strain H3 exhibited comparatively greater insect toxicity than strain H1 in terms of LD_{50} and LT_{50} values. Isolates IARI-EPN RP 03 of *Steinernema* sp. and IARI-EPN RP 06 of *Heterorhabditis* sp. were found to be highly virulent against insect pests.

Chemo and bioprospecting for agrochemicals through design, discovery and development of novel processes was undertaken. Synthesized compounds active against *Sclerotium rolfsii, Alternaria solani* and root knot nematode (*M. incognita*) were identified. Molecular docking and simulation studies of these compounds showed higher binding affinity towards L-glutamine: d-fructose-6-phosphate amidotransferase [GlcN-6-P] (PDB:2POC). Concomitant data generation, fine-tuning of composition and field performance evaluation of EPN biogel formulations has been accomplished. Evaluation of neem and citronella nano emulsions for antifungal activity revealed one nano emulsion which was found to be most effective against both *R. solani* (ED_{50} 13.69 mg L^{-1}) and *S. rolfsii* (ED_{50} 14.71 mg L^{-1}). Based on the *in vitro* antifungal evaluation studies, five potent antifungal halogen substituted benzylidene aryl amines were identified and synthesized for their formulation development. The method for extraction of aflatoxin from ground nut, almond, pistachios, walnut and cashew nut was optimized using buffered QuEChERS method. HPLC-PDA method for determination of trace level of residues of cyantraniliprole and its two metabolites in soil, water and vegetable were optimized. QuEChERS based multi residue method coupled LC-MS/MS was developed for the trace level analysis of 50 pesticides in coconut (oilseed).

The basic and strategic research at IARI was focused on phenomics, CRISPR-Cas9 genome editing and transgenics in crops, mapping QTLs for biotic and abiotic stress tolerance, climate change, development of remote sensing and GIS techniques for assessment and management of crops and natural resources. CRISPR-Cas9 genome editing platform was established in rice and mutants of *DST* (*DROUGHT AND SALT TOLERANCE*) gene were developed and confirmed by DNA sequencing. Phenotypic analysis showed that the *dst* mutation significantly increased leaf width and decreased stomatal number. To reduce the seed phytate content, CRISPR-Cas9 genome editing was used to mutate *GmIPK1* gene, which codes for the terminal step of phytate biosynthesis. Phytate analysis of T0 stable soybean knock out mutants showed about 6-9-fold reduction in phytate content. Towards gene functional validation abscisic acid receptor *OsPYL10* was overexpressed in rice, and found that *PYL10* gene confers cold and drought tolerance to rice. Similarly, overexpression of *Isopentenyltransferase 9* (*IPT9*) gene conferred both drought and salt stress tolerance to transgenic rice. Towards unraveling the mechanism of virus resistance in tomato, Tomato leaf curl New Delhi virus-derived AC4 protein was studied and results revealed that AC4 protein suppresses RNA silencing activity of host plant, and thus altered DNA methylation. Mutational analysis of AC4 showed that Asn-50 in the SKNT-51 motif, in the C-terminal region, is a critical

determinant of its RNA silencing suppressor activity. AC4 showed interaction with genes involved in plant hormones jasmonic acid and auxin biosynthesis. AC4 was also found to downregulate Auxin biosynthesis, and thus affect the plant growth.

Genetic improvement in water use efficiency and drought tolerance of rice and wheat is critical for sustaining food security in climate change scenario. Phenomics of transpiration in 150 rice germplasm lines revealed that about 15-30% of water is used by rice genotypes in night. Genotypes which use significantly less water than that of Nagina 22 were identified. In wheat, phenomics of 184 RILs of HD2967 (high yielding) × C306 (drought tolerant) led to the identification of RILs superior to C306. Phenotyping revealed that physiological traits such as stem reserve mobilization, epicuticular wax, phloem immobile mineral nutrients and carotenoids play important role in wheat under heat stress, and donors for these traits were identified. Nitrogen use efficiency (NUE) of cereal crops is around 33% only, resulting in huge economic loss and environmental degradation. Phenotyping of 300 rice genotypes for N deficiency tolerance lead to the identification of IR-83929 and N-L-42 were showing high NUE and will be suitable for improved NUE under aerobic rice cultivation. Phenotyping for dual nutrient deficiency (nitrogen and phosphorus) tolerance led to the identification of HD 2781 is genetically efficient wheat genotype. Elevated CO_2 (EC) decreased nitrate uptake and assimilation through NO and thus reduced the protein content. Identification of mechanisms and genotypes that maintains nitrate uptake and assimilation is critical to sustain grain quality under EC conditions.

Genetic analysis and QTL mapping resulted in identification of QTLs for stress tolerance and yield in different field and horticultural crops. In wheat, backcross-derived mapping population of C306/*2HD2733 were used to detect 63 QTLs for drought and heat tolerance. Marker-assisted breeding approach was used to pyramid genes for all three types of rust resistance in wheat. Marker-assisted backcross breeding was employed to transfer the mutant allele of herbicide tolerance gene (*ALS)* from a donor parent, HTM-N22 (Imazethapyr tolerant EMS induced mutant of Nagina 22) into two elite *Basmati* rice varieties viz., Pusa Basmati 1121 and Pusa Basmati 1509. Three promising lines with herbicide tolerance were developed. In mustard, molecular mechanisms of heat tolerance was analyzed and found that *HSF3*, *HSF3B*, *HSP20* and *DWF-4* may play important roles. Genetics of blast resistance in pearl millet and MAS for white rust resistance in mustard are in progress.

Nutritional quality improvement and development of varieties with processing quality are in progress in different crops. A Rancidity Matrix of Pearl Millet was developed based on Acid value, Peroxide value and the activity of enzymes involved in lipid oxidation, and genotypes with low, medium and high rancid types were identified for improving pearl millet. In wheat, efforts are being made to develop wheat varieties with reduced celiac immunogenicity using a MAS programme from crosses between nullisomic and ditelosomic lines for chromosome 1A and 6A with *durum* wheat variety HI 8663. In wheat a MABB approach was initiated with genes *PinaD1*, *PinbD1*, *Glu-A1*, *Glu-B1*, *Glu-D1*, *Glu-3A*, *Glu-3B* and *Glu-3D* in important wheat varieties for improving desired quality parameter for biscuit making. To reduce anti nutrient, phytate, in maize two dominant gene based markers for LPA locus were developed and validated across seven F_2 populations. This marker will be useful to develop hybrids with low phytate content. Genome wide association study (GWAS) was employed in rice to map significant QTLs for Fe and Zn for enhancing the endosperm mineral micronutrient density as rice is widely consumed after polishing. In pearl millet, QTLs for grain Fe and Zn content were mapped using 210 RILs (PPMI 683 × PPMI 627) phenotyped for three years at Jodhpur. Four major QTLs for Fe, three major QTLs for Zn were mapped. Two QTLs for iron and zinc were co-mapped on linkage group 2 and 3. These QTLs will be useful to improve grain micronutrients. In vegetable crops, doubled haploid production has been standardized in cauliflower, cucumber and onion. QTLs for disease resistance and MAS led to identification of new QTLs and introgression of known QTLs for different quality traits and disease resistance in vegetable crops.

Remote Sensing and GIS approaches have been used to develop methods for crop and resources management. Canopy spectral reflectance measured

using hyperspectral sensor in maize-wheat system was used to compute spectral reflectance indices (SRI) using HyperAgri software. Spectral index NDREI showed highest correlation with grain yield (r=0.853) and hence NDREI at booting stage can be used successfully for prediction of grain and biomass yields of wheat.

Drone remote sensing has been standardized for field phenotyping of wheat crop and mapping of horticultural crops. A study conducted with drone fitted with multispectral sensor to assess the genotypic variation to water and nitrogen stress response in wheat crop during *rabi* season 2017-18 showed that spectral indices maps of nitrogen, temperature and plant water status is useful to assess response of wheat genotypes to drought and N stress. In a collaborative study with ISRO and NASA, ground based spectroradiometer and air borne AVIRIS – NG instrument were used to map eight horticultural crops in Sabour, Bhagalpur region of Bihar, India. The results showed that hyperspectral remote sensing based spectral separability analysis could distinguish different fruit crops.

Crop residue burning is a major problem in Punjab and Haryana. The Institute acquired thermal image from seven satellites at the IARI satellite ground station and used for the detection of fires for both day and night passes. Daily bulletin of fire events of paddy straw burning were prepared and their locations were put on CREAMS Geoportal (http://creams.iari.res.in) for visualization as maps. High resolution satellite image analysis was carried out for 20 major paddy growing districts of Punjab and 10 major paddy growing districts of Haryana, depending on availability of cloud free data and districts with significant paddy area with burning as monitored by satellites during the season. The threshold cutoffs for differences in NBR (delNBR) and NDVI was used for estimating rice burnt area.

The School of Social Sciences and Technology Transfer worked in the major areas of Farmer Producer Organization (FPO), Aadhar enabled Fertilizer Distribution System (AeFDS), tariff hike on crude and refined palm oil, tank irrigation system, bioenergy potential of crop residue, Farmer Led Innovations (FLIs), Nutritional Security and Innovative extension models.The assessment of the performance of the FPO results suggest that the revenue from pigeon pea has been increased by 18 per cent after grading and marketing of pigeon pea through FPOs for the *Rabi* 2017. The results of an ex-post assessment of the AeFDS revealed that the share of farmers in the budgetary subsidies increased from 63.27 per cent in the triennium average ending (TE) 1995-96 to 85.55 per cent in TE 2005-06, and then decreased to 64.91 per cent in TE 2015-16. Both the farmers and retailers felt better after AeFDS as they did not feel shortage of urea in crop season. A study on total dry crop residue production and its bioenergy potential in India estimated that overall bioenergy potential based on all crop residues was 1892 PJ in 2015-16 which is equivalent to the 6.7 per cent of the total primary energy consumption or 34 per cent of total electricity consumption of India.

Farmer Led Innovations (FLIs) were either reconfiguration of existing resources giving incremental adjustments or innovations generated to solve an immediate problem. Eight cases of FLIs were documented. Relevancy, relative advantage, sustainable source of funding, observability of the results and complexity were ranked as the top determinants of the scalability of farmer led innovations. Lack of separate price policy, exclusive extension personnel for promotion, etc. were found to be major constraints. An institutional mechanism for up scaling and out scaling farmer led innovations was devised in collaboration with various ATARIs of ICAR.

In order to bring "agriculture and nutrition together", A2N (Agriculture to Nutrition) model is being tested through nutria-smart villages for Nutri Farming System (NFS). To study the food consumption pattern of India using the 68th round survey of National Sample Survey Office (NSSO) on household consumer expenditure for the period of 2011-12 showed that in urban area consumption for all food items were higher than that of rural areas, except cereals. The regression results revealed that income and per capita consumption of food items were directly related, that is as income of the households increases quantity also increases.

Under IARI-Post office Linkage Extension Model, seeds of IARI varieties were disseminated. Socio-economic impact of this model revealed that the information source preference has been changed

from input dealer to KVK and post master for crop planning. To promote climate change adaptation in villages of Gurugram and Mewat districts of Haryana, Bareilly district of U.P. and Gaya district of Bihar, demonstrations of zero-tillage (43) and raised bed (5) in wheat and direct seeded rice (31) were conducted through community initiatives. Cotton has been adopted as contingency crop in adopted villages Mumtajpur and Lokra of Pataudi block of Gurugram district and Sanghel village of Mewat district of Haryana. Different climate resilient technologies like short duration rice variety (Pusa 1612), flood resistant rice variety (Swarna-SUB1A), intercropping of jute and *moong*, etc. were promoted in adopted villages of Darjeeling and Jalpaiguri districts.

The institute is implementing *Mera Gaon Mera Gaurav*, the flagship programme of Govt. of India, along with IASRI and NBPGR in 120 clusters comprising 600 villages, which were visited by 480 scientists regularly. The objective of the program is to provide farmers with required information, knowledge and advisories on regular basis by adopting villages. Demonstrations on wheat, mustard, paddy and other field and horticultural crops were conducted.

During *Rabi* 2017-18, a total number of 447 demonstrations were conducted covering an area of 106.71 ha across 10 locations for wheat, onion, lentil, pea and spinach, mustard, carrot, bottle guard, cauliflower, amaranths, onion, marigold, pumpkin and pea. During *Kharif* 2018, a total of 704 demonstrations on paddy, pigeon pea, *moong*, *palak*, bottle guard, chilli, sponge guard, cauliflower, cowpea, bitter gourd, brinjal and marigold covering an area of 186.4 ha were conducted at ICAR Institutes / SAUs. Agricultural Technology Information Centers (ATIC) is effectively providing products, technologies, services and information to the different stakeholders through a '*Single Window Delivery System*'. In ATIC, farm advisory services are also given through Pusa Helpline, Pusa Agricom, exhibitions, farm literatures and letters. The Institute's *Krishi Vigyan Kendra* at Shikohpur, Gurugram, conducted four OFTs, organized around 83 training programmes and 295 agricultural extension activities covering various themes and 320demonstrations covering 153 ha area in various crops for the speedy dissemination of technologies. Around 74 rural youth and women were trained under ARYA project. Weather based Agromet advisory with value added medium range weather forecast information (for the next 5 days), crop management, advance warning to farmers on rainfall variation, weather variables, pest/ disease problems, etc. were prepared in Hindi and English on every Tuesday and Friday and given to farmers through different media and uploaded on the Institute website (www.iari.res.in), IMD website (www.imdagrimet.gov.in) and farmer portal (http://farmer.gov.in). This helped the farmers to decide on crop management, application of nutrients, irrigation scheduling, sowing, harvesting, etc.

The *Pusa Krishi Vigyan Mela* 2019 with a major theme of "*Krishi Vikas: Innovative Technologies*" was organized at the institute during March 5-7, 2019. The *mela* was inaugurated by Dr. Trilochan Mohapatra, Secretary (DARE) & DG (ICAR). He felicitated 31 awardees including farmers and scientists with ICAR awards. The *mela* was also graced with the presence of then Hon'ble Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh on the second day. He visited 1 acre IFS model and other live demonstrations exhibited on the *Mela* ground and interacted with farmers and scientists. Shri Sanjay Agarwal, Secretary, DAC&FW, awarded 32 innovative farmers and 5 fellow farmers during Innovative Farmers Meet. Different ICAR institutes, SAUs, development agencies, leading companies from public and private sector and Voluntary Organizations participated and displayed their technologies and products. Over one lakh visitors and 170 public and private exhibitors from across the country participated and gained from the *mela*.

The Post Graduate School of IARI continues to provide national and international leadership in Human Resource Development by awarding Post Graduate degrees in 26 disciplines. So far, 4148 M.Sc., 69 M.Tech. and 4885 Ph.D. students have been awarded degrees including 399 international students. The Institute has received accreditation from the National Assessment and Accreditation Council of UGC (3.51/4.00, A+; 2016-2021) as well as National Agricultural Education Accreditation Board of ICAR (2015-2020).

The 57th Convocation of the Post Graduate School of the IARI was held on February 8, 2019. Hon'ble

Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh was the Chief Guest. Dr. T. Mohapatra, Secretary, DARE & Director-General, ICAR presided over the function. During this Convocation, 239 candidates (123 M.Sc., 22 M.Tech. and 94 Ph.D.) were awarded degrees, including 08 (05 M.Sc./M.Tech. and 03 Ph.D.) international students. One student each in M.Sc. (Mr. Bishwaranjan Behera, Discipline of Agronomy) and Ph.D. (Ms. Jyoti Nishad, Discipline of Post Harvest Technology) were awarded the Best Student of the Year Awards. Five students each in M.Sc. and Ph.D. received IARI Merit Medals. Dr. A.R. Rao, Professor of Bioinformatics received the Best Teacher Award-2018 for his achievements in academics.

The excellence of IARI is recognized internationally. IARI is playing key role in establishing Afghan National University of Agricultural Sciences and Technology (ANASTU), Kandahar, Afghanistan and Advanced Centre for Agricultural Research and Education (ACARE) at Yezin Agricultural University, Myanmar in collaboration with Ministry of External Affairs (MEA), Government of India. Hon'ble President of India, Shri Ram Nath Kovind dedicated Advanced Centre for Agricultural Research and Education (ACARE) to the people of Myanmar on December12, 2018. The Institute has been awarded with ICAR-NAHEP CAAST project on "Genomics assisted crop improvement and management". Under this project, skills of students in the frontier areas of genomics are enhanced through research and training.

The Institute brought out several quality publications in the form of scientific peer reviewed research papers in high impact journals, symposia papers, books/chapters in books, popular articles, technical bulletins, regular and *ad-hoc* publications, both in English and Hindi, to disseminate the information on the Institute's mandated activities. During the year under report, six patents have been granted, one PPV&FR application filed and six trademarks have been registered. The Institute is making consistent progress in the use of Official Language (*Raj Bhasha*) in agricultural research, education, extension as well as in administration. Several national and international short-term training courses and refresher courses were conducted in specialized areas for the scientists of NAREES. In addition, some special training courses, and other capacity building programmes were also organized for the benefit of professionals, farmers and extension workers. New linkages and collaborations with several national and international institutions were initiated. Many scientists, students and faculty of the Institute received several prestigious awards and recognitions, and brought laurels to the Institute.

1.CROP IMPROVEMENT

The crop improvement programme of the institute is primarily aimed at enhancing the productivity and nutritional quality of various field crops. Modern tools of molecular breeding are increasingly used to complement the conventional methods of crop improvement. Improved varieties with higher yield, better nutritional quality and tolerance to biotic and abiotic stresses suited to different agro-ecological conditions have been developed during the reporting period. Besides, a large number of promising genotypes in several crops are under various stages of evaluation in All India Coordinated trials. The crop improvement programme was complemented by quality seed production and progress in other relevant areas of seed science.

1.1 CEREALS

1.1.1 Wheat

1.1.1.1 Varieties released

HD 3226 (Pusa Yashasvi). A high yielding variety with an average yield of 5.75 t/ha and potential yield of 7.96 t/ha was released for commercial cultivation under irrigated timely sown conditions in North Western Plains Zone (NWPZ). It is highly resistant to all three rusts (yellow, brown and black), Karnal bunt, powdery mildew, flag smut and foot rot disease. Its grains possess high protein content (13 %), high wet (30.85 %) and dry gluten content (10.10 %) and perfect Glu-1 Score (10). This variety is, thus suitable for both bread and *chapatti* making. The variety is suitable for early seeding under zero till condition.

A high yielding wheat var. HD 3226

HD 3237. A high yielding variety with an average yield of 4.84 t/ha, was released for commercial cultivation under restricted irrigation conditions in NWPZ. It showed resistance to yellow and brown rust both under natural and artificial epiphytotic conditions and moderate resistance against leaf blight, powdery mildew, Karnal bunt and flag smut. HD3237 is most amenable to zero and one irrigation as it has shown minimum reduction in yield in zero irrigation. It has the best HMW sub-units' combination for bread making with Glu-1 score of 8/10 and has the higher value of bread loaf volume, protein content and grain appearance.

Field view of wheat var. HD 3237

HI 1620. A bread wheat variety with an average yield of 4.91 t/ha and potential yield of 6.18 t/ha was released for commercial cultivation under restricted irrigation conditions in NWPZ. It

also showed significantly high yield gain at one irrigation (28.8%) and two irrigations (40.7%) over no irrigation conditions. HI 1620 showed high levels of field resistance to stripe and leaf rusts and good level of resistance to leaf blight, Karnal bunt, *Fusarium* head blight, loose smut and flag smut. It also showed good levels of adult plant resistance to prevalent and virulent stripe rust pathotypes 46S119 and 110S119; and leaf rust pathotypes 77-5 and 77-9. HI 1620 has excellent *chapatti* quality (7.52) with high sedimentation value (52 ml) along with good biscuit quality (6.82). It has high protein content (11.9%) and perfect Glu-1 score (10/10) and presence of 5+10 subunit of Glu-D1 reflecting higher gluten strength.

A bread wheat var. HI 1620 at harvest stage

1.1.1.2 Entries under AICRP trials

A total of 65 genotypes were evaluated in all India coordinated testing under various production conditions in all the wheat zones of the country. It includes six genotypes under Advanced Varietal Trials-II (AVT-II), 17 under AVT-I and 42 new entries under various national initial varietal trials (NIVTs). Besides, five nominations were also made to biofortification nursery.

Details of wheat entries in coordinated testing

AVT-II	HI 1628, HD 3249 , HD 3271, HI 1621, HI 8805 and HI 8802
AVT -I	HD 3277, HD 3293, HI 8811 HI 8812, HD 3343, HD 3345, HI 1633, HI 1634, HI 8807, HI 8808, HD 3343, HI 1633, HI 8807, HS 562, HS 673, HS 674 and HD 3298
NIVT	HD 3318, HD 339, HD 3320, HD 3321, HD 3322, HD 3323, HD 3324, HD 3325, HD 3326, HD 3327, HD 3328, HI 1636, HI 1637, HI 1638, HI 1639, HI 1640, HW 1904, HD 3329, HD 3330, HD 3331, HD 3332, HD 3333, HD 3334, HI 8818, HI 8819, HI 8820, HI 8821, HI 8822, HD 3335, HD 3336, HD 3337, HD 3338, HD 3339, HI 1643, HI 1644, HI 1645, HI 8823, HI 8824, HD 3340, HS 667, HS 668 and HS 669
Biofortification Nursery	QBP 18-7, QBP 18-8, QBP 18-9, QBP 18-10 and QBP 18-11

1.1.1.3 Marker-assisted transfer of genes for rust resistance in wheat

Leaf rust resistance gene *LrTrk* from durum wheat cultivar *Trinakryia* and stripe rust resistance gene *Yr5* from hexaploid wheat *Spelta album* were targeted for transfer in three popular wheat varieties, HD 2967, HD 2733 and HD 2932. Near Isogenic Lines (NILs) carrying individual rust resistance genes *LrTrk* and *Yr5* were produced. NILs were also inter-crossed to combine *LrTrk* and *Yr5* in the genetic background of the three wheat varieties. Apart from the seedling rust resistance genes, Adult Plant Resistance (APR) genes for leaf rust resistance, *Lr34*, *Lr46*, *Lr67* and *Lr68* are being transferred in wheat varieties HD 2733 and HD 3059. NILs carrying individual APR gene in the background of HD 2733 and HD 3059 were identified in BC_2F_2 generation. Crosses were made to combine different APR genes together. In HD 2733, NILs with *Lr34+Lr46* and *Lr34+Lr68* were identified in $NILF_2$ stage. Crosses were made to combine three APR genes in the common genetic background. Combinations of seedling and APR genes are expected to provide durable rust resistance in wheat.

1.1.2 Barley

Elite barley lines advanced under AICRP. Five barley entries viz., BHS 472, BHS 474, BHS 475, BHS 476 and BHS 477 were nominated for testing in coordinated trials of barley under timely sown rainfed conditions of Northern Hills Zone.

1.1.3 Rice

1.1.3.1 Variety Released

Pusa Samba 1850. Pusa Samba 1850 is a MAS-derived near isogenic line of a popular medium slender grain rice variety BPT 5204 (Samba Mahsuri), possessing three genes for blast resistance (*Pi54*, *Pi1* and *Pita)*. It produces an average yield of 4.77 t/ha with a seed to seed maturity of 140-145 days. It has been released for the states of Chhattisgarh and Odisha.

Field view of the crop (left); and paddy, milled rice and cooked grains of Pusa Samba 1850

1.1.3.2 Entries under AICRP trials

A total of 23 genotypes were nominated in different stages of testing in the AICRP trials during *Kharif* 2018. These include two entries (Pusa1692-10-20-1-1-1 and Pusa 1847-12-62- 190-39-7-15) in AVT-BT, one entry (Pusa 5173-9-1-1-1-1) in AVT-IM, two entries (Pusa 1823-12-62 and Pusa 1823-12-82) in AVT1-NILs-Drt, two entries (Pusa 1853-12-288 and Pusa 1853-12-192) in AVT1-NIL- Blight+Blast, three entries (Pusa1301-95-12-5-2-4-2, Pusa 1882-12-102-6 and a *Basmati* hybrid Pusa RH 55) in IVT-BT, two entries (Pusa 5268-2-11-1-112-40 and Pusa 2060-29-18) in IVT-ETP, two entries (Pusa 5173-7-4-1-1 and Pusa 5251-3-4-1-2-1) in IVT-IME, three entries (Pusa 1824-12-84-17-4-3 , Pusa 1824-12-84-17-4-8 and Pusa 1836-12-5) in IVT-IM, one entry (Pusa 5183-2-3-2-1) in IVT-L, two entries (Pusa 1827-12-14 and Pusa 1827-12-55) in IVT-Aerobic and three hybrids including two entries (Pusa RH 56 and Pusa RH 57) in IHRT-E and 1 entry (Pusa RH 58) in IHRT-M were tested in the AICRIP trials during *Kharif* 2018.

1.1.3.3 Marker-assisted development of BB and blast resistant near isogenic lines (BB=Blast-NILs) in the genetic background of elite *Basmati* rice varieties PB 1121, PB 1509 and Pusa Basmati 6

Marker-assisted breeding was adopted to develop near-isogenic lines pyramided with two genes each for bacterial blight (*xa13, Xa21*) and blast resistance (*Pi2, Pi54*) in the genetic background of popular *Basmati* rice varieties, Pusa Basmati 1121, Pusa Basmati 1509 and Pusa Basmati 6. The improved BB+Blast NILs were evaluated in replicated trials at three locations viz., Delhi, Karnal and Rakhra during *Kharif* 2018. Based on agronomic performance, grain and cooking quality, two promising BB=Blast resistant NILs have been identified in the genetic background of each of the popular *Basmati* rice varieties.

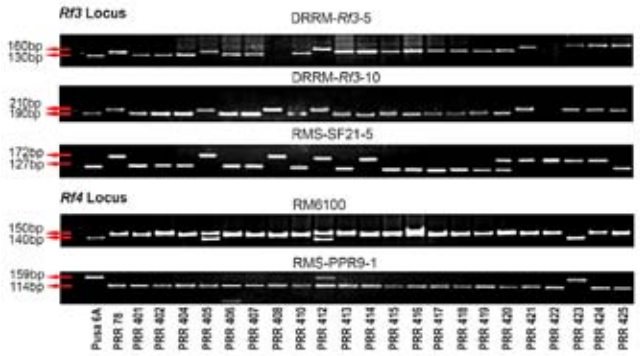
1.1.3.4 Development of low phosphorus tolerant Pusa 44 near isogenic lines

Marker-assisted backcross breeding was adopted to incorporate the QTLs governing phosphorus starvation tolerance *Pup1* in the genetic background of Pusa 44. *Pup1* is a QTL that contains *OsPSTOL1*, a serine threonine protein kinase gene, responsible for improved root system under P-deficient conditions. Two promising lines along with the recurrent parent Pusa 44 were tested at IARI-CORC at Rakhra in Patiala during *Kharif* 2018.

1.1.3.5 Marker assisted identification of restorer lines from *indica-japonica* derivatives and their potential in hybrid rice improvement

In the initial screening, out of 310 tropical japonica derived lines (TPJ), 94 lines (30.3%) were identified as restorers and were found possessing either of the *Rf* gene(s) or in combination. Among these, 36 lines (11.6 %) carried *Rf3*, 45 lines (14.5%) carried *Rf4*, and 13 lines (4.2%) carried both the genes, *Rf3* and *Rf4*. Remaining 69.7% did not possess either of the *Rf* gene(s) and were recognized as non-restorers. Based on the NPT characteristics of the lines, particularly grain number per panicle and number of panicles per plant, 52

restorers were excluded from this study and a subset of 42 lines was used for further validation of the *Rf* loci using the remaining candidate gene-based/ functional markers.



Representative gel picture showing allelic profile of *Rf3* and *Rf4* gene based markers in selected TPJ derived lines

1.1.4 Maize

1.1.4.1 Hybrids released

Pusa Super Sweet Corn 1. It is a *shrunken2*-based sweet corn hybrid with an average brix value of 15.9%. It has been released for Northern Hills Zone (NHZ), North Western Plains Zone (NWPZ), North Eastern Plains Zone (NEPZ) and Peninsular Zone (PZ). Its average green cob yield is 13.0 t/ha. The average dehusked cob yield is 9.3 t/ha with a potential of 10.2 t/ha. It provides 16.2 t/ha of green fodder as well. It matures in average of 78 days.

Ear characteristics of Pusa Super Sweet Corn 1

Pusa Jawahar Hybrid Maize 1 (PJHM 1). It has been released in collaboration with Jawaharlal Nehru Krishi Vishwa Vidhyalay, Jabalpur for cultivation in Madhya Pradesh. This hybrid has an average grain yield of 6.5 t/ha with potential yield of 10.2 t/ha. It has dark green foliage, slightly upright leaves, semi-dent and orange color seed. It has enough field tolerance to flowering stalk rot and Rajasthan downey mildew. Because of its stay green nature, PJHM 1 can also be treated as dual propose hybrid. Green foliage of the plant can be utilized as fodder after harvesting cobs.

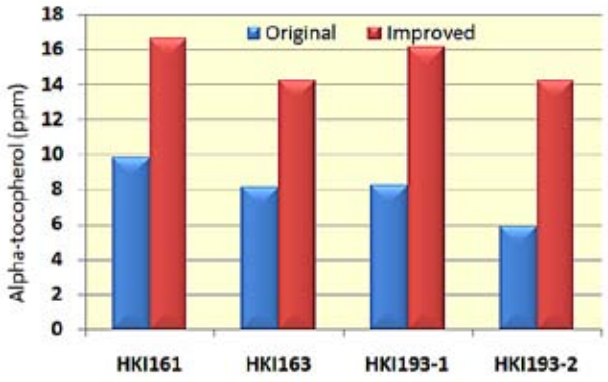
Ear characteristics of PJHM 1

1.1.4.2 Entries under AICRP trials

Biofortified hybrids (APH 27, APQH 5 and APQH 7 in AVT-II; APQH 1, APQH 8 and APH 1 in AVT-I; APH 2 in NIVT) were evaluated in AICRP trials. Among specialty corn, hybrids of sweet corn (ASKH 1 in AVT-II), pop corn (APCH 2 and APCH 3), baby corn (AH 7043 and AH 5021 in AVT-II, AH 7204 and AH 7188 in NIVT) were also evaluated. Field corn entries in early maturity group (AH 8106 and AH 8127 in NIVT), medium maturity group (AH 7067R, AH 8181-2, AH 4158 and AH 4271 in NIVT; AH 1606 in AVT-I) and under rainfed condition (ADH 8106 in NIVT) were tested in different zones Three entries (AFH 6, AH-8070 and AH 8071R in NIVT) were also evaluated in fodder trial.

1.1.4.3 Development of vitamin-E enriched inbreds

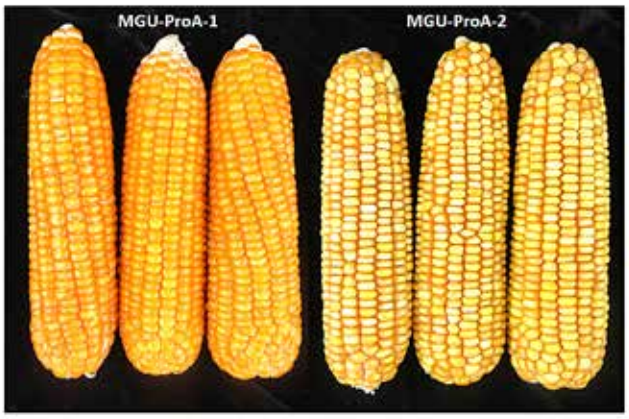
QPM and provitamin-A version of four elite hybrids viz., HQPM 1, HQPM 4, HQPM 5 and HQPM 7 were targeted for marker-assisted introgression of *VTE4* allele. The α-tocopherol in the improved lines (HKI 161-PV-VT, HKI 163-PV-VT, HKI 193-PV-VT and HKI 193-2-PV-VT) was significantly higher (14.23-16.62 ppm) than the original lines (5.89-9.82 ppm).



Alpha-tocopherol content among improved and original lines

1.1.4.4 Development of new provitamin-A rich maize hybrids

Seventy five *crtRB1*-based new crosses were evaluated at three locations viz., Delhi, Karnal and Dharwad. The inbreds were developed by selection of *crtRB1* allele using marker-assisted selection. Eight hybrids (MGU-ProA-1 to 8) with ≥10.0 t/ha of grain yield were selected. These new hybrids were significantly superior to available proA check hybrids and possessed >8.0 ppm of proA after three months of storage under normal conditions. The proA level in normal hybrids after three months of storage is <2.00 ppm.



Grain and ear characteristics of newly developed proA rich maize hybrids

1.1.4.5 Development of *lpa1* and *lpa2* based low phytate inbreds

Three elite QPM inbreds viz., HKI 323Q, HKI 1105Q, HKI 1128Q; and four elite QPM + provitamin-A inbreds, HKI 161-PV, HKI 163-PV, HKI 193-1-PV and HKI 193-2-PV which are the parents of nine hybrids (HM 4, HM 8, HM 9, HM 10, HM 11, HQPM 1, HQPM 4, HQPM 5 and HQPM 7) were targeted for introgression of *lpa1-1* and *lpa2-1* alleles separately. Promising 55 BC_2F_2 progenies with homozygosity for *lpa1-1* or *lpa2-1* were selected for grain quality analyses. Across genetic backgrounds, *lpa1-1/lpa1-1* (1.74 mg/g) and *lpa2-1/lpa2-1* (1.82 mg/g) possessed significantly lower average phytic acid compared to wild types (*LPA1/LPA1*: 2.65 mg/g; *LPA2/LPA2*: 2.59 mg/g). The promising inbreds have been used to develop low phytic acid hybrids, which possess great potential to enhance the bioavailability of iron and zinc in humans.

1.1.4.6 White maize with higher protein quality using *opaque2* and *opaque16*

White maize is a preferred option as human food. Parental lines of white grained hybrids viz., HM 5 (HKI1344 × HK1348-6-2) and HM 12 (HKI1344 × HKI1378) were targeted for marker-assisted introgression of both *opaque2* and *opaque16*. Promising BC_2F_2 progenies homozygous for *o2* and *o16* were selected. These possess >90% recurrent parent genome and high degree of similarity for plant, grain and ear characteristics with their original versions. These newly derived inbreds have been used to generate QPM hybrids.

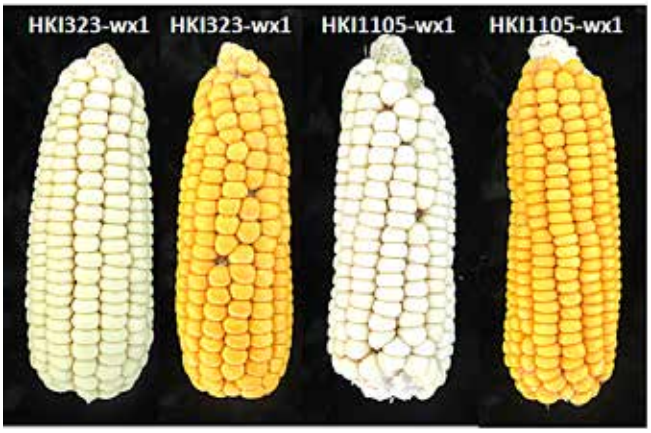
1.1.4.7 Development of biofortified sweet corn hybrids

ASKH 1 (SWT016 × SWT017) and ASKH 2 (SWT016 × SWT018), promising sweet corn hybrids developed at IARI, New Delhi were targeted for enrichment of lysine, tryptophan and provitamin-A by introgressing *opaque2* and *crtRB1* alleles in different combinations. Progenies homozygous for *shrunken2*, *opaque2* and *crtRB1* were developed in SWT016, SWT017 and SWT018 genetic backgrounds. The improved hybrids possessed provitamin-A, lysine and tryptophan as high as 25.41 ppm, 0.47% and 0.14%, respectively, as compared to the highest values achieved among original hybrids (provitamin-A: 3.68 ppm, lysine: 0.29% and tryptophan: 0.06%).

Ear and grain characteristics of multinutrient rich sweet corn hybrid (ASKH 1)

1.1.4.8 Development of sticky maize

Sticky maize due to its high amylopectin is a popular choice in North-Eastern states. Recessive *waxy1* (*wx1*) allele enhances amylopectin to 95-100%, in contrast to 70-75% amylopectin in normal maize. Recessive *wx1* has been targeted for introgression in seven elite inbreds (HKI 323, HKI 1105, HKI 1128, HKI 161, HKI 163, HKI 193-1 and HKI 193-2) that are the parents of nine popular hybrids. BC_2F_2 generations were genotyped and segregants homozygous for *wx1* with high recovery of background genome and phenotypic similarity were selected.



Ear and grain characteristics of MAS-derived waxy inbreds with white and yellow grains

1.1.4.9 Development of male sterile baby corn

Male sterile baby corn does not require manual detasseling which is a laborious and time consuming operation leading to increase in cost of cultivation. Donor with cytoplasmic male sterility has been crossed with 15 elite inbreds. HM 4 is a popular baby corn hybrid, but possesses male fertility. CMS-based male sterile version of HM 4 evaluated in *Kharif* 2018, was found to have no anthers, thus no pollen was produced.

Tassel characteristics of male sterile and fertile version of HM 4 (baby corn hybrid)

1.1.4.10 Development of new inbreds for grain purpose

Four pools (pool 21, pool 22, pool 25 and pool 26) received from CIMMYT, Mexico were specific to heterotic group of medium to late maturity. Trait specific line derivation is in progress by following selfing of desired individuals in each pool. The inbreds are in S4 stage.

1.1.4.11 Development of new inbred lines for disease resistance

One hundred inbreds were evaluated for yield, Turcicum Leaf Blight (TLB) and Maydis Leaf Blight (MLB). The inbreds, PDM 96, DIM 303, CDM 1318, CDM 1350, CDM 1304 were promising with grain yield of >3.0 t/ha and TLB and MLB score of <2.5 under natural epiphytotics.

1.1.4.12 Generation of new experimental single cross hybrids

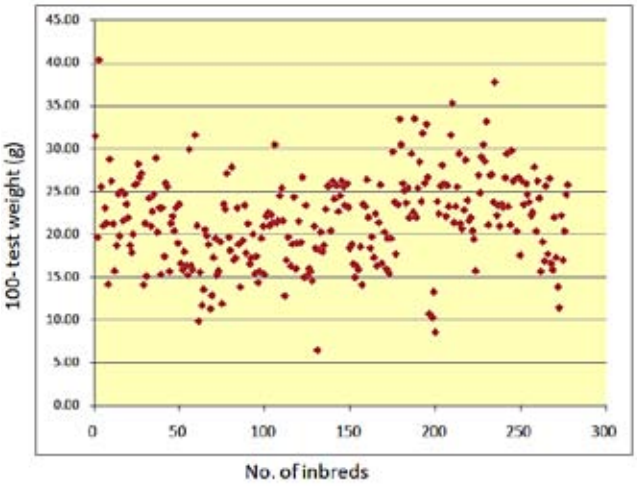
A total 350 new single cross hybrids (130 late and 220 early to medium maturity) were evaluated under

different agro-climatic conditions (Delhi, Punjab and Karnataka) along with national checks. In each maturity groups, top 10 hybrids were selected based on their *per se* yield performance. Among the medium maturing hybrids, AH 4271 and AH 4158 ranked top and produced >9.0 t/ha grain yield. Of these two, hybrid AH 4271 was promoted to AVT-I under AICRP testing system.

Besides, a set of 300 single cross hybrids was also evaluated for yield superiority and biotic stress resistance. H 8622, H 7670, H 7241 in early group, H 7852, H 7956, H 8575 in medium category and H 8461, H 8464, H 7726, H 7777 in late category were promising with more than 15% standard heterosis over best checks. These hybrids were also moderately resistant to TLB and MLB. The hybrids, AH 7080, AH 7078, AH 8181, AH 8183 and AH 8315 are promising with a TLB score of < 2.0.

1.1.4.13 Variation in seed size and weight for enhancing grain yield

A set of 280 tropical maize germplasm was evaluated for seed size and seed weight. AI 243 was identified as genotype with low test weight (8g/100 seed) and BM 1441 was identified as genotype with high test weight (34 g /100 seed). No significant association with seed size and kernel row number suggested that they can be targeted simultaneously for the improvement of yield.



Variation in test weight among maize germplasm

1.2 MILLET

1.2.1 Pearl Millet

1.2.1.1 Entries under AICRP trials

Three hybrids, Pusa 1801 (MH 2417), Pusa 1802 (MH 2418) and Pusa 1803 (MH 2419) were tested at 15 locations in Initial Hybrid Trial-M in Zone-A. Pusa 1801 gave an average yield of 3197 kg/ha followed by Pusa 1802 (3061 kg/ha) and Pusa 1803 (2833 kg/ha) and out yielded the Check, MPMH17 (2809 kg/ha) by a margin of 13.81%, 8.97% and 0.85 %, respectively. These are superior in dry fodder yield also. Out of 37 hybrids, Pusa 1803 was at rank one with respect to dry fodder yield. All the three hybrids have shown resistance to all the five major diseases of pearl millet.

Pusa 1801

1.2.1.2 Hybrid development and evaluation

Four hundred thirty seven new hybrids were developed involving high yielding, downy mildew resistant, blast resistant and high iron and zinc enriched parents belonging to early and medium maturity group. Twenty seven hybrids belonging to medium and early maturity group were evaluated in Intermediate Station Trial and one hybrid (ICMA 04111 x 17681) was found promising. Thirty two hybrids were evaluated belonging to medium and early maturity group in Initial Station Trial and four hybrids (ICMA 91777 x ICMR 13333; ICMA 11222 x R-62; ICMA 91777 x R-42 and ICMA 91777 x R-89) were found promising.

Twenty eight hybrids including three checks were tested in Intermediate Station Trial involving iron and

zinc enriched parental lines. Two hybrid combinations (ICMA 08666 x HFeIT-15/27; ICMA 08666 x J 2574; ICMA 03999 x FCB-96 and 6ICMA 08666 x R-67) were found promising. Fifteen hybrids developed by crossing of iron enriched parents were tested in Initial Station Trial and two hybrid combination (ICMA 98222 x FZ-15 and ICMA 11222 x FZ-12) were found promising.

1.2.1.3 Performance of IARI lines in various trials

Elite Inbred Joint Biofortification Trial. Four biofortified restorer lines viz., PPMI 1089, PPMI 1239, PPMI 1243 and PPMI 1249 were nominated in Elite Inbred Joint Biofortification Trial conducted during *Kharif* 2018. This trial was conducted at four locations Dhule, Mandor, Jodhpur and Hisar. With respect to iron and zinc, PPMI 1249 (Fe: 88 ppm; Zn: 53 ppm) surpassed the check Dhanshakti (Fe: 82 ppm; Zn: 46 ppm).

CRP Biofortification Parental line trials. Two entries, PPMI 952 and PPMI 958 were nominated in CRP Biofortification Parental Line trials conducted at five locations viz., Mandor, Jaipur, Hisar, Jamnagar and Dhule during *Kharif* 2018. Both the entries, PPMI 952 (Fe: 103 ppm; Zn: 53 ppm) and PPMI 958 (Fe: 111 ppm; Zn: 60ppm) surpassed both the checks ICMB 98222 (Fe: 75 ppm; Zn: 47ppm) and Dhanshakti (Fe: 93 ppm; Zn: 57 ppm).

Heat stress tolerance trial. The experiment was conducted at Mandor and Jaipur for identification of heat stress tolerance in pearl millet genotypes at seedling stage. The genotypes, PPMI 1263 and PPMI 1239 performed better having high shoot length, seedling dry weight and SVI at Jaipur and PPMI 1263 performed better at Mandor.

Pearl Millet Blast Virulence Nursery (PMBVN). Three entries, namely, PPMI 1213, PPMI 1249 and PPMI 1262 were nominated in PMBVN. These entries were evaluated at 11 locations (Anand, Aurangabad, Dhule, Jaipur, Gwalior, Hisar, Mysore, New Delhi, Jamnagar, Mandor and Patancheru) and PPMI 1249 was found highly resistant (2.6).

1.3 GRAIN LEGUMES

1.3.1 Chickpea

1.3.1.1 Entries under AICRP trials

BG 3062, a promising Fusarium wilt resistant *desi* chickpea genotype suitable for machine harvesting has been promoted to AVT-2 (central zone). Two *desi* entries, BG 3088 and BG 3091 were promoted to AVT-1 in different zones. Eight *desi* entries (BG 4000, BG 4001, BG 4002, BG 4003, BG 4004, BG 4006, BG 4007, BGD1536) and two large seeded *Kabuli* types (BG 4008 and BG 4009) were entered in five different IVTs during 2018-19.

1.3.1.2 Introgression lines for drought conditions

BG 3097 (in background of Pusa 362) and BGM 10216 (in the background of Pusa 372) with 11.5% and 8% yield advantage, respectively, over their respective recurrent parents under drought conditions were promoted to final year of testing in AVT-2 (DTIL) trial in AICRP. Two introgression lines for drought tolerance and two for wilt resistance were entered into AVT-1.

1.3.1.3 Promising genotypes evaluated in multi-location trials in Karnataka

Two chickpea entries (BGD 133 and BGD 138) were evaluated under multi-location trials for two years (2016-17 and 2017-18). Both the entries recorded significantly higher grain yield in zones-3 and 8 of Karnataka. In zone-3, BGD 133 recorded average grain yield of 1836 kg/ha and, in zone-8 it has recorded 1995 kg/ha. These entries will be proposed for on- farm trial during 2019-20.

1.3.1.4 Development of erect, tall and non-lodging cultivars suited to mechanical harvesting

F_4 fro m 5 crosses and F_5 /F_6 from 23 crosses were screened in wilt sick plot during 2017-18 along with susceptible checks (JG 62 and BGD 1005). More than 650 single plants were selected based on wilt reaction (<10% mortality) and plant type amenable to mechanical harvesting. A preliminary yield trial (PYT-MH), station

trial (ST-MH-1, -2 and -3) and advance trial (AT-MH) were conducted with 654, 84 and 12 erect breeding lines, respectively. Based on plant type and yield, entries were promoted to next tier.

Erect plant types at maturity

1.3.2 Pigeonpea

1.3.2.1 Entries under AICRP trials

Pusa 2018-1, Pusa 2018-2 and Pusa 2018-3 (NIVT-extra early), Pusa 2018-4 and Pusa 2018- 5 (NIVT-early) were contributed to AICRP trials. Among hybrids, PAH 3, PAH 4 and PAH 5 were contributed to IHT-early trial.

1.3.2.2 Development of short duration lines with improved plant type

Ten semi-erect, compact and indeterminate bold seeded lines (9 g/100 seeds) with 4 seeds/pod and 2-3 pods/cluster; 4 determinate, semi-dwarf lines with erect and compact plant type, 4 seeds /pod, bold seeds (9 g/100 seeds) with 130 days maturity; a determinate, semi-dwarf line with 7-9 pods/cluster, 4- 5 seeds/pod with early maturity (126 days); 15 determinate, semi-dwarf and early maturing (135 days) lines derived from the cross Pusa Dwarf x ICP 8863 having 3-4 seeds/pod and 6-8 pods/cluster; and 5 determinate, semi-dwarf (104 cm) compact erect genotypes with 4 seeds/pod, 3-4 pods/cluster and 129 days to maturity have been developed.

1.3.2.3 Development of short duration A lines

Using cytoplasmic source from *C. scarabaeoides*, 4 new short duration A lines viz., Pusa 992 A, Pusa 2001A, Pusa 2002 A and Pusa Dwarf A have been developed and are being used to develop CGMS based pigeonpea hybrids.

1.3.2.4 Development of short duration R lines

Four determinate, dwarf and short duration R lines from A x R crosses; a determinate,dwarf (Plant height: 77.8 cm) and extra early maturing (110 days) R line with complete senescence at maturity with 3-5 seeds/pod, 3-5 pods/cluster; and a determinate compact erect early maturing (136 days) line with plant height of 121 cm have been developed.

Determinate and early maruring plant type

1.3.3 Mungbean and Lentil

1.3.3.1 Entries under AICRP trials

Lentil. AVT II - L 4729 (Bold seeded Central Zone), AVTI - Two, IVT - Eight, State trials - Ten (UP, Bihar, J&K).

Mungbean. AVT II- Pusa 0871 (*Kharif*-Uttar Pradesh), IVT - Eight, State trials - AVT I - Three.

1.3.3.2 Hybridization

Sixty five crosses were generated in lentil and 52 in mungbean involving donors for earliness, bold seed size, better nutritional quality and resistance to biotic and abiotic stresses.

1.3.3.3 Breeding material evaluation

- Three thousand seven hundred and thirty four single plant selections from different generations

were raised and evaluated in mungbean; and in lentil three thousand and one hundred forty seven single plant selections were evaluated.

- Sixty nine elite entries of lentil and 53 of mungbean were evaluated in unreplicated observation trial.
- LIPBN, LIEN, LIEN-L, LIEN-MH, LIEN-S, LIEN-E, LIMN, and LIDTN nurseries from ICARDA were evaluated.
- One hundred and fifty three mungbean genotypes were studied for traits related to phosphorus use efficiency (PUE). Variation for root and shoot traits have been recorded in screening carried out at normal phosphorus under hydroponic condition and under low phosphorus. Roots were analysed using Wizrizho.
- Twelve lentil varieties were grown at five location to study G x E interactions for grain Fe and Zn concentration in lentil. Four hundred lentil germplasm lines were multiplied to study diversity for grain Fe and Zn concentration.

1.3.3.4 Microgreens

Twenty varieties each of lentil and mungbean were grown in different densities under Phytotron facility at Delhi. In mungbean, Pusa Vishal (3.2 kg per m^2) and Pusa Ratna (3.3 kg per m^2) were found the best at 2.3 plants per cm^2 at 7th day of harvesting. Similarly, for lentil IPL321 (1.45 kg per m^2) and DPL62 (1.56 kg per m^2) were found the best at 2.4 plants per cm^2 at 10th day of harvesting. The radical scavenging activity using DPPH and H_2O_2, while antioxidant activities using Ferric Reducing Antioxidant Power (FRAP) were found maximum in lentil genotypes DPL 62, K 75 and L 4147, respectively, at 10th day of harvesting, whereas it was maximum in the mungbean genotypes MH 318, Pusa 9072 and Pusa Ratna, respectively, at 7th day of harvesting.

Five-day old lentil microgreens

1.4 OILSEED CROPS

1.4.1 Mustard

1.4.1.1 Entries in AICRP trials

Total 20 entries were contributed to AICRP-RM evaluation trials at national/zonal level including four in different Advance Varietal Trials (NPJ 203 in AVT 1 Timely Sown Irrigated in Zone IV; LES 54 and LES 57 in AVT Q and NPJ 216 in AVT1 Late Sown). Test entries were contributed for their evaluation in AICRP-RM Initial Varietal/Hybrid Trials viz., IVT-Early (NPJ 221, NPJ 222); IVT Timely Sown (NPJ 223, NPJ 224); IVT-Rainfed (NPJ 225, NPJ 226); IHT Early (Pusa MH 5, Pusa MH 7), IHT Timely Sown (Pusa MH 16, Pusa MH 20), IVT-Late (NPJ 227, NPJ 228); IVT-Quality [PDZ 11 (00), PDZ 12 (00), LES 58, LES 59]. In addition, four entries viz., NPJ 217, NPJ 218, NPJ 219 and NPJ 220 were contributed for testing in National Disease Nursery for second year.

1.4.1.2 Phenotyping for identification of '0' and '00' genotypes

For identifying low erucic acid and double low genotypes in segregating generations and maintenance of double/ single low varieties and advance lines, a large number of single plants and bulks were phenotyped through biochemical analysis. For low erucic acid, 2453 single plants/bulks were analysed, of which 2306 were having < 2% erucic acid. Single plants/bulks, 2326 in number, from double low quality material/progenies were also analyzed for total glucosinolates content of which 906 plants/bulks were possessing < 30ppm glucosinolates.

1.4.1.3 Hybridization and pre-breeding

Two hundred and six fresh crosses were attempted for improving the yield (seed and oil), yield component

traits, disease resistance and quality.To infuse genetic variability and improve agronomic traits, other *Brassica* species are being utilized. One hundred ninety one Introgression Lines (BC_1F_4 and F_4 from three way crosses) derived from *B. juncea* x *B. carinata* were raised under irrigated and rain-fed conditions for their evaluation. F_1s and multiple crosses/backcrosses, 53 in number, attempted with *eru-rapa* derived *B. juncea* introgression lines and re-synthesized *B. juncea* lines with improved *B. juncea* genotypes were raised.

1.4.1.4 Breeding material advanced

Breeding material generated for improvement of various traits was evaluated under different sowing situations and total 1085 single plants (SPs) and 108 bulks were selected which include timely sown (SPs 576, bulks 20), early sown (SPs 263, bulks 34), late sown (SPs SPs 188, bulks 44) and quality traits (SPs 58, bulks 8). Total 112 F_1s were also evaluated for yield and other important traits and 103 single plants were selected and advanced to next generation. In addition, 253 backcrosses (BC_1-BC_6) for disease resistance and quality were also evaluated and desirable single plants were selected/backcrossed.

1.4.1.5 Cytoplasm diversification and CMS line development

To transfer nuclear genome from 23 genetic backgrounds to different sterility inducing cytoplasms viz., *Moricandia arvensis (mori), Diplotaxis erucoides (eru)* and *Diplotaxis berthautii (ber)*, 64 backcrosses (BC_5 – BC_{12}) were attempted in three pairs each with pollen tested plants. Many of these fixed CMS lines were used for hybrid seed production.

Paired crosses attempted with selected backcross progenies for development of CMS lines

1.4.1.6 Restorer development and maintenance

Backcrosses (BC_4-BC_6) were attempted to transfer the *Rf* gene, which restores fertility in *mori*, *eru* and *ber* sterile cytoplasms, to 44 nuclear backgrounds. One hundred forty five progenies of homozygous dominant plants carrying restorer gene (*RfRf*) were evaluated and selfed for their further utilization.

1.4.1.7 Hybrid evaluation and seed multiplication

Thirty-one hybrids were evaluated in different hybrid trials viz., station trials (20); multi-location trials under CRP Hybrid Technology (21) [CRPMLT1 Short Duration - (6); CRPMLT 2 Medium Duration – (5), CRPMLT 3 Short Duration- (10)]. Open pollinated seed of 25 hybrids was multiplied in nets by raising A and R lines alternatively in a row ratio of 8:1.

1.4.1.8 Promising lines/hybrids being evaluated in station trials

Ninety three advance lines and 29 CGMS based hybrids were evaluated in seven mustard station trials (MST) viz., MST (Early sown), MST (Timely Sown), MST (Rainfed), MST Quality, MST (Hybrid) and MST (Late Sown). Out of the 15 short duration hybrids evaluated under multilocation CRPHT 1 trial, Pusa MH 5 has been identified as promising.

Pusa MH 5

1.4.2 Soybean

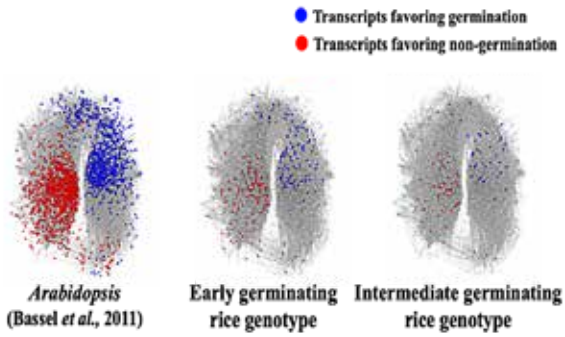
Entries in AICRP trials. DS 3110 was tested in IVT, while DS 3108 and DS 3106 were evaluated in AVT-I and AVT-II, respectively. DS 3106 is highly resistant to MYMV and pod blight.

1.5 SEED SCIENCE AND TECHNOLOGY

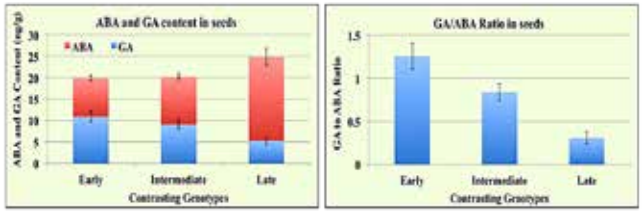
1.5.1 Studies on Seed Quality Traits

1.5.1.1 Seed germination in rice: transcriptome analysis and hormone assay

Differentially expressed genes (DEGs) obtained from the rice microarray data of the matured dry seeds of rice genotypes with the contrasting phenotype for speed of germination, the candidate orthologues/ homologues of *Arabidopsis* genes associated with germination/non-germination were identified and mapped to the germination co-expression network of *Arabidopsis*. From the network, it was deduced that the seed of early germinating rice genotypes are well equipped with transcriptional machinery, which facilitates in early germination compared to the seeds of intermediate and late germinating genotypes. Similarly, GA and ABA quantification from the seeds of early, intermediate and late germinating genotypes revealed that the seeds of early genotype had higher GA and lower ABA contents, reinforcing our concept from the microarray data that the seeds of early germinating genotypes are better prepared for the germination than the intermediate and late germinating genotypes.



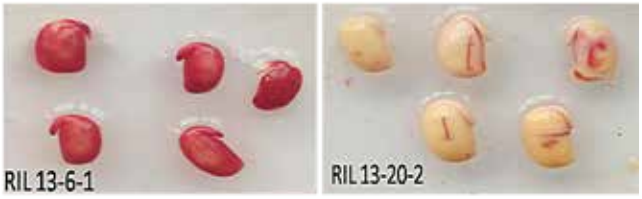
Germination co-expression network of *Arabidopsis* and rice genotypes with contrasting phenotype for speed of germination



Ga and ABA content in the dry seeds of rice genotypes with contrasting phenotype for speed of germination

1.5.1.2 Effect of seed storage period on Ascorbate Pool and viability in RILs of soybean

Ascorbic acid (ASH), dehydro ascorbic acid (DHA), and their corresponding redox ratios were estimated to investigate the effect of ageing in soybean RILs. The ASH/DHA ratio was 1.66, 5.98, 1.03, 1.81, and 7.40 in *G.max*, 2-6-2, 4-8-1, 4-32-1 and*G. soja*, respectively. The redox ratios are the indicators of efficiency of seed to combat the oxidative stress aroused due to ageing. The comparative studies in the parents and RILs revealed that the Ascorbate-Glutathione system possessed weaker reduced/oxidized forms in aged seeds of *G.max* followed by 4-32-1 and 4-8-1, as indicated by low ASA/DHA ratios which might lead to decrease in efficiency of the seed to quench ROS, hence results in seed deterioration during storage. On the other hand,*G. soja* and 2-6-2 showed better reduced/oxidized forms, maintained even after ageing. A total of 46 RILs of soybean were tested for viability using Tetrazolium test. It was found that 25 RILs showed viable seed while rest were non-viable after one year of storage.



Viability testing using tetrazolium test in soybean RILs

1.5.1.3 Mungbean characterization for tolerance to pre-harvest sprouting

Studies were taken up to understand the tolerance to pre-harvest sprouting in mungbean cultivars. Initially 106 genotypes of mungbean were characterized for pod and seed characters and then screened using standardized pod and seed germination protocols. The variation in pod characters was higher than the variation among seed characters. Among the pod characters, minimum variance (0.002) was observed in pod wall thickness and maximum variance (481.19) was observed in pod water absorption. Similarly, in case of seed characters, minimum variance (0.001) in

seed roundedness and maximum variance (2.66) in seed area were recorded. Correlation studies among pod characters revealed significant negative correlation between presence of hard seeds and pod germination (-0.77) and pod water absorption (-0.36). All the seed characters studied showed negative correlation with hard seededness except the roundness of seeds. Significant negative correlation was observed between hard seededness and seed size characters as well as 100- seed weight (-0.37). Considering both pod and seed characters, six promising cultivars (three tolerant: TM 96-25, KM 16-80, TM 96-2 and three susceptible: KM 16-60, Pusa 1331 and KM 12-29) with contrasting tolerance to pre-harvest sprouting (seed dormancy) were identified. Further, these six genotypes were studied for their seed water absorption, and a clear-cut variation in per cent increase in seed weight was noticed after 6 h of soaking . However, precise difference in the actual water content (g water g^{-1} dry weight) among dormant and non-dormant genotypes was observed only after 26 h of soaking, indicating more time and water is required for complete saturation of internal tissues across genotypes.

Pod germination on third day after soaking for 24 h in water

1.5.1.4 Hardness breaking force: an alternative method to evaluate hardseededness in mungbean (*Vigna radiata* (L.) Wilczek)

Seed germination test requires seven days to evaluate hardseededness. Hence, experiment to find out rapid alternate procedure for large scale evaluation and screening of breeding materials for hardseededness was initiated. Fifty one mungbean genotypes were grown during *Kharif* 2017 and 2018 with similar growing conditions, and number of hardseeds were recorded after standard seed germination test. The hardness breaking force (Newton) was applied using Texture Analyzer machine on 5 seeds each in 3 replications for each genotype. Based on mean and standard deviation values, the genotypes were classified into three groups viz., low (<27 Newton), medium (28-56 N) and high (>56 N) hardness breaking force. Seven genotypes during both the years showed average hardness breaking force of 22.2 N and 22.32 N with mean per cent hard seeds of 7.83% and 8.25%, respectively. Similarly, 26 genotypes in both the years required hardness breaking force of 40.72 N and 41.21 N with average per cent hard seeds of 18.1% and 18.7%, respectively. Eight genotypes in both the years required mean hardness breaking force of 62.9N and 63.75N with average per cent hard seeds of 27.2% and 27.25%, respectively. The hardness breaking force character was stable over two years in the genotypes. Thus, this parameter reported for the first time can be used as an alternate to standard germination test for screening for hardseededness of large breeding materials in short period of time.

1.5.1.5 Seed enhancement treatments for improved storability of conventional and quality type Indian mustard

With increasing consumer awareness and demand, quality Indian mustard (*B. juncea*) i.e. single zero and double zero varieties have been developed by the IARI. Studies were undertaken to investigate the seed quality traits in quality Indian mustard genotypes in response to various seed treatments in an attempt to enhance planting value of seed. Six genotypes consisting of three conventional, two single zero and one double zero varieties were taken and subjected to three seed treatments consisting of thiram @2.5g/kg seed, imidacloprid @ 5g/kg seed and combination of both along with control and kept under ambient storage conditions. The results showed significant differences among the varieties and treatment after 15 months of

storage. All the genotypes showed high germination (>95%) in fresh seeds but germination reduced to 75, 83 and 82% in control, thiram+imidacloprid and thiram treated seeds, respectively, after 12 months of storage. Though, only in the seeds treated with imidacloprid 85% germination was maintained which is at par with the Indian Minimum Seed Certification Standards (IMSCS). However, significantly higher vigour index I (1136) and II (1.23) over all other treatments was observed in seeds treated with thiram+imidacloprid, compared with the control after 15 months of storage under ambient conditions. These treatments also resulted in significant reduction of storage pest particularly in double zero variety. Significant reduction in seed vigour indices was also observed in this genotype.

1.5.1.6 Effect of terminal heat stress in parental lines of wheat hybrids

Stay green duration in wheat is critical trait for stress breeding. Maximum reduction in stay green duration was observed in lines viz., CMS 2046 (25.0%) followed by CMS 2019 (24.4%). Among restorers, T2003R exhibited highest reduction of 17.2 %. The mean value of membrane thermo-stability index in normal sown condition was found significantly high in CMS, maintainer and restorer lines as 59.96%, 58.96% and 61.23%, respectively, while the same got reduced in late sown condition under high temperature stress i.e. 45.95%, 48.10% and 47.84% for CMS, maintainer and restorer lines, respectively. Other parameters viz., plant height, flag leaf area, tiller number and pollen viability also reduced under late sown condition in comparison to normal sown condition. Based on morpho-physiological and yield component traits under late sown conditions, CMS 3083 was best performer for all the characters except tiller number and 1000-seed weight, whereas, CMS 2041, CMS 2046 and CMS 2019 showed better performance for tiller number and 1000-seed weight under late sown condition. Among restorers, R 965 was best performer for all morpho-physio and yield traits, except days to 50% anthesis, number of tillers, seeds per spike and 1000-seed weight. Restorers R 902 and R 958 performed better for 1000-seed weight, tiller number and seeds per spike.

1.5.1.7 Effect of GA responsive reduced height genes on seedling vigour traits in wheat (*Triticum aestivum* L.)

Wheat varieties with longer coleoptile length and good seedling vigour, are suitable for conservation agriculture. Sixty wheat genotypes, including advance lines, were categorised into three different coleoptile length groups i.e. short (2.5-4.5 cm), medium (4.6-6.5 cm) and long (6.6-9 cm). These three classes of genotypes were sown at three different depths of 5cm, 7.5cm and 10cm. In short and medium coleoptile length genotype, significant reduction in emergence was recorded when sown at 10 cm depth as compared to emergence from 5 cm and 7.5 cm sowing depths. Coleoptile length was found directly proportional to seedling shoot length. Longer coleoptile length genotypes also had higher embryo size, seed vigour indices, higher root surface area, root volume and number of forks which provide these genotypes an early seedling vigour under stress conditions.

1.5.2 Evaluation of Controlled Pollination Methods with Reference to Seed Yield and Quality Parameters in Pigeonpea

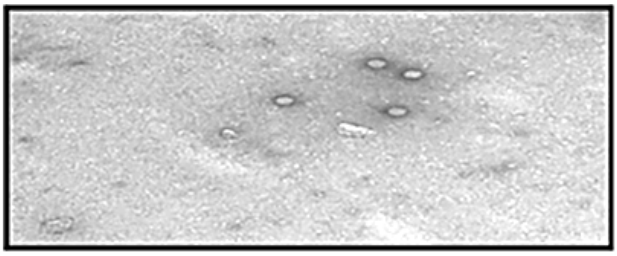
Four different types of customized selfing net bags viz., large nets (5m x 3m x 3m) and net bags (1m x 1m x 1.65m, 86cm x 46cm, 50cm x 28cm,) were used to evaluate their role in influencing seed yield and quality parameters in pigeon pea varieties Pusa 991, Pusa 992, Pusa 2001 and Pusa 2002 during *Kharif* 2016, 2017 and 2018. The large nets were used for a single plot of 3m x 3m, covering about 120 plants, whereas the net bags of 1m x 1m x 1.65 m were used to cover the individual plants. The net bags of size 86 cm x 46 cm and 50 cm x 28 cm were used to cover the individual branches on a plant. The plants were covered with nets after bud initiation, but prior to flowering ensuring no entry of insects. Uncovered plants/plot were used as control (open pollination). Twenty plants/branches in three replications were tagged in each treatment for recording the data on plant height, days to flowering, number of branches/plant, number of pods/plant, seed

yield/plant, 100 - seed weight, seed germination and vigour indices. Seed yield and quality parameters were significantly influenced by the size of the net bags. Based on seed yield, seed setting and seed quality parameters, it is concluded that large nets (5m x 3m x 3m) and net bags (1m x 1m x 1.65 m) can be used for maintenance of pigeonpea varieties on plot and individual plant basis, respectively.

1.5.3 Seed Health

1.5.3.1 First report of soybean yellow mottle mosaic virus on soybean (*Glycine max*) in India

While surveying for the seed borne viruses of soybean, 38 leaf samples of initial varietal trials exhibiting symptoms such as mosaic, mottling, necrosis and puckering were collected from IARI fields and tested for *Cowpea mild mottle virus, Groundnut bud necrosis virus, Soybean mosaic virus, Soybean vein necrosis virus, Soybean yellow mottle mosaic virus (SYMMV)* and *Tobacco streak virus.* Three of 38 samples strongly reacted with SYMMV polyclonal antibodies in DAC-ELISA (A_{405nm}= 1.2 to 1.8), showed the 1065bp amplicon in RT-PCR with coat protein specific primers (F:5′-ATGAATTCATGAATGGA ACAATGCTCACCGT-3′; R: 5′-CAAAGCTTAGT GTGTGGGTTTTAACTGGCGTTGTTA-3′) (GenBank accession no. MG768974). SYMMV occurrence in soybean was further confirmed through mechanical sap inoculation on French bean cv. Pusa Parvati there by testing with SYMMV polyclonal antibodies and RT-PCR with coat protein specific primers.



Confirmation of SYMMV virus particles in electron microscopy

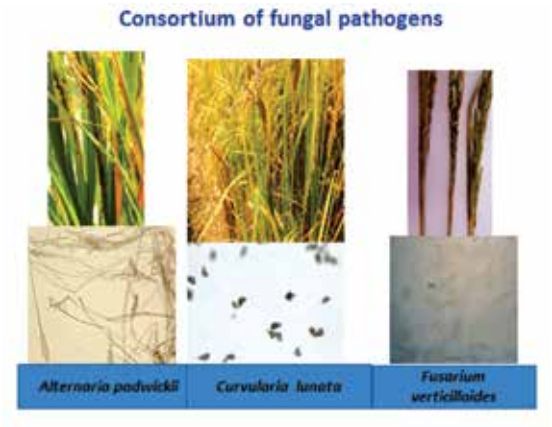
Infected leaf samples showing mottling and puckering symptoms on soybean

1.5.3.2 Morpho - molecular characterization of diversity in *Sarocladium oryzae* causing sheath rot in paddy

In morphological characterization Czapek Dox Agar medium was found better in comparison to Potato Dextrose Agar medium for growth as well as sporulation of the pathogen. Maximum growth and sporulation was observed at 30°C in CDA medium. The molecular characterization using two marker systems i.e. Inter Simple Sequence Repeat (ISSR) and Random Amplified Polymorphic DNA (RAPD) was carried out which revealed differences in isolates collected from different geographical locations. Out of 22 ISSR and 24 RAPD primers, 8 ISSR and 7 RAPD primers after preliminary screening were used against all the thirty isolates as these primers gave very good reproducible banding pattern. The association of three more fungal genera viz., *Fusarium verticilloides, Alternaria padwickii* and *Curvularia lunata* were often seen on blotter paper which suggests consortia of fungal pathogens associated with sheath rot of paddy.

Symptoms of sheath rot of paddy

Spore behaviour of congregation



1.6 SEED PRODUCTION OF FIELD CROPS

The Seed Production Unit at IARI, New Delhi and three regional Stations of IARI viz., Karnal, Indore, Pusa Bihar were involved in the seed production of different varieties of field crops which include nucleus, breeder and truthfully labelled seed. The details are as follows:

Seed Production (t)

Crop Group	Nucleus Seed	Breeder Seed	IARI Seed	Total Seed
Seed Production Unit IARI, New Delhi				
Cereals	5.54	112.58	252.465	**370.585**
Pulses	-	2.92	19.96	**22.88**
Oilseeds	-	3.12	10.63	**13.75**
Others	-	1.20	3.97	**5.17**
Regional Station, Karnal				
Cereals	0.94	130.76	250.75	**382.45**
Pulses	0.02	2.94	0.66	**3.62**
Forages	0.03	0.57		**0.60**
Oilseeds	0.01	0.3	0.83	**1.14**
Others	-	-	1.00	**1.00**
Regional Station, Indore				
Cereals	-	154.3	-	**154.3**
Regional Station, Pusa (Bihar)				
Cereals	-	81.25	111.54	**192.79**
Pulses	-	0.075	2.26	**2.335**
Oilseeds	-	-	0.74	**0.74**
TOTAL	**6.54**	**490.015**	**654.805**	**1151.36**

2. HORTICULTURAL SCIENCE

There has been record increase in area and production under horticultural crops since 2013-2014. This trend indicates healthy sign in country's march towards nutritional security, besides its role in food, nutritional and livelihood security. The School of Horticultural Sciences was created in 2013 by reorganizing the School of Crop Improvement. The focused attention is currently on making technological innovations in the form of genetic enhancement; and efficient production and resource management strategies. A number of improved varieties/ rootstocks in different horticultural crops having not only yield gains but also having added traits to economize production cost like biotic and or abiotic stress tolerance, better nutraceautical properties and processing attributes have been developed. Novel genotypes have been identified in several crops for their release at AICRP, Delhi State and Institute levels. Technologies for quality planting material and seed production and efficient production technologies have also been developed. Efforts have been made to integrate conventional strategies along with molecular technologies in achieving precision in breeding.

2.1 VEGETABLE CROPS

Varieties/F_1 hybrids notified. Eleven varieties, viz. onion cv. Pusa Sona (Sel. 153-1), garden pea cv. Pusa Prabal (GP473), brinjal cvs. Pusa Safed Baingan 1 (Sel.195) & Pusa Hara Baingan 1 (G 190), long melon cv. Pusa Utkarsh (DLM 27), round melon cv. Pusa Raunak (DRM 26), musk melon cv. Pusa Madhurima (DM 159-1), Sarda melon cv. Pusa Sarda (DHM 163), Chenopodium cv. Pusa Green (Bathua Selection 2), cucumber cv. Pusa Parthenocarpic Cucumber 6 (DPaC 6) and okra cv. Pusa Bhindi-5 (DOV 66) and two F_1 hybrids,viz., bitter gourd cv. Pusa Hybrid 4 (DBGH 12), sponge gourd cv. Pusa Shrestha (DSGH 9) have been notified by Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Horticultural Crops in 2019.

Varieties released. Two varieties viz., a cabbage F_1 hybrid Central Cabbage Pusa Hybrid 81 **(**KTCBH 81) and a Kale variety Central Kale Pusa 64 (KTK 64) were released by Central Sub-Committee on Crop Standard, Notification and Release of Varieties for Horticultural Crops.

Cabbage F_1 hybrid Central Cabbage Pusa Hybrid 81 (KTCBH 81): A cabbage F_1 hybrid Central Cabbage Pusa Hybrid 81 **(**KTCBH 81) has been released and notified by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Horticultural Crops for Zone-I. This is the second F_1 hybrid of cabbage developed by the ICAR-IARI, Regional Station, Katrain. This hybrid has dark green, 12-14 non-wrapping waxy leaves, plant height is 22-25 cm, round and very compact head covered with outer leaf. It matures in 60-65 days after transplanting, has very good field staying capacity (20-25 days) after head formation. It has given an average yield of 43.5 t/ha under multi-location trials.

Cabbage Pusa Hybrid 81

Kale var. Central Kale Pusa 64 (KTK 64): A Kale open-pollinated variety Central Kale Pusa 64 (KTK 64) has been

released and notified by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Horticultural Crops for zone-I. This is the first ever variety of vegetable kale released in India by the ICAR-IARI, Regional Station, Katrain. It has highly serrated, purplish green leaves, 40-50 cm in length and 15-20 cm in width, plant height is 50-60 cm. Leaves are available throughout the winter season in multiple harvestings, which can be consumed as cooked green vegetable like *methi* or mixed with other leafy vegetables, preparing soup and *salad*. It has higher contents of phenols, anthocyanins, ascorbic acid, chlorophylls, lycopene and total carotenoids than other varieties of *Brassica* vegetables. It has high tolerance to cold and frost conditions. Average leaf yield over locations is 35.0 t/ha.

Central Kale Pusa 64

Varieties identified by AICRP (VC). Four varieties, viz. cucumber cv. Pusa Long Green (DC 83), brinjal cv. DBL 175, cowpea cv. CP 55 and Dolichos bean cv. DB 10 were identified by AICRP (VC).

Cucumber cv. Pusa Long Green (DC 83): Identified and recommended by XXXVI Group Meeting of AICRP (VC) held at RARI, Durgapura during 2018 for Zone IV (Sub-humid Sutlej-Ganga Alluvial Plains, i.e., Punjab, Delhi, Uttar Pradesh and Bihar). The fruits of this variety are long (15-18cm), light green in colour with mild whitish-green stripes and dark green blotchy spots present near the blossom end, straight, rudimentary spines, soft skinned with tender and crispy flesh. The maturity period (days to first fruit harvest) is about 45-50 days. The three years average yield at eight locations was 206.8 t/ha, which is 32.5% higher than that of the commercial check, Pant Khira 1 (156 t/ha). It is suitable for cultivation in both spring-summer and rainy seasons in northern Indian plains.

Pusa Long Green

Brinjal cv. DBL 175: Identified and recommended by XXXVI Group Meeting of AICRP (VC) held at RARI, Durgapura during 2018 for Zone - VI (Delhi, Rajasthan, Haryana and Gujarat) and Zone-VII (Madhya Pradesh & Maharashtra). It is an early maturing variety suitable for growing in *Kharif* season. Plants are non-spiny having semi-erect branches with purple pigmentation on stem. Average plant height is 60-65 cm. Flowers are purple and of medium size. Fruits are long (18-20 cm length), cylindrical (3.5-4.5 cm diameter), shiny purple in colour with non spiny green calyx. Fruits are borne in solitary as well as in clusters. The average fruit

DBL 175

weight is 100-125 g. The variety takes 50-55 days from transplanting to first harvesting. Average fruit yield is 38.0 t/ha. It has shown field resistance to *Fusarium* wilt under Delhi conditions.

Cowpea cv. CP 55: It is a bush type cowpea identified by XXXVI AICRP Group meeting for its release in Zone-VI (Delhi, Rajasthan, Haryana and Gujarat). This is an early maturing variety having medium plant height. Stem and leaf are green in colour. The pods are smooth, slender, round, straight and light green in colour. The pod length ranges from 20-26 cm with pod diameter 0.6-0.8 cm. The dried seeds are kidney shaped bi-colour with white hilum. The half of the seed is dark brown surrounding the hilum and remaining half of the seed is creamish-white. The average pod yield is 12.0-15.0 t/ha. It is suitable for growing in rainy as well as spring-summer season. It is highly resistant to golden mosaic virus.

A cowpea cv. CP 55

Dolichos bean cv. DB 10: It is a pole type Dolichos bean identified by XXXVI AICRP Group meeting for its release in Zone-VII (Madhya Pradesh & Maharashtra). This variety has green stem and leaf colour. The pods are smooth, flat, light green in colour and bearing in cluster, slight incurved toward suture. It is early in maturing with profuse pod bearing habit. The pod length is 10-12 cm, width 2.2-2.5cm with acute beak (0.5-1.0 cm) having 4-5 seeds per pod. It has resistance to common been mosaic virus and *Cercospera* disease.

A Dolichos bean cv. DB 10

2.1.1 Cole Crops

2.1.1.1 Cauliflower

Development of promising genetic materials. In total, 98 F_1 hybrids (72 CMS based, 26 SI based) of early group cauliflower were evaluated of which promising (>24.0 t/ha) were DCEH 312367, DCEH 310471, DCEH 7571, DECH 7523 and DCEH 31523. Out of 47 CMS based F_1 hybrids of mid-early group the most promising were DCMEH 993 (39.1 t/ha), DCMEH 1093 (36.4 t/ha), DCMEH 1025 (35.9 t/ha), DCMEH 940 (34.3 t/ha) and DCMEH 2225 (32.2 t/ha). In mid-late maturity group, DCMLH 8404 (42.2 t/ha), DCMLH 1476 (41.6 t/ha), DCMLH 8405 (40.8 t/ha) and DCMLH 1544 (39.8 t/ha) were found to be promising among 30 tested CMS based F_1 hybrids for December end to January first week maturity. While, DCMLH 4012, DCMLH 153, DCMLH 2466, DCMLH 207 and DCMLH 205 (>36.3

DCMLH 207 - A promising hybrid in mid-late group

t/ha) were promising for second fortnight of January. Furthermore, six hybrids in early group, namely, DCH 4198, 167, 2398, 9867, 1523 and 988 and five in mid-maturity group,viz. DCMEH 2325, 1033, 1009, 4976 and 1476 have been advanced to AVT-II trial under AICRP (VC).

In snowball group, 22 F_1 hybrids received from IARI Regional Station Katrain were evaluated, of which the most promising hybrids were CFH 4 (47.2 t/ha), CFH 2 (43.8 t/ha),CFH 3 (34.7 t/ha) and CFH 20 (32.6 t/ha) that matured in February 2019.A purple cauliflower genotype PC 1 derived through recurrent selection from an exotic heterogenous material Sicilian Purple was observed to be promising having marketable curd weight of 812.5 g and yield (26.8 t/ha) during December-January. It produces attractive purple curds with high anthocyanin content (40.6±2.74 mg/100g FW) and potential seed yield of 24.0 g/plant.

Purple cauliflower PC 1

Evaluation of CMS and Inbred parental lines-based hybrids. Eighty F_1 hybrids along with two check cultivars were evaluated for yield and its contributing traits at Baragam Farm of ICAR-IARI Regional Station, Katrain. The marketable yield of top five hybrids,viz., KTCFH 40 (36.17 t/ha), KTCFH 23 (35.91 t/ha), KTCFH 79 (34.93 t/ha), KTCFH 68 (33.51 t/ha) and KTCFH 46 (33.28 t/ha) was found superior over both the check cultivars with the heterosis range of 8.08-17.46 and 0.54-9.26 per cent over Pusa Snowball Hybrid 1 (30.80 t/ha) and Casper RZ (33.11 t/ha), respectively.

KTCFH 40

KTCFH 23

Promising CMS and Inbred parental lines-based hybrids of snowball cauliflower

Evaluation of CMS and DH parental lines-based hybrids. Newly developed 70 F_1 hybrids (CMS and DH parental lines based) were evaluated at Baragam Farm of ICAR-IARI Regional Station, Katrain. The marketable yield of top five hybrids,viz., KTCF-DH-H 73 (43.42 t/ha), KTCF-DH-H 52 (43.33 t/ha), KTCF-DH-H 48 (36.97 t/ha), KTCF-DH-H 66 (35.77 t/ha) and KTCF-DH-H 3 (35.69 t/ha) was found higher than both the check cultivars with the heterosis range of 16.16-40.98 and 8.05-31.14 per cent over Pusa Snowball Hybrid 1 (30.80 t/ha) and Casper RZ (33.11 t/ha), respectively.

KTCF-DH-H 73

KTCF-DH-H 52

Promising CMS and DH parental lines-based hybrids of snowball cauliflower

Evaluation of promising hybrids in multi-location yield trials. Twenty promising F_1 hybrids developed and already tested by ICAR-IARI Regional Station, Katrain were evaluated at three different locations,viz., ICAR-IARI Regional Station, Katrain, ICAR-IARI, New Delhi and Dr YS Parmar UHF, Nauni, Solan. At ICAR-

IARI Regional Station, Katrain,the marketable yield of top five hybrids, viz., KTCFH 15 (42.08 t/ha), KTCFH 6 (35.91 t/ha), KTCFH 2 (35.37 t/ha), KTCFH 10 (34.97 t/ha) and KTCFH 7 (33.46 t/ha) was found superior over both the check cultivars with the heterosis range of 8.66-36.65 and 1.07-27.11% over Pusa Snowball Hybrid 1 (30.80 t/ha) and Casper RZ (33.11 t/ha), respectively. Based on their performance these hybrids will be carried forward for multi-locational trials.

KTCFH 15

KTCFH 6

Promising hybrids of snowball cauliflower evaluated in multi-location yield trials

Introgression of Trachystoma ballii and Diplotaxis catholica male sterile cytoplasm into the nuclear background. During summer season of 2018, we developed BC_4 and BC_5 population populations for the introgression of *Diplotaxis catholica* and *Trachystoma ballii* male sterile cytoplasms into cauliflower background. This year they will further be advanced to next generation through *in vitro* embryo rescue and backcrossing.

Introgression of β-carotene rich 'Or' and anthocyanin rich 'Pr' genes into snowball cauliflower. BC_1 population of the introgressed β-carotene (*Or* gene) and anthocyanin (*Pr* gene) rich genes into different genotypes (Pusa Snowball K 1 and Pusa Snowball K 25) was developed during summer 2018 and evaluated during winter 2018-19. The desired plants will be advanced to next generation through marker-assisted backcross selection.

2.1.1.2 Cabbage

Promising CMS and SI systems based hybrids. Thirty two CMS and 46 SI system based promising F_1 hybrids of white cabbage were evaluated for their performance for yield and horticultural traits against 8 check varieties. Among the SI based hybrids, highest yield was recorded by S-691 x S-681 (54.0 t/ha) followed by S-208 x S-645 (45.2 t/ha), S-208 x S-83-1 (45.0 t/ha), S-696 x S-208 (43.4 t/ha) and S-602 x S-208 (42.1 t/ha). All these hybrids were also found superior than check cultivar Pusa Cabbage 1 (31.2 t/ha). Out of 32 CMS based hybrids, highest yield was recorded by 208A x C-122 (66.7 t/ha) followed by 6A x Sel-5-83-5 (50.8 t/ha), 5A x Sel-5-83-5 (47.0 t/ha), 5A x Sel-5-122 (44.5 t/ha) and 836A x Sel-5-83-5 (43.5 t/ha), which were superior than best check cultivar Central Cabbage Pusa Hybrid 81 (43.1 t/ha).

Promising 'chill type' or temperate cabbage hybrids. Out of 16 F_1 hybrids of 'chill type' or temperate cabbage from IARI Regional Station, Katrain, the five most promising hybrids were Hyb 9 (46. 5 t/ha), Hyb 15 (45.1 t/ha), Hyb 11 (44.0 t/ha), Hyb 3 (43.8 t/ha) and Hyb 1 (42.5 t/ha). They also outperformed the check variety Pusa Cabbage Hybrid 1 (35.4 t/ha).

Evaluation of red cabbage hybrids. A set of 64 experimental hybrids developed by using 7 CMS lines were evaluated. Highest yield was recorded by RCGA × ZH (62.0 t/ha) followed by RRMA × ZH (53.8 t/ha), RJA × ZH (45.4 t/ha), KRA × ZH (44.6 t/ha) and RJA ×RRM (42.9 t/ha). All these hybrids surpassed the check cultivar Ruby Ball (26.8 t/ha).

Introgression of β-carotene rich 'Or' gene into cabbage and broccoli. BC_1 population of the introgressed β-carotene rich gene (*Or*) in cabbage (S 831) and broccoli (Pusa Broccoli KTS 1) was developed during summer 2018 and evaluated in winter 2018-19. The plants carrying β-carotene rich '*Or*' gene will be advanced to next generation through marker-assisted backcross selection.

Effect of 'Ogura' cytoplasm introgression in cabbage. Thirty hybrids each of 10 CMS lines (A lines) and their fertile counterparts, i.e. B lines with 3 common testers were compared. The 12-20 CMS-based hybrid for morphological traits and 7-22 CMS based hybrids for different quality traits performed better as compared to their fertile counterpart hybrids. Overall,

five hybrid combinations KTCB-1A x KTCB-24, KTCB-208A x KTCB-24, KTCB-R7A x KTCB-121, KTCB-208A x KTCB-52 and KTCB-83-6A x KTCB-52 were found superior for different morphological traits along with quality attributes. It was observed that introgression of '*Ogura*' cytoplasm has altered the different agro-morphological and quality traits of cabbage.

Introgression of fertility restorer gene (Rfo) into Brassica oleracea through inter-specific hybridization. The F_1 population of the introgressed fertility restorer gene (*Rfo*) into different genotypes of cauliflower and cabbage was screened with *Rfo* gene specific SSR markers. The plants carrying fertility restorer gene will be advanced to next generation.

2.1.1.3 Heading broccoli

Twenty four breeding lines/varieties were evaluated of which Pusa Purple Broccoli (19.5 t/ha) and DC-Brocco 13 (20.8 t/ha) and DC-Brocco 20-16-02 (16.8 t/ha) in green type out performed Pusa KTS 1 (15.6 t/ha) and Palam Samridhi (14.0 t/ha) during December end-January mid maturity.

Pusa Purple Broccoli

Evaluation of 25 experimental hybrids along with 3 checks revealed the superiority of VCHA × 676711 (16.50 t/ha) followed by Aish A × VCH (13.40 t/ha), 19KTSA × Sel-3 (13.10 t/ha), VCHA × 676710 (12.60 t/ha), KTSA × 676710 (11.70 t/ha) than best check cultivar Saki-F_1 (9.03 t/ha).

2.1.2 Cucurbitaceous crops

2.1.2.1 Bitter gourd

Inter-specific hybridization. By crossing *Mormordica charantia* variety Pusa Aushadhi (female) and *M. balsamina* (male), only one F_1 plant was obtained, which was selfed and backcrossed with Pusa Aushadhi and *M. balsmina*. The backcross progenies showed retarded growth and seedling chlorosis and SSR markers confirmed the introgressed genomic region of *M. balsamina*. The F_2 populations resembled the female parent for most of the phenotypic traits except fruit tubercle and ridgeness. The crosses failed to set the fruit when *M. balsamina* was used as female parent.

Backcross progeny with chlorotic leaves

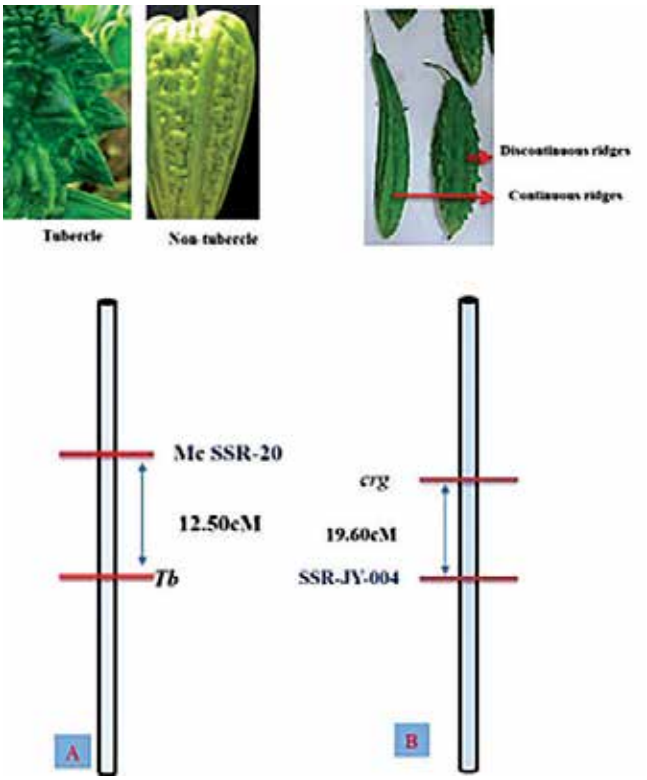
Heterosis studies. Among the 28 hybrids developed by half-diallel fashion, gynoecious × monoecious hybrids were most promising for earliness and yield traits. The highest standard heterosis for yield per plant was recorded for hybrid S-2 × PA (68.33%) followed by

Selection DBGS 06- 21

PDMGy-201 × PV (67.22%) and S-2 × PDM (56.67%). Among the parental lines, gynoecious line PDMGy-201 was a good general combiner for traits like earliness, sex ratio and flesh thickness; S-2 for fruit length; S-54 for fruit diameter; Pusa Do Maushumi for average fruit weight and Pusa Ausadhi for number of fruits and total yield per plant. The three best hybrids based on SCA for earliness and yields were S-2 × PA, PDMGy-201 × PV and S-2 × PDM.

Promising hybrids. Two previously developed high yielding early hybrids, namely, DBGH 11 and DBGH 26 were included in IET trials of AICRP-VC. Two hybrids, namely, DBGH 12 and DBGH 542 were prompted to AVT-I trials under AICRP-VC. Twenty eight hybrids were evaluated for yield and related traits and three best performing F_1 hybrids for yield identified were S-2 × PA (30.33t/ha), PDMGy-201 × PV (30.07t/ha) and S-2 × PDM (28.19 t/ha).

Promising genotypes. Forty two genotypes were evaluated for yield and yield related traits out of which six genotypes DBGS 06-21, DBGS 60-52, DBGS 52-46, DBGS 54-58, DBGS 03-23 and DBGS 57-55 were found promising. The fruits of DBGS 06-21 are dark green, 15-20cm long, 4.5-5.5 cm diameter with pointed tubercles, discontinuous ridges, individual fruit weight 85-90 g and estimated yield 21.6 t/ha under open field conditions. Two promising selections, namely, DBGS 32-1 and DBGS 57 were found promising under polyhouse growing conditions and produced fruit yield of 3.90 and 3.85 t/1000m² with individual fruit weight of 105 and 126 g, respectively.



Genetic linkage map of fruit tubercle (*Tb*) (A) and continuous ridges (*crg*) (B) in bitter gourd

Inheritance studies. Bitter gourd is widely grown in different parts of the world and the consumer preference too varies from region to region with respect to fruit colour, size, shape, external quality,etc. In India, the fruit external qualities such as tubercles (presence/absence), ridgeness (continuous/discontinuous) and colour (green/white) regulate the marketability of the fruits for different regions. Fruit tubercle (*Tb*), discontinuous ridges (*Cr*) and green colour of fruit (*WW*) were governed by single dominant gene, whereas seed coat colour was governed by semi-dominant gene. Gynoecious sex expression was governed by single recessive gene (*gy1*), whereas more than four genes controlled inheritance of fruit length.

Molecular markers associated with fruit traits (ridge and tubercle). The genotype selected based on molecular markers has added advantages in bitter gourd crop improvement. The codominant SSR marker 'McSSR-20', which was found linked to fruit tubercle gene (*Tb*) was located at a distance of 12.5 cM. In the cross DBGS-2× DBGS-34, a SSR marker 'JY-004' was tagged to fruit ridgeness (*cr*) at a distance of 19.6cM (LOD= 10.65). Three minor QTLs,viz., *qFD*,*qFL*and *qFS* were identified in the cross DBGS-54 × DBGS-34, which linked to SSR markers S-32 (qFD and qFL)and McSSR-35 (*qFS*) with LOD value of 3.38, 3.71 and 3.59, respectively. The SSR marker MCSSR-20 was validated on different genotypes and can be utilized in MAS for fruit tubercle trait in bitter gourd crop improvement programme.

2.1.2.2 Cucumber

Promising genotypes. Out of 25 selections evaluated, DC 22 and DC 43 showed consistently good

performance with respect to fruit size and quality traits, besides yielding 17.3 t and 16.4 t/ha showing an increase of 23.6 and 15.5%, respectively, over national check Pant Khira 1(13.6 t/ha). During *Kharif* season 2018, 138 lines were screened for downy mildew resistance. DC 77 (17.1 t/ha) and DC 70 (16.3 t/ha) showed tolerance against downy mildew besides having high yield and other desired horticultural traits as compared to local check Barsati (14.8 t/ha), Pharai Barsati (14.2 t/ha) and Panipat Local (15.3 t/ha).

Promising hybrids. Out of 46 F_1 hybrids evaluated, the gynoecious based hybrids DGCH 31 and DGCH 40 yielded 25.9 and 26.2 t/ha, respectively, as compared to national check Pant Sankar Khira (18.9 t/ha), were advanced to at AVT-II of AICRP (VC) trial. Another new hybrid DGCH 56 having large size fruit and desirable horticultural traits and yield (27.3 t/ha) was advanced to AVT-I of AICRP (VC) trial. Out of 17F_1 hybrids evaluated during *Kharif* 2018, DCH 16 (19.9 t/ha) and DCH 19 (1.9.3 t/ha) were found promising for yield and tolerance to downy mildew.

Promising genotypes and hybrids for protected cultivation. In order to introgress gynoecious parthenocarpic traits into indigenous varieties having desirable horticultural traits, crosses were attempted with the promising lines DC 83, DC 43 and DC 48 as recurrent parent and Pusa Seedless Cucumber 6 as non-recurrent parent (male parent). Ten true breeding gynoecious parthenocarpic lines including promising DPaC 9 were maintained and eight gynoecious parthenocarpic F_1 hybrids were broken by using silver thiosulphate for induction of male flowers and simultaneously selfing and individual plant selection were carried out on the basis of true gynoecious and parthenocarpic traits. Six gynoecious parthenocarpic hybrids, which were developed during 2018 were further evaluated. Line DG 8 was entered in the multi-location trial for its future release. A natural variant, DC 48 with stay green trait and extended shelf-life was maintained and used in the breeding programme for its introgression into the promising genotypes.

2.1.2.3 Luffa

Promising genotypes. In sponge gourd, a total of 53 germplasm including 3 accessions of wild species *Luffa echinata*, 4 accessions of *L. graveolens* and 20 accessions of *L. hermaphrodita* (Satputia) were evaluated and maintained. Out of 16 selections evaluated during spring summer, the lines DSG 43 (14.1 t/ha) and DSG 33 (13.9 t/ha) were found promising with respect to yield and desired fruit quality traits as compared to national check Kalyanpur Hari Chikni (11.9 t/ha). Out of 30 F_1 hybrids evaluated and two hybrids,viz., DSGH 95 (16.5 t/ha) and DSGH 34 (15.9 t/ha) were found to be very promising as compared to national check Kalyanpur Hari Chikni (11.9 t/ha). Promising line DSGH 95 was entered in IET of AICRP (VC) trial.

Evolving genotype with resistance against ToLCNDV. Eighteen *Tomato Leaf Curl New Delhi Virus* resistant lines were evaluated during *Kharif* season. The lines, DSG 7 (DSGVRL 13) and DSG 5 (DSGVRL 4) were found to be most promising having high tolerance to disease with a vulnerability index of 3.3 and 3.9%, respectively.

DSG 7 (IC 0588957) showing highly resistant reaction to *Tomato Leaf Curl New Delhi Virus*

CHSG 1 showing highly susceptible reaction to *Tomato Leaf Curl New Delhi Virus*

New genotypes. Out of 16 selections, DRG 7 having attractive green long fruit (35-40cm) was found to be very promising showing an yield of 17.1 t/ha as compared to Pusa Nutan (16.3 t/ha) advanced to AVT-1 of AICRP (VC) trial. Eight gynoecious lines isolated from the crosses of Pusa Nutan and Satputia were evaluated on the basis of colour, shape and size. DRGGL 8 showing light green attractive colour, long fruit (20-25 cm) and true gynoecious trait was most promising and was further maintained. Out of 20 F_1 hybrids evaluated, gynoecious F_1 hybrids DRGH 4 and DGRGH 8 were found promising with an average yield of 18.8 and 19.2 t/ha, respectively, as compared to Pusa Nutan (16.5 t/ha). Hybrid DRGH 8 was entered in IET, while DRGH 4 was advanced to AVT-1 of AICRP (VC) trial. Out of 30 satputia (*Luffa hermaphrodita*) lines evaluated during rainy season, DSat 4 was found to be very promising with respect to yield (2.5 to 3 kg/plant; 20-25 t/ha) and other desirable traits, was entered in multi-location trial.

2.1.2.4 Pumpkin

Promising genotypes. Forty five genotypes were evaluated for yield and yield related traits, out of which four genotypes DPU 14, DPU 41, DPU 45 and DPU 58 were found promising. The plants of DPU 14 are medium viny with flattish-round fruits, medium ribs, orange flesh, average fruit weight of 2.85 kg and flesh thickness of 3.0 cm. The fruits of DPU 41 and DPU 45 are flattish having average fruit weight of 2.0 and 2.3 kg and flesh thickness of 2 and 2.6 cm, respectively. The genotypes DPU 41, DPU 43 and Narendra Upkar showed field resistance against poty virus and begmovirus.

Three pumpkin genotypes were crossed with Waltham Butternut and butternut squash hybrids and *vice versa* with the objective to select higher carotenoids content types in the segregating generations thereby improving flesh quality.

Promising hybrids. Twenty five F_1 hybrids were developed and evaluated for yield and related traits in the spring-summer season. Three promising F_1 hybrids were DPU 41 x DPU 45 (average fruit weight 2.4 kg, flesh thickness 2.7 cm), Narendra Agrim x DPU 63 (av. fruit weight 2.6 kg, flesh thickness 3.1 cm) and DPU 46 x DPU 45 (av. fruit weight 1.75 kg, flesh thickness 2.5 cm).

Fruits of promising hybrid DPU 41 x DPU 45

2.1.2.5 Summer squash

Promising genotype. A prolific bearing summer squash line, DS 17 was isolated from a segregating population and maintained through single plant selection. It has segmented leaves, which can be used as a morphological marker. The fruits are attractive green in colour with dark green stripes and creamish spots throughout the fruit surface. The average number of fruits per plant is 4-5 and average fruit weight is 600-700g. The plants are bushy and the fruits resemble with that of pumpkin. It can be successfully grown during winter season (November-January) under polyhouse, low tunnel when pumpkins are not available in market.

Summer Squash line DS 17

2.1.2.6 Muskmelon

Promising genotypes. Out of 26 genotypes evaluated, muskmelon genotype DM 154 was most promising for open field cultivation at station trial in summer 2018 with an yield of 22.8 t/ha having green

flesh and TSS 11.9^{0}Brix followed by DM 156 (22.5 t/ha, TSS 11.6^{0}Brix) and DM 193 (22.0 t/ha, TSS 11.8 ^{0}Brix).

Speciality melon (*C. melo* var. *inodorous)* genotypes DHM 39 (5.2 t/1000 m^2 with orange flesh & TSS 13.8^{0}Brix) and DHM 162 (5.4 t/1000 m^2 with green flesh & TSS 13.6^{0}Brix) were found most promising for protected conditions. The shelf-life of these two genotypes was 15 days, which is better than muskmelon genotypes of *cantalupensis* group.

Promising hybrids. Two hybrids from *C. melo* var. *cantalupensis* group DMH 5 (26.0 t/ha, TSS 11.9^{0}Brix) and DMH 11(23.0 t/ha, TSS 11.4^{0}Brix) were found most promising and is now under IET hybrid trial of AICRP (VC). Speciality melon hybrid DMH 112 was found to be most promising (5.8 t/1000 m$^{2)}$ in evaluation under net house during off-season cultivation (September to November).

2.1.2.7 Watermelon

Screening of germplasm for resistance against watermelon bud necrosis virus. Seventy two watermelon germplasm from *C. lanatus* var. *citroid*, *C. lanatus* var. *lanatus* and *C. colocynthis* were evaluated in open field as well as net house. The *C. colocynthis* line DWM 210 was found highly resistant to *Watermelon bud necrosis virus*.

2.1.2.8 Bottle gourd

Field screening of germplasm for resistant to Cercospora leaf spot. A total of 122 accessions including 101 indigenous and 4 exotic collections from National Gene Bank and 17 released varieties of bottle gourd were screened against *Cercospora* leaf spot under natural epiphytotic conditions during rainy season of 2018. The causal organism was isolated and identified as *Cercospora citrullina* on the basis of pathology and morphological characteristics. Symptoms were observed and each plant was given a leaf spotting score (Williams, 1977). Based on their reaction, genotypes were categorized into immune, resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible. However, none of the genotypes were found to be immune. Fifteen accessions, viz., IC 546185, IC 362403, IC 385814, IC 398534, IC 426990, IC 536594, IC 550741, IC 567545, IC 541223, IC 548580, IC 277094, IC 279634, IC 279731, IC 297489 and one exotic collection,viz., EC 800998 were having occasional scattered leaf spots and were classified as resistant. Nine indigenous collections and one variety Narendra Madhuri were classified as moderately resistant, 70 genotypes were susceptible, while three were classified as highly susceptible.

2.1.3 Solanaceous Crops

2.1.3.1 Brinjal

Promising lines. Among the long fruited lines, DBL 8 (dark purple, 41.23 t/ha), DBGL 225-2-5-17 (green, 36.45 t/ha), and DBWL 22-1-11 (white long, 41.2 t/ha) were found very promising for fruit yield. Among the round fruited lines, DBR 92 (shiny purple, 43.64 t/ha), and DBR 22 (purple, 40.36 t/ha) were found very promising.

Promising hybrids. Twenty six hybrid combinations were evaluated for yield and combinations, viz., DBHR 2019 (dark purple round, 69.32 t/ha), DBHR 9 (shiny purple long, 56.87 t/ha), DBHR 40 (dark purple round, 60.24 t/ha), and DBHR 1120 (dark purple round, 64.52 t/ha) were found to be superior over the check Navina (50.63 t/ha), and Pusa Hybrid 6 (41.87 t/ha).

Fusarium wilt resistant genotypes. A total of 19 genotypes were screened under sick plot for *Fusarium*

wilt resistance and the lines G 181 and G 203 were found to be resistant.

Wild accessions resistant to root knot nematode. Eleven wild accessions were evaluated against root knot nematode (*Meloidogyne incognita*) after artificial inoculation with second stage juvenile (J2) in pot conditions. Out of these wild accessions, two species (*Solanum torvum* and *S. sisymbrifolium*) were found to be resistant.

Genetics studies of fruit colour. Genetics of fruit colour was studied using 168 F_2 plants from a cross of Pusa Safed Baingan 1 and Pusa Uttam. The fruit of F_1 plants was intermediate revealed incomplete dominance. Out of 168 F_2 plants, 125 were purple coloured, 31 green and 12 white, which clearly segregated into 12:3:1 (P:G:W) ratio suggesting dominant epistasis with λ^2 value of 0.28 (*P*=0.80-0.90).

2.1.3.2 Tomato

Promising hybrids. During spring-summer (February-May 2018), a total of 40 F_1s, were evaluated for yield and quality parameters. Four hybrids, i.e. H 367 (90.0 t/ha), H 248 (85.0 t/ha), H 259 (72.0 t/ha) and H 249 (70.0 t/ha) were found promising for high yield. In summer trial (March-June, 2018), the promising genotypes for yield per plant were IARI 407-2-5-11 (1.5 kg/plant; 27.0 t/ha); IARI 22 (1.25 kg/plant); VTRH 16-4 (2.18 kg/plant) compared to Abinava (F_1) check (0.45 kg/plant).

In autumn-winter (August to March 2018-19; *Kharif*), a total of 309 F_1s were evaluated for their reaction to ToLCD virus. The hybrid combinations include R x R (both parents carrying *Ty-3* gene) as well as R x S combinations (one parent carrying *Ty-3* gene). R x S combination hybrids were susceptible to ToLCD disease. However, all the R x R combination showed resistance. Multilocation trials were conducted at ICAR-IIHR, Bengaluru and ICAR-IIVR, Varanasi. A total of 12 promising F_1s were sent to ICAR-IIVR and three to ICAR-IIHR for TOLCV resistance station trial. Two hybrids, promising for ToLCD resistance and yield were included in AICRP (VC) trials.

Promising genotypes and hybrids for protected cultivation. Twenty eight F_1 cross combinations were evaluated under protected conditions. Hybrid DTPH 60 recorded total yield of 1.56 t/ 100 m^2, 5.2°Brix TSS and 5.8 mg/100g lycopene with average fruit weight of 108g. It was found at par to GS 600 in yield and other traits.The hybrid DTPH 60 when evaluated at farmer's field at Chomu, Rajasthan, recorded high yield,i.e.16 kg fruits/ m^2 and profit up to Rs. 224/ m^2 under polyhouse.

Tomato hybrid DTPH 60 under protected condition

Ten advance cherry tomato lines have been developed through reverse breeding. Out of 10 selections, 7 had red fruit colour and 3 yellow /orange fruit colour. These advance lines (F_6 and F_7 generations), showed uniform and stable performance. Under protected condition, Selection 2 recorded average fruit

yield of 1.0t/100m^2 with average number of fruits (45/cluster) and high TSS (10.1^{0}Brix) having red fruit colour and desired fruit weight (10g).


Cherry tomato selection 2 under protected condition

A total of 20 F_1s (including nine cherry hybrids), were evaluated under naturally ventilated polyhouse during October-November 2018 – March 2019. Hybrid H 247 was found promising (6.7 t/1000m^2), while tomato hybrid H 214 had high yield (9.0 t/1000m^2).

Inter-specific hybridization. For genetic enhance of *Solanum lycopersicum*, F_1s of (15SB x LA1777) with Pusa Early Dwarf (PED) and Roma were found promising for fruiting at high temperature. The F_1s were selfed and F_2 seeds obtained for further characterization. The advanced interspecific lines developed using LA1777 were advanced to F_5 generation.

2.1.3.3 Chilli

Inter-specific hybridization. Inter-specific crosses between *C. annuum*, *C. frutescens* and *C. chinense* were attempted to study their compatibility. Five *C. frutescens* genotypes (EC 787094, EC 787097, EC 787101, EC 787149 and EC 787123) and three *C. chinense* (EC 787135, EC 787146, EC 787147) were utilized in hybridization with *C. annuum*. Successful crosses were obtained with EC 787135, EC 787146, EC787097 and EC 787123.

Screening for heat tolerance. Single plant selections from heat tolerant lines have been evaluated along with national check Kashi Anmol and local check Pusa Sadabahar. The selections DLS 10-8, DLS 17-10, DLS 20-11, DLS 152-1, DLS 10-11, DLS 25-11, DLS 161-1 and DLS 146-5 have been consistently found having high temperature tolerance in terms of fruit set. The heat tolerant selections gave fruit set in the months of May and June when average maximum temperature was 43^{0}C and minimum temperature of 28^{0}C. The check varieties in comparison to heat tolerant genotypes failed to set fruits during May to July. Under first station trial, DLS 161-1 and DLS 146-5 have out yielded the national check Kashi Anmol, whereas the heat tolerant genotypes gave three harvests from the month of May to July.

Field view of DLS 161-1

Field view of DLS 146-5

2.1.3.4 Sweet pepper

Transfer of fertility restorer gene. In order to develop fertility restorer lines, one genotype, i.e. KTC 15R carrying fertility restorer gene was crossed with 10 other genotypes. During this year, the F_1 population of each cross combination will be backcrossed with their respective recurrent parent.

Evaluation of hybrids. A total of 108 hybrids were evaluated for yield and its contributing traits. Among them, KTCH 15 (26.77 t/ha) followed by KTCH 7

(26.39 t/ha) and KTCH 13 (24.09 t/ha) were found most promising based on yield, fruit shape, size and colour.

2.1.4 Root and Bulbous Crops

2.1.4.1 Carrot

Promising genotypes. Thirty nine genotypes/ breeding lines in August end sowing were evaluated for quantitative and quality traits. Root length, root diameter, root weight and core diameter ranged from 17.2 cm (DCat 131) to 25.46 cm (DCat 10), 3.48 cm (DCat 10) to 4.57 cm (DCat 35), 90 g (DCat 126) to 180 g (DCat 88) and 6.06 mm (DCat 8) to 19.90 mm (DCat 16), respectively. Based on the quality for root shape, surface, external & internal colour and external appearance, the promising genotypes identified were DCat 4, DCat 8, DCat 13 and DCat 122.

In normal season, 48 genotypes/ breeding lines were assessed for quantitative and quality traits. Based on the quality for root shape, surface, external & internal colour and external appearance, the promising genotypes identified were DCat 7, DCat 13, DCat 53, DCat 76, DCat 98 and DCat 122. Three promising lines, viz., IPC 13 red, IPC 98 and IPC Ht-1 were advanced to AVT-II of AICRP (VC) trial.

Promising hybrids. Forty three-way hybrids were assessed for quantitative and quality traits in August end sowing. Based on the quality for root shape, surface, external & internal colour and external appearance, the hybrid DCatH 74-122 was found promising.

In normal season, 80 CMS based F_1 hybrids of tropical-subtropical carrot were assessed for quantitative and quality traits. Based on the root shape, surface, external & internal colour and external appearance, the promising F_1 hybrids were DCatH 5392, DCatH 700, DCatH 9892, DCatH 983, DCatH 9126, DCatH 734 and DCatH 754 with average root weight of 150 g, 146.7 g, 160 g, 141.7 g, 146.7 g, 143.3 and 136.7 g, respectively. In temperate group, 13 F_1 hybrids from Katrain station were evaluated at Delhi centre and promising hybrids were Kt-7 x NK, Kt-10 x KS-59 and Kt-28 x NK.

Promising carrot hybrid DCatH 700

In temperate carrot, 98 hybrids developed by using 10 petaloid type of CMS lines were evaluated against Pusa Nayanjyoti as standard check. Hybrid KT-28A x KS-50 (24.9 t/ha) followed by KT-8542A x KS-20 (24.0 t/ha) and KT-8542A x KS-22 (23.6 t/ha) recorded higher yield than the standard check Pusa Nayanjyoti (20.8 t/ha).

2.1.4.2 Onion & Garlic

Breeding for higher yield in onion and garlic during Rabi season. In onion, 58 accessions were analyzed for yield and other horticultural traits. It was observed that Pusa White Flat recorded highest yield (46.0 t/ha) followed by ALR and Pusa Ratnar. In garlic, 26 accessions were evaluated for yield and other horticultural traits. Genotype PGS 210 recorded significantly higher yield (11.0 t/ha) followed by PGS 206 (10.7 t/ha), PGS 204 (10.6 t/ha) and PGS 207 (10.3 t/ha). Bhima Omkar (4.1 t/ha) recorded the lowest yield.

Breeding for Kharif onion. A total of 300 second generation inbreds were planted during *Kharif* season for assessing their suitability for survival and bulb production. It was observed that Bhima Dark Red and Bhima Super performed best in terms of bulbing in second year too. Hence, could be recommended for *Kharif* sowing under north Indian conditions. From the breeding material, KH 015, KH 045, KH 047, KH 081, KH 084 and KH 353 performed best in terms of bulbing efficiency. Bulbs of these genotypes were further planted for flowering to obtain third generation inbreds.

Breeding for bolting tolerance. Sixty eight onion accessions were planted in first fortnight of November to screen for bolting behaviour. Bolting percentage ranged from 0-100%. Accessions AKON 85 and L 653 exhibited no bolting at all, whereas AKON 82, SWSL, AKON 79, JRO 4 and AKON 69 recorded less than 10% bolting. The non-bolting bulbs from these lines were selected and stored for production of inbred lines for bolting tolerance.

Breeding for Stemphylium blight resistance. One hundred onion and allied species accessions were screened for *Stemphylium* blight resistance under field conditions. It was observed that one accession of leek (*Allium ampeloprasum* L.) was resistant, seven accessions of *A. fistulosum* L. were moderately resistant and the rest of 92 onion accessions were categorised into moderately to susceptible category, while ACC 068 was most susceptible.

Evaluation and development of improved selections. Thirty two onion genotypes were evaluated during *Kharif* season, where yield varied from 5.98 to 25.66 t/ha. Twelve genotypes produced more than 20.0 t/ha marketable bulb. The three best lines were KP-M1 (25.66 t/ha), KP 36 (24.77 t/ha) and KP 41(24.24 t/ha). In KP-M1, there were uniform neck drying and the bulbs were medium sized (equatorial diameter 42.17 mm) and the roots were completely dried.

KP-M1

KP 36

KP 41

Allium fistulosum typically produces white stalk. *A. fistulosum* with different colour stalk were selected from a natural cross population with Pusa Riddhi (*A.cepa*) and being maintained for further study.

Three long day local onion collections were evaluated and segregating materials planted for seed multiplication for further study.

Screening of onion genotypes against Purple Blotch. Thirty five onion genotypes and Pusa Soumya (*Allium fistulosum*) were screened under challenge inoculation condition for purple blotch resistance/tolerance. Pusa Soumya was found resistant. Arka Lalima, KhPB 11, KhPB 1, Bhima Kiran, KhPB 50, KhPB 10 KhPB 3 and KhPB 13 were found moderately resistant.

2.1.5 Leguminous Crops

2.1.5.1 Garden pea

New genetic material developed for high yield and disease resistance. Evaluated 10 new bulks derived

from F_5-F_6 generations breeding materials against the 2 checks (Pusa Shree & Arkel), the promising genotypes having attractive long green curved pods were GP 1501 GP 1502, GP 1503, GP 1504, GP 1701 (pleiofila), GP 1703, and GP 1705 with average pod yield range of 11-13.5t/ha against the check.

Development of wilt resistant lines. Eighteen germplasm and 60 F_3 crosses were evaluated in wilt sick plot for screening and selection. The genotypes GP17, GP 55, GP 6, GP 48, GP 473, and the crosses 2011/PEV-3xGP48, GP17x2011/PEV-2, GP55x2011/PEV-2, GP901xEC~211, PPxGP6, GP48x GP473-1, GP48x2011/PEV-3, and GP473xVP233 were found resistant and retained for further evaluation.

Development of powdery mildew resistant lines. The genotypes found highly resistant to powdery mildew were GP 6, GP 473,GP 1001, GP 1101, GP 1102, GP 1501 GP 1502, GP 1705.

Screening of lines for heat tolerance and disease resistance. Thirty genotypes were screened for high temperature tolerance so as to extend the fresh pod availability beyond mid - March in north Indian plains. The genotypes GP 916, GP 473, GP 912-II, VP 438-2, and Bonneville were found promising for pod set at high temperature during last week of March or early April, while others dried by third week of March. However, genotypes GP 916, GP 438-2, GP 55, GP 912-I, GP 912-II, Bonneville, 2015/PEV-2, 2015/PEV-5, GP 1104, EC598216, and EC 598646 plants remained green till 15-20th April, but 2015/PEV-2, 2015/PEV-5 and Bonneville showed very less fruiting at higher temperature.

Host-pathogen resistance against Fusarium oxysporum f.sp.pisi. Total 50 *Pisum* accessions including alien species,viz., *Pisum fulvum*, *P. elatius*, *P. sativum* var. *elatius*, *P. sativum* and commercial susceptible garden pea varieties (Kashi Nandini, Kashi Uday, MA 7, Pusa Pragati, Arkel and PB 89) were grown in the artificial wilt sick pots, using four virulent *Fop* isolates. Total eight accessions were found highly resistant against all the four virulent *Fop* isolates in which two were of *P. fulvum*, one of *P. elatius, four* of *P. sativum* var. *elatius* and one of *P. sativum.*

Highly resistant genotypes reported after artificial screening in sick pot against *Fop* isolates. (a) *Pisum fulvum,* (b) *Pisum elatius,* (c) *P. sativum* var. *elatius,* and (d) *P. sativum* var. *hortense* (susceptible)

2.1.5.2 Other legumes

Two dolichos bean pole types (DB 3 & DB 5) were promoted for AVT-II and DB 22 in AVT-I and DB 23 to IET. Genotype DB 15 was most promising when tested under AICRP for three consecutive years (pod yield 20.7t/ha).

2.1.6 Malvaceous crop

2.1.6.1 Okra

New genetic material developed. Forty parental lines, 27 advance lines, 54 F_1s and 12 back cross populations (BC_1 to BC_3) and 28 new collections from NBPGR, were evaluated for yield, quality traits and biotic stress during *Kharif* 2018. Advance lines DOV 88, DOV 77, DOV 33, and DOV 37, were found resistant to *Bhindi yellow vein mosaic virus* (YVMV). However, DOV 92 showed multiple resistance to YVMV and ELCV and tolerance to leaf hopper and mites. These lines recorded yield ranging from 18 to 20.5 t/ha having dark green attractive pods. However, among hybrids, DOH 2, DOH 3 and DOH 4 were found superior in pod yield and quality along with resistant to YVMV and ELCV and tolerant to leafhopper and recorded 23.5, 22 and 21.5 t/ha pod yield, respectively, with smooth dark green attractive pods. DOV 77 and DOV 88 were short fruited type (5-6 cm fruit length), DOV 17 and DOV 18

were red fruited genotypes having high anthocyanin content (402 and 473mg/100 g, respectively). To assess the genetic diversity in okra germplasm including wild and cultivated species, EST-SSR markers were tested on 96 genotypes. Out of 186 SSR markers, three SSR markers, i.e. AVRDC Okra-1, AVRDC Okra-56, and AVRDC Okra-63 primers were found useful for diversity analysis in okra.

Fruits and plants of promising okra Hybrid (DOH 2): resistance to YVMV and tolerance to leaf hopper and mites

Pre-breeding in okra. Forty four wild okra accessions representing five species were evaluated. Six accessions of *A. tetraphyllus*, three of *A. moschatus* and one of *A. caillei* were found free from YVMV and ELCV, while other accessions showed YVMV symptom after 85 days of sowing. The F_1 combinations of Pusa A 4 and *A. tetraphyllus* were free from YVMV disease symptom, but very poor seed set was recorded. One advance cross combination of Pusa A 4 and *A. moschatus* recorded normal fruit set with improved fruit quality. The advance lines, C 3-715, $C_2$50 mizo-12, $C_2$50 mizo-20, $C_2$50 mizo-19 and $C_2$50 mizo-33 were found 100% free from YVMV symptoms. Resistant plants from crosses of cultivated species and *A. tetraphyllus* and *A. caillei* were selected for further advancement of generation.

2.1.7 Lettuce

Promising genotypes. Thirty-six germplasm/ advanced breeding lines were evaluated and maintained. Out of the 36 lines, 3 lines (leafy type),viz., DL 13 (leafy type), DL 11 (leafy type) and EC 687387 (romaine type) showed good performance and yielded 43.8 t/ha, 41.06 t/ha and 37.69 t/ha showing an increase of 24.64, 16.85 and 7.26%, respectively, over check variety Chinese Yellow (35.14 t/ha). Among the heading type, selection DL 36 (37.6 t/ha) was found very promising and showed an increase of 44.55% over check Great Lakes (26.04 t/ha). Two selections (DL 13 and DL 36) were advanced to IET trial in AICRP (VC). Over 114 F_5 lines were phenotyped and advanced to next generation on the basis of heading and leafy type and leaf colours (green, purple, green-purple and purple-green, light purple) during 2018-19.

2.2 FRUIT CROPS

2.2.1 Mango

Hybridization. During March 2019, seven cross combinations were attempted on 995 panicles having 7,059 flowers employing Amrapali as female parent and Sensation, Vanraj, Tommy Atkins, PusaArunima, Bhadauran, Erwin and Hyb. 11-2 as male donor parents. From March 2018 crosses, 65 hybrid stones were obtained, 62 stones germinated and 58 hybrid plants are surviving in nursery. In rootstock breeding, total 254 flowers were crossed with various combinations of the Olour, Kurrukan, Bappakai, M 13-1, Amrapali and Peach have been crossed using Olour, Kurukkan and Amrapali as donor parents.

Evaluation of hybrids and germplasm. Mango hybrids (80) and germplasm (54) were evaluated for 20 physico-chemical traits. Among mango F_1 hybrids from different cross combinations, the maximum fruit weight was noted in H 11-2 (281.8 g). Fruits of H 12-5, H 11-2, H 8-11 and H 3-2 had red colouration on shoulder. Hybrid NH 7-2 had bright yellow-apricot coloured oblong fruits with bright orange pulp, moderate peel thickness (1.52 mm) and high total soluble solids (22.37°Brix). Significant variation was observed for fruit shape, peel colour, pulp colour and pulp weight in the hybrids. The maximum TSS (26.4°Brix) was noted in NH 8-5. The F_1 hybrids have been phenotyped for organic acids, viz., citric acid, malic acid, ascorbic acid, succinic acid and sugars,viz., sucrose, glucose and fructose. The data showed that F_1 population had significant variation for sugar and organic acid profiles. Hybrid 8-11 showed field tolerance to floral mango malformation.

Fruit of NH 7-2

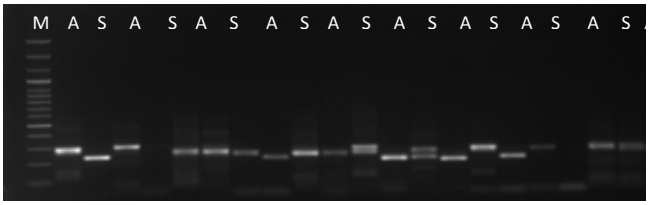
Fruits of H 11-2

Evaluation of Exotic genotypes. Among the exotic mango germplasm, Eldon had the maximum fruit weight (263.4 g) followed by Tommy Atkins (223.7 g). However, the minimum fruit weight was noted in Willard (98.55 g). These exotic germplasm had moderate TSS compared to indigenous germplasm. Among indigenous genotypes, Vanraj bore the biggest fruit (360.4 g) followed by Khas ul Khas (309.68 g) and Totapari (290.80 g). However, the minimum fruit weight (52.35 g) was observed in Illaichi. Flowering pattern of some of the mango hybrids and genotypes were also studied.

Collection and evaluation of superior seedling types, clones, and mango germplasm. Fruits of seedling type variants, namely, Sel. 1 Bijnor, C 1, C 5, C 301, C NB, Angoor, Sel. 2 Khan, Office 2 and Chausa were evaluated for physico-chemical parameters. The maximum fruit weight (315.1 g) was observed in Chausa Variant followed by C 301 (228.05 g) and C 1 (219.4 g). The average stone weight in C 301 was only 29.4 g with stone: fruit weight ratio in C 301 (7.76). However, the minimum fruit weight was found in Angoorlata (42.0 g).

Fruit of C 301 showing high pulp:stone ratio

Polymophism studies using Novel Hyper Variable SSRs. A genome wide set of 245 hyper-variable mango SSR markers were used for identification of polymorphic SSRs between parents Amrapali and Sensation. In which 109 HMSSRs were polymorphic, and 122 were monomorphic. Studies on segregation of polymorphic HMSSRs among F_1 mango population is underway. Isolation, purification and quantification of DNA from 122 individuals of mapping population and parents were completed during the period.

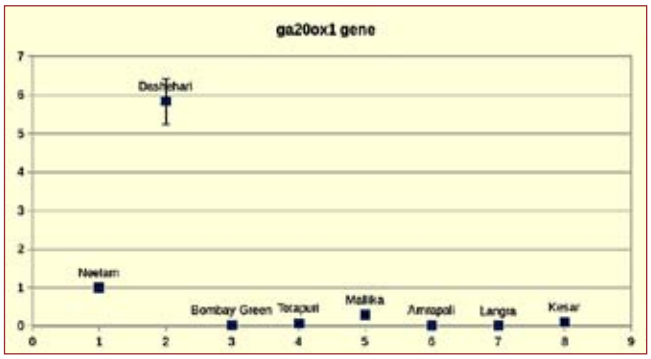


Representative HMSSRs profile showing polymorphism between parental Amrapali and Sensation genotypes

Comparative transcriptome analysis for alternate bearing trait. To understand a comprehensive perspective on the molecular mechanisms underlying alternate bearing in mango (*Mangifera indica* L.), transcriptome wide gene expression profiling was conducted in both regular and irregular varieties. Transcriptome data of regular (Neelam) and irregular (Dashehari) mango varieties revealed a total of 42,397 genes. Out of that 12,557 genes were differentially expressed and 25,194 genes were found to be significant. Numbers of up and down regulated genes were 6,453 and 6,104, respectively. Furthermore, many of the common unigenes, which were involved in hormonal regulation, metabolic process, oxidative stress, ion homeostasis, alternate bearing, etc. showed significant differences between these two varieties. Pathway analysis showed that the highest numbers of

differentially expressed genes were related with the metabolic process (523).

A total of 15 differentially expressed genes from three important pathways,viz., alternate bearing, carbohydrate metabolism and hormone analysis along with control (*ß-actin* gene) were validated using Real time PCR and results were at par with *in silico* analysis. The expression pattern of alternate bearing genes like *LOC103413993,LOC103432486*, *LOC103434184*, *LOC103452666*, *LOC18790008*, *rbcL*, Rumani *GA-20-oxidase*, *SAD1*, *SAD3*, *SPL,etc*. were almost identical to that of qRT-PCR results except one gene *LOC103420644*, which was found to be down regulated in Dashehari.



Comparison of expression level GA-20-oxidase-like gene using qRT-PCR. Gene expression is normalized to the ß-actin. Expression study was conducted in regular and irregular eight mango varieties. The results are means of three biological replicates

2.2.2 Citrus

Hybridization. During March 2019, a total of 318 flowers of different female parents (Hamlin and Mosambi) were crossed with Pummelo (pink aril), tangerine and seedless pummelo mutant (PM-3 and PM-4). Cross Mosambi x tangerine recorded the highest fruit set (10.87%), while it was lowest in Mosambi x PM-3. In acid citrus fruits, a total of 338 flowers of female parents, i.e. lemon (Konakn Seedless, Kagzi Kalan) and acid lime (Pusa Udit and Pusa Abhinav) were hybridized with selected male parents. The highest fruit set was recorded in Konkan Seedless x Pusa Udit crosses (52.23%). In rootstock improvement, total 580 flowers have been crossed in different combinations.

Development of scion hybrids. During 2018-19, 23 citrus scion hybrids (Pummelo x Sweet orange) were evaluated for growth, yield and fruit quality. Of these, hybrids SCSH 7-10/12, SCSH 17-14/14, SCSH 17-11/12 and SCSH 17-19/13 yielded fruit > 500 g weight. Juice recovery was highest in SCSH 11-15/12 (40.03%) followed by SCSH 19-5/14 (38.55%) and SCSH 19-10/14 (37.94%). Hybrids SCSH 5-10/12, SCSH 11-15/12 and SCSH 17-17/12 had the peel thickness < 5 mm. Hybrid SCSH 13-9/13 had seedless fruit.

Evaluation of hybrids against salinity and phytophthora root rot. Of the 36 citrus rootstocks hybrids (Pummelo x Sacaton and Pummelo x Troyer citange) evaluated against NaCl (50 mM) induced salinity ($EC_{(1:2)}$6.10 dS/m), 10 hybrids, namely, P x Sacaton-326, 338, and 351 and P x Troyer -323, 324, 328, 336, 346, 347 and 348 were found tolerant based on morphological and biochemical traits. Similarly, 29 citrus rootstock hybrids were resistant against *P. nicotianae* on the basis of lesion length.

Clonal selection in sweet orange. Performance of twelve clones of sweet orange cultivar Malta was assessed against two check varieties,viz., Pusa Sharad and Pusa Round for growth, yield and fruit quality traits. Among these twelve clones, fruit weight varied from 147.31 g in MS 20 to 269.46 g in MS 1 as compared to Pusa Sharad (234.68 g) and Pusa Round (228.72 g). Furthermore, significantly highest juice content was noted in MS 4 (45.77%), followed by MS 7 (44.78%), MS 15 (44.09%) and MS 20 (43.66%), Pusa Round (45.23%) and Pusa Sharad (43.04%). The highest TSS was found in MS 21(10.7^{0}Brix) followed by MS 3 (10.33^{0}Brix). The lowest acidity was found in MS 24 (0.29%) followed by MS 3 (0.47%) and MS 1 (0.50%). MS 3 clone yielded the highest (36.33 kg/tree) with highest fruiting density (0.55 fruits/m^3 CV) and yield efficiency (0.12 kg/m^3 CV). Clones MS 3, MS 7, MS 9 and MS 21 were found most promising.

Clonal selections in acid lime and lemon. In acid lime clones, the number of fruits varied from 31 fruits/tree (second year fruiting) in ALC 6 to 517 fruits/tree in ALC 76. Clones such as ALC 4, ALC 64, ALC 70, ALC 76 and ALC 82 had fruit weight more than 40 g, being the highest in ALC 82 (50.08 g) as compared to Pusa Udit

(38.31 g) and Pusa Abhinav (39.05 g). Furthermore, > 50% juice recovery was recorded in ALC 103, ALC 90, ALC 5 and ALC 4. Most of the promising clones had acidity more than 6%. Clones ALC 24, ALC 64, ALC 71, ALC 76, ALC 89 and ALC 101 have been found better in terms of yield and fruit quality parameters. Among different lemon accessions, LS 3 proved most vigorous (67.21 m^3 canopy volume). During summer season, LS 1 excelled over others in respect of highest fruit weight (75.74g), juice content (52.65%), acidity (6.21%) and ascorbic acid content (40.77mg/100ml juice), with lowest seed number (2.20/ fruit). During winter season, LS 1 also proved best collection due to highest acid content (4.81%) and ascorbic acid (36.23 mg/100 ml juice). The highest fruit weight was recorded in LS 5 (146.06g), while LS 6 recorded the highest juice (40.87%) and TSS (7.20°B) contents.

Bearing in lemon clone LS 3

Mutagenic studies on Kinnow and sweet orange. **Kinnow**: The bearing mutants in Kinnow developed over the years through different doses of gamma (γ) irradiation, ethyl methane sulphonate (EMS) and colchicine revealed significantly higher plant height (3.9, 3.6 m) in the mutants M 10-4 & M 15-7, while it was recorded lowest (1.9 m) in Col-0.02%-1 followed by Col-0.1%-2 (2.2m). The heaviest fruit (258.0 g) was recorded in the mutant M 15-2, while it was lowest (146.31g) in M 30-1 but with high juice recovery (64.93%) and TSS (12.2°Brix). The number of seeds (<10) was recorded in the mutants M 15-1 and M 20-1 as compared to the parent type which had more than 30 seeds/fruit. Observations on fruit quality parameters developed through chemical mutagen (EMS) exhibited higher fruit weight in EMS 0.2%-3 (216.24 g) which also had highest juice recovery (46%) and lower number of seeds per fruit (<15). Average fruit yield kg/plant was highest (65.00 kg/tree) in M 20-8. As regards the colchiploids, fruit weight was recorded highest in Col-0.02%-1 (222.18 g). The juice recovery was, however, recorded maximum in Col 0.1%-1 (48.50%), which also significantly had lower number of seeds/fruit (<12). Flow cytometery analysis led to the identification of one putative tetraploid.

Bearing in colchicine induced variant Col 0.1%-1

Sweet orange: Mutants in Mosambi developed after irradiation with gamma irradiation (15, 20, 25, 30, 35 and 40 Gray) revealed maximum (2.8m) and minimum (0.90 m) plant height in the mutants SO 15-2 and SO 40-3, respectively. Observations on maiden fruiting in mutants exhibited heavier fruits in SO 15-6 (262.90 g), while it was lowest in mutant SO 15-1 (129.98g) but with high TSS (11.0°Brix). The juice recovery was recorded maximum in SO 10-2 (60.52%), which also had a lower number of seeds per fruit (<10).

Characterization of pummelo clones. Vegetative and reproductive characterization indicated the existence of variability in the seedling population. Flowering and fruit set were recorded in all the five clones. Application for issuing IC numbers for these clones was submitted with the NBPGR, New Delhi. Very heavy flowering and fruit set was observed in all the five seedling pummelo clones.

Ploidy manipulation in Kinnow mandarin and sweet orange: Characterization of Colchiploids. The fruits from the colchicine treated 13 Mosambi sweet orange plants and 18 Kinnow mandarin plants of were analysed. In Mosambi, heaviest fruits were recorded in *in situ* 2–4 plant (212. 4 g). In Kinnow, the fruit

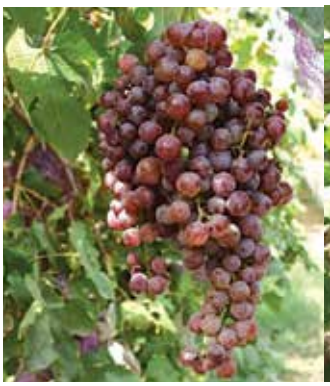
parameters were at par amongst the colchicine treated resultant plants. Biggest fruits were recorded in the plant Ex−2−15 (219. 1g) and rind thickness (7. 8 mm) was highest in the fruits of Ex−1−4. Maximum TSS in Ex−1−4 (10. 0^0Brix), indicating the importance of colchicine treatment in creating variability. Some plants exhibited acute dwarfness with reduced internodal distance, indicating towards hyperploidy. Similarly, early flowering was recorded in all the treated plants of Mosambi in comparison. Flowcytometric analysis of the 14 colchiploids, resulted in identification of two putative tetraploids.

Fruits and rind thickness in colchiploid of Kinnow mandadrin

Fruits and rind thickness in colchiploid of Mosambi sweet orange

2.2.3 Grape

Germplasm and hybrid evaluation. Sixty-five grape genotypes, including hybrids and varieties from seedless coloured/white, seeded coloured, seeded colorless, groups were evaluated as per the Grape Descriptors. Among the seedless genotypes, Flame Seedless performed better in terms of yield (14.50 kg/vine), fruit quality (TSS 19.5°Brix, titratable acidity 0.84%) with early maturity (June first week) and was found most promising in terms of fruit quality and yield under north Indian plains on Bower system of training. Black Muscat performed better among the seeded varieties in terms of yield (12.20 kg/vine), berry quality (TSS 18.5°B), loose bunch with minimum berry cracking on Kniffin system. For juice purpose, Pusa Navrang and Punjab Purple performed better in terms of berry quality, yield and early maturity. Pusa Seedless, Pusa Urvashi and Pusa Aditi were found better in terms of seedlessness, early maturity, yield, berry quality and fruitfulness. However, Pusa Swarnika was found most promising in terms of berry size (20.5 mm diameter), weight of 100 berries (465.25 g), TSS (21.5°B), loose bunch and early maturity. Among the newly developed hybrids, three hybrids consistently performed better in terms of extra-early maturity (last week of May to first week of June) and berry quality, viz., Hy. ER-R_2P_{36} (Higher TSS > 23^0Brix, large bunch, early maturing, coloured, seedless, heavy yielder), Hy.16/2A-R_1P_9 (early maturing, bold berry, seeded, loose bunch, golden-yellow berry) and Hy. 16/2A-R_1P_{14} (early maturing, bold berry, seeded, loose bunch, coloured).



Flame Seedless

Hybrid Pusa Swarnika

Hybrid ER R_2P_{36}

Potential varieties and hybrids of grape having early maturity with better fruit quality

Varietal notification. During 2018-19, Delhi State Variety Release Committee notified grape hybrid

Pusa Aditi for Delhi State and NCR. It is developed through hybridization between Banqui Abyad and Perlette. It matures early and takes 80-85 days after full bloom, having large bunch (440 g), bold berry (2.8 g), round yellowish-green in colour, firm pulp (6N), good TSS (19.3°Brix), and high yield (15.5 t/ha on bower training system). Bunches are free from shot berry disorder and are uniformly developed. The vine is moderately vigorous, and is a spur pruned. The hybrid has good traits for table purpose and juice making. It is moderately tolerant to anthracnose and powdery mildew. Recommended for sub-tropical agro-climatic conditions of North India plains including Delhi, NCR, Punjab and Haryana.

Heavy bearing in hybrid Pusa Aditi

2.2.4 Guava

Crop improvement. Hybridization was carried out using Khasipur collection, Pant Prabhat, Thai guava, Shweta, Hisar Safeda, Arka Kiran, Arka Reshmi, Black Guava and Hisar Surkha variant, Punjab Pink, Lalit, Thai Pink and Allahabad Surkha as parents. A total of 2,872 flowers were crossed and 147 fruits were harvested and sown in the field. The seeds were raised and a total of 1,726 numbers of F_1 population was produced. Among the mutant population, three genotypes were found to have fruits with less number of seeds. Plants were recorded for plant height, flowering, and fruits characters. The F_1 populations were screened for different traits and three very promising types from a cross combination of (Trichy x Punjab Pink- having the red peel and pulp), (Hisar Safeda x Lalit- White pulped with red peel) with average fruit weight of 145.87 to 238 g, TSS 13.2 to 15.3°Brix, acidity of 0.427%, vitamin C content of 293.12-345.43 mg/100g were observed.

Hybridization in guava was done as per diallel mating design by involving five parents: Shweta, Punjab Pink, Pant Prabhat, Black Guava and Hisar Surkha. A total of 904 crosses were made, of which 123 fruits were harvested. Harvested combinations were Punjab Pink x Shweta (56), Punjab Pink x Black guava (5), Punjab Pink x Hisar Surkha (2), Punjab Pink x Pant Prabhat (14), Shweta x Punjab Pink (5), Hisar Surkha x Punjab Pink (1), Hisar Surkha x Pant Prabhat (1), Pant Prabhat x Punjab Pink (11), Pant Prabhat x Shweta (4), Pant Prabhat x Black guava (9), Pant Prabhat x Hisar Surkha (2), Punjab Pink (selfed, 7), Hisar Surkha (selfed, 1), Black guava (selfed, 2), Pant Prabhat (selfed, 1), Shweta (selfed, 2). Punjab Pink x Shweta was highest compatible cross combination resulting in higher recovery of hybrid fruits (35.67%). Hybrid fruit retention (excluding the selfed ones) at 15, 30, and 45 days after crossing was 32.12, 23.39 and 18.96%, respectively. Fifty nine F_1 plants were transplanted in the field for evaluation.

Study of self-and cross-incompatibility was done for five parents, namely, Shweta, Punjab Pink, Pant Prabhat, Black Guava and Hisar Surkha. During April-May, 2018, 50 single buds and 50 multiple buds were bagged. Under single bud bagging condition, fruit set was noted in Punjab Pink (7), Hisar Surkha (1), Black guava (2), Pant Prabhat (1), and Shweta (2); compared to multiple buds bagging condition, fruit set took place in Punjab Pink (18), Hisar Surkha (0), Black guava (6), Pant Prabhat (14), and Shweta (8). More refinement is required to draw conclusion on self- and cross-incompatibility in these genotypes.

G 1-15 (Hisar Safeda x Lalit)

Guava F1 hybrid (Trichy x Punjab Pink)

2.2.5 Papaya

Evaluation of genotypes against papaya ringspot virus (PRSV). Total 14 papaya genotypes, namely, P 9-5, P 7-2, P 7-14, P 7-9, P 9-12, P 7-15, Tripura Local, Sinta, Pune Selection 1, Pune Selection 3, Pusa Nanha, Red Lady, including *Vascocellea cauliflora* and *V.cundianamarcensis* were evaluated against *Papaya ringspot virus* (PRSV) infection through mechanical sap inoculation at early stage of seedling. Most of the *Carica* genotypes showed moderate level of PRSV infection, 15 days after inoculation (DAI). Based on ELISA test values recorded at three intervals, it was proved that none of the *Carica* genotypes were resistant to PRSV infection except *V. cauliflora* and *V. cundinamarcensis.* The ELISA test values were significantly higher in the genotype P 7-14 (0.068) followed by P 9-5 (0.64) and was lowest in the *V. cundianamarcensis* (0.008). However, ELISA test values were static for Pune Sel. 3 and Pune Sel. 1 after PRSV infection. The genotype *V. cauliflora* showed maximum increase in plant height {20 DAI (12.15%), 40 DAI (10.58%) and 60 DAI (11.31%)}. After 20 DAI, the genotype P 7-9 showed the maximum (84.25%) per cent increase in number of leaves and minimum in the genotypes *V. cauliflora* (41.82%) and *V. cundinamarcensis* (34.90%). The maximum per cent increase in petiole length was in Red Lady (5.16%) at 20 DAI, while it was minimum in *V. cauliflora*(2.98%), but was statistically at par with Tripura Local (3.06%). At 60 DAI, *V. cundinamarcensis* showed maximum (4.80%) increase in petiole length followed by Red Lady (4.70%). No PRSV infection symptoms were recorded on leaf and petiole of the *V. cauliflora* and *V. cundinamarcensis.* Leaf relative water content was found to be highest in *V. cundinamarcensis* (89.42%) at all the stages. Lowest membrane injury index (10.66%) in Pune Selection 3, followed by *V. cundinamarcensis* (11.99%) and the highest in Red Lady (24.00%) after 20 DAI. After 40 DAI, the maximum chlorophyll content was present in the wild relative of papaya, *V. cauliflora* (43.53 SPAD units), which was statistically similar with *V. cundinamarcensis* (40.96 SPAD units) and lowest in P 9-12 (14.66 SPAD units) at 60 DAI. The highest SOD activity (7.46U mg/TSP/min) was in *V. cundinamarcensis* (7.46 U mg/TSP/min) and lowest activity was noticed in Pusa Nanha (2.52 U mg/TSP/min) after 60 DAI. The proline content was enhanced in seedling leaf post PRSV infection in all the *Carica* genotypes. The maximum proline content was noticed in *V. cauliflora* (0.256 mg. g^{-1} FW) at 20 DAI followed by Pune Sel. 3 (0.174 mg. g^{-1} FW) and Pune Sel. 1 (0.170 mg. g^{-1} FW). Similar trend was recorded even after 40 and 60 DAI. The total phenol content was recorded highest in *V. cundinamarcensis* (238.99 mg/100g) after 20 DAI followed by Pune Sel. 3 (179.52 mg/100g). Study revealed that the *V. cauliflora* and *V. Cundinamarcensis* are source of resistance against PRSV and Pune Sel. 3 had a significant level of tolerance against PRSV infection.

Evaluation of mutants. Five mutant plants,viz. M 04, M 09, M 22, M 28 and M 33 were selected from two lower doses,i.e. 0.1 and 0.15 kGy, which were particularly outstanding in vigour having dwarf stature and bearing height in M 04 population. Minimum height at first fruiting (89.54 cm), plant girth (60.36 mm), nodes to first flowering (34.28), days to flower initiation (76.28), length of middle internode (3.8 cm), petiole length (42.30 cm) and plant spread E-W (130.4 cm) was noted in M 04 plant, while maximum first fruiting height (138.62 cm), plant girth (74.15mm), nodes to first flowering (48.86), days to flower initiation (85.52), length of middle internode (4.8 cm), length of petiole (55.12 cm) and plant spread in east-west direction (154.8 cm) was found in control. Maximum fruiting length (88.40 cm), number of fruits (52.4), weight of fruit (1.160 kg) and yield of fruit (54.82 kg/ plant) were recorded in M 04 plant, while minimum fruiting length (74.20 cm), number of fruits (33.4), weight of fruit (1.160 kg) and fruit yield (34.6 kg) were found in control. Maximum fruit length (21.84 cm), fruit width (12.23cm), and pulp thickness (3.00

cm) were observed in M 04 plant followed by M 09 plants, while minimum was in control. Maximum TSS (9.26°Brix) was also recorded in M 04 plant followed by M 33 plant (8.92°Brix), while minimum (8.0°Brix) was in control.

2.2.6 Production Technology of Fruit Crops

Rootstock research and canopy management in mango. In Pusa Arunima, significantly taller tree (4.67 m) was observed on K 3 rootstock, which was statistical similar with Olour (4.08 m). Extremely dwarf (2.67 m) trees of Pusa Arunima were found on K 2 rootstock. Overall, K 2 proved to be the least vigorous rootstock for Pusa Arunima and Pusa Surya cultivars, while it was K 5, which proved its superiority in terms of less vigour for Amrapali. In case of yield, K 3 appeared to be most productive for Pusa Arunima (37.55 kg/tree) and Pusa Surya (14.17 kg/tree), while it was Olour which yielded the highest for Amrapali (40.66 kg/tree). Furthermore, trees of Pusa Arunima and Pusa Surya produced the highest fruiting density/m^3 CV on K 2 rootstock, while it was K 5, which yielded the highest fruiting density in Amrapali. The heaviest fruits in Pusa Arunima (233.15 g), Pusa Surya (268.28 g) and Amrapali (152.43 g) were recorded on Olour rootstock. Pulp TSS was significantly higher in Pusa Arunima both on K 3 or K 2 rootstocks, while the highest acidity was recorded on K 5 rootstock.

In vigorous mango varieties, the tallest trees of Mallika (3.64 m) and Dushehari (3.53 m) were recorded on Kurakkan and Olour rootstocks, respectively. After 11 years, growth on Olour rootstock yielded < 4.0 m canopy diameter in both directions, while for Dushehari, both K 5 and Kurakkan rootstocks gave trees with < 3 m canopy diameters. The highest yield (39.83 and 33.33 kg/tree) were observed on K 5 rootstock, showing parity with Olour rootstocks in case of Dushehari. Yield efficiency (0.16kg/ m^3 CV) and fruiting density (0.68 fruits/m^3 CV) were found highest on Olour rootstock for Mallika, while for Dushehari, it was K 5 rootstock, which yielded highest yield efficiency (2.58 kg/m^3 CV) and fruiting density (0.33 fruits/m^3 CV), which also resulted in heaviest fruits too.

Rootstocks evaluation in Kinnow mandarin. Kinnow mandarin grafted on seven different rootstocks were evaluated with respect to their growth, fruit yield and quality. Plant height, and canopy volume were recorded maximum on *Jatti khatti* rootstock (4.37m; 42.12m^3) followed by *Karna khatta* (3.74 m; 31.00m^3). The transverse cross sectional area (TCSA) of the rootstock was significantly higher (482.04 cm^2) on Carrizo citrange, while it was recorded minimum on Rangpur lime (220.24 cm^2). Among different rootstock-scion combinations, Kinnow/ *Karna khatta* (1.15 per cm^2 TCSA) and Kinnow/ Rangpur lime (1.00 per cm^2 TCSA) had the higher fruiting density, while it was lowest for Kinnow/Carrizo citrange combination. Amongst the root-scion combinations, fruit weight (330.83 g) was recorded maximum on *Jattikhatti* rootstock followed by rough lemon (293.48 g) and *Karna khatta* (275.03g). The juice recovery percentage was however, recorded maximum (57.20, 55.37 and 54.21%) in fruits of scion grown on sour orange, Rangpur lime and *Jatti khatti* rootstocks, while minimum juice recovery percentage was recorded on Carrizo citrange rootstock (28.05%). The TSS°Brix was recorded maximum in Kinnow budded on Rangpur lime (13.16) and *Jattikhatti* rootstocks (12.83). The number of seeds/fruit on different rootstocks ranged between 14 in Rangpur lime to 32 seeds/fruit on rough lemon. The average Kinnow yield was recorded maximum on *Jatti khatti* (134.62 kg) followed by Rough lemon (92.35 kg), while it was minimum in Kinnow grafted on Carrizo rootstock (235.83 kg).

Evaluation of different rootstocks on grapefruit. The tree growth of grapefruit cultivars Marsh Seedless and Redblush was studied. The trees of Marsh Seedless proved most vigorous (211.17m^3) on sour orange. The highest fruit yield was recorded in Marsh Seedless (57.19 kg/tree) and Redblush (61.04 kg /tree) on Troyer citrange rootstock. The fruits of Marsh Seedless had the lowest peel thickness (3.24mm) on *Billikichli* rootstock. In Redblush cultivar, except rough lemon and Billikichli, all the rootstocks proved equally effective to produce the fruits with low peel thickness (3.28-3.85mm).The different rootstocks exhibited the significant variations in fruit quality attributes of both the grapefruit cultivars except juice content. The

highest content of TSS in the fruits of Marsh Seedless (8.60°Brix) and Redblush (9.13°Brix) were recorded on RLC-4 and *Billikichli* rootstocks, respectively. The highest ascorbic acid content in Marsh Seedless (47.23mg/100ml juice) was recorded on *Billikichli* rootstock followed by *Jattikhatti*.

Evaluation of newly developed mango hybrids under INM schedule and drip irrigation. There was significant effect of INM treatments, mango cultivars and interaction effect of INM treatments. Maximum shoot length (194.36 cm) was recorded in treatment NPK 100% + AMF (250g)+ *Azotobacter* (250g) followed by 189.24 cm in treatment NPK 75% + AMF (250g) + *Azotobacter* (250g), while minimum (174.32 cm) in treatment NPK 50%+ AMF (250g). Maximum shoot diameter (54.66 mm) was recorded in treatment NPK 100% + AMF (250g)+ *Azotobacter* (250g) followed by 44.58 mm in treatment NPK 75% + AMF (250g) + *Azotobacter* (250g), while minimum (35.24 mm) in treatment NPK 50%+ AMF (250g). Among cultivars, maximum plant height (3.30 m) was recorded in Pusa Arunima with minimum (3.10 m) in Pusa Pratibha. Maximum number of fruits (16.06) was recorded in treatment NPK 100% + AMF (250g)+ *Azotobacter* (250g) followed by 15.08 in treatment NPK 75% + AMF (250g) + *Azotobacter* (250g). Among varieties maximum fruit weight (186.89 g) was found in Pusa Arunima followed by Pusa Shreshth (178.95 g) and minimum (161.11 g) in Pusa Pratibha. Maximum fruit yield (4.215 kg) was recorded in treatment NPK 100% + AMF (250g)+ *Azotobacter* (250g) followed by 3.888 kg in treatment NPK 75% + AMF (250g) + *Azotobacter* (250g). Among varieties, maximum yield (4.088 kg/ tree) was found in Pusa Arunima followed by Pusa Shreshth (3.574 kg/ tree), while it was minimum (3.248 kg) in Pusa Pratibha.

Temperate fruits.The most promising rootstock selections so far tested at IARI Research Farm, Dhanda, Shimla have been ornamental peach, *Prunus persica* Japan. This rootstock has shown high yield efficiency, precocity, graft compatibility and smaller in size than the standard rootstock. Based on the performance of this rootstock on plant architecture (dwarfing), graft / budding compatibility, precocity, productivity, fruit size, fruit colour and quality, abiotic stress resistance (cold), it has been recommended as dwarfing rootstock for stone fruits for high density orcharding and low chilling areas.

Performance of Japanese plum varieties Black Amber, Satsuma, Mariposa, Santa Rosa were evaluated on *Prunus japonica* rootstock. The fruit weight varied from 42.84-58.55g with maximum in Santa Rosa (58.55g). Fruit TSS varied from 14.8-20.5^{0}Brix with highest in Santa Rosa (20.5^{0}brix).

Twenty five Russian /temperate type pomegranate accessions were collected from ICAR-NRCP, Solapur was established for evaluation after multiplication. There were fruiting in 6 germplasm,viz. Boskalinisi, GR Pink, Spin Sakaharin, Shirin Anar, Kayaki Anar, and AHPGC-3. Fruit weight varied from 157-196g, TSS varied from 13-17^{0}Brix in different genotypes. These are expected to grow in higher altitude along with other temperate fruit crops and evolve as alternate cropping systems.

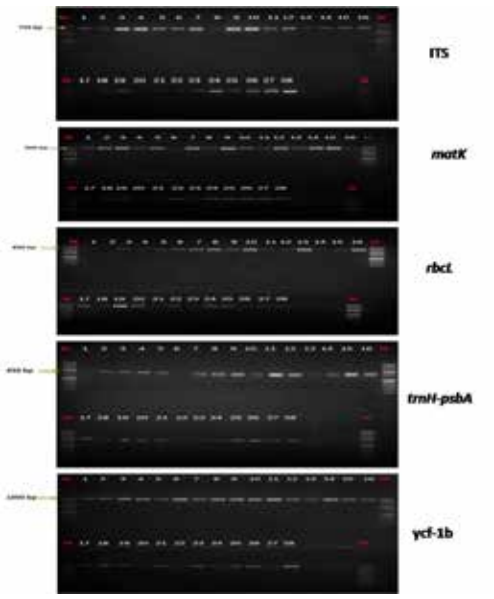
Different crab apples (*Malus baccata*) genotypes were evaluated as pollinizers for commercial cultivars, use in breeding programme and as rootstock. Hybridization in kiwi and apple was undertaken and seeds were collected, stratified and sown for raising F_1 generation. Fifty F_1 seedlings have been raised for evaluation.

2.3 ORNAMENTAL CROPS

2.3.1 Rose

Phylogenetic relationships in the Rosa sp. based on DNA barcode. Phylogenetic relationships were studied in 28 species of genus *Rosa* (Rosaceae) based on nuclear and chloroplast markers.A total of five pairs of primer

sets were selected based on previous studies for DNA barcoding of *Rosa* species. Out of five, four primers were from chloroplastal DNA (*matK* gene, *rbcL* gene, *ycf-1b* gene and *trnH-psbA* intergenic spacer) while one set of primer was from nuclear ribosomal *ITS* region. Amplification products sizes of different barcodes were found to be ~750bp for *ITS*, ~950 for *matK*, ~800 bp for *rbcL*, ~450bp for *trnH-psbA* and ~1000bp for *ycf-1b*.



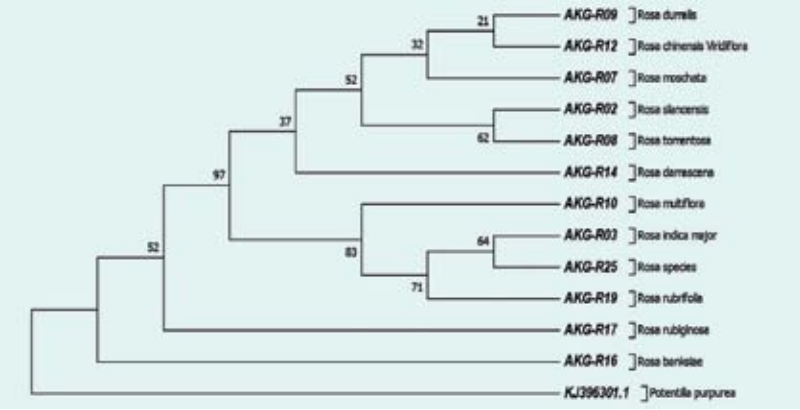
Amplification products of different markers of *Rosa* sp. Lane 1-28 represents different *Rosa* species. Lane M represents 50 bpDNA ladder

A total of 101 novel nucleotide sequences of genus *Rosa* (*ITS*-16, *matK*-17, *rbcL*-23, *trnH-psbA*-21 and *ycf*-1b-24) were submitted to Genbank database of the National Center for Biotechnology Information (NCBI), USA for the first time and accession numbers were obtained.

Different species formed six distinctive clusters; out of that, 3 clusters had only one species. *R. dumalis, R. chinensis* 'Viridiflora' and *R. moschata* placed into one cluster, *R. slancensis* and *R. tomentosa* grouped in one cluster, *R. multiflora*, *R. indica major*, *Rosa* sp. and *R. rubrifolia* placed into another cluster. *R. damascena, R. rubiginosa* and *R. banksiae* did not group into any cluster and were placed singly. Hence, 12 rose species were identified and recommended nucleotide sequences as tag for these species.

Promising OP seedling/natural mutant (Bud sport) of Rosa × hybrida L. RS 1-2018 is a open-pollinated seedling of cv. Jantar Mantar. It produces white coloured large sized blooms. The plants are short and narrow bushy. It belongs to floribunda type. The promising seedling is suitable for garden display purpose in northern plains. Another genotype RM 1-2018 is a natural mutant (bud sport) of cv. Folklore. It produces light orange coloured large sized blooms having white coloured stripes. The plants are medium in height, bushy Hybrid Tea type. The promising seedling is suitable for garden display purpose under northern plains.

Hybridization in Rosa × hybrida L. Crosses were made among promising rose varieties to develop new varieties for loose, cut and fragrant flowers and garden display. The parents utilized in the crossing



Phylogenetic tree from combining four marker (*ITS*, *matK*, *trnH-psbA* and *ycf-1b*) sequences (3006bp) of *Rosa* sp.(Bootstrap values (%) are shown on each branch

programme were Rose Sherbet, Pusa Mahak, Jantar-Mantar, Surabhi, Pusa Virangana, Shola, Pink Queen Elizabeth, Delhi Princess, Golden Shower, Oklahoma, Jadis, Dr. Benjamin Pal, Pusa Abhishek, Mridula, Dr Bharat Ram, Culcatta 1Borolina, Paradise, Dr S.S. Bhatnagar, Grand Gala, A Royal Rose, Doris Tystermann, Borolina, Happiness, Barbara Bush, Rani Sahiba, Viomala, Krishna, Pink Knock Out, Tajmahal, Preyasi, Surekha, Echo and Midas Touch. The cross combinations exhibited differential hip set abilities.

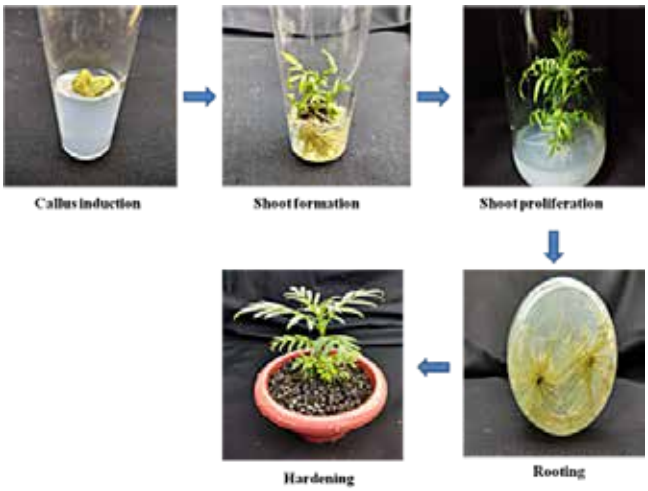
Screening of promising pre-breeding lines against powdery mildew. Screening was carried out in pre-breeding lines such as PBL-R-PM-1-2016, PBL-R-PM-5-2016, PBL-R-PM-8-2016, PBL-R-PM-11-2016, PBL-R-PM-12-2016, PBL-R-PM-15-2016, and PBL-R-PM-17-2016 against powdery mildew caused by *Sphaerotheca pannosa* var. *rosae*. Among these pre-breeding lines, PBL-R-PM - 8-2016 and PBL-R-PM-17-2016 were found moderately resistant.

2.3.2 Chrysanthemum

In vitro screening of chrysanthemum varieties for salt tolerance. Six promising varieties of chrysanthemum,viz., Pusa Chitraksha, Lalit, Pusa Aditya, Basanti, Himanshu and Pusa Sona were screened under *in vitro* conditions upon inoculation on Murashige and Skoog (1962) medium supplemented with 0, 50, 100 and 150 mM NaCl. With increasing salt level, there was decline in shoot length, fresh weight, number of leaves and rooting percentage. Whereas, much significant difference was not observed in the number of shoots per plant. Maximum reduction in plant growth was recorded in the variety Pusa Sona, while minimum was observed in variety Pusa Aditya. Increasing salt stress had an adverse effect on rooting abilities. In medium supplemented with 150mM NaCl, the maximum rooting was recorded in the varieties Pusa Aditya and Basanti whereas, least was observed in Pusa Sona and Himanshu.

2.3.3 Marigold

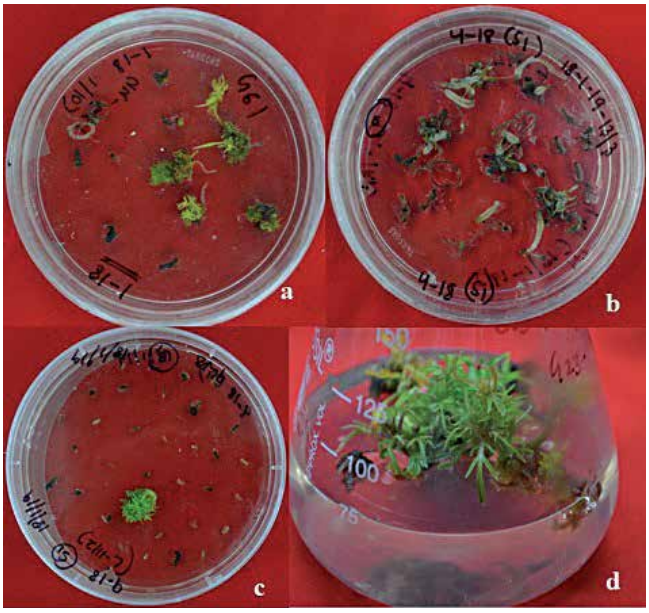
Standardization of protocol for in vitro mass multiplication of doubled haploid line of African marigold. A reliable and efficient protocol was developed for *in vitro* mass multiplication of doubled haploid line of African marigold (*Tagetes erecta* L.) var. Local Orange derived through ovule culture. Among pre-treatments of leaves, treatment - Bavistin (0.2%) + Ridomil (0.2%) + 8-HQC (200 mg/l) for 60 min. resulted in minimum microbial contamination and maximum survival of explant. Surface sterilization with $HgCl_2$ (0.1%) for 3 min. reduced microbial contamination and simultaneously increased the explant survival. Treatment combination MS + BAP (0.5 mg/l) + NAA (0.25 mg/l) showed the maximum regeneration in the three types of leaf explant. Leas segments from basal portion was found most responsive. Treatment MS +BAP (0.5 mg/l) + NAA (0.25 mg/l) + putrescine (50.0 mg/l) was found best for morphogenesis and multiple shoot emergence. For rhizogenesis, treatment (½MS+IBA 0.5 mg/l) was found optimum. *In vitro* hardening of plantlets, treatment comprising of vermiculite, cocopeat and perlite in ratio of 1:1:1 (v/v) in plastic pots, moistened with ½-strength MS and subsequently covered with polythene sheets was found better.



In vitro mass multiplication of doubled haploid line of African marigold var. Local Orange

Development of protocol for production of doubled haploids in African marigold. The *in vitro* gynogenetic response of three petaloid-type African marigold genotypes, viz., Arka Bangara 2, BM 1 and BM 2 was assessed. The best response was observed in Arka

Bangara 2 (52.9%) followed by BM 2 (47.5%). Very poor response was observed in BM 1 genotype. Among the different media tested, the best *in vitro* response was obtained on B5 (with NLN vitamins) basal medium supplemented with 250mgl^{-1} polyvinylpyrrolidine, 300mgl^{-1}casein hydrolysate, 45gl^{-1} maltose and 2.6gl^{-1} gelrite. The germinated shoots were successfully maintained on B5 medium supplemented with 250mgl^{-1} polyvinylpyrrolidine, 300mgl^{-1} casein hydrolysate, 40 mgl^{-1}adenine sulfate, 2.5 mgl^{-1} BAP, 0.1 mgl^{-1}GA$_3$ and 0.25mgl^{-1}NAA.



The *in vitro* gynogenetic response in African marigold, a) Arka Bangara 2; b) BM 2; c) BM 1; d) gyno-genetically induced shoots

2.3.4 Gladiolus

Development of promising gladiolus hybrids. Twenty nine hybrids including one check White Prosperity were evaluated for flowering and corm traits. The performance of gladiolus hybrids indicated that three hybrids, namely, Melody Open Seedling, Chandni x Snow Princess and P-16-1 x Eurovision showed earliness in flowering and took 78.33, 84.00 and 86.00 days, respectively, after planting. While Pink Parassol Open Seedling, Smokey Lady x Mayur, Swarnima x Viola and Vidushi Mutant had flowered late and took 113.66, 112.00, 110.00 and 108.66 days, respectively. Hybrid Salmon Queen Open Seedling, Yellow Stone x Melody and Bindiya x Creamy Green had recorded maximum plant height 153.66, 149.00, 144.00 cm and spike length 135.66, 132.33 and 133.66 cm, respectively. Maximum number of florets per spike recorded in hybrid Yellow Stone x Melody (20.66), Bindiya x Creamy Green (20.33), Salmon Queen Open Seedling (20.0). Seven hybrids such as Smokey Lady x Oscar, Bindiya x Creamy Green, Yellow Stone x Melody and Melody Open Seedling had produced more than 3.00 corms per mother plant, whereas, it was minimum 1.66 in check variety White Prosperity.

2.3.5 Turf Grass

Screening of turf grass varieties or species. Eight species of turf grass, namely, St. Augustine, Crow foot grass, Zoysia grass, Bermuda grass, Bahia grass, Seashore paspalum, Centipede grass, and carpet grass were evaluated under different shade levels, i.e. 25, 50 and 75% and in open conditions to examine the effect of reduced irradiance on photosynthetic capacity, pigment content, quality and growth behaviour. For most of the grass species leaf elongation was higher under reduced irradiance compared to open conditions. Grass coverage decreased under shading gradually in comparison to open conditions. At highest shade level, i.e. 75% turf species crow foot grass, St. Augustine and zoysia performed well. For most of the species greater reduction in quality parameters like texture, colour, etc. was found under reduced irradiance.

2.3.6 Licoris

Optimisation of nutrient requirement for size enlargement of bulblet in Licoris. The experiment was conducted with Hoagland Solution: ¼, 1/2 and full-strength for enlargement of size of bulblet to bulb. Uniform size of bulb let (1.0cm) was planted in 6" size pot. Application of full strength of Hoagland increased bulb-let diameter (1.75cm), height (25.5cm), width (1.50cm), and biomass (6.5g plant^{-1} DW).

2.3.7 Easter Lily

Studies on the multiplication through seeds of Easter lily. The experiment was conducted with plant growth regulator to hasten the germination of Easter lily. It was observed that treating seeds with 2000 ppm thiourea increased germination (96%) and survivality (65.50%) followed by 1000ppm IBA (germination- 92%, survivality-45.25%).

An experiment was conducted for optimization of growing media and nutrition for increasing the size of bulblet. Application of NPK (400:250:200 ppm) in coco-peat medium increased the bulblet size (2.75cm) followed by NPK (300:200:150 ppm) in vermiculite (2.5 cm). In Easter lily, application of NPK 300:300:300 kg/ha increased spike length (50.25cm) and flower size (14cm.)

2.3.8 Bulbous plants

To enrich the gene pool of indigenous bulbous flowering plants, several species were collected, namely, *Allium*-1; *Begonia*-1; *Crocosmia*-1;*Curcuma*-1; *Hedichium*-2; *Zephyranthes*-1; *Hemarocallis*-2; and Tiger lily-1.

2.3.9 Lilium

Evaluation of interspecific Lilium hybrids. Seedlings of interspecific crosses made in 2017 were evaluated for different parameters. A cross between (KILH 13 x Navona) x Sapporo took minimum duration (153.3 days) to flowering followed by a cross between (KILH 13 x Navona) x Viviana (156.8 days). Inflorescence length of 20.7 cm was recorded in (KILH 13 x Navona) x Brunello. Plant height (78.7 cm) and larger sized bulbs (8.25 cm^2) were found in a cross between KILH 13 x Topeka. Similarly, seedlings of three crosses were also evaluated under polyhouse conditions. Earliest flowering was observed in a cross between KILH 13 x Navona (130.5 days). Plant height (91.5 cm), bud length (14.4 cm) and flower size (12.4 cm) were recorded maximum in KILH 13.

a) b)

c)

Interspecific Lilium hybrids: a) (KILH 13 x Navona) x Brunello, b) KILH 13 x Topeka, c) Polyhouse performance of KILH 13

Similarly, the seeds of the interspecific crosses made in 2018 were sown and evaluated for their germination. A cross between KILH 13 x Novana took minimum time (24.0 days) for germination followed by a cross between KILH 13 x Belem (27.0 days). Maximum seed germination percentage was found in a cross between KILH 13 x Sapporo (95.0%) followed by LILH 13 x *Lilium speciosum* (64%). The results have offered opportunities for the introduction of novel

traits including re-flowering, multiple sprouting and winter hardy, in seed propagated Lilium that can flower from seed within one year.

Evaluation of OT cultivars. Non-vernalized bulbs of nine OT cultivars of Lilium were collected and evaluated for flowering traits. Among different cultivars, Sambuca was earliest (215.0 days), plant height was maximum in cv. Zambassi (85.0 cm), while flower size was maximum (20.25 cm) in Ice Dreamer.

Field evaluation of Lilium cultivars

2.3.10 Alstroemeria

Propagation on Alstroemeria. Alstroemeria cultivars Aladdin and Pluto were propagated every two month intervals starting from November to March and planted under open field conditions for evaluation. The apices of aerial shoot on plants propagated in January and March showed flower initiation within 2-4 months. In both the cultivars, the main rhizomes continued to flower stem production up to November. Shoots of the cultivars propagated in November remained vegetative until the following spring.

2.4 SEED PRODUCTION OF HORTICULTURAL CROPS

The ICAR - IARI, New Delhi and its Regional Stations at Karnal, Katrain, and Pusa (Bihar) produced nucleus, breeder, and IARI-TFL seeds of different horticultural crops during the period under report. In addition to seed production, 20071 saplings of fruit crops were also produced at ICAR - IARI, New Delhi and Regional Stations at Karnal, and Pusa (Bihar).

Seed production of horticultural crops

ICAR-IARI / Regional Stations	Seed production (kg)			
	Nucleus	Breeder	IARI-TFL	Total
ICAR-IARI, New Delhi				
Vegetable crops	-	1104.00	3962.95	**5066.95**
Flower crop		96.50	16.70	**113.20**
Regional Station, Karnal				
Vegetable crops	154.74	2747.75	1156.10	**4058.59**
Regional Station, Katrain				
Vegetable crops	85.00	33.00	2195.00	**2313.00**
Total	**239.74**	**3981.25**	**7330.75**	**11,551.74**

Propagation of Horticultural crops

ICAR-IARI / Regional Stations	Number of saplings
ICAR - IARI, New Delhi	1000 (Mango, Grape, Guava, Papaya, Lemon, Mandarin, Acid Lime & Sweet Orange)
Regional Station, Pusa	11761 (Papaya, Mango &Litchi)
Regional Station, Karnal	7310 (Mango, Guava, Papaya & Lemon)
Total	**20071**

3. GENETIC RESOURCES AND BIOSYSTEMATICS

Plant genetic resources have a crucial role in crop improvement programmes. The institute has a vibrant programme for collection, maintenance, evaluation and utilization of germplasm in various field and horticultural crops. A large number of germplasm lines including some wild species were maintained, evaluated and utilized in pre-breeding and genetic enhancement in crops. The chapter also includes biosystematics and identification services related to pathogens, insects and nematodes to explore, conserve and enrich the culture collections.

3.1 CROP GENETIC RESOURCES

3.1.1 Wheat

Maintenance and utilization of wild and related species of wheat. Around 276 accessions of 38 wild and related species of wheat belonging to the genera *Triticum*, *Aegilops*, *Secale* and *Agropyron* were maintained in net house at IARI, New Delhi. In addition, 624 alien introgression lines derived from wild species like *T. militinae, T. timopheevi, T. turgidum, T. monococcum, T. spelta, Ae. variabilis, Ae. umbellulata, Ae. speltoides, Ae. markgrafii, Ae. geniculata* and *Secale cereal* were maintained. Twenty-two of these alien introgression lines exhibited high levels of adult plant resistance (APR) against all the three rusts. These were derived from *T. militinae, T. spelta, T. timopheevi, Ae. geniculata* and *Ae. markgrafii*. Leaf rust resistance was identified in 334 introgression lines, yellow rust resistance in 179 introgression lines and stem rust resistance in 121 introgression lines. These introgression lines have considerable potential as a source of rust resistance and may enhance the existing gene pool of resistance to yellow, stem and leaf rusts. One of the *Ae. markgrafii* introgression line ER9-3-700 having broad spectrum resistance against 16 diverse races of *Puccinia triticina* showed resistant reaction of '0;" to ';" at seedling stage. Some of the introgression lines were also tested for resistance against fungal diseases like Karnal bunt, Spot blotch and head scab. Thirty one introgression lines were found to be resistant to Karnal bunt with 0% disease incidence under artificially inoculated conditions.

Genetic resource developed and registered with NBPGR. Durum wheat line, HI 8774 (developed from a cross HI 8663/HI 8498**)** with multiple disease resistance was registered at ICAR-NBPGR, New Delhi as a genetic stock. It showed high levels of adult-plant resistance to most prevalent and virulent pathotypes like 46S119 and 78S84 of stripe rust in isolated nurseries. It also showed resistance to powdery mildew and Karnal bunt disease. HI 8744 can be used as potential resistance donor to breed new varieties. Wheat accessions, IC 252459, IC 536365, EC 339604, and EC 574482 were registered at ICAR-NBPGR, New Delhi for stem, leaf, and stripe rusts resistance genes with plant germplasm registration numbers INGR18013, INGR19007, INGR18012 and INGR19008, respectively.

Promising wheat genetic resources for multiple rust resistance. HS 661, a multiple rust resistant wheat genotype was developed from a double cross HS295*2/FLW20//HS295*2/FLW13 through molecular marker-

Yellow rust infestation in HS 295(a), and APR in HS 661 (b)

assisted selection and host pathogen interaction. HS 661 was validated for presence *Lr19/Sr25* using microsatellite marker *Xwmc221* and SCAR based marker $SCS265_{512}$. Presence of stripe rust resistance gene *Yr15* in HS 661 was also validated using microsatellite marker *Xgwm11*. The data revealed consistency between seedling resistance test and molecular marker-assisted validation for *Lr19/Sr25* and *Yr15* in HS 661. HS 661 with rust resistance genes could be a used as potential donor for rust resistance.

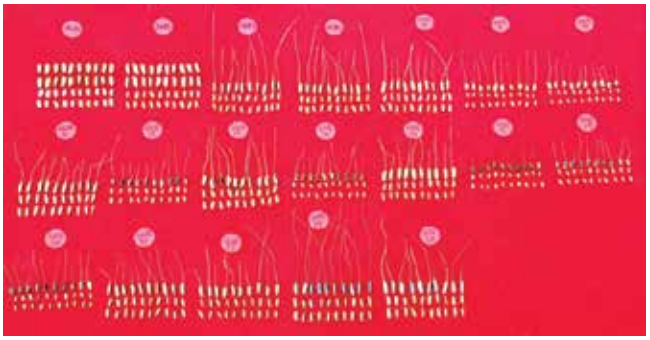
Evaluation of breeding lines for seedling and adult plant resistance to stripe rust. A set of 138 RILs from a three way cross, HD 3055/HS 507//HPW 349 was evaluated for stripe rust resistance under natural condition at rust hot spot Dalang-Maidan. Of these, 26%, 22% and 28 % lines showed resistant, moderately resistant and moderately susceptible reactions, respectively. The same set was also screened against virulent pathotype 110S119 at adult plant stage under artificial inoculated conditions in a poly-tunnel. Twenty eight genotypes were recorded TR-5MR infection type, indicating accumulation of rust resistance genes to stripe rust in derivative lines. Among 166 advanced wheat breeding lines evaluated under CVT-SRT, only six were found to possess seedling resistance to most virulent pathotype 110S119 of wheat.

Evaluation of wheat genotypes against stem and leaf rusts resistance at Indore. A total of 589 genotypes of preliminary disease screening nursery were evaluated for field resistance to stem and leaf rusts under artificial inoculations using mixtures of important pathotypes during *Rabi* 2017-18. Of these, 201 entries (~34 % of the total) showed resistance (Coefficient of Infection value up to 10.0) to both stem and leaf rusts at Indore. Out of 100 bread wheat entries from Indore, few entries were found to be resistant to all three rusts. The resistant genotypes are: HAS 2525, HAS 2528, HAS 2529 and HAS 2558. A total of 124 wheat lines (77.5 %), out of 160 lines under different CVTs, showed resistance response against stem rust pathotype 40A when screened at seedling stage.

National off-season nursery. Nearly 18,000 wheat, barley and oats varieties, >2000 mustard lines and 350 lines of flax were raised under National Off-season Nursery at IARI Regional Station, Wellington. A total of 9,445 wheat lines received from breeders were evaluated for rust resistance and only 1.2% lines expressed highly susceptible reaction to brown rust while ninety percent lines were either immune or moderately resistant to stem rust under field conditions at Wellington. Incidence and intensity of powdery mildew was high in almost all these lines at early stages of growth.

3.1.2 Rice

Pre-breeding - development and evaluation of introgression lines. A set of 120 different accessions of wild rice collections of *O. rufipogon, O. nivara, O. longistaminata, etc.* were evaluated and data has been recorded for different traits. These lines were also utilized in wide crossing for introgression of useful traits.



Representative wild rice accessions evaluated during *Kharif* 2018

Evaluation of rice germplasm for yield and other components. A set of 500 rice genotypes, including mega varieties, short grain aromatic rice, NPTs and lines collected from different parts of country were evaluated for yield and other traits such as number of tillers per plants, plant height, panicle length, days to 50% flowering, days to maturity, number of grains per panicle, spikelet fertility and 1000-grain weight during *Kharif* 2018. Further, these lines were also inoculated, for screening, by different isolates of *Xanthomonas oryzae pv. oryzae* (*Xoo*), the causal organism of bacterial blight (BB), and resistant lines have been identified which will be further characterized for utilization in breeding programme.

Field evaluation of rice germplasm lines during *Kharif* 2018

3.1.3 Maize

Maize × teosinte derivatives. Seventeen elite maize inbreds were crossed with a teosinte accession (*Zea mays* ssp. *parviglumis*) as male parent. A selected set of F_3 progenies were evaluated at Delhi during *Kharif* 2018. Segregants with grain and ear characteristics of maize were selected. Some of the ears also showed segregation of white kernels thereby depicting that teosinte grains (where seeds' endosperm is not visible due to covering by stony fruitcase called cupule) possess white endosperm conditioned by recessive *y1* allele. These novel segregants would serve as the rich genetic resource for maize breeding programme.

Ear and grain characteristics of *maize x teosinte* derivatives

Identification of biotic stress tolerant genotypes. A set of 100 newly developed inbreds were screened against Turcicum leaf blight (TLB), and 25 inbreds against Maydis leaf blight (MLB), Curvularia leaf spot (CLS) and shoot borer under artificial epiphytotic conditions. PDM 4641, DDM 2207, DDM 2309, DIM 302, PML 4 and CDM 1308 were resistant to TLB, while MLB resistant lines were PDM 4131, PDM 4341, CDM 1345, CDM 1306, PML 80 and CM 138. Besides, DIM 335, PDM 4131, CDM 1306, PDM 188, CDM 1305 and PDM 4641 were resistant to CLS. Further, six lines tolerant to stem borer were also identified. PDM 188, CDM 1305 and PDM 4641 were resistant to TLB, MLB and CLS.

Resistance reaction against CLS in DM 4131

Maize germplasm for breeding programme. Diversity analysis (based on phenotypic traits) was performed on a panel comprising 485 accessions (ICs and ECs). Preponderance of medium to late maturing accessions was detected in the set. Only a few accessions were seen to possess white kernels with dent texture. Germplasm accessions were also evaluated for grain and biological yields besides grain - filling attributes. Strong correlations have been detected in grain filing traits with crop maturity and phenology.

3.1.4 Pearl Millet

Maintenance of germplasm. A total of 326 germplasm lines have been maintained at IARI for different traits like early flowering, high tillering, thick spike, bristled spike, long spike, variations in compactness of the spike, grain color, high iron and zinc content, heat and drought tolerance.

Maintenance breeding of cytoplasmic male sterile lines. Seventy CMS lines were maintained by attempting 2671 paired crosses. Nucleus seed multiplication of 19 promising CMS lines (411A/411B, 431A/431B, ICMA 843-22/ICMB 843-22, ICMA 841A/B, ICMA 92777A/B, 576A/B, ICMA 96222/B, ICMA 96666 /B, ICMA 97111/B, ICMA 98444/B, ICMA 99111/B, ICMA 99444/B, ICMA 01222/B, ICMA 01555/B, ICMA 04111/B, ICMA 04999/B, ICMA 08666/B, ICMA 11222/B, and ICMA 13222/B) was undertaken.

Maintenance breeding of restores/inbreds. Four hundred and seventy nine elite inbred lines were maintained by selfing. These inbred lines possessed desirable traits like early maturity, thick spike, compact spike, disease resistance, good tillering and overall agronomic superiority, and are to be tested for combining ability. Some of them are also having high lysine, tryptophan, Fe and Zn content.

3.1.5 Chickpea

Evaluation of chickpea global core germplasm for root nodulation. The global chickpea germplasm collected from major chickpea growing regions representing more than 30 countries, constituted as Chickpea Global Core germplasm, was obtained from Gene Bank, ICRISAT, Patencheru, Telangana. The experiment consisting of 1950 core germplasm lines and 8 controls was conducted in augmented design. The nodule numbers were counted after 30-35 days after sowing. The nodule number varied from 2.0 to 36.6 in the core germplasm.

3.1.6 Mustard

Germplasm maintained and utilized. A total of 512 germplasm lines including *B. juncea*, *B. carinata*, *B. napus*, *B. rapa*, *B. oleracea* *B. nigra*, *B. tournifortii*, *B. caudatus*, *R. caudatus*, *R. sativa*, *S. alba*, *Eruca sativa*, *Crambe* spp., *Lapidium* spp and *Crambe* spp. were maintained by selfing and utilized in breeding programme. These also include 30 quality accessions with low erucic acid and/or glucosinolates. Exotic genotypes viz., EC 27, EC 28, EC 30, EC 60, EC 61 and EC 62 were purified and maintained by raising 216 progenies. Sterility inducing cytoplasm viz., *mori, eru, ber* and *ogu* are being maintained through crossing respective A and B lines.

A field view of germplasm lines of *Brassica* spp.

3.1.7 Soybean

Identification of salinity tolerance at seedling stage. A random set of 82 diverse soybean genotypes were screened for salt tolerance (120 mM NaCl) at early seedling growth stage. The screening method is based on a glasshouse, aerated hydroponics test in which salt is added to the nutrient hydroponic solution subjected to seedlings growth without soil. The results illustrated significant variations among all the genotypes under saline condition at 120 mM NaCl level. Data was recorded on root length, shoot length, symptoms based on chlorophyll content (SPAD value) and visual salt tolerance rating (STR) value under effective salinity level (120 mM NaCl) with respect to their non-stressed plants. Out of 82 genotypes screened, 74 were found to be susceptible (STR 4-5). Only two genotypes (Pusa 9712 and A 13) were found to be highly tolerant (STR-1), one

Hydroponics set up for screening of salinity tolerance

genotype (PS 1572) showed tolerant reaction (STR-2) and five genotypes (E 20, JS 20-19, Lee and SL 1180) were moderately tolerant (STR-3). The sensitive genotypes showed greater reduction in the measured parameters under salinity stress.

3.1.8 Vegetable Crops

Cauliflower. Fertile inbred lines (130) were evaluated in three different maturity groups, viz., early (59), mid-early (47) and mid-late (24) and maintained by selfing or sibbing. Eight SI lines of early maturity group, namely, CC 12, CC 13, CC 14, CC 15, 395aa, 351aa, vv and xx three SI lines (CC 32, CC 35 and ccm-5) of mid group were maintained by bud-pollination. Thirteen fixed CMS lines (BC_{7-12}), namely, DC 8441-5, DC 8498-10, DC 999-23, DC 999-PM, DC 999-41-5, DC 31 PM, DC 31-41-5, DC 31-23, DC-MD-PM, DC-MD-41-5, DC 394-41-5, DC 394-PM and DC 175-8 were maintained. Conversion process of 30 elite inbred lines using established *Ogura* sterile cytoplasm and seven lines with *Eru* sterile cytoplasm have been advanced to BC_{4-7} and BC_4 stages, respectively.

Characterization of 48 CMS lines was done using 16 morhpometric traits and 55 DNA markers (36 genomic and 19 mtDNA). An mtDNA marker BnTR4 showed an amplicons of 219 bp only in DC 151PM *Eru* CMS line (Source: NRCPB) due to 31 bases deletion at 147-178th base position, while another, marker BnTR1 produced an amplicon of 267 bp only in same CMS line due to insertion of 30 bases at 150th base position. Further, advanced 190 RILs (from PHJ/PS x BR-2/161/207/202) for black rot resistance were screened by artificial screening with *Xcc* race 1, 4 and 6 and also evaluated for horticultural traits and advanced to F_{8-10} generations.

In snowball group of cauliflower, 25 stable CMS lines along with their respective maintainers were planted in the field. These lines are at different stage of backcrossing (BC_8-BC_{13}) for the introgression of *Ogura* cytoplasm. The CMS lines were maintained with their respective male fertile counter-parts during summer 2018. Besides, seven doubled haploid (DH) and 15 other elite inbred lines with good agronomic traits were selected for CMS conversion. The '*Ogura*' CMS system was introgressed into these lines by crossing them with different *Ogura* CMS source lines, viz., *Ogu*1A, *Ogu*2A and *Ogu*3A being maintained at the IARI Regional station,Katrain.

Cabbage. Two inbred lines and two CMS lines of 'no-chill' cabbage were maintained and one genotype PA 2 has been entered in IET trail of AICRP (VC). At IARI Regional Station, Katrain, 80 germplasm of cabbage including 10 self-incompatible lines and 30 CMS lines along with their respective maintainers were purified and maintained.

Broccoli. *I*n broccoli, 24 varieties/ breeding lines were advanced to next generations (S_{3-5}/F_{4-6}) by bud-pollination. Two CMS lines were also advanced to BC_4 At IARI Regional Station, Katrain, fifteen germplasm and 6 CMS lines along with their maintainer lines were purified and maintained.

Wild Brassica. Thirty two different *Brassica* accessions collected from Kolasib, Mizoram and 10 wild Brassicaceae species, viz., *Alliaria petiolata*, *Brassica tournefortii*, *Brassica critica*, *Cardamine hirsute*, *Capsella bursa-pastoris*, *Nasturtium officinale*, *Rorippa islandica*, *Sisymbrium officinale*, *S. irio* and *S. orientale* collected from Kullu Valley were maintained and evaluated for insect resistance traits.

Cucumber. Sixty indigenous/ exotic cucumber species including 40 accessions of *Cucumis sativus* var. *hardwickii*, two accessions each of *C. hytivus*, *C. javanicas*, *C. prophetorum*, *C. trigonos*, *C. melo* var. *metuliferus*, three accessions each of *C. melo* var. *agrestis* and *C. melo* var. *leosperma* were maintained through selfing under nethouse. Six genotypes with high β-carotene were collected and maintained through selfing. Apart from IC-420422 and LOM-402 new carotene rich lines (AZMC 1 and KP 1291) collected from Mizoram through ICAR-NBPGR were found to be very promising with dark orange flesh colour on ripening. These were crossed with the released varieties for studying genetics, creation of mapping population and transfer of the high β-carotene trait in the desirable backgrounds.

Luffa. Fifty five germplasm/advance breeding and virus resistant lines were maintained. In ridge gourd, 30 advance breeding lines including Satputia and its genetic stock were maintained. Six gynoecious lines showing true gynoecious behaviour were maintained by using silver thiosulphate (3 mM) twice at 10-day intervals.

Pumpkin. Forty five germplasm/advanced breeding lines were evaluated and maintained. Pumpkin DPU 84 having lemon yellow flower colour, which can be used as a morphological marker is maintained.

Pumpkin DPU 84 having lemon yellow flower colour

Muskmelon and watermelon. One hundred twenty two germplasm of muskmelon from four horticultural groups (*Cantaloupensis, inodorous, momordica* and *conomon*) were evaluated for horticultural traits and resistance against *Fusarium* wilt and powdery mildew. Forty two muskmelon germplasm were screened in polyhouse for resistance against powdery mildew resistance and genotype EC 751844-3 and oriental melon were identified as source of resistance. Seventy two watermelon genotypes from *Citrullus lanatus* var. *lanatus*, var. *citroid* and *C. colocynthis* were evaluated and maintained.

Bottle gourd. At IARI Regional Station, Pune, a total of 100 accessions, including 02 registered genetic stock (INGR10064 and INGR99009) and 9 exotic collections have been augmented during 2017-18 from ICAR-NBPGR, New Delhi. All the germplasm received from the Division of Vegetable Science, IARI and NBPGR (total 283) were characterized and evaluated during summer and ***Kharif*** 2018. Two high yielding genotypes IC 415716 (estimated yield 29.0 t/ha), cylindrical fruit IC 570511 (estimated yield 26.0 t/ha), were identified. A unique genotype (IC 588084) having segmented leaf margin with uniform light green long fruit has also been identified.

Higy yield potential IC 415716 | **Cylindrical fruit IC 570511** | **Segmented leaf marging with uniform light green long fruit IC 588084**

High yielding and unique genotypes in bottle gourd

Long melon and round melon. Twelve germplasm/advanced breeding lines each of long melon and round melon were maintained. Long melon lines DLM 19-2 with segmented leaf and DLM 14-1 & DLM 24-1 having dark green skin colour were maintained.

Long melon DLM 14-1 with dark green fruit

Tomato. A total of 250 accessions of germplasm, wild species were multiplied and maintained. Fifteen tomatoes and eight cherry type lines for polyhouse cultivation were maintained.

Brinjal. A total of 50 working germplasm were purified, evaluated and maintained, 166 segregating progenies were advanced.

Chilli. Seventy six working germplasm lines were purified, evaluated and maintained. Apart from this, seeds of three Capsicum species, *C. frutescens*

(five genotypes), *C. chinense* (four genotypes) and *C. baccatum* (one genotype) have been multiplied. Forty nine *C. annuum* genotypes have been procured from NBPGR, New Delhi and multiplied and characterized.

Sweet pepper. Fifty germplasm lines of capsicum were maintained under open field conditions. Besides this, three CMS lines, viz., KTC 3A, KTC 4A and KTC 5A were also maintained by crossing them with their respective maintainers under polyhouse conditions.

Carrot. Forty inbred lines were planted for maintenance, seed multiplication and used in hybrid breeding. Two CMS lines were found to be uniform and are being maintained. Six CMS lines were heterozygous and effort was made to purify them. In temperate carrot, seventy four germplasm lines including 34 IC lines and 20 CMS lines along with their respective maintainers were purified and maintained.

Onion and garlic. Seventeen accessions of Pran (*Allium* x *cornutum* Clementi ex Visiani) were procured from ICAR-CITH, Srinagar and maintained under New Delhi conditions. 125 germplasm lines, 320 breeding lines, 47 second generation inbreds, 252 single bulb selection material, 150 test cross progenies and 35 onion and 12 garlic varieties were maintained. Twenty onion germplasm were collected and evaluated for *Kharif* season bulb production. Thirty genotypes of long day onion (red & yellow type) were purified and maintained at the regional station, Katrain.

Garden pea. One hundred germplasm were rejuvenated. Fourteen new lines of *Pisum* species were introduced and characterized for horticultural traits and *Fusarium* wilt resistance.

Okra. One hundred eight cultivated and 57 wild accessions and genetic stocks of okra were maintained.

Lettuce. Thirty eight germplasm lines were evaluated & maintained. One hundred sixty five advanced breeding lines were phenotyped based on the leaf colour, and evaluated and maintained.

Leafy vegetables. Six *palak*, 3 spinach and 5 *Chenopodium* advance breeding lines maintained.

3.1.9 Fruit Crops

Mango. Mango germplasm, namely, A.U. Rumani, Alampur Baneshan, Apple Mango kim-1, Arka Anmol, Arka Aruna, Badami, Bappakkai, Banganpalli, Chenna-Rasam, China Suvernrekha, Creeping, Dadamio, Dofasala, Doodhpenda, Delicious, Goa, Goa Mankurd, Hathijhula, Isreal hybrid, Kala Hapus, Karela, Kensigngton, Kent, Keitt, Konkan Ruchi, Konkan Samrat, Konkan Raja, Lily, Mahmood Bahar, Manjeera, Maya, Mulgoa, Najuk Pasand, Neelshan, Neelshan Gujarat, Neelkiran, Neelgoa, Osteen, Pairi, Palmer, Prabhashankar, Pulihara, S.B. Chousa, Sabre, Sindhu, Swarna Jahangir, Vashi Badami, Vellaikolumban and Yakuti were also introduced as scion, and grafting was done in the month of July 2018. During August, scion of mango germplasm (14), namely, Rajapuri, Hur, Kesar Jambo, Nagin, Lily, Sonpari, N-1, Aditya, Heedi, Angoor, C-301, C-1, Karela, Kg Mango have been collected and grafted on rootstocks. About 70 germplasm is being maintained in the Field Gene Bank.

Citrus. Maintains 19 clones and 11 varieties of sweet orange, 75 collections of lime, 9 collections of lemon, 7 cultivars of grapefruit, 2 cultivars of tangerine, 01 minneola, 2 *Poncirus*, 29 Citrus species, 7 rough lemon collections, 2 Rangpur lime collections, 5 citrus hybrids, 18 pummelo collections, besides 335 rootstock and scion hybrids.

Grape. Fifteen genotypes of grapes were collected from PAU, Ludhiana; NBPGR, Bhowali; NBPGR, Shimla; NRC Grapes. Rooted plants/scion sticks of three new hybrids (Pusa Trishar, Pusa Aditi and Pusa Swarnika) and one rootstock, i.e., *Vitis parviflora* were supplied to NRCG Pune for multi-location trials. New collections of *Vitis jacquemontii* from Himalayan states (Uttarakhand and Himachal Pradesh) were made. A total of 118 genotypes of grapes have been conserved for further improvement and evaluation includes 73 newly developed hybrids, 7 hybrids developed and released by IARI, 21 varieties (table, juice, raisin purpose), 6 wine purpose varieties, and 12 rootstocks (species/ hybrids). The grape genotypes consisted of coloured, white, seeded, seedless, early maturing, bold berry and high yielding.

Papaya. Over 32 genotypes and advance lines are being maintained under polyhouse conditions.

Guava. A total of 64 guava genotypes were maintained in the field gene bank. Of these, 11 guava genotypes were evaluated for growth, yield and quality traits. Genotypes G 7-9 and G A-15 were found very promising in terms of average fruit weight (180-275 g), TSS (11.2 to 14.5°Brix), ascorbic acid (197.12 to 232.27 mg/ 100 g) and antioxidant content (14.23 to 16.16 mg/100 g) with high flavoinoid contents.

Temperate fruit crops. Germplasm of temperate fruit crops maintained in the field gene bank of IARI Regional Station, Shimla are as follows:

Fruit crop	No. of germplasm evaluated
Apple	92
Pear	14
Peaches and nectarine	10
Prune and plum	6
Apricot	21
Strawberry	96
Kiwi	7
Walnut	16
Almond	07
Persimmon	03
Cherry	15

3.1.10 Flower Crops

Rose. Nine varieties of rose such as Upper Class-Red, High & Magic Bicolour, High & Yellow Magic, High & Peace, High & Sparkling, Lenny, Arka Swadesh, Arka Savi and Arka Sukanya were procured from secondary sources to enrich the germplasm.

Temperate flowers. Fifty cultivars and five species of *Lilium*, 22 species/varieties of iris, 20 varieties of dahlia, 9 varieties of *Alstroemeria*, 100 breeding lines of gladiolus, 20 lines of ornamental kale, 15 genotype of *Eustoma* and other bulbous crops like, torch lily, wattsonia, canna, *Amaryllis*, crinum, *Freesia*, wild tulip, tithonia, tuberous begonia, cyclamen, zinger lily, *Lycoris*, primula, primrose, temperate orchids and some wild ornamentals are being maintained and used in crop improvement programmes.

3.2 MICROBIAL GENETIC RESOURCES

Conservation of microbial diversity. Forty-six fungal cultures belong to different genera viz., *Fusarium*, *Bipolaris*, *Chaetomium*, *Alternaria*, *Trichothecium*, *Sphaerellopsis*, *Acremonium* and *Cladosporium* which were isolated and identified based on morphological characters and purified from wheat and other graminaceous hosts in southern hills of India were subcultured periodically and are being maintained. *Meloidogyne incognita* population in microplots is being maintained at Wellington.

3.3 BIOSYSTEMATICS AND IDENTIFICATION SERVICES

3.3.1 Type Culture Collection, Identification and Maintenance

About 50,400 fungal specimens at *Herbarium Cryptogamae Indiae Orientalis* (HCIO); 4,040 fungal cultures at Indian Type Culture Collection (ITCC) were maintained under different preservative methods. The fungal collection was enriched by new addition of 28 fungal diseased specimens at HCIO and 40 different fungal cultures at ITCC. In all 510 authentic fungal cultures were supplied on payment to various scientific and industrial institutions on request. A total of 360 cultures/ specimens were identified up to species level representing plant pathogens, post-harvest pathogens, bio-control agents and industrial use fungi belong to Hyphomycetes followed by Coelomycetes and Zygomycetes. HCIO checklist of *Cercospora* spp. has documented having 1100 accessions. A total of 30 isolates of *Colletotrichum gloeosporioides* cryptic species associated with anthracnose disease were studied for genetic diversity and population structure. Twelve ISSR primers were used for studying genetic variability. Out of the 12 primers, 11 generated a total of 552 alleles with an average of 50.18 polymorphic bands per primer. A total of 15 yeast isolates were studied for molecular characterization for the ITS1-5.8S-ITS4

region. *Saccharomyces cerevisiae* (75%) was found as the dominant yeast.

3.3.2 Insect Biosystematics

Hemiptera. Survey and collection were carried out in 15 different locations at IARI, Arunachal Pradesh, Himachal Pradesh, and Uttarakhand. Collected specimens were sorted, of which 1470 specimens belonging to 8 sub-families. Twenty eight species of Cicadellidae were augmented in the National Pusa Collection. About 203 specimens of Hemiptera received from different places were identified. Approximately, 289 photographs were taken showing distinguishing characters on male genitalia for Vartini, Chiasmini, Paralimnini, and Agallini. The genus *Xenovarta* Viraktamath is recorded from India for the first time *Xenovarta viraktamathi* sp. nov. disagreeing in having a small ventral process on segment X. It also appears to differ from other species of *Xenovarta* in having the forewing apex rounded rather than truncate. It resembles *Xenovarta acuta* Viraktamath externally but differs from this and other species by the more rounded apex of the forewing and simple symmetrical aedeagus with a pair of subapical lateral processes. A new species of leafhopper *Paradorydium kirkaldyi* sp. nov. (from Himachal Pradesh: Kinnaur: Powri) from India, is described. Detailed photographic illustration, annotated checklist and modified key to the species of India were also provided. This species closely resembled *P. khasianum* Viraktamath but differs in male genitalia characters and molecular analysis using COI gene confirmed the difference and also the taxonomic positon of this species in the tribe got established with *Histone H3* gene. Two new species of leafhoppers, *Durgades sineprocessus* sp. nov. (From Himachal Pradesh: Kalpa) and *Japanagallia dolabra* sp. nov. (From Sikkim: Lachung) were described and illustrated. The important pests as well as vectors of rice diseases, small brown plant hopper *Laodelphax striatellus* (Fallen) has been newly reported from National Capital Region, Delhi.

Hymenoptera. A total of 2173 insect specimens were identified for various correspondents. Two new species of non-pollinating fig wasp genus *Sycoscapter* Saunders, 1883, namely, *Sycoscapter benghalensis* Pramanik & Dey, sp. nov. collected from *Ficus benghalensis* and *S. benjaminae* Pramanik & Dey, sp. nov. collected from *F. benjamina* were described and illustrated. A diagnostic key was formulated for distinguishing both sexes of 11 known *Sycoscapter* species reported from India including the new species. Furthermore, the affinity of males and females of *Sycoscapter* species to closely related genera of subfamily Sycoryctinae was also analysed.

Lepidoptera. Extensive survey of 17 localities in Ladakh, J&K region was carried out for codling moth and molecular characterization done for the first time from India (no sequences in NCBI or BOLD from India). First report of overwintering of codling moth inside the kernel of apricot. First report of poplar leaf miner, *Phyllonorycter populifoliella*(Treitschke, 1833) (Lepidoptera: Gracillariidae) from Ladakh region of India.

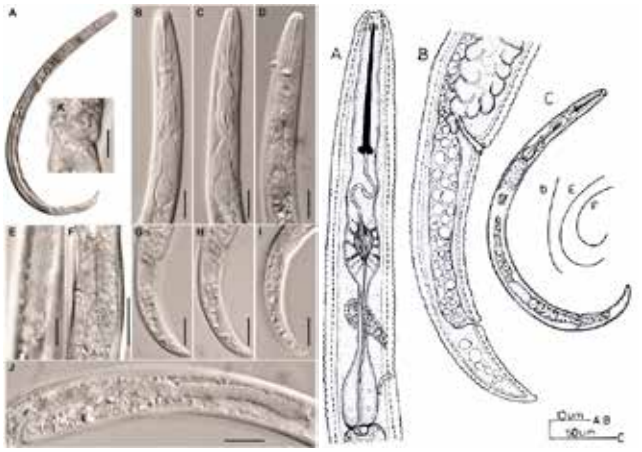
DNA barcodes were generated for the other five lepidopteran pests of Ladakh region, viz., *Lymantria obfuscata*, *Phyllonorycter populifoliella*, *Pieris brassicae*, *Thysanoplusia orichalcea* and *Yponomeuta rorrelus*. To understand diversity of high altitude moths, 24 species of high altitude Noctuid moths were collected and identified from Leh, Kargil and Spithi region.

Identification of efficient pollinators for carrot seed production. Intensive surveys were conducted to record the important native pollinators for temperate carrot seed production. Thirty one species of insects were found to visit carrot umbel at Katrain, Himachal Pradesh. Flower visiting fauna represented five insect orders, viz., Diptera (16 species), Hymenoptera (8 species), Lepidoptera (3 species), Coleoptera (2 species) and Hemiptera (2 species). Pollination efficiency of three most common pollinators, viz., Indian honey bee *Apis cerena indica*, common house fly *Musca domestica* and syrphid *Eristalis tenax* was compared in small cages (5 m × 5 m). *Musca domestica* was found to be most efficient pollinator for carrot seed production (75% increase in seed yield over control) at population density of 5 flies/ m^2. With comparable population density, pollination by *Apis cerena indica* and *Eristalis tenax* resulted in 60% and 58% increase in seed yield, respectively. Findings of the study established that

Musca domestica can be used successfully as an efficient pollinator for hybrid seed production of carrot under cage condition.

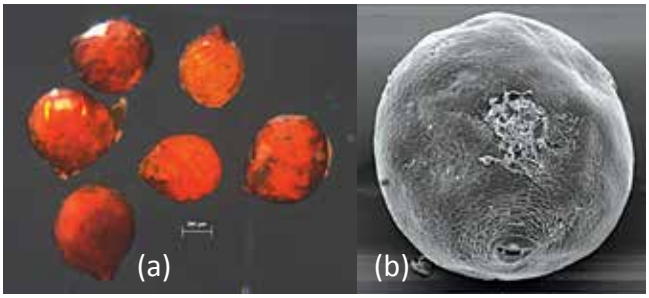
3.3.3 Nematode Biosystematics

Identification of nematode species and diversity analysis. A new species of pin nematode, *Paratylenchus jasmineae* sp. n. was isolated and described morphologically and molecularly from the rhizosphere of jasmine. Phylogenetic analysis based on ITS and D2D3 molecular markers resulted in clear separation of *P. jasmineae* sp. n. from other *Paratylenchus* species.



Light photomicrographs of *Paratylenchus jasmineae* sp. n. Female. A: Entire body; B-D: Anterior region; E: Lateral field with four lateral lines; F: Secretary-Excretory pore; G-I: Posterior region; J: Entire female gonad; K: Vulval region. (Scale bar: 10 µm) and Line drawings of *Paratylenchus jasmineae* sp. n. Female. A: Anterior region; B: Posterior region; C: Entire body; D-F: Different postures of fixed female specimens (not to scale)

Populations of root knot nematode (*Meloidogyne* spp.) infecting guava collected from West Bengal (Kalyani), Gujarat (Anand), Karnataka (Bengaluru), Tamil Nadu (Coimbatore), Uttarakhand (Pantnagar), UP (Lucknow) and Haryana (Hisar) were preliminarily identified based on perennial pattern morphology. Using species specific SCAR markers further confirmed that population infecting guava in West Bengal is *M. incognita*, while populations infecting guava in Tamil Nadu, Haryana and Uttarakhand are *M. enterolobii.* Morphological and molecular studies on the cyst population collected from bamboo (*Bambusa tulda*) plants of Assam confirmed occurrence of *Heterodera koreana*. This is believed to be first report of *H. koreana* from India. Another population was considered to be close to *H. bamboosi*, however no males were found in the soil.



Cyst of *Heterodera koreana*, a) light microscopic photograph b) SEM showing hypertrophied vulval lip

Samples collected from Hapur district of western UP for identification and community analysis. Nematode species identified were *Pratylenchus* sp., *Tylenchorhynchus mashhoodi*, *Hoplolaimus indicus*, *Meloidogyneincognita*, *Heterodera* sp., *Helicotylenchus indicus*, *Scutellonema* sp., *Basiria graminicola* among plant feeding nematodes and *Aporcelaimellus* sp., *Aporcedorus* sp., *Labronema vulvapapillatum*, *Laimydorus baldus*, *Mylonchulus* sp., *Acrobeles* sp., *Panagrolaimus* sp., *Pseudiplogastroides* sp. and *Eucephalobus* sp. among beneficial nematodes. Analysis of nematode communities revealed that *Pratylenchus* sp. was more frequent, whereas *M. incognita* was the most abundant and prominent nematode. A new predatory nematode population of *Mylonchulus* sp. (Nematoda: Mononchida) recovered from the rhizosphere of tuberose(*Polianthes tuberosa*) grown in Anwarpur of Hapur district, UP was also characterized.

Digitization of National Nematode Collection of India (NNCI). Eighty specimens from 54 type slides were digitized using programmable motorized Axioimager microscope. Digitization was done at 63x oil objective at 0.5 µm depths and at 40x for large nematodes. Nine slides of type specimens belonging to two species were deposited in the NNCI during 2018-19, bringing the total number of type slide collection to 2613.

4. CROP AND NATURAL RESOURCE MANAGEMENT FOR SUSTAINABLE ENVIRONMENT

Several innovations for enhancing the productivity, profitability, and sustainability of crops/cropping systems were developed by various disciplines of the School of Natural Resource Management. Specialized integrated farming system approach, precision and bio-inoculants mediated nutrient management strategies were developed. Various tenets of conservation agriculture showed positive effects on crop yields, soil health, and farmers' income. In-depth research carried out on soil quality and mineral concentration, wastewater treatment and reuse, hydrological responses and drought monitoring through development of specialized indices for accurate forecasting. Development and standardization of low cost agro-techniques for various vegetable and horticultural crops/varieties; design of polyhouse with efficient cladding materials formed the major thrust area for research in protected cultivation technology. Raised bed planter, corms harvester (both for gladiolus), spinach-cum-coriander rotary cutter, data logger for low-cost cold storage and real-time tractor wheel slip measuring device were developed and tested with better results. Novel technologies and processes were developed for enhancing the shelf life and nutritional value of various fruits and vegetables. Microbial techniques were designed for efficient biomass utilization as fuel and for *in-situ* degradation of crop residues, along with successful on-farm evaluation of microbial inoculants in different crops and cropping systems. Comprehensive studies also focused on the effect of irrigation and crop diversification on greenhouse gas emissions; impact of air pollution on different crops, and the effect of crop residue burning on soil health.

4.1 AGRONOMY

4.1.1 Specialized Integrated Farming System Approach for Enhancing Income of Marginal Farm Holders

A horticulture crop-based specialized integrated farming system model for marginal farm holders (0.4 ha) was developed to ensure balanced family nutrition and livelihood security, generate regular income and employment along with economic viability. The system gave a net income of Rs. 2.40 lakh/year by integrating polyhouse crops cultures, mushroom cultivation, and horticulture enterprises. Highest net return was obtained with polyhouse vegetables and flowers cultivation (Rs. 1.21 lakh/year). Mushroom provided a net income of Rs. 0.33 lakh/year. The net gain from other crops/enterprises was Rs. 0.86 lakh/year.

4.1.2 Precision Nutrient Management in Maize under Maize-Wheat Cropping System

Decision support tools such as Nutrient Expert® (NE) and GreenSeeker (GS) were evaluated to enhance the productivity of maize under maize-wheat system.

Cucumber and gerbera cultivation under polyhouse

Application of nutrients (N, P and K) on the basis of NE (targeted maize yield, 7 t ha^{-1}) along with 2 splits of N at 25 and 42 days after sowing (DAS) based GS resulted in significantly higher maize yield over *Ad-hoc* state recommendation. Further, real time N application at 25 and 42 DAS through GS along with NE recommendation for 7 t ha^{-1} yield target led to reduction of 26 kg N ha^{-1} over state recommendation with highest agronomic efficiency. Overall, the maximum system productivity (12.5 t ha^{-1}) and system net gain (Rs. 38318 ha^{-1}) under maize-wheat system were obtained under 7 and 5 t ha^{-1} targeted maize and wheat yields, respectively, using NE coupled with GS based N fertilizer application.

4.1.3 Performance of Soybean and Wheat Genotypes under Different Crop Establishment, Irrigation and Fertility

A study on promising crop genotypes under soybean-wheat cropping system indicated that the CT-furrow irrigated raised beds (FIRB) gave significantly higher soybean seed yield (2.1 t ha^{-1}) over CT. Irrigating soybean at 25% depletion of available soil moisture (DASM) registered higher seed yield (1.93 t ha^{-1}) than applying irrigation at 50% and 75% DASM. Plots with 100% recommended dose of fertilizers (RDF) resulted in higher seed yields (1.9 t ha^{-1}) than that of the plots with 50% RDF. Soybean cultivar DS 1213 produced significantly higher seed yield over Pusa 9712 under ZT with 25% DASM and 100% RDF, while PS 9712 produced significantly higher seed yield with CT-FIRB, 25% DASM and 100% RDF over others. Wheat under CT-FIRB produced significantly higher grain (4.81 t ha^{-1}) and biological (10.3 t ha^{-1}) yields. Irrigation at 25% DASM recorded higher grain (4.98 t ha^{-1}) and biological (10.77 t ha^{-1}) yields over 50 and 75% DASM. Wheat genotype HD 3086 produced significantly higher grain and biological yields under CT-FIRB with 25% DASM and 100% RDF over HD 2967.

4.1.4 Calcium Cyanamide for Higher Nitrogen-Use Efficiency in Wheat

Application of 30 kg N ha^{-1} by calcium cyanamide (CC) in combination with additional 30 kg N ha^{-1} alone as neem coated urea (NCU) or diammonium phosphate (DAP) or in combination with both, saved N by 25 to 50% without affecting grain yield of wheat. Application of 24 kg N ha^{-1} through DAP + 6 kg N ha^{-1} as NCU + 30 kg N ha^{-1} through CC enhanced nitrogen-use efficiency and recorded the highest agronomic efficiency of N in wheat.

4.1.5 Bio-inoculant Mediated Nutrient Management Enhances Wheat Productivity

Bio-inoculant (BI) cultures comprising of N-fixers [*Rhizobium leguminosarum* (pigeonpea), *Azotobacter chroococcum* (wheat)], P-solubilizers [*Pseudomonas putida*, *P. striata*, *Bacillus subtilis*, *B. megaterium*] and K-mobilizer [*B. mucilagenosus* and *Frateuria aurantia*] were studied in wheat. A higher grain yield (5.88 t ha^{-1}) was recorded with recommended dose of fertilizer (RDF) + BI over other treatments. Also, higher grain yield (5.54 t ha^{-1}) was obtained with the application of vermicompost (VC) along with BI followed by FYM + BI and leaf compost + BI. The FYM+BI resulted in significantly higher net returns (Rs. 82,200 ha^{-1}) than all other treatments.

4.1.6 Agri-horti System for Enhancing Farm Productivity and Profitability under Limited Irrigation

An agri-horti system has been developed for round the year cultivation of crops and generation of produce for regular income and employment. The whole system is irrigated by drip irrigation system from the pond. The rain water is harvested and stored in pond for life saving irrigation. The maximum system productivity was obtained from phalsa-mungbean-potato agri-horti system, closely followed by *Moringa*-mungbean-potato system. The maximum net system returns was obtained from *Karonda*-mungbean-potato system due to better prevailing market prices. Overall, net returns of Rs 2.66 lakh ha^{-1} with higher profitability/day (Rs 731/day) was obtained in the *Karonda*–mungbean–potato system under limited irrigation conditions.

4.1.7 Integrated Crop Management (ICM) in Pigeon pea for Higher Profitability and Resource-Use-Efficiency

The influence of nine different ICM modules [Four conventional tillage (CT) based: ICM_1–

ICM_4; four conservation agriculture (CA) based: ICM_5–ICM_8; one organic agriculture based: ICM_9] on productivity, PAR interception, resource-use efficiency and energetics in pigeon pea was evaluated. Pigeon pea seed yield (1.92 t ha^{-1}) and profitability (Rs. 82,776 ha^{-1}) were significantly higher in ICM_7, which was a CA-based ICM module [ZT-PRB + CRR @ 3 t ha^{-1} + 100% recommended dose of fertilizers (RDF) + (glyphosate-PP fb pendimethalin-PE fb imazethapyr-POE + 1 HW-mulch) + 2 irrigations + need based IDM/IPM]. Overall, the CA-based ICM modules showed an edge over CT based ICM modules with respect to growth, LAI, PAR interception, root biomass, yield, net returns and B:C ratio. The resource-use-efficiency in terms of total water-use efficiency (TWUE), economic water productivity (WP_E) and production- (PE) and monetary-efficiency (ME) followed similar trend as seed yield with highest TWUE, WP_E, PE and ME in ICM_7. The energy output was also highest in ICM_7 (2,23,664 MJ ha^{-1}).

4.1.8 Conservation Agriculture (CA)-based Direct-Seeded Rice-Wheat-Mungbean System as an Alternative to Conventional Rice-Wheat System

Long-term CA-based direct-seeded rice (DSR)-wheat cropping system is being undertaken for 8 years to replace transplanted puddled rice (TPR) - conventional till wheat (CTW) system, which has encountered host of problems related to water, nutrients, labour, fuel/energy, weed, and GHGs emission. A triple ZT system with three crops (rice, wheat, mungbean) residue, which involved ZT-DSR with summer mungbean (SMB) residue - ZT wheat (ZTW) with rice residue (RR)– ZT SMB with wheat residue (~MBR+ZT DSR - RR+ZTW-WR+SMB) gave 13% higher wheat yield and 40% higher system productivity than TPR-CTW system, although it had 7% lower rice yield. This triple ZT system with 3 crops residues led to a saving of almost 60 kg N ha^{-1} in rice and wheat crops in a year. This CA-based system could be a superior alternative to rice-wheat system and an important adaptation and mitigation strategy to climate change.

Rice, wheat and system productivity of rice-wheat cropping system with CA practices

Treatments	Rice yield (t ha^{-1})	Wheat yield (t ha^{-1})	System productivity (rice eq.) (t ha^{-1})
ZT DSR – ZTW (Double ZT system)	4.22^{d}	6.11^{e}	10.80^{e}
ZT DSR+BM – ZTW	3.12^{e}	6.16^{de}	9.75^{f}
WR+ZT DSR - RR+ZTW	3.22^{e}	6.28^{cde}	9.99^{f}
WR+ZTDSR+BM - RR+ZTW	3.20^{e}	6.45^{abc}	10.14^{f}
ZT DSR – ZTW – ZT SMB (Triple ZT system)	4.45^{c}	6.33^{bcd}	15.17^{b} (3.91)*
MBR+ZT DSR - RR+ZTW -WR+ SMB	4.64^{c}	6.57^{a}	15.76^{a} (4.05)*
TPR-ZTW	5.23^{a}	6.48^{ab}	12.20^{c}
TPR-CTW	4.99^{b}	5.81^{f}	11.24^{d}

*Rice equivalent yield of mungbean grain yield (t ha^{-1}) in parentheses

4.1.9 Cotton-Wheat System as a Promising Crop Diversification Option for Rice-Wheat System

All zero tilled (ZT) permanent broad-, narrow-, and flat-beds with residue were superior to CT practice in terms of the yields of cotton and wheat, and system productivity. The ZT permanent broad bed with residue and 100% N gave significantly higher yields of cotton and wheat, and increased the system productivity by 44.1% than conventional till system. The ZT permanent broad bed with residue and 75% N was comparable with it, which led to saving of 25% N. Thus, the CA-based cotton-wheat system could be a promising alternative to rice-wheat system and an important adaptation and mitigation strategy to climate change.

4.1.10 Permanent Bed Planting System Favours Root Proliferation and Increases Maize Yield

A long-term field experiment in maize-wheat cropping system conducted since 2010 included different CA-based bed planting practices with residues, such as permanent narrow bed with residue

Maize root growth under CA-based treatments

(PNB+R), permanent broad bed with residue (PBB+R) and permanent (ZT) flat bed with residue (FB+R) compared with conventional tillage (CT) practice. The CA-based practices promoted better root growth and proliferation compared to CT. Root length, biomass and volume were significantly higher under the permanent broad-, flat- and narrow-beds with residue compared to CT. These CA-based practices significantly improved yield attributes such as cobs per plant, grains per cob, and test weight of maize and gave significantly higher cob yield compared to CT. The CA-based practices increased maize yields by 7.9-12.7% over CT. Among these, the permanent broad bed with residue (PBB+R) was most superior and gave highest grain yield of maize (7.1 t ha^{-1}).

4.1.11 Diversified Cropping Systems for Enhanced Income under Peri-Urban Areas with Drip Irrigation

A field study comprising of four diversified intensive cropping systems indicated that baby corn-*palak*-okra system resulted in highest system productivity in terms of okra pod equivalent yield (24.2 t ha^{-1}), net returns (Rs. 2,38,300 ha^{-1}) and B:C ratio (1.85). Water productivity (WP) (249 kg/ ha^{-1}-mm) was also highest with aforesaid cropping systems. Bottle gourd-green onion-green onion was the second best cropping system for increasing system productivity, net returns, B: C ratio and water productivity.

4.1.12 Biomass Utilization Unit

Biomass Utilization Unit produced nearly 4000 tonnes of good quality composts during 2018-19. The Unit distributed approximately 2500 t of FYM and residue mixed compost, 200 t of leaf compost to the different divisions and units of Institute. About 3000 tonnes of CRFYM and 225 tonnes leaf compost are ready for distribution in the next season. A net revenue of Rs. 6,57,378/- has been generated during the year through sale of composts. The approximate value of materials prepared in the unit is about Rs 1.9 crores during 2018-19. The unit has provided training on different aspects of composting to the farmers, students, teachers, small scale entrepreneurs, NGOs and officials from State Governments. About 500 people were benefitted by the exposure visits, demonstrations, training and lectures conducted by the Biomass Utilization Unit.

4.2 SOIL MANAGEMENT

4.2.1 Land Use Systems, Altitudes and Depths Affect Carbon Stability in Clay–Humus Complex

Carbon stability of clay–humus complex was studied in rice–fallow, forest, mandarin and bamboo

Diversified intensive cropping systems

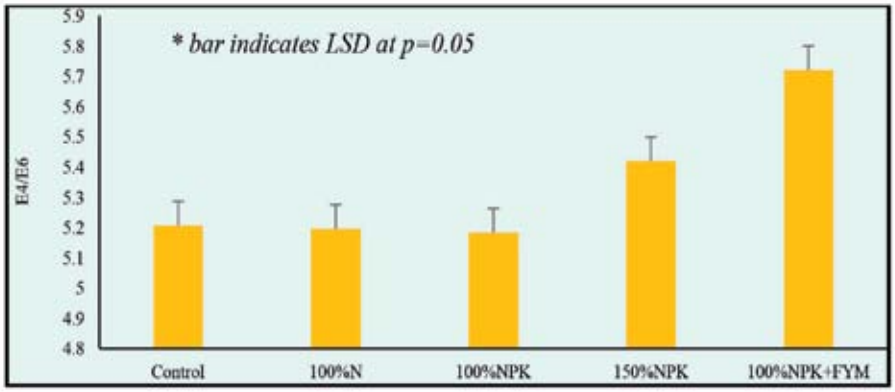
land uses at <500 m amsl, >500–1000 m amsl and >1000 m amsl from Siang districts of Arunachal Pradesh. Results indicated that stability of clay–humus complex across the altitude, land use and depth followed an order (>1000 m amsl) > (<500 m amsl)> (>500–1000 m amsl), forest>mandarin>bamboo>rice–fallow and 0–15>15–30>30–45 cm. Mean <53 µm aggregate and water stable microaggregates were highest at >1000 m amsl. XRD and semi–quantitative analysis showed illite like mica and chlorite interstratified mica (CIM) was higher at >1000 m amsl, while kaolinite was higher at <1000 m amsl. The assessment of stability of clay–humus complex through sequential extraction suggests that conversion of forest to rice–fallow across the altitude and depth would deteriorate clay–humus stability as well as soil fertility status in Siang basin.

4.2.2 Soil Organic Carbon Stability Indices, Clay Minerals and Nutrient Release Kinetics in Four Major Soil Groups of India

The conceptual framework (CF) based soil organic carbon (SOC) stability indices were developed by integrating physical, chemical and biochemical indicators in Mollisol (Pantnagar), Vertisol (Jabalpur), Inceptisol (Ludhiana), and Alfisol (Ranchi) under rice-wheat cropping system (except Alfisol under maize-wheat system). The stability index of SOC varied from 0.21 to 0.88, and 0.10 to 0.51, and 0.21 to 0.63, and 0.08 to 0.52 in Mollisol, Inceptisol, Vertisol, and Alfisol, respectively. Inceptisol of Ludhiana were mainly dominated by illite and illite rich minerals (IRM) (69%), followed by kaolinite and kaolinite-rich minerals (KRM) (21%), and smectite and smectite-rich minerals (SRM) (10.5%). In Vertisol, soil clays contained SRM (49%), IRM (35%), along with some KRM (16%). Clays in Mollisol contained more or less similar amounts of IRM (40%) and KRM (38%), along with relatively lower amounts of SRM (21%). In Alfisol, clay particles contained 44% IRM and 56% KRM, while the amounts of minerals under SRM category were negligible. The stability index of SOC was recorded highest with 50%NPK+50%N-FYM, followed by 50%NPK+50%N-GM in all the soil order. Overall, long-term application of 50% fertilizer N by FYM or green manure along with 50% NPK fertilizer in rice-wheat/maize-wheat cropping system emerged as the best management practices for enhancing stability (physical, chemical and biochemical) of SOC.

4.2.3 Long-term Fertilization and Manuring Affects Quality of Humic Acid

Structural variation of humic acid (HA) was compared in different nutrient supplying options under long-term fertilizer experiment (AICRP-LTFE). Selected treatments for the study consisted of control, N, NPK, 150% NPK, NPK+ FYM. The purified HA from 150% NPK and 100% NPK+FYM treatment was found to have lower value of acidity showing lower degree of humification. Higher E4/E6 ratio of HA extracted from 150% NPK and 100% NPK+FYM treatments also confirmed the presence of less humified organic matter in soils under these treatments. Such results indicate the presence of relatively more labile organic matter under balanced application of nutrients either through chemical or integrated nutrient sources. Hence, these treatments have potential of supplying nutrients adequately.



Long-term effect of different nutrient management treatments on E4/E6 ratio of humic acid

4.2.4 Organic Carbon and Nitrogen Mineralization, Microbial Community Structure and Soil Quality under Conservation Agriculture

Effect of conservation agriculture (CA) practices on mineralization of organic carbon and nitrogen in two different hydro-thermal regimes was assessed using a first-order kinetic model. It was observed that under residue retained plots of CA, the decay rates of SOC and N were significantly lower compared to that under conventional tillage (CT). Better aggregation, improved soil moisture regime and moderation of temperature led to stabilization of soil organic matter (SOM) under CA along with lower decay rates. Under residue retained plots, supply of fresh crop residues ensured higher rate of SOM formation. The abundance of bacterial and fungal population in conventional tillage plots are 1.86 and 1.43 times less than that of conservation agriculture (CA) based permanent narrow bed + residues plots. The total PLFA concentrations (nmoles/g soil) in surface soil of PBB+R plots were 79.9 and 82.3% higher compared to that of CT plots in pigeon pea-wheat and maize-wheat system, respectively. Soil quality indices were worked out to assess the relative order of performance CA management practices (carried out for 8 consecutive years) in affecting soil quality at 0-5 cm and 5-15 cm soil layer. The relative order SQI was MBR+ZTDSR-RR+ZTM-ZTMB (mungbean residue + zero-till direct seeded rice-rice residue+ zero-till mustard–zero-till mungbean) > ZTDSR-ZTM+ZTMB (zero-till direct seeded rice-zero-till mustard–zero-till mungbean)> ZTDSR-ZTM (zero-till direct seeded rice - zero-till mustard) > TPR-ZTM (transplanted rice - zero-till mustard) > TPR-CTM (transplanted rice–conventional tillage mustard).

4.2.5 Metal Buildup in Soil due to Polluted Water Irrigation and Feasibility of Gladiolus for Remediation

A case study was carried out with the objectives of assessing the impact of Hindon river water irrigation on soil health and risk involved in relation to transfer of metals to human food chain. Forty five paired soil and plant samples (mustard, rice, pumpkin, cucumber, spinach, turmeric, brinjal, marigold, pearl millet, mung bean, carrot and pigeon pea) were collected from river irrigated soils covering Makreda, Rewari, Nithari, Kinauni, Barnawa, Parsi villages of Western U.P. Geo-accumulation indices indicated that all the river water irrigated soils were loaded with elevated level of metals (Zn, Cu, Ni, Pb, and Cd). Extent of soil health deterioration due to metal pollution followed the order: Nithari (0.28) = Barnawa (0.28) >Makreda (0.30) >Rewari (0.38) >Parsi (0.39) >Kinauni (0.44) as evident from soil quality index. All the crop plants grown on river water irrigated soils accumulated much higher amount of Zn, Cu, Ni, Pb and Cd compared to plants grown on tubewell-irrigated soils. Taking all crops together, relative orders of transfer of metals from soil to plants grown on river water irrigated soils were Zn > Cu > Ni > Cd > Pb. Consequently, there was higher uptake of these metals by gladiolus (*Gladiolus grandiflorus* L.) grown on waste water irrigated soil compared to ground water irrigated ones, indicating the potential of this crop for phytoremediation of heavy metals from metal contaminated soils.

4.2.6 Storage Conditions of Soil Samples for Analyzing Microbiological Properties

A laboratory experiment was conducted to evaluate the effect of duration of storage of soil samples on soil microbiological and biochemical properties. The results revealed significant (P≤05) reduction in dehydrogenase activity (DHA) after 60 days of storage at 4°C irrespective of type of soil, although the degree of reduction was maximum in Ultisol and minimum in Inceptisol (West Bengal). Variable reduction in DHA from days 15 was noticed at 0 and -20 °C in all the soil types. Similar results were recorded in fluorescein diacetate, acid and alkaline phosphomonoesters and phenol oxidase activities as well as microbial biomass carbon of soil. This study showed that more than 60 days storage of samples before microbiological or biochemical analysis should be discouraged and optimum temperature of soil storage is 4°C.

4.2.7 Nutrient-use Efficiency Enhancement through Novel Fertilizer Application

4.2.7.1 Nitrogen

Nitrogen use efficiency of applied urea ammonium nitrate (UAN) was evaluated with and without

nanoclay polymer composites (NCPCs) in rice. The highest N uptake was obtained with 100% N applied through urea + NCPC due to less loss and higher nitrogen availability of N throughout crop growth. Nitrogen (100%) applied through urea was at par with 75% N applied through urea + NCPC with respect to N uptake, whereas100% N applied through UAN and 50% N applied through UAN + NCPC were equally effective. In terms of apparent N recovery, 50% N applied through urea + NCPC, 75% N applied through urea + NCPC, 100% N applied through urea + NCPC and 50% N applied through UAN + NCPC were statistically at par. For maize, results of field trial indicated that N applied through NCPC was the most efficient in enhancing yield of maize over control. The highest yield (5.49 t ha^{-1}) and N content (1.63%) in maize grain were recorded under 100% N applied through NCPC treatment. Maize yield of 5.41 t ha^{-1} was recorded in conventional urea applied plot, which was at par with 75% N through NCPC applied plots (5.17 t ha^{-1}) as well as 75% N applied through PCU (5.14 t ha^{-1}).

4.2.7.2 Phosphorus

In order to enhance the use efficiency of applied phosphorus (P), super absorbent P loaded nano-clay polymer composite (NCPC), nano-clay bio polymer composite and self-polymerizing natural oil coated DAP (OC-DAP) were prepared and evaluated. Results indicated that fertilizer products, viz. NCBPC and OC-DAP were able to maintain higher P compared to DAP fertilizer, which was also reflected in biomass yield of wheat. There is an indication that 25-50% of applied P could be curtailed using polymer based prophetic fertilizer loaded NCBPC.

4.2.7.3 Zinc

An attempt was made to synthesize, characterize and evaluate starch based nano clay biopolymer composites (NCBPCs) in order to enhance the use efficiency of Zn. Greenhouse study exhibited that soil application of $1/5^{th}$ of recommended rate of Zn (0.5 mg kg^{-1}) applied through NCBPC was equally effective in enhancing the yield of wheat as that obtained with application of 2.5 mg kg^{-1} through conventional source ($ZnSO_4$). Application of 2.5 mg Zn/kg and 0.5 mg Zn/kg through $ZnSO_4$ and nano clay biopolymer composite (up to 20% substitution with natural polymer) was equally effective in enhancing the Zn content in wheat grain.

4.2.8 Interactive Effect of Calcium and Boron on the Availability of Boron in Acid Soils

Interactive effect of calcium and boron on the availability of boron in acid soils was studied using tomato as a test crop. Results indicated that the highest biomass yield of tomato (21.3 g pot^{-1}) was obtained with combined application of calcium @ 2/3 LR and B @ 1.5 mg kg^{-1}. Applied Ca @ 2/3 LR significantly increased the uptake of N, P, K, Ca, Mg and S, whereas Fe, Mn and B uptake decreased with applied Ca. While in case of B application, uptake of all the nutrients increased over control. Study emphasizes the importance of mandatory addition of B, while liming the acid soils for maximizing productivity.

4.2.9 Rock Phosphate and Waste Mica as a Source of P and K

A field experiment was carried out to evaluate the efficacy of rock phosphate (RP) and waste mica as affected by phosphate solubilizing bacteria (PSB) and potassium solubilizing bacteria (KSB) for supplying phosphorus and potassium on an Inceptisol. Significant increase in yield and uptake of P and K by wheat were obtained due to application of RP and waste mica treated with PSB and KSB. Available P and K as well as enzymatic activities like dehydrogenase and acid and alkaline phosphatase in soil after wheat harvest were also improved due to application of RP and waste mica treated with organic acids and PSB and KSB.

4.2.10 Soil Test Crop Response based Integrated Fertilizer Prescription for Sesame

Soil test crop response correlation studies under Integrated Plant Nutrient System (STCR-IPNS) were carried out to develop N, P and K prescription for targeted yield of sesame (var.TKG 21) on an Inceptisol. The per cent contribution of nutrients from soil, fertilizer and farm yard manure (FYM) were 21.41, 53.27 and 7.77 for N, 42.84, 22.95 and 2.47 for P and

12.32, 60.26 and 5.66 for K, respectively. Soil test based fertilizer prescription equations were developed which can be used for preparing the ready reckoners of fertilizer prescription with and without integration with FYM.

Soil test based fertilizer prescription equations for targeted yield of sesame

Fertilization programme	Fertilizer prescription equation
NPK alone	FN = 13.20 T – 0.40 SN
	FP = 7.03 T – 1.87 SP
	FK = 6.34 T – 0.20 SK
NPK + FYM	FN = 13.20 T – 0.40 SN - 0.15 FYM
	FP = 7.03 T – 1.87 SP - 0.11 FYM
	FK = 6.34 T – 0.20 SK - 0.09 FYM

FN, FP and FK – fertilizer N, P and K in kg ha^{-1}, respectively; T- target yield in q ha^{-1}; SN, SP and SK– Alkaline $KMnO_4$ – N, Olsen's-P and Neutral Normal Ammonium Acetate K in kg ha^{-1}, respectively; FYM represents dose of farmyard manure (t ha^{-1})

4.3 WATER MANAGEMENT

4.3.1 Wastewater Use in Agriculture

4.3.1.1 Wastewater irrigation on heavy metal contamination and yield of *brinjal*

Impacts of wastewater treated through *Typha latifolia* (Cattail), *Phragmites karka* (Reed) and *Acorus calamus* (Vachh) planted wetlands were studied on soil health, yield and quality of brinjal. Use of untreated municipal wastewater for irrigation produced the highest crop yield (42 t ha^{-1}) while the lowest yield (35.5 t ha^{-1}) was obtained with groundwater use. The average fruit yield of brinjal using treated wastewater was 37.7 t ha^{-1}. Compared to treated wastewater irrigation usage, application of untreated wastewater led to marginal increase of N, P and K but 1.4, 1.2, 1.3, 1.3, 1.3 and 1.2 times higher concentration of Ni, Pb, Cu, Zn, Mn and Fe in soil. Above ground biomass of brinjal indicated Pb contents higher than the safe limits and hazard quotient (HQ) for Pb was 2.3 folds higher compared to groundwater and 1.7 times more than treated wastewater used for irrigation.

4.3.1.2 Effect of heavy metal spiked wastewater irrigation with lime and bentonite on baby corn

Wastewater spiked with Pb, Cr, and Ni containing 2 and 5 times of their permissible limits was used for irrigation along with amendments, lime and bentonite. The results showed that wastewater irrigated plots recorded significantly higher yield (35%) compared to ground water irrigated plots. While lime and bentonite applied plots recorded yield of 8 t ha^{-1} and 7.5 t ha^{-1}, respectively. The nitrogen and potassium content of the cobs were not significantly affected by both the wastewater and amendments, while the phosphorus content was significantly affected by the amendments.

4.3.1.3 Sequential extraction of Ni and Cr from electroplating industry effluent with rice biochar and egg shell

Sequential extractions of Ni and Cr from electroplating industry effluent having 400 and 680 ppm of Ni and Cr were assessed by adding 2 gram of rice straw biochar in 250 ml of industrial effluent. Results showed that, biochar removed 61% Ni and 35% Cr from the effluent in the first extraction and 12% Ni and 17% Cr in second extraction. In the subsequent third to fifth extractions, 3-8% Ni and 3-4% Cr was removed. Similarly, using eggshell 72% of Ni and 42% of Cr was removed in the first extraction. In the subsequent second to fifth extractions, only 1-4% Ni and 1-8% Cr could be removed. Overall, from all the five extractions, 88% of Ni and 62% of Cr were removed using rice straw biochar, whereas 83% Ni and 58% Cr using egg shell.

4.3.1.4 Commissioned eco-friendly wastewater treatment facility at Farah, Mathura

A community scale (75,000 LPD) low-cost wastewater treatment facility at Farah, Mathura was established. Average sewage flow of 23,034 LPD with maximum 64,892 LPD is received by the plant. Results showed that reduction in salt, BOD, turbidity, nitrate,

Out-scaled ICAR-IARI wastewater treatment facility at Pandit Deen Dayal Upadhyay Village, Farah (Mathura)

phosphate and sulphate were 20%, 82%, 100%, 64%, 61% and 32%, respectively. Inlet sewage water had total bacteria load ranging from 1.4 × 10^6 to 4.2×10^6cfu/100 ml. Lactose utilizing bacteria ranged from 1.37×10^5 to 8.0×10^5 MPN/100 ml. *Escherichia coli* load was 2.6×10^4 to 3.6×10^5cfu/100ml.16SrRNA gene based molecular identification of predominant bacterial morphotypes from EMB plates led to identification of six major groups, viz. *Enterobacter cloacae* (matching with isolates from soil, brackish water, as PGPR & as probiotics from curd), *Escherichia coli* (matching with isolates from healthy human being and their faeces), *Pseudomonas aeruginosa* (matching with isolates from saline soils & hydrocarbon degradation consortium) and *Citrobacter sedlakii* (matching with isolates from soil, mud and fish water). In contrast to the inlet sewage waters, the outlet treated wastewater presumptive MPN test indicated a bacterial load of just 1.6×10^3 to 2.0×10^3 MPN/100ml, along with non-detectable *E.coli* counts. Therefore, treated wastewater was observed to be within safe limits as regards the total pathogen load.

4.3.2 Irrigation Water Management using Fresh Water

4.3.2.1 Nomographs for enhancing water application efficiency in maize and wheat

Nomographs for enhancing water application efficiency with respect to basin size, flow rate, irrigation water used, water application efficiency, irrigation water use efficiency and water productivity was developed from experiments conducted at IARI, New Delhi. The water application efficiency in surface irrigation under different basin sizes and flow rates ranged from 60 to 75% and 75 to 85% and the water productivity varied from 11 to 12.3 kg $ha^{-1}mm^{-1}$ and 14 to 15.7 kg $ha^{-1}mm^{-1}$for maize and wheat, respectively. The developed nomographs would assist stakeholder in deciding the basin size and flow rate to arrive at a given water application efficiency and water productivity for maize and wheat grown in similar soil and climate.

4.3.2.2 Decision support system IFSHED for irrigation and fertigation scheduling in vegetable crops

Decision support system (DSS) IFSHED was developed to generate scenarios of irrigation and fertigation schedules to optimize the use of water and fertilizer in vegetable crops. In surface irrigation methods, irrigation interval is fixed mainly based on soil moisture holding capacity and the crop growth stage. Similar criteria was followed in sprinkler irrigation method but in case of drip and micro-sprinkler systems, the irrigation interval is normally based on the ease of operation on alternate days or week. The DSS IFSHED determines the irrigation and fertigation schedule based on crop needs governed by climate, soil properties and the capacity of the irrigation system using the basic data on these parameters. The system provides generic values of most parameters based on a large background database of soil, climate and fertilizer available in the DSS.

4.3.3 Water Conservation under Rainfed Conditions

4.3.3.1 Hydrological responses and nutrient flux in a rainfed agri-horti system under different water conservation practices

A study with three legumes (viz., soybean, cowpea, and mungbean) grown under *bael* trees with three water conservation practices (WCPs), (viz., trench, micro-catchment (MC), ring basin (RB) and no moisture conservation practices (NMC) under tree and no-tree as control) was conducted to determine throughfall, stemflow and interception losses. Throughfall, stemflow and interception losses due to 16 rainfall events were 339.3 mm (76.3%), 16.9 mm (3.8%) and 88.5 mm (19.9%), respectively. Throughfall and stemflow under different WCPs were in the order of trench> RB > MC > NMC, whereas the reverse was true for interception loss. The order of soil moisture availability was trench> MC > RB > NMC. Soil moisture storage was 333.7, 349.5 and 335 mm in soybean, cowpea and mungbean plots, respectively, and corresponding deficit of moisture were 276.3, 15.7 and 56.4 mm. The combination of *bael* + cowpea + trench exhibited the least soil loss (3.14 t ha^{-1}) followed by *bael* + trench + mungbean (3.44 t ha^{-1}). Nitrogen content in throughfall water was about 12 times more and in stemflow 14 times more as compared to rainfall. P and K contents were also two times higher in throughfall and stemflow over rainfall. Overall, the *bael* tree intercropped with cowpea grown with trench can enhance farm productivity, income and soil fertility under rainfed conditions.

4.3.3.2 Composite drought index for drought monitoring

A study was carried out to characterize drought in Marathwada region, Maharashtra, which is one of the most frequent drought prone areas of India, through meteorological, hydrological and agricultural drought indices, viz., standardized precipitation index (SPI), streamflow drought index (SDI), and remote sensing-based indices, such as vegetation condition index (VCI) and water condition index (WCI). The area under drought observed by remote sensing based indices (VCI_N, VCI_E and WCI) was also correlated with foodgrains production to identify the most suitable drought index for characterization of agricultural drought in the region. Correlation analysis indicated that all three indices had good correlation with food grains production during *Kharif* season for 5 months' scale (June to October). The best performing index from each category, viz. 3 months SPI (meteorological), 6 months SDI (hydrological) and 5 months VCI_N (agricultural) were used to develop a composite drought index (CDI) using principal component analysis technique. The developed CDI was evaluated using foodgrains production for 15 years (2000-2014) during *Kharif* season. Overall, the study revealed that among all the drought indices used in this study, CDI had maximum correlation with the foodgrains production. Therefore, CDI can be a better indictor for effective drought monitoring in the region.

4.4 PROTECTED CULTIVATION TECHNOLOGY

4.4.1 Cucumber Varieties under Naturally Ventilated Polyhouse

An experiment on cucumber varieties/ hybrids with 25 days old plug seedlings were planted under naturally-ventilated polyhouse with drip irrigation system. It was observed that four varieties of parthenocarpic cucumber i.e. Fadia, Terminator,

Evaluation of cucumber varieties under naturally ventilated polyhouse

Multistar and Hilton grown with 5 doses of N:P:K (F_1=10:7.5:12.5; F_2= 15.0:11.2:18.8; F_3=20.0:15.0:25.0; F_4= 25.0:18.8:31.2 and F_5= 30.0:22.5:37.5 kg/1000m^2 applied twice weekly) varied significantly on fresh fruit yield. Total 8 pickings were done and crop cycle was completed on January 21, 2019. The maximum fresh fruit yield (96.3 kg/m^2 i.e., 96.3 t ha^{-1}) was obtained in variety Fadia fertigated with N:P:K @25.0:18.8:31.2 kg/ 1000m^2.

4.4.2 Standardization of Low Cost Agro-Techniques for Brinjal Production under Insect Proof-Net House

An experiment was conducted on brinjal crop to identify suitable dose of nutrient and varieties/ hybrids under insect proof net house planted at 60 cm x 60 cm with drip irrigation system. Nine different varieties of brinjal (green and purple) ,namely, Green Long, Sharapova, Frida, KSP 1267, Michal, CPCT 21, PPL, Pusa Uttam, Pusa Kranti were evaluated with four doses of fertilizers. The maximum fruit yield (3.85kg/ plant) and net return (Rs.65.4) and B:C ratio (Rs.1:2.10)/ m^2 was recorded in Frida followed by Sharapova and Michal. Among the green types, maximum fruit yield (2.35kg) /plant was recorded in genotype CPCT 21 in combination with optimum dose of NPK @ 35:25:40 kg per 1000 m^2.

Production of brinjal crop under insect proof-net house

4.4.3. Genetic Improvement of Tomato Suitable for Protected Environment

A total of 125 diverse tomato accessions were collected from different sources and raised under protected conditions. Among these, tomato accession nos. 292, 293, 172, 123, 177, 112, 115, 117, 181, 182, 206, 304 were found highly suitable for protected cultivation. A slow ripening yellow coloured genotype no. 68 with good bearing ability, fruit size and keeping quality was also identified. These had TSS varying from 4.5 to 6.6^0 Brix and lycopene from 4.4 to 4.8 mg/100g with an average fruit weight of 85g to 130g. Among cherry tomato, accession nos. 214, 220, 262, 305, 597 were found promising. Among the crosses made during last year, H 30, H 42, H 71, H 110, H 193, H 198, H 173, H 199, H 202, H 210 and H 212 were found promising. However, among the cherry tomato hybrids, H 126 and H 200 were found promising.

Evaluation of tomato varieties suitable for protected cultivation

4.4.4 Long and Round Fruited Indeterminate (Vine) Type Varieties of Summer Squash (Zucchini) Suitable for Protected Structures during Off-season

With a view to develop summer squash lines for protected conditions, hybridization program was initiated by combining a dwarf variety and an indeterminate *desi* type local germplasm of summer squash. The breeding materials were evaluated and the lines selected from different segregants were followed by selfing every year to see generation. The selected lines having desired plant types and continued up to 5th having long internode, medium leaf canopy, thick stem, good fruits characters, indeterminate growth habit were evaluated for yield potential. The yield of selected line was found 3-5 kg/plant during off-season (November- March) under protected structure.

Evaluation of summer squash varieties

4.4.5 Evaluation and Selection of Indeterminate Type Tomato Lines for Protected Cultivation

An experiment was conducted under polyhouse condition for the evaluation of 50 lines of indeterminate tomato under protected conditions at CPCT since 2011-12. In current year, ten lines of indeterminate tomato (IDGT 16, 17, 37, 51, 52, 53, 55, 56, 57, 69) gave superior performance in terms of yield, colour, quality, better size, plant nature, tolerance to stress, etc.

Evaluation of intermediate hybrids in tomato

4.4.6 Standardization of Agro-Techniques for Off-season Bitter Gourd Production under Different Protected Structures

An experiment for off-season bitter gourd production under net-house and polyhouse condition was conducted. After and before transplanting, the recommended GAP protocol and package of practices including drip-irrigation-cum-fertigation technique were applied for realizing full potential. The new variety of bitter gourd (Pusa Rasdar) produced maximum fruit yield (13.75 kg), net return of Rs. 222 and B:C ratio 1:2.23 per m^2 when planted in 2nd week of August with closer spacing 20 cm x 50 cm and with optimum dose of NPK @ 25:17:26 kg/1000m^2.

Off-season bitter gourd protection under different structures

4.4.7 Response to Bio-Film Molecules and their Mode of Application in *Chrysanthemum*

An experiment was conducted on variety, Zembla to study the effect of bio-filmed on *Chrysanthemum*. The results revealed that fresh and dry weight accumulated by the plants were maximum (114.9g and 84.7g/plant) on amendment done with Bio-F1 in the plug nursery as compared to field application (112.4 g and 79.9g/plant). An early flowering was observed in the untreated plants. However, long stems were (a maximum of 97.08 cm) due to amendments with Bio-F1 molecules

Response to bio-films in *Chrysanthemum*

in the growing media due to an increase in the internode length (1.96 cm). However, the plants treated either at nursery stage or in field with Bio-F3 formulation during transplanting had no significant effects on plant growth parameters.

4.4.8 Evaluation of Gerbera under Low Cost Polyhouse

Eight varieties of gerbera (Cormoran, Feliks, Szogeh, Salsa, Martyana, Samuraj, Pal and Isodora) were planted under low cost small (20 m x11m = 220 m^2) polyhouse to evaluate their performance. It was noted that except Feliks and Pal, all the varieties could gave good quality cut flowers in terms of stem length (> 65 cm) and flower size (>9.2 cm diameter across).

Evaluation of gerbera and rose under low cost polyhouse

4.4.9 Soil Moisture, EC, pH and Climatic Sensors Controlled Fertigation Scheduling in Greenhouse Chrysanthemum

Tensiometers, Ec, pH, temperature, humidity and solar radiation sensors were used to control fertigation scheduling for chrysanthemum and various plant and flower characteristics were estimated. The plant height, number of leaves/plant, stem diameter and flower size of *Chrysanthemum* varied from (38-53cm), (10-22), (0.34-0.44 cm) and (7.9-9.7cm), respectively, for combinations of different treatments. Fertigation scheduling corresponding to 80% ETc gave the maximum stem diameter (0.44cm) and flower size (9.7cm) while 100% Etc resulted in maximum plant height (53cm) and number of leaves/ plant (22), respectively. Crop water productivity was found to be maximum (280 stems/$m^{3)}$ and minimum (240 stems/ m^3) for treatment corresponding to 100% Etc and 80% Etc, respectively. The final values set for the sensors for maximum crop water productivity were at tensiometer (20-25 centibar), soil Ec (0.28 dS/m), fertigation Ec (2.3 dS/m), fertigation pH (6.5), greenhouse temp (19-25^{0}c), greenhouse humidity (51-62^{0}c) and solar radiation (280-340 watt/m^2).

Sensor controlled experiment on Greenhouse *Chrysanthemum*

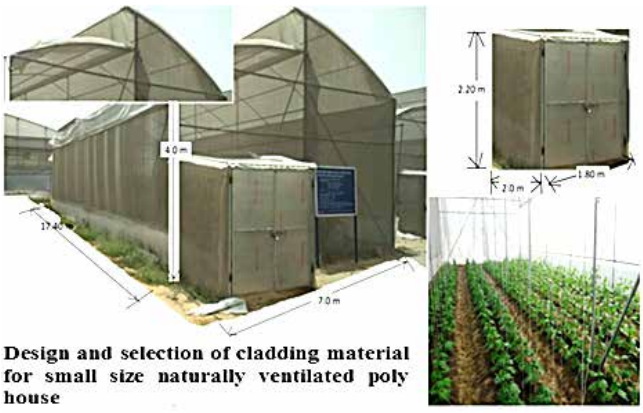
4.4.10 Design and Selection of Cladding Material for Small Size Naturally Ventilated Poly House

A naturally ventilated polyhouse suitable for small and marginal farmers was designed. Twenty one foundation dig of 60 cm x 60 cm x 60 cm size were dogged at 2.9 x 3.50 m distance. Base plate are fixed with foundation and filled with mortar of 1:2:4 (Cement: Coarse sand: Graded stone) aggregate (20 mm nominal size) for fixing of foundation pipe having size of 1 inch. Then foundation post of G.I. pipe having diameter of 1.25 inch were erected with k10 nuts bolts of G.I. UV stabilized film of 180 gsm was used to cover room and 46 x 60 mess size insect net for ventilation system for about 45% ventilated area. Total height of poly house was 5.5 m and gutter height was 4.0 m with 1 m meter top.

Design specifications of low cost polyhouse (17.2 x 7 m = 120 m2)

Sl. No.	Item of work / detail of material	Requirement (Qty)	Unit cost (Rs.)	Total cost (Rs.)
A.	**Structural material**			
1	G.I. Pipe of 25.40 mm. ϕ for foundation	21.00 m	190	3990
2	G.I. Pipe of 31.75mm. ϕ for foundation posts	94.50 m	240	22680
3	G.I. Pipe of 25.40 mm. ϕ for purlins & arches	302 m	190	57380
4	Base plates for foundation post (50 x 50 x 6mm ϕ)	21.0 nos.	130	2730
5	G.I. pipe of 25.40 mm. for making entrance room (2m x 1.5 m 2.10 m)	22.20 m	190	4218
6	Welding rods 3 boxes, 8 hardware likes bolts and nuts, welding rods, aluminium oxide, painting, etc.	L.S	5000	5000
B.	**Cladding material**			
1	UV stabilised film (180 Micron)	350 m^2	52	18200
2	Net 40 x 60 mess size	191.50 m^2	35	6702
C.	**Construction material**			
1	Earth work excavation for foundation	4.90 m^3	139.30	685
2	Plain cement concrete for foundation (1:2:4)	4.50 m^3	1843	8293
	Total cost of installation of poly house			1,29,878

This naturally ventilated polyhouse was used to grow cucumber crop in two seasons with four type of cladding material (C1, C2, C3 and C4). These were used in four polyhouses each having floor area of 120 m^2 and three cucumber varieties (Kiyan, Fadia and Terminator).



Design and selection of cladding material for small size naturally ventilated poly house

It was observed that in winter season crop, yield in polyhouse 4 having cladding material C4 type showed maximum cucumber yield (3.74 kg/m^2) and in summer season crop yield was maximum (9.11 kg/m^2) in polyhouse 1 having cladding material C1. Temperature was varied with change in cladding material. The maximum temperature difference of 5^0C was noticed with change of cladding material. Cladding material C1 may be used in summer and cladding material C4 may be used in winter. Cucumber var. Fadia gave maximum yield in winter season while terminator performed better in summer season.

4.5 AGRICULTURAL ENGINEERING

4.5.1 Tractor Drawn Raised Bed Planter for Gladiolus

A tractor drawn raised bed gladiolus planter was developed. The top width of the raised bed formed by the planter was 46.2 cm. Four rows of planting can be made with plant spacing of 20 cm and row spacing of 20 cm in two beds. The planter was evaluated in the experimental field of floriculture division. Initial field parameters like bulk density and soil moisture were observed as 1.14±0.3 g/cc and 18.19±1.8%, respectively. Average depth of planting was of 10.85cm and as per the recommendation. Average speed of operation of the tractor drawn planter was 2.11 km h^{-1} with wheel slip 10.82%. The field efficiency, field capacity, fuel consumption and draft requirement were observed as,

72.75%, 0.16 ha h^{-1}, 3.18 l h^{-1}, and 689.25 kgf, respectively. The planter had miss index, multiple index and quality feed index as 2.56%, 10.8% and 86.64%, respectively.

4.5.2 Evaluation of the Gladiolus Corms Harvester

Two types of harvesters were evaluated on the field i.e. commercially available potato harvester and the developed harvester for harvesting of gladiolus corm. The harvesters were evaluated on sandy loam type soil, where the bulk density and moisture contents were recorded as 1.36±0.3 g/cc and 14.06±0.4%, respectively. It was observed that the potato digger caused more mechanical damage than the developed harvester. While in operation, the developed harvester's blade penetrated up to 8.25cm and wheel slip was 8.32%. The field capacity and field efficiency of the harvester were recorded as 0.128 ha h^{-1} and 83.25%, respectively. The losses due to the harvester in terms of conveyor loss, unexposed corms and cut corms were observed as 3.56%, 2.92% and 0.83% respectively. The digging efficiency and separation efficiency of the harvester were recorded as 98.51% and 92.74%, respectively.

Field evaluation of gladiolus harvester

4.5.3 Multi-Crop Planter for Small Vegetable Seeds

The developed multi-crop planter was evaluated in soil bin for planting of small and irregular seeds at desired spacing. The manually operated prototype has the provision of soil covering after planting with average depths of placement of seeds at 15-20 mm. The average multiple index and miss index were 0 and 10, respectively in laboratory condition. The quality of feed index was computed as 90%. By changing the vertical roller, the spacing between the seeds in a row can be changed and used for different seeds. Seeds spacing can also be adjusted by changing the sprockets used in the transmission system. The average field capacity of the planter was 0.024 ha h^{-1} for continuous operation at an average speed of 1.04 km h^{-1}. Field efficiency of the planter was observed to be 66%. The cost of operation of machine per ha was substantially lower than the manually planting/ dibbling of seeds. The developed machine is very useful for small plots, where other machines cannot be operated.

4.5.4 E-Power Assisted Spinach-Cum-Coriander Offset Rotary Cutter for Small Farmers

A walk-behind e-power assisted single row offset rotary cutter was developed for cutting spinach and coriander. The cut crop is laid in windrow, which is lifted manually. The developed cutter consisted of 25W DC motor, two 12V 12Ah batteries, power transmission unit, rotary blade with provision to lay crop in windrow, frame and handle. The cutting width was about 100 mm with the rotary blade. The weight, main frame (l x w), ground wheel diameter & width, reflector for making windrow & shape, cutting height, power enhancement ratio from drive to blade was 21 kg, 560 mm x 190 mm, 255 mm and 30 mm, 10 mm and arch, 30-50 mm and 2.7, respectively.

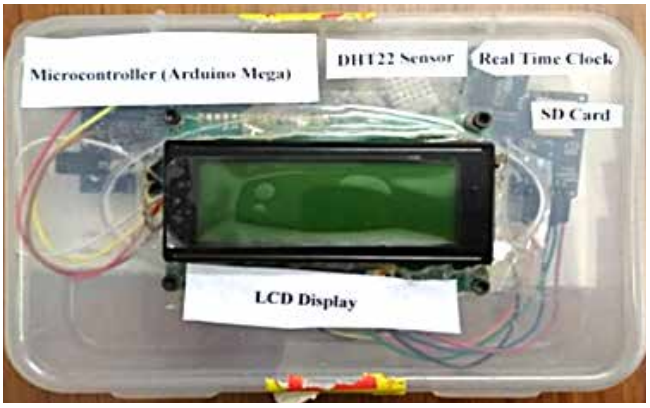
E-power assisted spinach-cum-coriander offset rotary cutter

The output with the cutter for cutting spinach was 193.3 m^2/h at walking speed of 0.9 km/h, while it was 172 m^2/h at walking speed of 0.8 km/h. Overall, output

with cutter including making bundle of spinach and coriander was 82.8 m^2/h and 80.9 m^2/h, respectively. The efficiency enhancement with cutter over manual cutting was of 2.56 times. The force required in moving the cutter was 44-54 N during initial pulling while in acceleration it was 15-29 N.

4.5.5 Data Logger for Low Cost Storage Structure for Rural Areas

For grain storage, temperature and humidity are major ecological factors that directly influence the quality of grains. Hence, there is a necessity to monitor vital parameters continuously during storage and communicate the status in real time which becomes a challenge. Efforts were made to build a low cost, automatic, smart real time embedded arduino based data logger, which could improve the level of grains storage and reduce the grain losses, man power and labour intensity during storage procedure. A programme was developed to integrate all modules in one platform to operate sequentially, which consisted of four modules DHT 22, LCD, Sd Card and RTC 3231 for real time monitoring and data recording of temperature and humidity. These data can be displayed on the LCD screen or it can be saved to the SD card for further interpretation and analysis.



Development of data logger for low cost storage structure for rural areas

4.5.6 Evaluation of Integral Power Equipment for Small Farm Mechanization

The developed Integral Power Equipment with different attachments of rotary tillage, shallow tillage and sowing was evaluated for wheel slip at different normal loads in field. The maximum slip (6.3%) was observed at a normal load of 80 kg but was within the permissible limit of less than 15%. During the evaluation of adjustable plough, the average depth of operation was observed as 14 cm and average width of cut as 30 cm. The average field capacity was 0.046 ha/h with an average fuel consumption of 1.29 l/h and the draft of the MB plough was observed as 70 kgf. However, during evaluation of Integral Power Equipment with single bottom MB plough, average width of cut was 23 cm, average depth of cut was 13.76 cm and average field capacity of 0.04 ha/h. The average draft requirement (kgf) was 72.6 with a fuel consumption of 1.36 l/h. The integral power equipment was evaluated with rotary attachment and during a single turn an average width of 66 cm was covered with an average depth of cut as 4.8 cm. The average field capacity during rotary tillage was observed as 0.11 ha/h and based upon the field performance the speed of 1.53 km/h and 2.58 km/h was recommended for rotary tilling with Integral power equipment. A preliminary evaluation of Integral Power Equipment for sowing of wheat with two row seed drill was conducted. The effective capacity of the machine was 0.07 ha/h with field efficiency of about 78 percent.

4.5.7 Performance Evaluation of Prototype UAN Applicator

The machine performance of UAN applicator was studied by determining draft, slip, field capacity and

Field evaluation of prototype UAN applicator

field efficiency. The average soil moisture content during field evaluation was 9.5 per cent (w/w). The average draft requirement of the applicator at full tank load (300 l) was 3.2 kN. The average slip and labour requirement were 6.23% and 8.70 man-h ha^{-1}. An average field capacity of 0.23 ha h^{-1} was obtained for continuous operation of UAN applicator at an average speed of 1.78 km h^{-1}. A field efficiency of 72 % was observed. The refilling of fertilizer tank was major cause for time loss in field. Seeds were placed in recommended range of seed depth of 30-50 mm and the average depth of placement was observed as 42 mm.

4.5.8 Real-Time Tractor Wheel Slip Measuring Device

Slip measuring device was developed using the Hall effect sensor embedded with microcontroller program for wheel slip and speed calculation. The major components used in the development of device were Arduino Mega, RTC, SD card module, buck converter, LCD, LEDs switch and buzzer. The device was mounted on the tractor and field experiments were conducted at three soil moisture (5.4-5.9%, 12.4-13.6%, and 15.2-17.1%) with three implements (disc plough, cultivator, and SWI planter) for slip measurement. The results obtained from the developed device and BIS procedure showed that the values were statistically similar (SEm± 0.5599 and 0.452) for forward speed and wheel slip, respectively. The developed device is capable of giving warning signals through LEDs and buzzer when wheel slip value exceeds the adequate range (8 to 15%).

4.5.9 Solar Powered Evaporatively Cooled Storage Structure (ECSS) for Fruits and Vegetables

Solar powered evaporatively cooled storage structure was designed and developed for storage of 500 kg fresh fruits and vegetables to increase their shelf life. The structure consists of a solar powered exhaust fan and cooling pump for providing water to the pads. Cooling pads of different materials such as wood wool, khas and CELdek were used. The system works on the principle of a simple desert cooler wherein, the pads are wetted with the help of circulating water by a solar powered pump and an exhaust fan sucks the cool air into the structure. The SPV system consisting of 4 solar panels of $100W_p$ each, solar inverter and a battery bank (including 2 batteries) was used to power the pump and exhaust fan. The results showed that under the no-load condition, the average air cooling efficiency was highest for CELdek at 78.67 %, compared to 73.82 % for wood wool and 70.75 % for khas pad material. The average temperature inside the storage was found to be 30-32°C compared to ambient temperature of 35-42°C in the month of June, while higher relative humidity (RH) of 74% was found inside the storage structure compared to ambient RH of 36-46%. This environment helped in keeping the vegetables fresh for significantly more time and increased their shelf life by 1 to 5 days.

Solar powered evaporatively cooled storage structure with solar power pack

4.5.10 Farm, Horticulture and Landscape Operation Services

The Farm, Horticulture and Landscape Operation Service Unit (FHLOSU) has five main components, namely, i) farm operation management, ii) irrigation system management, iii) biomass/crop residue management, vi) management of non-cropped area, and v) ornamental horticulture and landscaping unit (OHLU). All field operations starting from land preparations to harvesting and threshing of 750 acres of IARI research farm utilizing conventional and precision farm machineries during all three seasons *i.e. Rabi*, *Kharif* and spring summer were managed, along with transportation of farm produces from different divisional fields to Pusa Produce Sale Centre. Scheduled, preventive and breakdown maintenance of farm machinery was done either in-house workshop or specialized workshop. Technical service for operation, repair and maintenance of farm machines owned by different divisions/units were also imparted. FOSU brigade also contributed significantly in cracking the exigencies and restoring normalcy. A contingent of farm machinery, namely, Tractors of 45 HP& 75 HP, Self-driven Backhoe Loader, Fertilizer Spreader, Offset Disc Harrow Puddler Type, Offset Disc Harrow General Purpose, Zero-till Seed drill, Seed Drill General Purpose, Multi-Crop Thresher and two Water Tanker were added for carrying out farm operations well in time. The Fertilizer Spreader was operated for 100 acre land to spread fertilizer, which saved 97% human power and 95% cost of operation with respect to conventional (manual) method. The pilot integration of GPS tracking system for real time, digital and efficient monitoring of farm machinery operation in field was initiated. The FOSU, with close collaborative efforts of Divisions of Agronomy and Agricultural Engineering, effectively collected and transported the crop residue and other biomass (approx. 46200 cuf/yr) produced at IARI experimental farms for composting to earmarked farm area. In order to facilitate operational ease, cleanliness and aesthetic sense of non-cropped area i.e., farm road sides, bund and channels, *nala* side and security road were maintained weed free with help of human work force, hand tools, manual and smart machines. The overall management of the DPLs and contractual labours for all divisions and projects of IARI, management of gardens/lawns and landscaping tasks were efficiently undertaken, and significantly contributed in organizing seminars, *Pusa Krishi Mela 2019* and other functions of the institute.

4.6 FOOD SCIENCE AND POST-HARVEST TECHNOLOGY

4.6.1 Influence of Exotic and Indigenously Developed Particle Films on Apple and Pomegranate

Exotic (Surround) and indigenously developed particle film (PF; PCS-4) were tested on apple (cv. Royal Delicious) and pomegranate (cv. Kandhari) along with control. Both the films were sprayed thrice on apple and pomegranate and it was observed that both the films were better over control for colour development and quality maintenance in apple and pomegranate. The quality as well as incidence of diseases or insect-pests on the treated apple of pomegranates either with Surround or Indigenously developed PF was non-significant.

4.6.2 Fruit Bagging in Litchi

Studies on fruit bagging in Shahi litchi were attempted with four different types of bags (paper,

A view of fruit bagging in litchi

brown paper, parchment and PP non-woven). Bagging was done at pea stage of fruit development (5th April, 2018) and bags were removed on the day of harvesting (8th July, 2018). It was observed that bagging with PP non-woven bags was the best. There was significant increase in fruit weight (55.2 g), TSS (21.2%) and reduction in fruit cracking (5.6%) and fruit borer incidence (1.2%) over non-bagged fruits.

4.6.3 Infusion of Active Ingredients into Pre-cut Cauliflower

Cauliflower cv. Pusa Sharad was subjected to vacuum for infusion of active ingredients such as browning inhibitors and calcium into the matrix. On subjecting the florets to vacuum of 100 mm Hg followed by a soak of 10 min. in the ascorbic acid solution, the freshness and overall quality of the florets could be successfully maintained for 13 days under 10°C. In another set of experiment, when the pre-cut florets of cauliflower were infused with calcium solutions after exposing to vacuum for 15 min., a 13% increase in the calcium content was attained. Thus, vacuum impregnation is a potential alternative for infusing active ingredients into the minimally processed food matrix.

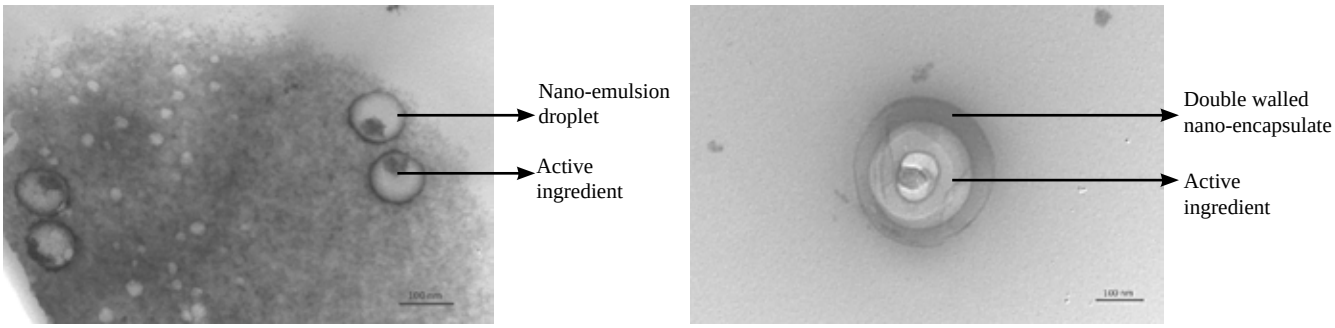
4.6.4 Preparation and Storage of Osmo-Vac Dehydrated Guava Slices

To standardize the procedure of preparation of osmo-vac dehydrated guava slices, four different sugar concentrations and sugar syrup temperatures were studied. On the basis of retention of maximum ascorbic acid, sugar content and sensory score in respect of colour, flavor and texture of the dehydrated slices, a concentration of 60°B and 60°C temperature were found to be suitable for preparation of osmo-dehydrated guava slices. For storage stability, the dehydrated guava slices were packed in 200 gauge HDPE, 200 gauge ALPE and 250 gauge COEX pouches and stored at room temperature and low temperature. After 4 months of storage, the osmo-vac dehydrated guava slices packed in Co-extruded film (250 gauge) pouches followed by storing at low temperature was found to be the best for retaining the quality of osmotic dehydrated guava slices.

Osmo-vac dehydrated guava slices

4.6.5 Antioxidant Efficacy of Phenolic Rich Extract in Mustard Oil during Accelerated Storage

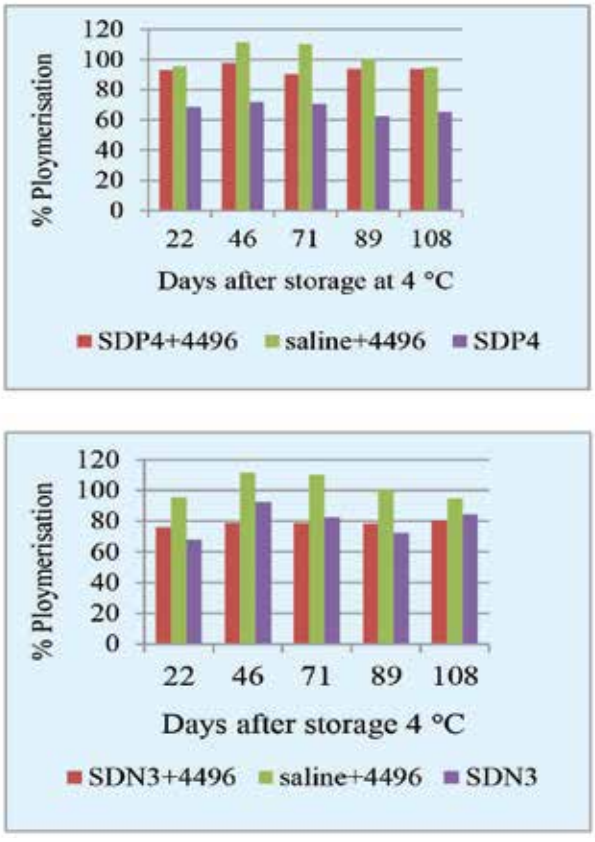
Citrus peel phenolics (CPP) were evaluated for their antioxidant efficacy, i.e., preventing oxidation in food matrices high in fat content, viz., mustard oil and meatballs. The peel extract was formulated in a nano-emulsion using ultrasonication prior to incorporation in mustard oil. The process variables used in ultrasonication, viz., amplitude, emulsifier and sonication time were optimized using RSM considering particle size as the response. Optimization and validation of the quadratic model revealed 9.49 min of sonication at 30.12% amplitude and 0.52% span 80 to be best to yield a nano-emulsion with a minimum droplet size of 29.73 nm. Further, the formulation was added in mustard oil in different concentrations ranging from 100-400 ppm and compared for its efficiency against its non-encapsulated counterparts (100-400 ppm) and TBHQ (200 ppm). Results of peroxide value, anisdine and TBARS during accelerated storage studies revealed that phenolics in nano-emulsion produced more potent antioxidants than non-encapsulated ones, and showed good efficiency in retarding rancidity of mustard oil.



Synergistic effect of nutmeg and citrus peel extract in extending oxidative stability of meatballs during frozen storage

4.6.6 Formulation and Storage Study of a Black Carrot (Bc) Lactic Drink

The formulated lactic drink prepared by 5 days fermentation using consortium of culture(s) was bottled after sulphitation with potassium metabisulphite @ 80 ppm molecular SO_2. Storage of the drink for 108 days under refrigeration (4°C) showed colour stability as indicated by pigment polymerisation. Among the cultures finalized for use, the culture *Lactobacillus sanfranciencis* (SDP_4) was more effective in the consortium than a native lactic bacterial strain SDN_3 (isolated from a fermenting dough), when present in fermenting medium along with *Lactobacillus plantarum* 4496.



Comparison of *Lactobacillus sanfranciencis* (SDP_4) with a native lactic bacterial culture (SDN_3) used for fermenting a lactic drink with *L. plantarum*.

4.6.7 Formulation of Low Fat Gluten-free Buckwheat Biscuits

Buckwheat has recently emerged as nutritionists delight as a result of quest for grains rich in dietary fibre, micronutrients and functional components while being gluten free. The flour was used to prepare coconut biscuits. Replacement of fat by 10 to 40% was done with Psyllium husk and mucilage from okra and basil seeds was used. The replacement of fat led to changes in textural hardness and crispiness. Psyllium husk incorporation yielded most satisfactory results followed by basil seeds. The biscuits prepared were found rich in micronutrients while having lower

Low fat gluten-free buckwheat biscuits

calorific value. The fibre content in biscuits rated high on sensory scores was as high as 10%. Acceptable low calorie gluten free biscuits rich in minerals can thus be prepared from buckwheat flour.

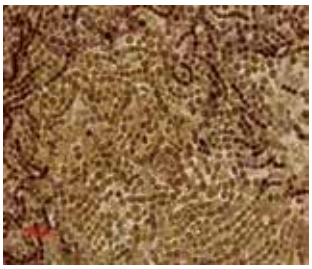
4.7 MICROBIOLOGY

4.7.1 BGA based Composite Liquid Inoculant for Improving Crop Productivity and Soil Health

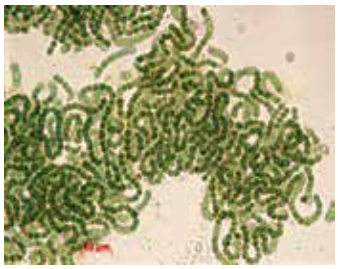
The effect of BGA based composite liquid formulation (LF) on wheat (variety HD 3059) was studied. The available nitrogen content at mid crop stage in treatments, viz. absolute control, recommended dose of fertilizers (RDF) and RDF+LF was 168.97, 241.79 and 247.92 kg ha^{-1} followed by 161.7, 235.2 and 239.6 kg ha^{-1} at harvest, respectively. An increase in grain yield was observed with use of BGA based composite liquid formulation which was 1.84, 3.10 and 3.22 tons ha^{-1} under absolute control, RDF and RDF+LF treatments, respectively. The cyanobacterial diversity in BGA LF inoculated field was higher with presence of both heterocystous and non-heterocystous forms showing the presence of *Aulosira* and *Phormidium* besides *Cylinderospermum, Anabaena, Westiellopsis, Calothrix, Nostoc and Lyngbya.*

4.7.2 Bioprospecting Rhizospheric and Endophytic Cyanobacterial Diversity amongst Selected Genotypes of Rice for N Uptake and Crop Yield

Twenty five efficient (high EPS producer) and identified cyanobacterial strains representing the genus *Plectonema*, *Phormidium*, *Nostoc* and *Anabaena* exhibited nitrogenase activity expressed as acetylene reduction assay in the range of 1.08±0.05 - 89.13±0.14 nmole C_2H_4 μg^{-1} Chl-a h^{-1}. The EPS production was in the range of 0.32±0.91 to 1.89±0.09 and the highest was produced by *Nostoc* sp. CCC 753 followed by *Anabaena sp* CCC746. Overall the production of EPS was high in case of diazotrophic form than the non-heterocystous forms.



***Nostoc* sp. CCC 753**



***Anabaena* sp. CCC746**

4.7.3 Conservation Agriculture Practices for Improved Resource Use Efficiency and Crop Productivity

The effect of direct seeded rice and zero till wheat crop (DSR-ZTW) on soil microbial parameters of an irrigated rice–wheat cropping system was studied. Eight different treatments involving zero tilled wheat (ZTW), direct seeded rice (DSR), conventional tilled wheat (CTW) and transplanted rice (TPR) and their combinations with rice residue and leguminous mulch, i.e., without residue (-R) and with residue (+R) were assessed for microbial activities in the surface (0-5 cm) and subsurface (5-15 cm) soil. Soils under DSR-ZTW were found to have higher mycorrhizal spores (18%) metabolically active fungal hyphae (28%), glomalin (27.6%) and microbial biomass carbon (18.2 %) at surface soil than the transplanted rice - ZTW. At soil depth (5-15cm) a similar trend except that of soil glomalin was recorded. A significant increase in the soil nitrate reductase activity at the two soil depths following rice crop residue addition in DSR-ZTW(110.4%, 21.8%)was observed.

4.7.4 Microbes Mediated Water Stress Alleviation in Crops

Pot and field experimental observations showed that inoculation with osmotolerant bacteria sustained plant growth under water stress conditions in mustard. Inoculation with *Bacillus casamancensis* MKS 6 and *Bacillus* sp. MR D17 improved the P and K content in grain and plant for susceptible and tolerant genotypes under water stress compared to FC grown plants. Response to inoculation by the two genotypes was almost at par under water stress conditions in terms of P and K improvement, however under FC, MKS 6 and

MR D 17 inoculated plants had higher P and K content, respectively, in susceptible variety. Interestingly, under FC, tolerant variety's response to both bacteria was higher for K content in grains (15% compared to 8% in suceptible).

4.7.5 Bacterial Endophytes for Plant Growth Promotion

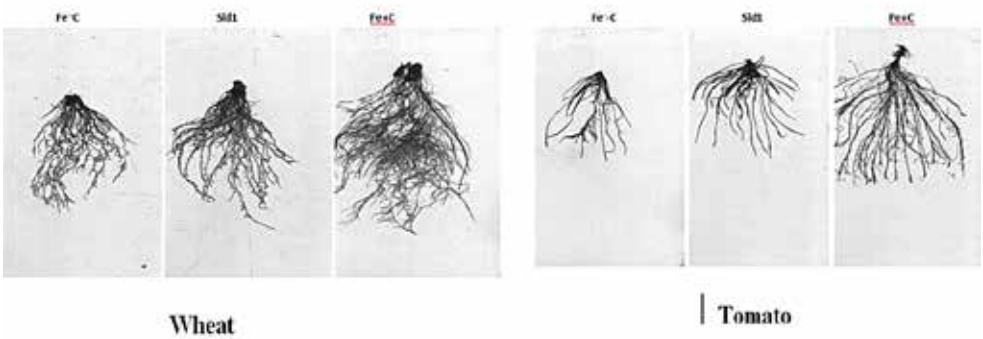
The effect of three siderophore producing isolates (BC1: *Pantoea agglomerans*; BC2: *Pseudomonas plecoglossida*; BC3: *Lactococcus lactis)* and their respective siderophore preparations Sid1(Catecholate:BC1); Sid2(Hydroxymate BC2); Sid3 (Carboxylate BC3) on plant growth and other parameters taking wheat and tomato as test crops in Fe-sufficient and Fe-deficient soils was studied. Inoculation with bacterial isolates improved most of the biometric parameters than their siderophore preparations. In Fe deficient soil, Sid1 improved shoot length by 23.7% of wheat and BC3 by 20% of tomato over uninoculated control (C- control). While all treatments were at par for wheat grown under Fe^+ soil for shoot length, Sid1 improved shoot length by 27.9% more than the uninoculated control in tomato. Root length was improved best by BC1 in wheat whereas, *Pseudomonas plecoglossida* BC2 and *Lactococcus lactis* BC3 improved root length by 56.7% and 54.1% than uninoculated control in tomato. Mean Sid improved ferrous content by 2.60% and 3.33% than bacterial cultures in Fe^+ and Fe^- soil in wheat. In tomato, isolates BC2 and BC1 improved ferrous iron concentration by 8.9% and 4.6% (Fe^+ soil) and isolate BC1 improved by 8.3% (Fe^- soil) over uninoculated control. On Fe^+ soil, B2 and B1 improved ferrous iron concentration maximum of 8.9% and 4.6% than uninoculated control (C- control), respectively. On Fe^- soil, BC1 improved maximum ferrous iron concentration which was 8.3% higher than in uninoculated control (C- control) followed by Sid1.

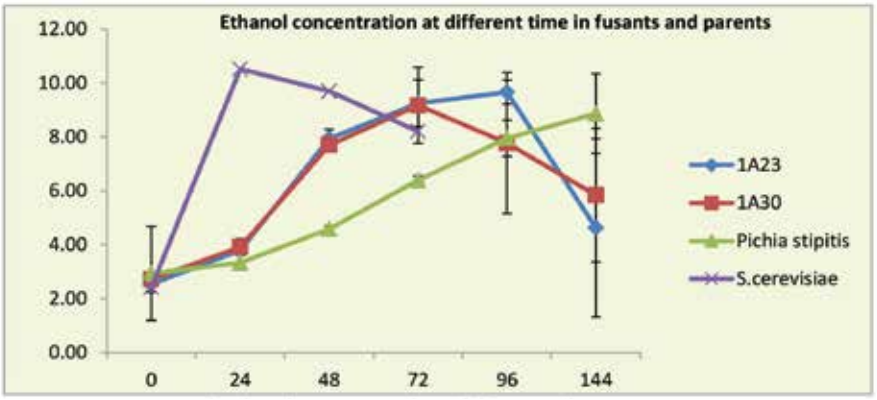
4.7.6 Functional Diversity of *Azospirillum* for Potential Application in Rainfed Pearl Millet

Twenty bacterial isolates from rainfed pearl millet rhizospheres were identified as *Azospirillum formosense* spp. based on 16S rRNA sequences (NCBI accession nos. MK351280 to MK351297, MK351299, MK351301). Based on their plant growth promoting traits, six were evaluated under field conditions (*Kharif* 2018) with variety RHB 173. Bacterial inoculations improved shoot and root biomass and number of crown roots. An increase of 2 to 27 % in grain yield was recorded in the inoculated treatments, with strain Azo 38 showing maximum increase in yield (27%) closely followed by Azo 57 (25.7%), indicating their potential application to boost the productivity of rainfed pearl millet.

4.7.7 Efficient Low Cost Technologies for Utilization of Biomass as Fuel

Ethanol production by SSF was done with optimized parameters (substrate loading (6.71% w/v), enzyme loading (25.71 FPU/g dry rice straw), pH (4.15) and inoculum (thermotolerant *Saccharomyces cerevisiae* JRC6) rate (13.2% v/v) in a lab scale fermenter. The results obtained indicated that the single pot process will lead to substantial energy saving because the saccharification temperature was 10°C lower compared to commercial cellulases. To maximise ethanol production by fermenting glucose as well as xylose (a pentose sugar), two fusants were selected





Ethanol production by fusants and parents on rice straw hydrolysate

by protoplast fusion of *S. cerevisiae* LN and *P. stipitis*. HPLC analyses showed that *S.cerevisiae* LN consumed all the glucose within 24 h while both fusants depleted glucose in 48-72h. Fusants and *P. stipitis* showed co-utilisation of glucose and xylose and depleted glucose till late growth. *P. stipitis* depleted glucose in 144 h and also consumed xylose (> 80%) while fusants consumed ~55% xylose from hydrolysates in 144 h and depleted glucose by 72 h. *S.cerevisiae* LN showed highest ethanol production at 24 h while fusants showed at 72 h and *P. stipitis* showed highest ethanol at 144 h, thus showing that despite improvement in mixed sugar utilization by fusants, *S.cerevisiae* LN still shows the highest ethanol productivity.

4.7.8 Fungal Inoculants for *in-situ* Degradation of Crop Residues

Two lignocellulolytic fungi, namely, *Coprinopsis cinerea* LA2 and *Cyathus stercoreus* ITCC 3745 were used for *in situ* degradation of rice straw. The highest activity of cellulase (0.46 IU/g/day) was recorded at 60 days in soil where mixed cultures of both the fungi were inoculated in soil. Similarly, xylanase activity was observed to be maximum (0.06 IU /g of soil/day) in the same treatment after 30 days. β glucosidase activity was significantly reduced from 0 to 60 days after treatment. Highest β glucosidase activity (0.27IU/g/h) was recorded in microbes treated plot followed by residue retained treatment (0.23 IU/g/h) whereas, the lowest β -glucosidase activity was recorded in residue removed treatment at all the sampling intervals. Therefore, microbial priming may be a suitable option for *in situ* management of paddy straw.

4.7.9 Microbial Consortium Evaluation at Farmer's Fields

Paddy straw degradation was studied below the soil at village Holambikalan, New Delhi and Sherpur, Ambala using Pusa decomposer as well as for pit method of composting. Two treatments were taken at each site one as control and other was inoculated with Pusa decomposer as microbial consortium using knapsack sprayer immediately after harvesting paddy. At Holambikalan, a slight increase in organic carbon from 0.24 to 0.28 % was observed at 60 days after incorporation of paddy straw and microbial inoculant treatment. There was marginal increase in P from 22.8 to 23.9 kg P ha^{-1} and in K from 250 to 278 kg K ha^{-1}. At Sherpur, marginal improvement in all the physico-chemical parameters were observed after 60 days of incorporation of paddy straw residue in the field having 0.25% organic carbon, 18.5 kg P ha^{-1} and 218 kg K ha^{-1}, respectively.

4.7.10 On-Farm Evaluation of Microbial Inoculants in Crops and Agro-Ecosystems

Farmers' participatory on-farm testing (OFT) and front line demonstrations (FLD) was continued for the fifth year by involving 21 *Krishi Vigyan Kendras* (KVKs) in 12 states of India. In this programme, several biofertilizers, namely, blue green algae (BGA), *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate solubilizing bacteria (PSB), AM fungi, *Azolla*, and four liquid formulations [namely, *Azotobacter*, *Azospirillum*, Zn solubilizing bacteria (ZNSB), K solubilizing bacteria

(KSB)] were evaluated in farmers' fields involving important food, pulse, oilseed, vegetable, and plantation crops of the adopted areas. These microbial inoculants were compared with farmers' practice (FP) of nutrient management. At KVK Saharanpur (UP), the combined inoculation of BGA @ 1.25 kg ha^{-1}, PSB and liquid ZnSB replaced 24.8% of chemical fertilizer and gave 283 and 174 kg ha^{-1} additional yield over recommended dose of fertilizers (RDF) and FP, respectively. Treatments with 75% chemical fertilizer+ BGA+ PSB and 75% chemical fertilizer + liquid *Azotobacter* + PSB+ liquid ZnSB gave Rs. 72,850 and Rs. 85,350 ha^{-1} net returns, whereas RDF and FP gave Rs. 58,650 and Rs. 60,750 ha^{-1}, respectively. The average increase in rice grain yield across the locations due to application of BGA and PSB ranged between 3.5-9.3% over the FP. Soil physical condition showed visible improvement due to BGA inoculation. Farmers could save ~ 10-25 kg N ha^{-1} (one bag of urea having 23 kg N costing ~ Rs. 350) with the application of BGA. In pulse crops, increase in yield due to *Rhizobium* inoculation was 10.8-18.2% in green gram, 12.8-14.9% in chickpea and 11.6-18.4% in field pea. In brinjal, also considerable increment in yield (3.3-7.8%) was found due to biofertilizer inoculation. Liquid formulations (*Azotobacter*, *Azospirillum*, ZnSB and KSB) of biofertilizers were found user friendly, effective and potential sources of crop nutrition in rice, brinjal and other crops at different locations. Liquid formulations could be used in high value crops through drip irrigation. Inoculation of liquid *Azotobacter*, ZnSB and KSB increased wheat grain yield by 5.4-13.6%, 3.7-9.7%, and 2.5-4.8%, respectively, over the FP across locations. Large number of farmers (>500) were trained about the benefits and use of biofertilizers in crop production.

4.8 ENVIRONMENT SCIENCE AND CLIMATE RESILIENT AGRICULTURE

4.8.1 Reactive Nitrogen Loss Reduction in Rice

Measurement of nitrous oxide, ammonia and nitrate leaching was carried out in rice under leaf colour chart based application of neem coated urea (NCU), 50% N through FYM + 50% N through NCU (LCC) + biofertilizer and unfertilized control in four rice cultivar of Pusa 44, IR 64, CR Dhan 310 and MTU 1010. The leaching losses of ammoniacal and nitrate N ranged from 7.89 to 10.33% of applied N in different varieties. Lowest ammonia emissions were observed in the integrated organic and inorganic treatment (NCU+FYM+BF), whereas nitrous oxide emissions were at par in the NCU and NCU+FYM+BF treatments. The loss of applied N ranged from 25% in NCU+FYM+BF to 35% in NCU alone. Highest N uptake was observed in CR Dhan 310 applied at 136 kg N ha^{-1} in the integrated treatment.

4.8.2 Greenhouse Gas Emission from *Kharif* Rice in Different Systems of India

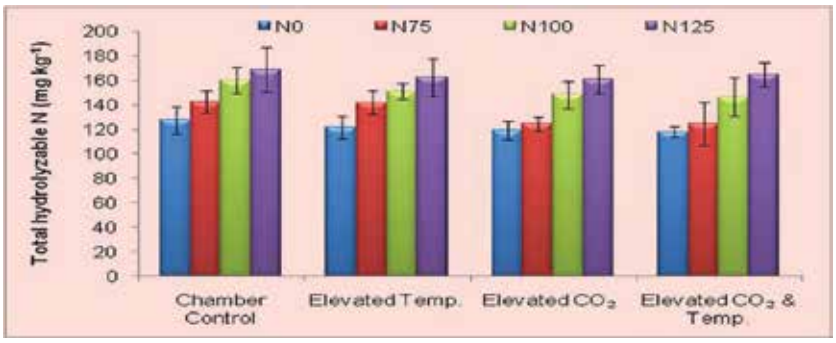
Methane and nitrous oxide emissions from *Kharif* rice in different cropping systems in India were measured. Samples were collected from rice-fallow system of Neempeeth, Sundarbans (West Bengal), rice-rice-rice system in Aduthurai (Tamil Nadu), and rice-wheat system of Mumtazpur (Haryana) and Varanasi (Uttar Pradesh). Nitrogen fertilizer application rates varied from 90-150 kg ha^{-1} across the locations. The global warming potential (GWP) of *Kharif* rice was maximum in Sundarban region and minimum in Varanasi.

Global warming potential (GWP) of *Kharif* rice in different rice based cropping systems

Cropping system/ location	CH_4 (kg ha^{-1})	N_2O (kg ha^{-1})	GWP (kg CO_2 eq ha^{-1})
Rice - Fallow (Sundarbans)	166.40	1.54	4619
Rice - Rice - Rice (Aduthurai)	125.00	1.40	3542
Rice - Wheat (Mumtazpur)	36.56	0.87	1174
Rice -Wheat (Varanasi)	20.85	1.23	888

4.8.3 Crop Diversification impacts on Greenhouse Gas Emissions

Measurement of methane, and nitrous oxide was carried out for the second year in rice-mustard-



Total hydrolysable N (mg kg^{-1}) of soil under elevated CO_2 and high temperature

mungbean (direct seeded rice), maize-mustard-mungbean, maize-potato-onion and fodder maize + cowpea-wheat-mungbean to quantify the impact of crop diversification on greenhouse gas emission. The global warming potential (GWP) of different cropping systems ranged from 1054 to 1415 kg CO_2 equivalent ha^{-1}. The GWP in maize-potato-onion was at par with maize+cowpea–wheat-mungbean system.

4.8.4 Impact of Irrigation Methods on Greenhouse Gas Mitigation in Rice

Measurement of methane and nitrous oxide in conventional transplanted rice, aerobic rice and aerobic rice with drip fertigation was compared for their global warming mitigation potential (GWP). The GWP reduced by 42% in aerobic rice cultivation and 83% in aerobic rice with drip fertigation in contrast to conventional rice. Aerobic rice cultivation decreased CH_4 emission but increased N_2O emissions due to alternate wetting and drying cycles of the soil. However, drip fertigation could reduce both methane and N_2O emissions, but with yield penalty of 9%.

4.8.5 Elevated Carbon Dioxide and Temperature Affect Soil Nitrogen in Rice

Rice crop (Pusa Basmati 1509) was grown in crates inside Open Top Chambers (OTCs) under ambient (400 ppm) and elevated CO_2 level (550 ± 25 ppm). Two temperature levels were also maintained inside the OTCs, i.e. chamber control and elevated (+2°C). Under elevated CO_2 and high temperature, soil organic N declined to meet N demand by rice crop. Elevated CO_2 concentration significantly decreased total hydrolysable N in soil from 147 to 138 mg kg^{-1}. Effect of elevated CO_2 in reducing hydrolysable N in soil was more pronounced in the treatments with lower N doses. Application of super optimal dose of N caused lesser depletion of soil N and met N demand of plant. The study revealed that better N management either by providing additional N dose or by enhancing N-use efficiency will cause less depletion of native soil N under future climate change scenario and might be helpful in sequestering N in soil.

4.8.6 Plant Growth Promoting Rhizobacteria (PGPR) and Elevated Carbon Dioxide Affect Growth and Yield of Black Gram under Elevated Tropospheric Ozone

Black gram variety T 9 was grown with PGPR treated and untreated seed with two fertilizers (100% urea N and 50% urea N +50% FYM N) treatments under elevated O_3 (60-68 ppb) and elevated CO_2 (542-585ppm). The presence of elevated CO_2 along with elevated O_3 increased the number of nodules by 58% and subsequently, there was a further 15% increase

Global warming potential and grain yield of rice under different water management practices

Planting and irrigation method	Nitrous oxide (kg ha^{-1})	Methane (kg ha^{-1})	GWP (kg CO_2 eq)	Yield (t ha^{-1})
Conventional transplanted rice	1.10	37.38	1261.77	5.21
Aerobic rice	1.66	9.45	730.61	4.90
Aerobic rice with drip fertigation	0.49	2.62	210.85	4.73

in number of nodules due to PGPR application. Due to elevated O_3 exposure, seed yield decreased by 11%, however the seed yield significantly increased by 22.8% in the presence of elevated CO_2 and PGPR treated seed. Thus, the presence of elevated CO_2 and PGPR treated seed was able to ameliorate the negative impact of elevated O_3 exposure in black gram.

4.8.7 Surplus Crop Residue Estimation in India for Biofuel Production

The amount of surplus crop biomass generated in the country and its bioethanol production potential at district level in three crop growing seasons (*Kharif, Rabi* and summer) for all the 662 districts of the country was quantified. The crops were selected based on their acreage and total production across the country. The total gross and net cultivated area of the country is about 195 million hectare and 142 million hectare, respectively. The area under cultivation for the selected eleven crops is 137 M ha, i.e. about 70% of gross cultivated area. These eleven crops generated about 683 million tonnes (MT) of total dry biomass in three crop growing seasons. Out of this total annual crop biomass, 59% was generated during *Kharif* and 39% during *Rabi* season. The remaining about 2% was generated during summer season. The total annual surplus crop biomass was estimated to be approximately 179 MT, which is about 26% of the total dry biomass generated. The season-wise surplus biomass is highest in *Kharif* season (72%) followed by *Rabi* season (26%). The major crops contributing to surplus biomass are rice, sugarcane, cotton and soybean. The surplus biomass generated during summer is negligible. The total annual bio-ethanol production potential from this surplus crop biomass generated in the country would be 51.35 billion liters from eleven selected crops. The study provides district scale season-wise crop area, crop dry biomass, surplus biomass and bioethanol maps for each of the eleven crops for use by different stakeholders.

4.8.8 Crop Residues Burning Affects Physico-Chemical and Biological Properties of Soil

Soil samples of rice fields were collected from three different depths of soil (0-5 cm, 5-15 cm and 15-30cm) at the harvesting time from three different sites after and before burning (BB & AB). The first sampling was done from the burning sites of Panipat district (villages: Waisari and Jatal), second from Karnal district (villages: Trawadi and Tikhana), Haryana and third from IARI fields to study the impacts of crop residues burning on soil health. There were no changes observed in soil texture (clay loam) after burning at all the sampling sites. The soil pH slightly increased after burning, which might be due to higher temperature and fire and increased from 7.39 - 8.61 (BB) to 7.72 - 9.13 (AB) in 0-5 cm depth. Electrical conductivity (EC) of soil also increased from 0.225-0.533 mmho/cm (BB) to 0.238 - 0.669 mmho/cm (AB) in surface soil. The activities of dehydrogenases and ureases decreased after burning due to decline in soil microbial populations.

4.8.9 Particulate Matter, SO_2 and NO_2 Pollutions on Growth and N and S Nutrition of Crops

A radiological method based on use of radio-labeled sulfur (^{35}S) to measure the contribution of sulfur dioxide pollution towards S nutrition of crops was developed. The effect of particulate and gaseous pollution was studied on cereal, oilseed, leafy, and root crops using specially designed plastic sheet fabricated gas-tight enclosure used to cover carrot, spinach, tomato, mustard, wheat, okra, bottle guard, luffa and brinjal; exposed to SO_2 and NO_2 in a concentration range of ambient (control), ambient + 2 μg m^{-3} (low), ambient + 4 μg m^{-3} (high) for one hour daily for seven days at 30 days after sowing. Following this, plants were sampled to record plant mass, total leaf area and necrotic leaf area, leaf chlorophyll, H_2O_2 production, total antioxidant activity, membrane stability, S and N content of healthy and necrotic tissues and activity of rate limiting enzymes of S metabolism. Carrot, tomato and wheat accumulated exceptionally higher S in necrotic than healthy leaf tissue, while reverse trend was measured in mustard. Mean leaf chlorophyll did not change with exposure to sulfur dioxide, while MSI declined drastically and depended on severity of the air pollution stress but improved significantly with plant growth to reach equivalence of unstressed control by 15th day after the stress treatment.

4.8.10 Does Particulate Pollutant Contribute Heavy Metals to Plants?

Dust particles, irrespective of their size, possess heavy metals such as Zn and may affect gas exchange attributes of the affected plants. Further, whether these dust particle associated heavy metals are absorbed into the crop plants or not is not known. In collaboration with the Department of Environment Science, JNU, the uptake of foliar applied dust associated ^{65}Zn into mulberry plants at different days of treatment was measured. Two different sizes of dust particles and loads were used and partitioning of ^{65}Zn in different plant tissues was measured. Results showed that metals on the dust particles entered the plant through foliar application, and got transported via phloem to the roots and other tissues in significant amounts.

4.8.11 Impact of Air Pollution on Crops near NTPC Dadri

Levels of air pollutants such as TSP, SO_2, NO_2, and O_3 and aerial dust deposition on crop canopy were quantified at the selected experimental sites (Akilpur Jagir, Pyawali Tajpur, Jarcha, Uncha Amirpur, Khangoda, Nagla Kashi, Nidhauli, Ranauli Latifpur, Tatarpur and Salarpur Kalan) in the vicinity of NTPC, Dadri. Growth of selected crops varieties at vegetative and flowering stages and yields were obtained at all selected sites. It was observed that SO_2 and NO_2 concentration was highest near the TPP. Concentration showed a normal probability distribution curve. Variation in concentration was higher near to source with a peak, then curve became less steep with downwind distance. The maximum SO_2 and NO_2 concentration was found in 1-6 km distance, thereafter a continuous decrease was observed. GPM performance evaluation index was evaluated by comparing the observed SO_2 and NO_2 concentration with predicted or simulated values by the model at same points. This d value showed that agreement between predicted and observed data was good to average. The d value varied might be due to stochastic nature of atmospheric turbulence. Maximum d value was found at Khangoda (0.66) followed by Nagla Kashi (0.57) and Jarcha (0.52).

Performance evaluation index at selected sites for SO_2 and NO_2

Selected sites	Performance evaluation index	
	SO_2	NO_2
Khangoda	0.66	0.32
Jarcha	0.52	0.54
Nagla Kashi	0.57	0.48

4.8.12 Phytotoxicity of Cadmium in Rice Grown in Inceptisol

To assess the effect of cadmium (Cd) on rice crop grown in an inceptisol, soil was spiked with 25 ppm Cd before growing the crop. The distribution of Cd in different parts of rice plant was found in the order: roots > stems > grains. Rice grain yield in Cd contaminated soil was at par with uncontaminated soil. Catalase, superoxide dismutase (SOD) and ascorbate peroxidase activities in rice shoot and panicle were reduced significantly in Cd contaminated soil compared to uncontaminated soil, whereas activities of catalase, SOD and ascorbate peroxidase in root was found to be higher in Cd contaminated soil. Lipase esterase activity in soil was more in Cd contaminated soil compared to uncontaminated soil, but the activities of urease, fluorescein diacetate (FDA) and dehydrogenase decreased in Cd contaminated soil. The study showed that even though the yield was not affected by Cd contamination, enzymatic activities in soil and rice plant were affected significantly.

4.8.13 Microbial Bio-sorbents for Bioremediation of Heavy Metals Contaminated Waste Water

With the aim to isolate metal resistant bacteria, heavy metal contaminated waste water was sampled from microcosms systems, which are artificially spiked with different levels of nickel (Ni), chromium (Cr) and lead (Pb) and planted with different aquatic hyper accumulator plants. Four Pb resistant bacteria were isolated with 600 ppm minimum inhibitory concentration (MIC), out of which isolate PBN-6 was found to show good absorption capacity. This strain was

sequenced and identified as *Brevibacillus laterosporus.* Lead removal capacity by *Brevibacillus laterosporus* was assessed using Ca-alginate based immobilization technique. Microbial cells were immobilized in different percentage of Ca-alginate beads and used for bio-sorption based removal capacity. Other two critical factors (in different combinations), viz., temperature and initial lead concentration were verified. Using Box Bhenken design (BBD) (Design Expert; version 7), responses in each combination of BBD were analyzed through fitting into a second order quadratic model. Out of four resistant microbial isolates, optimum condition for maximum removal of Pb^{2+} by isolate-PBN-6 (*Brevibacillus laterosporus*) was assessed. At a combination of bacterial Ca-Alginate (3.5%), initial lead concentration 67 ppm, and incubation temperature 50°C, the model-predicted maximum removal was 86.9%. This was validated in laboratory and 84.3% removal was obtained.

5. CROP PROTECTION

Changing climate is affecting pest and pathogen dynamics every year so there is need to reorient crop protection strategies that include all options of management for providing effective and sustainable solution. The School of Crop Protection develops and implements innovative management strategy for counteracting the impact of insect-pest on field and horticultural crops. During the year under report, identification of new diseases, insect pests, vectors, development of diagnostic tools, diversity studies, host pathogen interaction, resistant sources, and development of new molecules and their efficacy against different pathogens and insects were undertaken. Identification of resistant sources against major pests and pathogens will help in developing resistant varieties.

5.1 PLANT PATHOLOGY

5.1.1 Genetic Variability, Pathogen Characterization and New Records

Identification and expression analysis of pathogenicity-related genes in Tilletia indica inciting Karnal bunt of wheat. Fifteen pathogenicity related genes were selected on basis of secretomics, PHI database and transcriptome data of *T. indica*. Expression studies conducted in the presence of resistant and susceptible host factor amendment showed the maximum of 3 fold increase in expression of all the genes, when amended with susceptible genotype host factor under *in vitro* conditions. Out of the 7 genes taken for *in planta* conditions, 3 genes (*Ti 2035, Ti 2347,* and *Ti 3774*) showed maximum expression at 3 days post inoculation in both the genotypes. Further two genes (*Ti 57* and *Ti 198*) showed maximum expression at 3dpi followed by 10dpi and 15dpi. These genes may have role in penetration, infection and in establishment of local systemic infection.

Transcriptome of dormant and germinating teliospores of T. indica and development and validation of rapid diagnostic LAMP assay for detection of Tilletia indica. Whole transcriptome was performed for teliospores of *T. indica* using Illumina platform. 9771 CDS (coding sequence) belong to dormant teliospores, 21,505 CDS belong to germinating teliospores and 9680 CDS were found commonly expressed in both teliospores. Gene ontology analysis, 2053 and 3065 were annotated for dormant teliospores and germinating teliospores, respectively. The CDS were categorized in 24 different KASS pathways. The majority of CDS were annotated in translation related pathways. 686 CDS were significantly up-regulated and 114 down-regulated in germinating teliospores. Transcriptome data of teliospores of *Tilletia indica* has submitted to database (NCBI SRA accession: PRJNA522347). A rapid diagnostic loop mediated isothermal amplification (LAMP) based protocol was standardized and validated for detection of quarantine fungus *Tilletia indica*.

Identification of phytoplasma associated with flat stem disease of sapota (Manilkara zapota). During a survey in June 2018-19 in the sapota (*Manilkara zapota*) orchards at Lembucherra, West Tripura, 2% incidence of flat stem symptoms were recorded on young emerging shoots of the old sapota trees. Nested PCR assay using generic primers P1/P7-R16F2n/R16R2 of 16S rDNA showed that the phytoplasma associated with sapota flat stem (SFS) had 100% nucleotide identity with the corresponding sequence of the type strain '*Candidatus* Phytoplasma asteris'. Further, phylogenetic analysis of the 16S rRNA sequences of SFS strain clustered with the sequences of 16SrI group. Virtual RFLP analysis using *iphyclassifier* tool also confirmed the phytoplasma associated with SFS belonged to sub-group 16SrI-B.

Molecular characterization of Candidatus Phytoplasma aurantifolia associated with flower virescence disease of Anacardium occidentale. During 2018-19, cashew flower virescence (CaFV) symptoms were observed in cashew (*Anacardium occidentale*) orchard in Nagicherra, West Tripura. A 1.25kb product was amplified from all the symptomatic cashew nut plant samples along with positive control in nested PCR analysis. BLAST analysis of 1.25kb product of the 16S rRNA sequences of CaFV isolate shared 99% sequence identity with '*Candidatus* Phytoplasma aurantifolia' (16SrII group) strains. Phylogenetic analysis and computer simulated RFLP analysis of 16SrRNA gene sequence of CaFV isolate (GenBank Acc. no. MK076296) also suggested closest relationship with '*Ca. P. aurantifolia*' 16SrII-D subgroup related strain. Our results confirmed the first report of association of *Ca. P. aurantifolia* with CaFV diseases.

Candidatus Phytoplasma asteris (16SrI-B subgroup) strain infecting pineapple shoot proliferation and witches' broom disease. Phytoplasma suspected symptoms of shoot proliferation and witches' broom disease were observed with an incidence of 2 to 15% in Kew and Queen varieties of pineapple at different location of Tripura. DNA extracted from all the symptomatic samples of both pineapple varieties were processed for PCR amplification with universal primer pair (P1/P7 & R16F2n/R16Rn). Out of different pine apple samples processed, only symptomatic samples showing witches' broom and little leaf in Queen variety of pineapple showed amplification of 1.8 and 1.2 Kb, respectively, in first round and nested PCR assays. The nested amplified PCR product of 1.2 Kb of pineapple isolate of PiSP was sequenced. BLAST comparison of 16SrDNA sequence revealed the phytoplasma identified in pineapple (PiSP) exhibited 100% sequence identity of PiSP isolates with '*Ca.* P. asteris'. Further for sequence analysis of PiSP isolate through phylogeny simulated RFLP analysis confirmed the identity of PiSP isolate as 16SrI subgroup B and was submitted in GenBank (Accession no. MK209105, MK328881). This is the first report of occurrence of 16SrI-B strain associated with PiSP disease.

Identification and management of Ca. P. aurantifolia strain infecting cluster bean and sesame crops in Haryana province of India. Little leaf, phyllody and witches' broom symptoms with incidence of 8% to 20% were recorded on cluster bean (*Cyamopsis teragonoloba*), sesame (*Sesamum indicum*) and a weed (*Phyllanthus niruri*) in farmer's fields at Ranila and Begoa village of Bhiwani district, Haryana during September-October. The '*Ca. P. aurantifolia*' association was confirmed in symptomatic cluster bean, sesame and *P. niruri* samples by phytoplasma-specific universal primer pairs in nested PCR assays (P1/P7 and R16F2n/R16R2n). *Empoasca motti* feeding in symptomatic cluster bean and sesame fields was also found positive for association of '*Ca. P aurantifolia*' in nested PCR assays with same set of primers. Comparison of 16S rDNA sequence and virtual RFLP analysis of R16F2n/R16R2 primed 16S rDNA sequences of cluster bean little leaf, sesame phyllody, *P. niruri* witches' broom and leafhopper phytoplasma isolates confirmed the association of '*Ca. P. aurantifolia*' subgroup D. Spray of imidacloprid (2.0 ml / 10 l, 2 sprays) and thiamethoxam (2.0 g /10 l, 2 sprays) at 15 days interval effectively controlled the leaf hopper population and thereby reduced the incidence of phytoplasma disease in affected cluster bean and sesame fields.

Mixed infection of virus and phytoplasma causing leaf yellowing and streaks in gladiolus varieties in India. During 2016-2018, 8 to 96 per cent disease incidence of leaf yellowing and streaks were observed in 11 varieties of gladiolus at IARI, Delhi. The association of '*Candidatus* Phytoplasma trifolii' (16Sr VI-D) subgroup with all the eleven symptomatic varieties was confirmed by PCR amplification using phytoplasma specific primer pairs P1/P7 and R16F2n/R16R2 and 16Sr DNA sequence comparison. Mixed infection of cucumber mosaic virus was also confirmed by electron microscopy and coat protein sequence analysis of gladioli sample with CMV coat protein specific primer pairs. Our results suggest mixed infection of 16Sr VI-D subgroup phytoplasma and CMV associated with leaf yellowing and streaks symptoms in gladiolus varieties.

Molecular identification of Ca. P. oryzae in Garcinia gummi-gutta from Kerala, India. During a survey in 2017, witches' broom and little leaf symptoms were observed on *G.gummi-gutta* (GaWB) plants at Kumarakom Kottayam district of Kerala, India. For identifying the phytoplasma association with the GaWB, amplicons of 1.2 kb were consistently amplified from DNA extracted from all the symptomatic GaWB plants in nested PCR assays using primer pairs P1/P7 and R16F2n/R16Rn, however, no amplification was observed with any non-symptomatic samples. The 16S rDNA sequence of GaWB revealed 100% sequence identity with those of '*Ca.*P. oryzae' strains and computer simulated RFLP analysis of the GaWB 16SrDNA sequence confirmed it as strain of 16SrXI, subgroup B. This is the first report of *Ca.* P. oryzae (subgroup B strain) associated with little leaf and witches' broom disease of *Garcinia* from the world.

Survey on the incidence of huanglongbing (HLB) disease affecting citrus in the Eastern India. Citrus orchards at Dzongu, Lower Samdong and Danragaon (Tadong) in Sikkim; Rellie Road and Bara Mangwa in West Bengal and Renging in Arunachal Pradesh were extensively surveyed for the incidence of HLB disease. Samples were collected from orange (*Citrus reticulata* L.), rough lemon (*Citrus jambhiri*), Assam lemon {*Citrus limon* (L.) Osbeck}, Tangelo (*Citrus tangelo*), Kinnow (*Citrus reticulata* cv. Kinnow), Karna Khatta (*Citrus aurantium* var. *Khatta*), Rangpur lime (*Citrus limonia* Osb.) and Cleopatra mandarin showing apparent symptoms of HLB and indexed by RT-PCR. HLB was found to be present in all the orchards visited. High HLB incidence of 10.9-19.2% in Sikkim, 8.0-40% in Kalimpong and Darjeeling districts of West Bengal and 5.0-38.5% in Renging area (East Siang district) of Arunachal Pradesh was observed particularly in oranges. Psyllid vectors were observed in one of the orchards in Kalimpong.

Serological diagnostics of important viruses affecting brinjal and carrot. Five breeding lines of carrot showing yellow/white/bronze mottle and one breeding line showing severe downward leaf curling symptoms were screened using polyclonal antibodies {PcAb(s)} raised against Potato virus Y potyvirus (PVY), Potato virus X potexvirus (PVX) and Football lily mosaic virus (FlMV). The same set of antisera was also used to ascertain its reaction against six breeding lines of brinjal showing mosaic, blisters, mild mottling, crinkling and abaxial and adaxial cupping symptoms. Four out of the five carrot lines showing mottling of leaves reacted positively to PcAb(s) against PVY, while the carrot line showing curling of leaves reacted with none of the PcAb(s). All the six brinjal lines reacted positively to PcAb(s) against PVX. Five brinjal lines showed positive reaction with PcAb(s) to PVX while only one brinjal line reacted positively with PcAb(s) to FlMV.

Detection of apple viruses at Amartara Cottage, Shimla. RT-PCR protocol was standardized for detection of five viruses (ACLSV, ApMV, ASPV, ASGV and PNRSV). PCR based protocol was developed for detection of Apple scar skin viroid (ASSVd). Leaf samples brought from different panchayat's were indexed using RT-PCR for ACLSV, ASGV, ASPV, ApMV, PNRSV and a viroid ASSVd. Twelve virus free elite mother plants were selected on the basis of 3 years study on virus indexing and fruit quality data.

Mass rearing of Thrips palmi and thrips mediated transmission of groundnut bud necrosis tospovirus (GBNV) and watermelon bud necrosis tospovirus (WBNV). Developed an efficient and low cost technique for mass-culturing of GBNV and WBNV vector i.e. *Thrips palmi.* The method involved only the potted brinjal plants placed in the trays under the aseptic conditions, which are protected from external contaminations using the Mylar cages covered at one end with a muslin cloth. Each single brinjal plant covered with cage harbors the colony of iso-female *T. palmi* at the temperature 26-28 °C and 12 h:12 h light: dark periods. The brinjal plants yielded maximum number of thrips individuals (8-32 individuals / leaf) including larvae and adults 30 days post iso-female inoculation. The identity of each iso-female derived population of thrips were confirmed as *T. palmi* through RT-PCR using the primers specific to MtCO-I (Mitochondrial cytochrome oxidase-I) gene

followed by sequencing. Further, a simple and low cost technique for thrips mediated transmission of GBNV & WBNV was optimized using the micro-cages containing the semi-solid nutrient medium which can nurture the detached leaves of cowpea test plants for about 15-20 days. The optimized transmission protocol resulted in about 65-70% transmission as confirmed by typical symptoms of GBNV & WBNV, ELISA and RT-PCR.

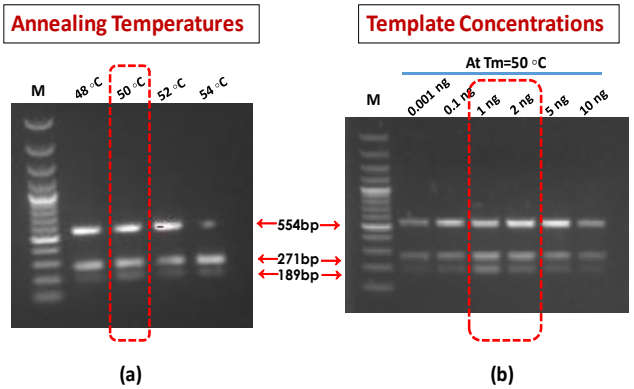
5.1.2 Molecular Diagnostics

Diagnostics for bakane disease of rice. PCR and loop mediated isothermal amplification (LAMP) based assays were developed for the detection of *Fusarium fujikuroi*. Based on the unique sequences (NRPS31 gene) of *F. fujikuroi* obtained from GenBank accession KY953210, a specific marker BMFf1900 was developed for the amplification of *F. fujikuroi* with a sensitivity of 10 pg. For precise quantification of the inoculum, real time primers (NRPS31RT-F and NRPS31RT-R) were designed and sensitivity of the assay was increased to 10 fg. These PCR and LAMP based assays have been validated under field conditions, seed testing and in resistance evaluation of rice genotypes.

Validation of multiplex nested PCR assay for detection of 16SrII group phytoplasma at subgroup level associated with chickpea stunt disease. An attempt was made to identify the phytoplasma association with CpS disease by developing a multiplex system in one go. Total DNA from symptomatic and non-symptomatic chickpea plants was extracted and a multiplex PCR assay was developed by optimizing PCR conditions. Three sets of specific primers viz., a 16S rDNA universal primer pair P1/P7 and nested primer pair R16F2n/R2 and 16Sr II-D subgroup specific primer pair *imp* (IMPIIF2 /IMPIIR1) were used in the assay. Expected fragments of 1.8 kb, 1.2 kb and 717 bp were successfully amplified by this multiplex PCR system ensuring sensitive and specific detection of the phytoplasma at subgroup level in one PCR cycle. Further results were confirmed based on sequence analysis using BLASTn and also by virtual RFLP analysis using *iphyclassifier* tool to confirm that the phytoplasma belong to the sub-group 16SrII-D. Our result validated the 16SII-D subgroup characterization by utilizing the newly developed multiplex PCR assays.

Easy PCR Kit for the species-specific detection of Tomato leaf curl New Delhi virus (ToLCNDV) and Chilli leaf curl virus (ChiLCV). Kits for species-specific detection of ToLCNDV and ChiLCV (genus *Begomo virus* family *Gemini viridae*) have been developed under the ICAR-Consortia Research Platform (CRP) on Vaccine and Diagnostics. A new approach was adopted to design primers that under specific annealing temperature differentiate closely related begomo viruses. The kit has been simplified in a single tube containing all the reagents required for running PCR and with the ease of use as only the test DNA to be added in the supplied tube to perform the PCR.

Multiplex RT-PCR technique for simultaneous detection of three major tospo viruses occurring in India. Groundnut bud necrosis tospo virus (GBNV), watermelon bud necrosis tospo virus (WBNV) and capsicum chlorosis ortho tospo virus (CaCV) are known to infect either singly or together to more-or-less the same hosts of family *Solanaceae, Cucurbitaceae* and some ornamentals. A multiplex RT-PCR protocol for simultaneous detection of CaCV, GBNV and WBNV have been optimized by using three forward primers



Multiplex RT-PCR gel electrophoresis showing optimum annealing temperature (a), and template concentrations (b) for specific and simultaneous detection of three tospo viruses occurring in India

specific to CaCV, GBNV & WBNV (CaF', GbF' & WbF') and a single degenerate reverse primer (CaGbWb-R') common to all. The optimized protocol resulted in specific and simultaneous amplification of the targeted N-gene segment of CaCV (~189 bp), GBNV (~271 bp), and WBNV (~554 bp). The optimized annealing temperature and template concentrations were 50°C and the 1-2ng of template DNA per reaction mixture of 25µl respectively.

Detection of Groundnut bud necrosis (GBNV) tospo virus infection on Phalaenopsis in India. Phalaenopsis plants showing symptoms of mild chlorotic spots/ specks, mild mosaic and dark green islands with light green/ chlorotic margins were collected from germplasm collections at National Research Centre for Orchids, Pakyong, Sikkim. Electron microscopy of symptomatic leaf samples showed the presence of enveloped quasi-spherical shaped particles resembling GBNV measuring 80-110 nm. Samples were subjected to DAC-ELISA using polyclonal antibodies (PAbs) to GBNV and detected the *Tospovirus* species belonging to the Serogroup IV. Partial NP gene sequence of 477 nucleotides (KY794416) revealed association of GBNV.

Multiplex RT-PCR of CymMV, ORSV and GBNV. Multiplex reverse transcription polymerase chain reaction (RT-PCR) assay was developed for simultaneous detection of *Cymbidium mosaic virus* (CymMV), *Odontoglossum ringspot virus* (ORSV) and *Ground nut bud necrosis virus* (GBNV). An amplicon of 672 bp to CymMV, 477 bp to ORSV and 255 bp to GBNV were obtained in mixed infections in orchids.

Recombinase Polymerase Amplification based diagnosis of Onion yellow dwarf virus (OYDV). Isothermal reverse transcription-recombinase polymerase amplification (RT-RPA) technique was developed using OYDV coat protein specific primers. RT-RPA primers were designed to amplify OYDV coat protein gene by performing multiple sequence alignment of OYDV nucleotide sequences available in NCBI GenBank database. RPA is performed using material and protocols provided with TwistAmp exoRT kit. In this technique RNA was used as template and used as per manufacturer's protocol. The whole reaction was achieved with isothermal temperature (42^{0}C) using dry bath. It took about 30 min to complete the reaction and the amplified product was checked on 1.5% agarose gel. The amplicon size of 286 bp showed the presence of OYDV in onion samples and the same primers were also used in amplification of OYDV in RT-PCR.

Detection of episomal Banana streak Imove virus in India. Identification of episomal *Banana streak IM virus* (BSIMV) isolates sampled from Champa Kola variety from unknown *Musa* spp, grown in Makha Limmu, Sikkim is reported in this study by sequence-independent improved rolling circle amplification (RCA). Full genome of the following isolate of BSIMV has been cloned in pUC 18 cloning vector. Based on initial sequencing results of RT/RNAse H region of ORF III (region responsible for species demarcation in case of BSVs) revealed that the Indian BSIMV isolates shared maximum sequence similarity of 91.20 % to the globally present BSIMV (Accession No. HQ659760, Australia) at nucleotide level. RCA coupled with restriction fragment length polymorphism revealed diverse restriction profile of BSIMV isolate.

Multiplex PCR for simultaneous detection of Cotton leaf curl disease (CLCuD)-begomo virus DNA A and its associated beta satellite and alpha satellite molecules in infected cotton of north west India. Oligonucleotide primers targeting CP gene of CLCuD-begomo virus DNA-A, βC1 gene of beta satellite and Rep gene of alpha satellite molecules were designed, synthesized and standardized. A multiplex PCR technique for quick and simultaneous detection of CLCuD-begomo virus and its satellite molecules in infected cotton plant was developed.

5.1.3 Whole Genome Sequencing and Host-Pathogen Interaction

Whole genome analysis of Bipolaris sorokiniana. This pathogen was sequenced using three platforms

viz. Illumina HiSeq, Ion torrent and Nanopore. The generated whole genome size is 35.64 MB with G+C content of 50.2% having 235 scaffolds and N_{50} of 1654800. This whole-genome data has been deposited in DDBJ/ENA/GenBank with accession number RCTM00000000. The BUSCO evaluation of *B. sorokiniana* genome sequence predicted that it was 97.6% complete genome. The gene prediction was performed on the basis of reference *Bipolaris sorokiniana* ND90Pr using AUGUSTUS tool. A total number of 10,460 genes were predicted having average gene density of 250-300 genes/Mb which have around 98% of predicted genes. Average gene length was 435-545 bp, maximum gene length was 8506 bp while minimum gene length was 35 bp. A total of 10,141genes were functionally annotated in the genome assembly. Gene ontology (GO) annotations of the genes were determined by the Blast2GO. A total of 10,460 genes were annotated, of which 1024 (3491), 493 (4165) and 1274 (7784) genes (hits) were for biological process, cellular component and molecular functions respectively.

Whole genome sequencing of pearl millet infecting blast fungus and molecular typing of Magnaporthe isolates from the whole genome data. Whole genome sequencing of pearl millet infecting *Magnaporthe grisea* PMg_Dl strain was performed using Illumina-Nextseq500 (2x150 bp) and PacBioRSII with P6-C4 chemistry. Total data generated was 13.1 Gb Paired end (Number of reads 43,962,401), 3.4 Gb Mate paired (Number of reads 17,160,010), and 1.1 Gb PacBio (Number of reads 148,768). The high quality PE, MP and PacBio reads of PMg_Dl sample were assembled into scaffolds by SPAdes genome assembler version 3.12.0 and scaffolding was carried out by SSPACE (SSAKE based Scaffolding of Pre-assembled Contigs after Extension) version v3.0. The hybrid approach revealed that the genome size is 47.90 Mb. A total of 10,451 genes were predicted in PMg_Dl using *Magnaporthe grisea* as a gene prediction model. A total of 3,151 genes were annotated into 24 functional categories based on KEGG pathway database *via* KAAS (KEGG Automatic Annotation Server). A total of 849 CDS involved in pathogenicity, virulence and effector genes were annotated. This Whole Genome Shotgun project has been deposited at DDBJ/ENA/GenBank under the accession RHLM00000000. This is first report of whole genome sequencing of pearly millet infecting blast fungus. New molecular typing tool was developed for *Magnaporthe oryzae* based on allelic variations in the selected housekeeping and virulence/ pathogenicity genes. Whole genome sequence data of 198 other isolates available in the database along with genome sequenced data of RMg_Dl was used. Partial sequences of 11 housekeeping genes and 7 effectors genes of 24 Indian isolates used as a query. String of allele numbers also called as Sequence Types (STs) was used to construct molecular phylogenetic tree for *Magnaporthe* isolates. Allele data was subjected to E-Burst algorithm based genetic analysis to study the evolutionary relationship. The methodology will enable tracking of pathogen movement across rice and other cereal growing regions.

Validation of Transcriptome data of Magnaporthe oryzae during conidial germination to mycelial stage to sporulation. Expression of three candidate genes such as EH2 (epoxide hydrolase 2), P450 (NADPH-P450 reductase) and BacC (bacilysin biosynthesis oxidoreductase bacC) from upregulated ones and three down regulated genes such as PRPP (phosphate-repressible phosphate permease), UracilP (uracil permease) and NRPS (non-ribosomal peptide synthetase) were validated. EH2 (epoxide hydrolase 2), and P450 (NADPH-P450 reductase) were found upregulated 38.6 and 61 fold, respectively.

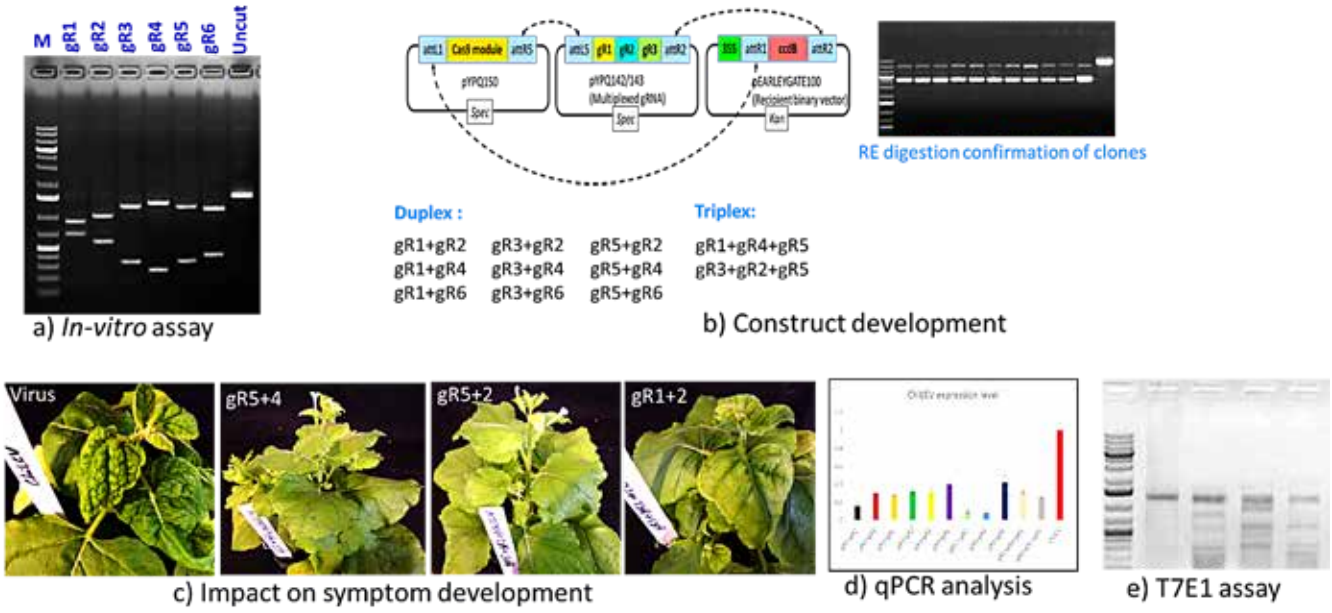
Function of pathogenicity genes of Colletotrichum orbiculare. Six constitutively expressing uncharacterised pathogenicity genes, ENH87556, ENH81967, ENH87679, ENH86880, ENH78781 and ENH89286 of a highly pathogenic *Colletotrichum orbiculare* (=*C. lagenarium*) isolate CUCO-MT, which were identified as candidate ones from earlier studies, were assessed for *in planta* expression in cucumber and chilli. Among them, only three genes,

ENH87556,ENH81967, and ENH87679 were induced in the inoculated plants, of which, only ENH87556 and ENH81967 were specific to cucumber.

Transcriptome analysis of bacterial wilt pathogen Ralstonia solanacearum during its plant colonization. Protocol was standardized to extract xylem fluid and *Ralstonia* cells from vascular elements of ginger, and the ginger xylem fluid was supplemented as sole nutritional source for growth of bacteria. Bacterial growth obtained in xylem fluid was subjected to comparative RNA seq analysis with cells generated in cassamino acid peptone glucose medium. Total RNA extracted from bacterial cell using Trizol method was quantitated and quality checked and subjected to bacterial Ribozero and Truseq stranded RNA Library preparation. These libraries were sequenced on HiSeq4000 sequencing platform, and 640 to 1025 MB data was generated. Over 97% of the sequence reads were of highly quality as indicated by the >Q30 value.

Genome editing based on CRISPR-Cas9 to inhibit Chilli leaf curl virus infection. CRISPR-Cas9 based genome editing approach has been applied for the precise degradation of Chilli leaf curl virus (ChiLCV) genome. Six spacer sequences were designed from the genome of ChiLCV. *In vitro* assays confirmed the cleavage behaviour of these spacer sequences. A new strategy of mulplexing of gRNAs to inhibit begomovirus infection was used where nine duplex and two triplex CRISPR-Cas9 constructs were developed and their efficacy to inhibit ChiLCV infection was evaluated *in planta* in *Nicotiana benthamiana*. Results indicated all the constructs caused reduced accumulation of viral DNA. Amongst them, three constructs, where significant symptom reduction noticed, were further evaluated for analysing genome editing in the virus. Results indicated the potential of employing multiplex gRNAs for imparting begomovirus resistance in plants.

Cellular localization of RNA silencing suppressors of Croton yellow vein mosaic virus. Three putative silencing suppressor proteins (V2, C2, and C4) of a begomovirus, croton yellow vein mosaic virus, and one silencing suppressor protein (bC1) of betasatellite have been studied for establishing their suppressor activity, cellular localization and interaction behaviour. All these genes were amplified and cloned into suitable



CRISPR-Cas9 technology to inhibit ChiLCV. a) In vitro cleavage of viral genomic fragment by six gRNAs, b) Development of multiplex gRNA-Cas9 constructs and their confirmation, c) Impact of viral genome editing on symptom phenotype, d) reduction of viral amplification in CRISPR-Cas9 applied plant, e) Confirmation of viral genome editing by T7E1 assay

vector systems through gateway cloning. A GUS assay system indicated silencing suppressor activity of these proteins. Cellular localization study indicated V2 is localized in nuclear membrane, C4 in cell membrane, while C2 and bC1 are located in nucleus. Interaction study indicated that none of these protein interacted with each other. Only V2 protein can form dimer.

Genetic diversity of Cotton leaf curl disease (CLCuD) - begomo virus in cotton growing areas of north west India. Complete CP gene (~750nt) sequences of twenty CLCuD-begomovirus isolates of NW India were cloned sequenced and analysed and compared with other CLCuD begomoviruses. The pair-wise sequence analysis showed 81-100% nt identity among them and the phylogenetic analysis distributed them into three CLCuD-begomovirus species, Cotton leafcurl Kokhran virus (CLCuKoV), Cotton leafcurl Multan virus (CLCuMuV) and Cotton leafcurl Alabad virus (CLCuAlV). Majorities of the present CLCuD-begomovirus isolates fell into CLCuKoV-Burewala strain.

Rhizoctonia solani anastomosis groups specific infection behavior in rice. Out of five *Rhizoctonia solani* isolates belonging to different anastomosis groups (AG) evaluated for the sheath blight disease of rice AG1, AG2, AG3, AG4 could produce infection cushions after 24 hrs of inoculation whereas, AG5 could not produce infectious structures after 24 hrs in rice variety Pusa Basmati 1. All isolates irrespective of AG groups could colonize the rice plant. Rice in India identified to be infected by AG1 and AG2 groups under field conditions.

Identification and validation of AG1-IA and AG2-2 anastomosis groups specific genes in Rhizoctonia solani. Whole proteome of *Rhizoctonia solani* AG1-IA (strain 1802KB Genebank ID: 16395) and AG2-2 (Genebank ID: 2318768) were compared using orthovenn and PHI database. A Total of 119 proteins were identified to be specific to AG1-IA and 604 were specific to AG2-2 and 5364 protein sequences were common to both AG's. Out of them 10 AG specific genes were selected for the validation in AG1 isolate UP114 and AG2 isolate UP105 in rice genotypes Pusa Basmati 1 (susceptible) and ILS 12-5 (tolerant). Genes (AG1_IPT, AG1_BrD, AG1_HmPr) found specific to *Rhizoctonia solani* AG1-IA and gene (AG2_LisH) was found specific to AG2-2. Expression pattern of five *Rhizoctonia solani* AG1 genes varied at different time points of infection in rice pathosystem. The gene AG1_IPT (Inorganic phosphate transporter) transcript abundance was highest in PB1 at 24hpi but at 48hpi the expression increased in IL-12-5. However at 72hpi, an 11 fold increase was observed in PB1 compared to ILS. AG1 Brd (Bromo domain containing protein) expressed significantly in PB1 at all time intervals compared to control (pathogen) and ILS. Expression of AG2_LisH (Lissencephaly-1 homolog) was maximum in control (pathogen), and for the gene AG2_HyMt (Ephrin type-A receptor) expression was highest in PB1 at 48hpi.

Core microbiome on rice philosopher. The core microbiome consisting of *Pantoea, Methylobacterium, Streptophyta, Microbacterium, Sphingomonas, Enterobacter, Pseudomonas, Erwinia, Agrobacterium, Hymenobacter, Klebsiella, Deinococcus,* and *Novosphingobium* species were identified on rice philosopher. Species belong to *Pantoea Microbacterium Sphingomonas, Acinetobacter, Aeromonas, Brevundimonas, Comamonas, Klebsiella, Paenibacillus* and *Pseudomonas* isolated on culture media exhibited competitive interaction with rice blast pathogen. Upon redeployment on philosopher, microbiome associated bacterial communities not only suppressed blast disease by direct antagonism but also activated defense related rice genes which revealed their potential as potential biocontrol option for rice blast.

Chemical profiling of phyllosphere bacterial flora isolated from pomegranate. Seven of the isolated phyllosphere bacteria *Acinetobacter lwooffii* (KY575588); *Bacillus megaterium* (KY575589); *Microbacterium arborescens* (KY575590); *Sphingomonas yunnanensis* (KY575591); *Aureimonas phyllosphaerae*(KY575592); *Bacillus cereus* (KY575594); *Staphylococcus hominis* (KY575595) were subjected to

SPME GC-MS based volatile chemical analysis. Data files were processed against NIST library and match >800 were considered positive. All samples were compared with media associated compounds and common compounds were filtered from sample file. Chemical analysis revealed rich diversity of volatile organic compounds in phyllosphere bacteria.

5.1.4 Biological Control

Development of a carrier based bio control consortium to induce Fusarium wilt resistance in tomato. A carrier-based formulation of each of the bioagents constituting the consortia was prepared and assessed for their shelf life at room temperature (28±2°C). Seed treatment and soil application of the carrier-based formulation of the bioagents challenge inoculated with *Fusarium oxysporum* f.sp. *lycopersici* resulted in a significantly lower incidence (61.9% reduction) of *Fusarium* wilt relative to the pathogen control without biocontrol agents in polyhouse (18–20 °C). This lower incidence was associated with an increase in the plant vigor index of 64.8%, relative to the pathogen control.

In-vitro evaluation of phosphite as fungicide and bactericide. Transgenic rice constitutively over-expressing codon optimized synthetic gene encoding phosphite dehydrogenase of *Pseudomonas stutzeri* (In japonica rice cultivar Nipponbare and indica cultivars MTU1010 and BPT) showed that the transgenic rice plants could metabolize potassium phosphite as a P source, whereas, the non-transgenic rice plants showed phosphate starvation symptoms at various concentrations of phosphite. Potassium phosphite fungicidal & bactericidal activity was found at lower dosage of 35-100 mM against microbial pathogens. Complete *in vitro* inhibition of fungal pathogens was observed at 80-95 mM on *Magnaporthe oryzae* causing blast disease, *Rhizoctonia solani* causing sheath blight and *Fusarium fujikuroii* causing bakanae disease. Potassium phosphite was able to completely inhibit *X. oryzae* pv. *oryzae* at 35 mM and above.

Efficacy of bacterial antagonists against bacterial leaf blight of rice. A field experiment was conducted during *Kharif* 2018 at Agricultural Research Station, Banswara to test efficacy of bacterial antagonists, *Bacillus subtilis* DTBS-5, *B. amyloliquefaciens* DSBA-11 and *Pseudomonas fluorescens* DTPF-3 along with agrochemicals like streptomycin and copper oxychloride, immunomodulator like 2-Bromo- 2 Nitro Propane- 1,3 diol and bacterimycin. Variety Kali Kamod was sprayed thrice at 15 days interval after appearance of bacterial leaf blight disease caused by *Xanthomonas oryzae* pv. *oryzae.* The results showed that treatment with *B. subtilis* DTBS-5 formulation significantly reduced BLB disease severity as compared to other treatments.

Induction of systemic resistance in chilli plants by plant growth promoting rhizobacteria (PGPR) against Ralstonia solanacearum. The total number of 48 rizobacterial strains were assessed, 8 isolates exhibited strong inhibition to *R. solanacearum*. The maximum antagonism was recorded by Kar-15 up to 77%. Growth promotion activities were assessed by screening siderophores (60% were found positive), HCN, ammonia, IAA and P solubilization and it was recorded that five isolates were able to produce IAA, eight isolates produced siderophores and were able to solubilize phosphate. Few isolates were found to produce ammonia and HCN.

Biodegradation of pesticides by using antagonistic bacterial strain Bacillus subtilis DTBS-5. *Bacillus subtilis* DTBS-5 is massively used as biocontrol of plant diseases, and also for growth promotion as well as evokes gene expression of natural defense in plants. It produces biosurfactants which help in biodegradation of hydrocarbons. The result indicated massive potential of DTBS-5 to degrade pesticides such as chlorpyrifos and glyphosate yielding diethylphosphoric acid (DETP). The DTBS-5 was able to degrade glyphosate upto 98.00% at 100ppm, 95.12% at 400 ppm and chlorpyrifos to 99.86% at 100 ppm and 98.00% at 400 ppm in 22 days.

***Evaluation of rhizosphere bacterial antagonists for their potential to bioprotect wheat against powdery mildew (Blumeria graminis tritici*).** The talcum based

bioformulation of three different rhizosphere bacterial antagonists viz., *Pseudomonas fluorescence* strain DTPF-3, *Bacillus amyloliquefacience* strain DTBA-11 and *Bacillus subtilis* strain DTBS-5 and their combination at three different concentrations @ 5.0, 7.5 and 10.0 gm/kg seeds were tested for their ability to induce resistance in wheat against powdery mildew under glasshouse conditions. Significant reduction in disease severity (93.45%) was observed with *B. subtilis* DTBS-5 @ 10.0 gm/kg seed in comparison to other microbial antagonists. The bio-control efficacy was higher in *B. subtilis* DTBS-5 treated plants, followed by *B. amyloliquefacience* DTBA-11 and *P. fluorescence* DTPF-3.

5.1.5 Evaluation of Crop Genotypes for Disease Resistance

Rice. Out of 635 genotypes evaluated against sheath blight, 8 entries were found moderately resistant. Out of 388 genotypes including wild accessions evaluated against bakanae disease, 8 entries were identified resistant. Among 360 rice germplasms evaluted for blast resistance under artificial conditions, 31 entries were found resistant. A total of 398 rice entries were evaluated under Uniform Blast Nursery (UBN) pattern using rice blast isolate (U77-i7-k177-z17-ta733) from Rothak (Haryana) region. Entries, Raminad STR-3, *O. minuta,* Zenith, Tetep and Rasi were found resistant.

Mung bean. Out of 60 mung bean germplasm tested against dry root rot (*Macrophomina phaseolina*) under artificial pot inoculation condition in net house, four entries (HUM-6, Ml 512, IC 546488 and M 958) were found resistant. Out of 57 mungbean entries (AICRP trial) tested against this disease under net house condition on pot, eight entries were found resistant.

Chickpea. Out of 31 entries tested under net house condition in artificial pot inoculation, 6 entries were found resistant against *Rhizoctonia bataticola*. Out of 223 chickpea accessions, 26 were found resistant under artificial inoculation.

Pearl millet. Out of 64 pearl millet entries, 5 entries (PMBVN 34, PMBVN 48, PMBVN 50, PMBVN 54, PMBVN 55) showed resistance against blast disease. Out of 24 entries, under Disease Screening of Advance Pearl Millet Hybrids and Varieties trial, two resistant entries (PAT 203, PAT 205) were identified.

Cauliflower. One hundred ten germplasm lines of cauliflower were evaluated against three races (races 1, 4, & 6) of *Xanthomonas campestris* pv. *campestris* under field conditions. Race 1 was more dominant.

Wheat. The powdery mildew infected wheat disease samples collected from Rampur, Pantnagar, Haldwani, Dhaulakuan, Bilaspur, Katrain, Shimla, Gurdaspur, Ludhiana, Pathankot and Jammu were used for virulence analysis using host differential sets consisting 14 Near-isogenic PM lines along with two universal susceptible checks. Virulence was observed on gene *Pm*3a, *Pm*3b, *Pm*3c, *Pm*5, *Pm*7 and *Pm*8. Out of 589 wheat lines evaluated for rusts and leaf blight resistance at different hot spot locations, 30 entries were found highly resistant against rusts and leaf blight. Genotypes, HS 661, HS 662, HS 665, HS 666, VL 1016, VL 1014, HPW 441, HPW 442, PBW 752, PBW 762, PBW 763, PBW 801, PBW 800, HD 3226, HD 3237, WH 1218, DDK 1054 and DDK 1029 possess high degree of adult plant resistance to both stripe rust pathotypes. Evaluation of IPPSN (1156), PPSN (410), EPPSN (51) and MDSN (53) wheat genotypes revealed that 543, 196, 39 and 25 entries, respectively were found to be resistant to moderately resistant against both stripe and leaf rust at Delhi.

A total of 589 genotypes of preliminary disease screening nursery were evaluated for field resistance to stem and leaf rusts under artificial inoculations using mixtures of important pathotypes at IARI, Indore. Of these, 201 entries (~34 % of the total) showed resistance to both rusts. Out of 100 bread wheat entries from Indore, resistant genotypes were HAS 2525, HAS 2528, HAS 2529 and HAS 2558. The IARI Common Varietal Trials entries (total 160) were evaluated for seedling response to stem rust pathotype 40A. Out of these entries, 124 were observed to be resistant. A total of 9,445 of wheat lines received from breeders were

evaluated at Wellington, 90.00 % lines were resistant to moderately resistant to stem rust. Incidence intensity of powdery mildew was high in almost all these lines at early stages of growth. Disease screening nursery trials under AICW&BIP programme were laid out during Rabi 2018-19 viz., IPPSN(1250), EPPSN (58), PDSN (541), MDSN (38), NIVT (260) and AVT (158) were screened for stem and leaf rust resistance.

Among 138 recombinant inbred lines of a three way cross HD 3055/HS507//HPW349 developed by IARI, Shimla were evaluated for stripe rust resistance under natural condition at rust hot spot Dalang-Maidan, 26% of lines were recorded as resistant, 22% were moderately resistant, 28% were moderately susceptible and 24% were highly susceptible. The same set was also evaluated against virulent pathotype 110S119 at adult plant stage under artificial inoculm pressure in poly-tunnel, 28 were recorded with TR-5MR infection type. Among 166 advanced wheat breeding lines evaluated under CVT-SRT at Shimla, only six were found to possess seedling resistance to most virulent pathotype 110S119 of wheat.

A set of wheat genotypes (241) was inoculated with *Tilletia indica* at Zadok's stage 49 at IARI, New Delhi. Out of 149 advance lines and popular cultivars screened for Karnal bunt, 59 lines were found free from disease. Fifty one lines showed resistance to KB (<5.00 % incidence) while 23 lines were found moderately resistant (5-10 % incidence). Fifteen genotypes, HI 8774 (D), HPPAU 05, HPW 433, HS 622, PBW 725, RKD 283 (D), VL 3012, WH 1181, HS 627, WH 1184, HD 3171, DBW 179, MACS 5046 (Dicoccum), NW 6094 and HD 3043 were found resistant (< 5.0 % incidence) to KB. A set of wheat genotypes (149) was inoculated with head scab (Fusarium head blight) pathogen at mid anthesis with cotton web technique in poly house at IARI, Delhi. Only three lines showed resistance to head scab pathogen, *Fusarium graminearum*. Disease score was more than 2 (0-5 scale) in 130 lines. Thirteen genotypes, HPW 433, PBW 725, PBW 760, VL 3012, AKAW 4842, MACS 5044 (Dicoccum), MACS 5046 (Dicoccum), VL 4001, DBW 220, PBW 757, PDW 344 (D), UAS 459 (D) and UP 2954 were found moderately resistant to head scab. Genotypes, HPW 433, PBW 725, VL 3012 and MACS 5046 (Dicoccum) showed resistance to Karnal bunt and moderate resistance to head scab.

Maize. Ten trials were conducted to evaluate 290 maize genotypes against leaf blight (MLB) and banded leaf and sheath blight (BLSB, *Rhizoctonia solani*) diseases. Out of the total genotypes, 46 were found resistant to MLB and 70 were resistant to moderately resistant for BLSB. Among them, 10 genotypes were resistant against both the diseases. In case of Quality Protein Maize (QPM I, II, III) also, all the 24 entries were not found resistant against both the diseases. Total chlorophyll content was estimated high in resistant inbred line SC-7 as compared to the susceptible inbred line CM 119. Expression of pheophytinase (PPH) gene, the key enzyme/gene of chlorophyll degradation pathway, was also studied during pathogenesis of MLB disease at different time points by qPCR. Up regulation of PPH gene was found in the CM 119 that indicated higher degradation of chlorophyll due to disease.

Pepper. In sweet pepper, EC787067 was found tolerant to cucumber mosaic virus at Pune.

Papaya. Crop was found severely affected by Papaya ring spot virus (PRSV) at Pune centre. All the Pune Selections were found tolerant to PRSV whereas Red Lady was severely infected.

5.1.6. Epidemiology and Disease management

Simulation of leaf wetness for wheat rust prediction. Based on simple daily minimum and maximum temperature record, leaf wetness or high RH (>95%) hours was predicted using micrometerological parameters and tested for known locations where rust infection (by *Puccinia striiformis* and *P. graminis* f sp *tritici*) is common every year. Rust infection index predicted using simulated leaf wetness was observed to match the infection period noted in the field. Simulation of leaf wetness hours from simple available weather data would be useful for disease management advisories as well development of decision support system.

Developing yield loss assessment model for stripe rust and validation. Data on physiological parameters (NDVI & RBG indices) at different growth stages and agronomic parameters were recorded for protected and unprotected conditions. Grain yield of each condition was used to calculate the potential yield losses in each wheat variety with the aim of developing predictive model for grain yield and yield losses. Epidemiological parameters found to be accurate predictors of grain yield and grain yield loss infected with stripe rust (R2 = 0.569 and R2 = 0.527, respectively). The combination of epidemiological parameters and days to heading (DH) together expounded 71.85% of the variability in grain yield (GY) and 63.21% of the grain yield losses (GYL).

Management of bakanae disease of rice. Out of 5 fungicides *viz.*, propiconazole, pencyuron, carbendazim, azoxystrobin+difenoconazole and azoxystrobin+tebuconazole evaluated against bakanae disease of rice as seedling treatment, minimum disease incidence (35%) was observed in pencyuron followed by carbendazim (40% disease incidence) under *Fusarium fujikuroi* inoculated field conditions of IARI where disease incidence of inoculated control was 78%.

Management of sheath rot in paddy. The seed treatment with Carboxin 37.5% and Thiram 37.5% WS @ 2.5 gm kg^{-1} seed in combination with seedling dip in suspension of streptocycline@200 ppm followed by one spray Tebuconazole 50% + Trifloxystrobin 25% @ 1 g/litre water at 50 days after transplanting was found most effective for management of sheath rot in paddy. Minimum disease incidence of 5.2% and maximum yield (5.87 t/ha) was recorded with this treatment while in control the disease incidence was 10.7%.

In planta evaluation of phosphite as fungicide against rice blast. Potassium phosphite controlled rice blast with spray at 100 mM that revealed its potential as fungicide. NGS based metagenomics and conventional microbiological tool based phyllosphere microbiome analysis revealed no adverse effect of ptxD gene expression on microbiome of rice as both the plants recorded identical phyllosphere microbial communities.

Effect of bio extract/plant products for maize blight. Ten non-chemical ingredients including nine botanicals and cow urine were evaluated for managing MLB disease during *kharif* 2016, 2017 and 2018. The pooled data showed no significant effect of any of the ten bio-extracts tested in restricting the MLB disease unsprayed control. However, neem and garlic resulted in 20% disease control followed by False Ashoka (15%). Significantly higher grain yield was obtained in neem extract (2.385 t/ha) followed by garlic (1.965 t/ha) and False ashoka (1.831 t/ha), whereas least was recorded in control (1.127 t/ha).

IDM module for managing maize diseases. For the management of BLSB, IDM module comprising soil amendment with *Trichoderma* formulation [@6 t/acre FYM] + seed treatment with salicylic acid [100 ppm] + foliar spray with Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC @0.1% using 500 l water/ha [at 3 DAI] and neem leaf extract [@1%, at 15 DAI] was the best with 68% disease control and 2.4 t/ha grain yield.

Management of spot blotch in wheat. Minimum % diseased leaf area (21.86 %) and maximum grain yield per plot (plot size 4/2m2) was recorded in treatment (seed treatment by Carboxin 37.5% + Thiram 37.5%WS @ 2.5 g kg-1 seed + two foliar sprays of Propiconazole25% EC @ 0.1% one at boot leaf stage and 20 days after1st spray) treated plots as compared to control . Disease score up to 56 was observed in control plot while in best treatment the score of only 12 or 23 was observed.

Integrated management of viral diseases in vegetable crops at IARI, Pune. Crop cover along with best treatment (silver colour polythene mulch, biopesticide and pesticide spray) was evaluated for virus disease incidence and vector population under field conditions for tomato. Crop cover was effective in decreasing disease incidence to 0.03% as compared to control (6.84%) and increasing yield to one and a half times in addition to reducing the number of sprays by half. The results of the experiment were validated at farmer's field at Narayangoan (Pune district). In the muskmelon field experiment, silver colour

polythene mulch with row cover and alternate spray of Agroneem (0.2%) and Imidacloprid (0.01%) was found most effective in managing viral diseases. The disease incidence was reduced to 2.95% when compared with control (13.68%) and the marketable yield was increased up to 2-3 folds as compared to control. To validate the results, a field trial was conducted at Farmer's field in Daund (Pune district) where cost benefit ratio was 2.02.

5.2 ENTOMOLOGY

5.2.1 Integrated Pest Management

5.2.1.1 Rice

Evaluation of rice germplasm against brown planthopper (BPH). Twenty rice germplasm possessing different resistant genes were evaluated against BPH under greenhouse conditions on 0-9 damage scale in the presence of TN-1 as susceptible check, using mass screening technique. Two germplasm were identified as highly resistant (2.8 damage score), one as moderately resistant (3.38) and two as susceptible (6.5-6.89), while remaining 15 germplasm were highly susceptible.

Evaluation of compatibility of insecticides and fungicides against rice pests. The objective of the experiment was to evaluate efficacy of insecticides and fungicides, solo and in combination, against insects and diseases. Insectcides viz., spinetoram 6% + methoxyfenozide 30% 36EC @ 0.75 ml/l and triflumezopyrim 106SC @0.48 ml/l; fungicides viz., hexaconazole 5SC @ 2.0 ml/l, and tricyclazole 75WP @ 0.6 ml/l, and their combinations viz., spinetoram 6% + methoxyfenozide30% + hexaconazole @ 0.75+2.0 ml/l, spinetoram 6% + methoxyfenozide 30% + tricyclazole @ 0.75+0.6 ml/l, triflumezopyrim+hexaconazole @ 0.48+2.0 g/l and triflumezopyrim+tricyclazole @ 0.48+0.6 g/l along with an untreated check were evaluated against rice pests on Pusa Basmati 1637 in randomized block design (RBD) with three replications. The different pesticides were applied at 16, 54, 67, 77 days after transplanting (DAT). Observations on pest incidence were commenced at 30DAT and continued until crop maturity at 10 days intervals. Among insects, only brown planthopper (BPH) was observed to be economically important, while rice diseases did not occur. The BPH population was low until 50DAT, varying from 0-12.6 hoppers/10 hills in different treatments. Between 60-90 DAT, BPH population ranged from 277-2241 hoppers/10 hills in untreated control, while in triflumezopyrim treated plots and in combination treatments having triflumezopyrim viz., triflumezopyrim + hexaconazole and triflumezopyrim + tricyclozole, the pest population varied between 0-19 hoppers/10 hills. The BPH population in these three treatments was significantly lower than untreated control, while in other treatments it was at par with untreated control. Triflumezopyrim was observed to be most effective treatment against BPH followed by triflumezopyrim+hexaconazole and triflumezopyrim + tricyclazole. Crop yield in triflumezopyrim treatments was significantly higher than untreated control, while it did not differ significantly from untreated control in other treatments. The yield was found to be highest in triflumezopyrim treatment. In triflumezopyrim + tricyclazole and triflumezopyrim+hexaconazole, the efficacy of triflumezopyrim insecticide did not seem to be affected by fungicides.

Evaluation of biopesticides against rice insect pests. Biopesticides viz., camphor oil @ 1000 ml/ha, cedarwood oil @ 1000 ml/ha, eucalyptus oil @ 1000 ml/ha, lemon grass oil@ 1000 ml/ha and neemazal @ 1000 ml/ha, were evaluated against rice insect pests on Pusa Basmati 1637 along with insecticidal checks viz., dinotefuran 20 SG@ 200 g/ ha and coragen 20SC @ 150 ml/ha, and an untreated control. Biopesticides and insecticides were applied at 12, 22, 31, 41, 50, 60 and 71 days after transplanting (DAT). Brown plant hopper (BPH) population remained very low in different treatment until 50 DAT, where it varied from 17.3 – 31 hoppers/10 hills at this stage. However, the pest population attained its peak at 90DAT. AT 60DAT, the BPH population in dinotefuran treated plots was significantly lower than untreated control, while it was at par with untreated control in coragen and all biopesticide treated plots. Between 70-90 DAT, the BPH population in different treatments including dinotefuran treatment did not differ significantly from

untreated control. Only dinotefuran thus proved to be somewhat effective against the pest.

Effect of crop phenology on rice insect pests. Effect of three sowing dates viz., 5th July, 18nd July and 5th August was evaluated against brown planthopper (BPH) on Pusa Basmati 1637. The BPH population at its peak was found to be significantly higher in II (31.1 hoppers/hill) and III (30.9 hoppers/hill) transplanting compared to I transplanting (8.9 hoppers/hill). The BPH population in II and III were almost equal. The late transplanted crop thus had higher BPH infestation, which has also been observed earlier. Likewise, incidence of rice leaf folder was also observed to be lower in I (4.9%) compared to III (7.6%) and II (8.8%) transplanting. On the other hand, whorl maggot damage was significantly lower in I (7.0%) and II (7.3%) transplanting was significantly lower than III transplanting (12.6%). The early transplanting thus had least incidence of all the three pests, BPH, leaf folder and whorl maggot.

Bio-efficacy of buprofezin against brown planthopper Nilaparvata lugens under elevated CO_2. The effect of elevated CO_2 (570±25ppm) on the brown plant hopper *Nilaparvta lugens* (Stal) (BPH) population, rice yield parameters and efficacy of buprofezin (0.05%) in terms of spray volume was studied during *kharif* 2018. The pest population did not vary between elevated and ambient CO_2 during the season. Under elevated CO2, rice plants had more vegetative tillers (18%) and reproductive tillers (22.1%), but there was decrease in 1000-seed weight (11.3%), seed number per panicle (13.1%) and grain yield (18.8%). The spray volumes of 700, 600, 500 and 400 l/ha each caused higher BPH mortality under ambient CO_2 compared to elevated CO_2. Spray volume of 500 l/ha was not effective at all under elevated CO_2. Insufficiency of spray volume of 500 l/ha could be ascribed to higher canopy size under elevated CO_2. Increased crop canopy under elevated CO_2 may thus require higher spray volume to ensure proper coverage. Thus there is need to revise spray volume recommendations to facilitate effective management of BPH under climate change.

Whitefly management. Imidacloprid resistant populations of whiteflies were tested for susceptibility to a diamide compound, cyantraniliprole. Whiteflies were collected from cotton fields at different locations viz., Pusa Campus (New Delhi), Sriganganagar (Rajasthan) and Hisar (Haryana) and reared under specified temperature and humidity conditions at IPCCC, Division of Entomology, IARI, New Delhi. *Bemisia tabaci* populations were identified based on specific mitochondrial cytochrome oxidase I primers and the genetic group of the populations were confirmed as Asia II using phylogenetic analysis. Bioassays were conducted on adult whitefly following the IRAC protocol. The LC_{50} values of whitefly populations to imidacloprid were 204.7 ppm (New Delhi), 889.7 ppm (Sriganganagar) and 361.5 ppm (Hisar), which showed resistance development of these populations to the chemical. Unlike imidacloprid, the LC_{50} values for cyantraniliprole was more or less same for all the three populations, viz., 5.03, 3.876 and 3.41 ppm for New Delhi, Sriganganagar and Hisar populations, respectively. This study confirms the substantial susceptibility of imidacloprid resistant whitefly populations to cyantraniliprole and the possibility of using the chemical in insecticide resistance management (IRM) programs of whitefly.

5.2.1.2 Vegetables and fruits

Cauliflower. Intercropping of cauliflower and selected flower crops (Candytuft, Calendula, Marigold, Daisy and Cineraria) were evaluated for insect pest management in cauliflower. The date of sowing of flower crops and cauliflower was adjusted to make peak flowering of flower strips to coincide with the pest incidence in cauliflower. The numbers of aphids (both *Brevicoryne brassicae* and *Lipaphis erysimi*) observed on the marked plants in the experimental and control plots increased steadily during the experimental period whereas, the proportionate decrease in the aphid count was noticed in flower intercropping except in Daisy intercropping system. During 10th SMW significantly more number of syrphids and coccinellid population was observed in all the flower intercrop system over the control. Where, Cineraria flower intercrop was

reported with more number of syrphids (12.00) and coccinellid beetle (9.33) population. Among the intercrop cineraria flower crop reported with less number of aphid and even attracted more number of syrphids as well as coccinellid beetle can be potential component in IPM programme.

Brinjal. A habitat management trial of brinjal was conducted with eight treatments that contained any one of the four intercrops viz., marigold, amaranthus, cluster bean, sunflower along with either of the two border crops viz., maize or french bean against insect pest. Results revealed that all the treatments were significantly superior over control. The treatment containing maize as border cropped having *amaranthus* as inter crop was most effective and it gave only 6.42% infestation due to Brinjal shoot and fruit borer (BSFB) which was followed by treatment with maize as border crop and cluster bean as intercrop incurred 8.12% BSFB infestation while check gave 22.1% infestation on weight basis.

Okra. Screening of 30 germplasm was undertaken against insect pests of okra. The results inferred that wild genotypes showed immune to shoot and fruit borer as compared to other cultivated varieties. Germplasm *DOV- 28* was found susceptible to mealy bug infestation and DOV- 92 found luxurious growth and more fruits while *Arka anamika* showed yellow vein mosaic virus symptoms.

5.2.1.3 Soybean

Seasonal incidence of insect pests. The soybean crop was found infested right from its seedling stage by whitefly, *Bemisia tabaci* (Gennadius). The numbers of whiteflies were recorded on the upper, middle and lower leaves from ten plants per plot. The mean numbers of whiteflies per plant were less compared to last year. Incidence of yellow mosaic virus disease transmitted by white flies was slightly higher (maximum average incidence rating of 8.00 on a scale of 1-9.

Field screening of AVT entries for resistance to major insect pests. Twenty three lines of AVT I&II were evaluated against stem fly and YMV of soybean under both protected and unprotected conditions. AVT lines *viz*., DSB 34, AMS 2014-1, PS 1611, PUSA 9712, RSC 1103, SL-688 and RSC 1071 were highly resistant to YMV disease; while AVT lines *viz*., KDS 992, MACS 450, MACS 1520, MACS-NRC 1575, SL 958, and RSC 1052 were found susceptible on a scale of 1-9 against YMV.

5.2.1.4 Pulses

Monitoring of chickpea pod borer, Helicoverpa armigera and Spodoptera exigua moths using pheromone traps. Adult population of chickpea pod borer, *Helicoverpa armigera* and *Spodoptera exigua* was monitored using pheromone traps in chickpea during 2015-16 to 2018-19 in Delhi. Data revealed that the activity of *H. armigera* started from 4th standard meteorological week (SMW) with highest activity during 8th to 16th SMW during the crop season in all four years. The peak activity was observed to be during 12th, 10th and 15th SMW during 2015-16, 2016-17 and 2017-18 & 2018-19, respectively. Similar trend was observed with *S. exigua* also.

Pigeon pea germplasm evaluation. Five extra early (115-120 days) test entries of pigeon pea were evaluated for their performance against different pests. There was no significant difference in number of *Maruca* webs/plant among different entries except in 44th SMW where EE 102 found to be more susceptible. Similarly significant difference could not be observed in case of *Helicoverpa* infestation except in 46th SMW where EE 103 was found to be susceptible. Out of seven early maturing (121-150 days) test entries evaluated, *Maruca* was found to be more on entry E207 on 44th and 46th SMW and E 202 during 45th SMW. Significant difference in *Helicoverpa* infestation was observed only during 44th SMW where E202 was found to be susceptible to *Helicoverpa*.

5.2.2 Biological Control

Bionomics and predatory potential of six spotted ladybird beetle on cotton mealybug. It was found that coccinellid beetle highly preferred second instar mealybug for predation. The most voracious predator

was female followed by male and fourth instar of *C. sexmaculata.* The total life span was higher for mated females (73 days) than mated males (61 days) and unmated females (47 days) than unmated males (39 days). Both male and female of *C. sexmaculata* were seen exhibiting type-II functional response. Studies revealed that the maximum prey killed by females (30) and males (20.5) was achieved at prey density of 80 which decreased to 26.8 and 15.6 at maximum prey density of 120. Higher handling time was recorded in male (0.046 days) as compared to female (0.025 days). The attack rate was found more in females (1.37) than in males (1.06) in *C. sexmaculata* against *P. solenopsis.* Maximum theoretical predation rate was 21 for males and 40 for females at 24 hrs of exposure. Females were found to be an efficient predator than males, as they consumed preys faster and spend less time than males, that's why handling time and attack rate is less for females than males of *C. sexmaculata* against *P. solenopsis.*

Intraguild Predation (IGP) in predatory coccinellids. Intraguild Predation (IGP) studies revealed that there existed intraguild interactions between *C. sexmaculata* and other coccinellid predators viz., *Coccinella septempunctata* Linnaeus, *Brumoides suturalis* Mulsant, *Cryptolaemus montrouzieri* Mulsant and *Scymnus coccivora* Ayyar. Among these predators, *C. septempunctata* was most competent as its adult was able to attack even the fourth instar of *C. sexmaculata*. It has been revealed that the presence of extraguild prey had a say in determining the frequency of IGP as it increased when the predators were starved of their common prey. Among the predators under study, it has been found that *C. montrouzieri* underwent lesser predation by other species and showed maximum preference to mealybugs rather than involving in IGP with other species. So this predator could be combined with *C. sexmaculata* for release to control mealybugs. The size, mobility, surface volatiles of intraguild prey along with the presence of extraguild prey might be determining the frequency of IGP.

Spatial distribution of predatory coccinellids and wheat aphids. Spatial distribution of mixed population of the aphids and predatory coccinellid beetles was analyzed using variance-mean ratio and regression models such as Taylor's power law and Iwao's mean crowding. The aphids and its predatory beetles were counted at 68, 75, 82, 91, 100, and 106 days after sowing (DAS) of wheat crop. The mean population for wheat aphid was 2.48, 7.88, 5.24, 1.33, 1.06 and 0.72/plant on 68, 75, 82, 91, 100, and 106 days, respectively. Variance-mean ratio of aphids indicated regular to aggregate distribution on the crop. Taylor's power law aggregation parameter (b = 2.62) and density contagiousness co-efficient (β = 1.20) of Iwao's mean crowding regression also revealed aggregated distribution for the wheat aphids. The mean population of coccinellid beetles varied from 0.72, 0.77, 0.77, 0.80, 1.43 and 1.06/plant on 68, 75, 82, 91, 100, and 106 days, respectively. Taylor's power law aggregation parameter (b = 3.63) and density contagiousness co-efficient (β = 2.08) of Iwao's mean crowding regression revealed aggregated type of distribution of the predators on the wheat crop.

Sequential sampling plan for wheat aphids with incorporation of predator effect. Sequential sampling plans were developed for wheat aphid management with and without predator effect through Taylor's power law and Iwao's mean crowding regression. The lower and upper decision line values, i.e. cumulative aphid population without predator effect after four sample units, were 25 and 56 aphids, respectively, as per the sequential sampling decision line with Taylor's power law. On the other hand with predator effect, the lower and upper decision line values were 40 and 116 aphids, respectively, which suggested need for management measures at higher population level of the pest. With Iwao's method the lower and upper decision line values without predator effect after four sample units (for example) were 29 and 51 aphids, respectively. However, the lower and upper decision line values with predator effect were 52 and 102 aphids, respectively. In case of indecisiveness, the maximum number of sampling was determined to be about seven sampling units. If decision is not reached even after 7 sampling units, then sampling would be suspended and resumed after 4-5 days interval. The sequential sampling with predator effect suggested

need for management interventions at higher aphid densities. This would also help in conserving predatory coccinellid beetles, reducing environmental contamination and would ensure higher profit to the growers.

Biology of Rhynocoris marginatus and Coranus fuscipennis (Hemiptera: Reduviidae). *R. marginatus* is known to be the highly potential heteropteran reduviid predator in southern Indian conditions. Adults were collected from maize field for studying life history attributes. Total developmental duration of bugs was observed varied between 38 to 43 days when reared on *Corcyra* larvae. Incubation period was found to be 3-5 days; nymphal period was 2-3, 4-5, 6-8 and 11-14 days for 1st, 2nd, 3rd and 4th instar bugs, respectively and total nymphal period was found to be 20-30 days. Pre-oviposition period lasted for 6 hours to one day and longevity of adults was found to be 6-10 days. Adults were also collected from cotton field. Total developmental duration of bugs was observed to vary between 25-35 days when reared on *Corcyra* larvae. Incubation period was found to be 2-4 days, during previous studies, same species eggs were not hatched under laboratory condition, during this season eggs were kept in rearing room with temperature 25 ± 5 ^{0}C as well as at normal room temperature with 30 ± 5 ^{0}C, eggs were hatched (50 - 60 %) at normal room temperature within 2-4 days with poor survival ability and th eggs kept under laboratory temperature did not emerge properly. Nymphal period was 2-3, 3-5, 3-7 and 8-11 days for 1st, 2nd, 3rd and 4th instar bugs, respectively and total nymphal period was found to be 16-20 days. Pre-oviposition period lasted for a day and longevity of adults was 4-7 days.

Behavioural response of Mallada boninensis to hydrocarbons. The preference of adult *M. boninensis* to plant hydrocarbons was tested in eight arm olfactometer. The attractancy of all hydrocarbons to *M. boninensis* was significantly higher than control hexane except pentacosane. Hexadecane attracted more *M. boninensis* followed by tricosane where the attractancy percentage was 16.00±3.11 and 15.00±1.93%, respectively. The preference of adults to remaining compounds are presented in descending order as follows tetracosane (13.30±2.40) > triacontane (10.00±0.88) > heneicosane (10.00±1.67) > docosane (10.00±2.04) > pentacosane (6.60±1.06%). Statistically no significant difference was noticed among the adult preference to hydrocarbons except hexadecane (Fisher's LSD, $p < 0.05$). The attractancy of tricosane, heneicosane and docosane to *M. boninensis* was equal (10.00%) with attractancy of non-responsive insects.

5.2.3 Insect Physiology

Effect of heat shock on survivability and reproduction of Spodoptera litura adults. Pre-sexed newly emerged adults of *S. litura* maintained at 26±1 ^{o}C were exposed to four higher temperatures *viz*., 40, 42.5, 45 and 47.5 ^{0}C for different durations ranging from 5 to 360 min depending on temperature and then they were recovered and maintained at 26±1 ^{o}C. The survival rate of both the sexes declined with the increase in temperature; however the longevity of males was longer as compared to female. The lethal time needed to cause 50% and 90% mortality decreased steeply with the increase in temperature from 40 to 47.5 ^{0}C. No eggs were deposited by *S. litura* adults exposed to 47.5 ^{0}C irrespective of duration.

Damage threshold of diapausing and nondiapausing Chilo partellus populations on resistant and susceptible maize genotypes. We measured differences in damage potential, development and survival of F_1 generation of diapausing and non-diapausing populations of *Chilo partellus* in resistant and susceptible maize genotypes. The observations were recorded on percent leaf damage, larval weight, per cent larval survival, food preference, leaf damage rating and deadhearts. There were significant differences in development, survival, and damage potential by diapause and non-diapause *C. partellus* populations on test resistant and susceptible maize genotypes. The *C. partellus* larvae from aestivation population preferred resistant as compared to susceptible maize genotype. However, the susceptible genotype was preferred over resistant by the non-diapause larvae. Highest leaf area damage in both susceptible and resistant maize genotypes

was found by hibernation than aestivation and non-diapause *C. partellus* populations. The larval survival was significantly higher in hibernation as compared to aestivation and non-diapause *C. partellus* populations on both resistant and susceptible maize genotypes. Among test maize genotypes the larval survival in all the three *C. partellus* populations was significantly lower on resistant as compared to susceptible maize genotypes. The larval weight was significantly higher in non-diapausing as compared to hibernation and aestivation populations on both resistant and susceptible maize genotypes. Among the diapause populations, the larval weight was significantly higher in hibernation than aestivation population on resistant and susceptible maize genotypes. The leaf damage rating and deadheart formation were significantly higher by hibernation as compared to aestivation and non-diapause *C. partellus* populations on both resistant and susceptible maize genotypes. These findings suggest that the identification of region-specific sources of resistance to *C. partellus* could be more rewarding for the management of this difficult to control pest in maize.

Fitness consequences of delayed mating on reproductive performance of Chilo partellus. We investigated effects of mating among different aged males and females on reproductive physiology, progeny production and longevity of *C. partellus* adults under laboratory conditions. Present studies involved virgin males (M) and females (F) of three different ages *viz.*, on the day of emergence (1D), next day (2D), and further next day (3D), thus comprising of a total of 9 mating treatments (1DM× 1DF, 1DM×2DF, 1DM×3DF, 2DM×1DF, 2DM×2DF, 2DM×3DF, 3DM×1DF, 3DM×2DF and 3DM×3DF). The observations were recorded on fecundity, fertility, hatchability, and longevity of male and female adults. Present study showed that the age of both males and females in a mating system significantly ($P<0.005$) affect the fecundity, eggs hatchability, eggs fertility and adult longevity. The fecundity was significantly higher in 1DM×1DF and lower in 3DM×3DF in comparison to other mating treatments. Furthermore, although the mating among different aged males and females showed significant differences, the fecundity was greatly influenced by age of the female more than that of male. There were significant differences in percent egg hatching among different mating treatments. The egg hatching was significantly higher in 3DM×1DF, and none of the eggs hatched in 3DM×3DF mating treatment. The hatching of the eggs obtained from the crosses between 3D females across all the ages of males was significantly on par with each other, being lower than the rest of the mating treatments. Further, the egg hatching was significantly higher in the cases where 1D females were used in the mating irrespective of age of the males as compared to other mating treatments. The percentage of unfertilized and unhatched eggs laid by the *C. partellus* females varied significantly across different mating treatments. Converse to egg hatching, percent unfertilized eggs were significantly higher when 3D females mated with males across all the ages as compared to other mating treatments, thus leading to lower percentage of unhatched eggs in these mating treatments. The longevity of male and female adults was significantly higher in 3DM×2DF, being lower in 1DM×1DF mating treatments as compared to other mating treatments, except female longevity in 2DM×3DF mating treatment which was on par with 3DM×2DF. Furthermore, there were significant differences in spermatophores recovered from the reproductive tract of females across different mating treatments. Highest mean number of spermatophores (also highest number of 2 spermatophores) were recovered from the reproductive tract of females in 3DM×1DF as compared to other mating treatments. However, no significant association was found between longevity of male ($R^2 = 0.23$; $df = 8$; $P = 0.57$) and female ($R^2 = 0.40$; $df = 8$; $P = 0.28$) adults and recovery of numbers of spermatophores from the females across different mating treatments.

Activation of certain biochemical constituents through enzymatic and nonenzymatic antioxidants impart resistance against Chilo partellus in sorghum. We studied the biochemical defense through activation of enzymatic and nonenzymatic

antioxidants in response to damage by *Chilo partellus* in diverse sorghum genotypes. The level of nutritional compounds such as total sugars, total soluble protein, total lipid and starch content were significantly lower; and anti-nutritional compounds like phenol, total antioxidant and ferric ion anti reducing power (FRAP) were higher significantly higher in *C. partellus* resistant than in susceptible sorghum genotypes both under *C. partellus* damaged and healthy plant conditions. However, total chlorophyll and total carotenoids were significantly lower in test sorghum genotypes than in susceptible genotype, Swarna. Further, the amounts of total sugars, total soluble protein, starch content, total lipid and FRAP increased, and that of total chlorophyll and carotenoids decreased across all the test sorghum genotypes in response to damage by *C. partellus*. Further, present studies demonstrated that the activity of plant enzymes *viz.*, ascorbate oxidase, ascorbate peroxidase and catalase these enzymes was significantly higher in test sorghum genotypes in comparison to susceptible genotype, Swarna, which also increased significantly in response to damage by *C. partellus* across test sorghum possibly result in physiological and chemical changes in the form of accumulation of plant defense compounds in test sorghum plants. Thus, the genotypes *viz.*, ICSV 1, ICSV 700, ICSV 93046, IS 18551 and IS 2205 impart biochemical defense through enzymatic and nonenzymatic antioxidants, and can be utilized in breeding for resistance against *C. partellus*.

Virus vector interactions in whitefly, Bemisia tabaci. Studies on virus vector dynamics showed *significant* differences in the rate of transmission between *B.tabaci* genetic groups, Asia I and Asia II-1. Asia II-1 population reared on tomato, cotton and brinjal showed transmission efficiency of 6.67±0.58, 5.67±0.58 and 5.33±0.58 per cent, respectively, which is significantly higher to Asia I populations of *B. tabaci* with the transmission efficiency being 3.67±1.53, 4.67±0.58, 3.00±0.00 respectively on hosts, tomato, cotton and brinjal. Our studies have shown differences in transmission efficiency of *Tomato leaf curl New Delhi virus* as influenced by genetic groups, sex of the whiteflies, host plants and insecticide susceptibility status of the genetic groups.

Emerging threat of new begomoviruses vector. Solanum whitefly *A.trachoides* has was identified as an emerging vector for the begomoviruses in solanaceous vegetables. *A. trachoides* infested field samples of *Duranta* sp (100%) and tomato (20%) were found positive for begomoviruses. The DNA samples of *A. trachoides* collected from virus positive *Duranta* and tomato plants also found positive for virus. *A. trachoides* could successfully transmit *Duranta leaf curl virus* to capsicum and tomato plants under controlled conditions. The rate of virus transmission by *A. trachoides* from tomato to tomato was high.

Characterization of gut bacterial isolates in key insect pests. Gut bacterial diversity of *Anomola* sp was explored. Molecular characterization of the isolates was done using 16s rRNA probes. Generic identity of the bacteria revealed that some of the prominent isolates include, *Pseudomonas aeruginosa, Bacillus pseudomycoides, Ochrobactrum, Bacillus qingshengii, Paenibacillus jamilae, Ochrobactrum anthropi, Citrobacter koseri, Bacillus aryabhattai* and *Bacillus cereus.* Cellulolytic and lipolytic activities of these gut bacterial isolates were profiled.

Influence of juvenile hormone analogue, parapheromone and adult dietary protein on mating behavior of sterile males of B. cucurbitae. Suppression or elimination of introduced populations is the attractive features of the SIT and that it is absolutely specific to the targeted pest, reduces the use of toxic insecticides, and its action is inverse-density dependent. The success of sterile males to compete wild males was influenced by methoprene, cue lure and yeast hydrolysate. The study on enhancement of mating performance of sterile males was carried out under laboratory conditions. The mating parameters *viz.*, lek initiation, lek participation, male calling, mating success and female acceptance index (FAI) were recorded. The sterile males treated with methoprene and access to yeast hydrolysate (M + P+) matured sexually 3-days earlier than males fed only on either sugar (M-P-) or methoprene (M+P-). High percentage of M + P + sterile males was involved in lek initiation (57.0), lek participation (48.0) and male

calling (43.0). Sterile males exposed to methoprene and proteins were more attractive to their mates and had frequent matings (35.0%) with Female Acceptance Index (FAI) of 0.82. Moreover, M+P+ exposed males had higher mating propensity up to the age of 18-days. The sterile males having access to yeast hydrolysate up to 10-12 days and then exposed to cue lure (P+CL+) had mating advantage over the males fed on either sugar only (P-CL-) or cue lure alone (P-CL+). Access to yeast hydrolysate-sugar diet following adult eclosion up to 10-12-days of age and then exposure to cue lure on a day before release is a promising way to enhance the mating performance of sterile males of *Bactrocera cucurbitae.* The combinations of methoprene application and yeast hydrolysate showed an additive effect on increased mating success in *B. cucurbitae* sterile males. The identified larval diet, radiation dose and pre-release adult diet supplementation with insect hormones could be of potential use to improve operational SIT application against melon fly.

Field evolved resistance to Bt cotton BGII expressing Cry1Ac and Cry2Ab in the pink bollworm, Pectinophora gossypiella. Transgenic Bt Cotton in India revolutionized the cotton production and bollworm complex control in India since its commercialization. However, the success of Bt cotton appears to be reduced as pink bollworm (PBW) has developed resistance at field level to BGI cotton expressing Cry1Ac in India in 2009. Nine PBW populations were collected from different locations and reared in the laboratory on semi-synthetic diet to evaluate their susceptibility to Cry1Ac, Cry2Ab and BGII (Cry1Ac+Cry2Ab). Five day old Delhi (Lab-Sus) population was found to be most susceptible and significantly different in toxicity from all nine populations followed by Dharwad (non Bt cotton) population. Populations from Guntur recorded highest LC_{50} value of 3.13 µg/ml of diet and 53.55 fold resistance to Cry1Ac followed by Junagarh population (42.85 fold). The median lethal concentration response to Cry2Ab ranged from 0.038 to 1.692 µg/ml of diet and Cry2Ab proved to be more toxic than Cry1Ac against most of the PBWpopulations. Guntur population recorded highest resistance ratio of 80 fold (LC_{50}=3.64 µg/ml of diet) to BG II seed powder followed by Raichur (34.06 fold) (Fig.1&2).In our earlier reports two years survey data indicated that high incidence of PBWin central and south cotton growing zone of India in concurrence with high LC_{50} values to Cry1Ac, Cry2Ab and BGII (Cry1A+Cry2Ab) in most of the cotton growing regions of Central and South India *vis a vis* susceptible population provided the evidence of field evolved resistance in the pink bollworm to BGII cotton.

Mechanism of BGII resistance in pink bollworm, Pectinophora gossypiella. To elucidate the mechanism of BGII resistance in PBW, activity of midgut enzymes *viz.,* alkaline phosphatase and aminopeptidase N were estimated in resistant as well as susceptible populations of PBW. Significantly high alkaline phosphatase activity observed in the BG II resistant Guntur population (221.037 µM/min/mg of protein) compared to Delhi (Lab-Sus) population (147.03 µM/min/mg of protein). Cry1Ac resistant (Guntur) and Cry2Ab resistant (Parbhani) populations also showed high activity of alkaline phosphatase than control. Specific activity of leucineaminopeptidase N was high in BG II resistant Guntur population (6.82 µM/min/mg of enzyme) which is significantly different from Delhi (Lab-Sus) population (1.69 µM/min/mg of enzyme). Increased activity of alkaline phosphatase and aminopeptidase N in BG II resistant populations indicates association of these two enzymes in imparting resistance in *P. gossypiella* against BG II.

Gut microbiota of Plutella xylostella inhibits multiplication of Bacillus thuringiensis. Chewing folivorous lepidopterans are one of most important consumers of plants foliage in the world. Among them diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Plutellidae) is the most destructive pest of cruciferous crops globally. It has developed field resistance to most of the insecticides representing all major classes. It is the only insect pest which has developed resistance to sprayed *Bt* formulations in the field. In spite of the important ecological mean of DBM, the knowledge about interaction among

symbiotic and pathogenic microbiota is meagre. In the present study 23culurable gut bacteria were isolated from DBM larvae and their 16S rDNA analysis showed that these gut bacteria belongs to *Staphylococcus* spp. (34.8%), *Enterobacter* spp. (26.1%) *Bacillus subtilis* (13%), *Serratia* spp. (13%), *Citrobacter* spp. (8.6%) and *Flavobcterium acidificun* (4.3%). A confrontation culture analyses of the 23 gut bacterial isolates against *Bacillus thuringiensis* sub sp *kurstaki* HD-1 strain showed that the seven gut bacteria had antibacterial activity against the *B. Thuringiensis* strains. *B. subtilis* showed highest activity followed by *Enterobacter* and *Serratia.Bacillus thuringiensis* and its Cry toxins are widely used for insect control but still its mechanism has not been completely deduced. These results propose that gut bacteria can potentially affect the susceptibility of DBM to *B. thuringiensis.*

5.2.4 Insect Toxicology

Plant Volatiles. Maize plant volatiles were collected through dynamic headspace collection by using Porapaq Q adsorbent. GC-EAD (Gas Chromatography-Electroantenno detection) analysis of maize plant volatiles against male individuals of Maize stem borer, *Chilo partellus* revealed the six insect responsive volatiles namely, toluene, 2-ethyl-1-hexanol, 4-hydroxy-4-methyl-2-pentanone, p-xylene, 1, 4-diclorobenzene, p-isopropyl benzaldehyde.

Field evaluation of insecticides impacting foraging activities of pollinators in cotton and mustard crops. Response of seven insecticides *viz*., imidacloprid and thiamethoxam (seed dresser), chlorantraniliprole, spinosad, flubendiamide, indoxacarb and fipronil (foliar application) on foraging activities of pollinators in cotton and seven insecticides viz., imidacloprid, thiamethoxam, thiacloprid, chlorpyriphos, dimethoate, acephate and fipronil in mustard were evaluated under open field conditions. *Apis dorsata, A. florae, Ceratina* and *Megachile* spp was the most dominating bee species in cotton whereas in mustard, *A. cerana indica* was the most dominating bee species throughout the crop growth period followed by *A. dorsata* and *A. florae.* Seed treatment of cotton with imidacloprid and thiamethoxam has not shown any visible impact on foraging activities of pollinators in cotton. Impact of seed treatment normally persists for 30-35 days after sowing and flowing in Bt cotton normally appears 60-65 days after sowing and by that time residue of insecticides might be dissipated resulting no adverse impact of seed treatment on foraging activities of pollinators. Foliar application of insecticides affected adversely on foraging activities of pollinators. Pollinators usually avoided visiting treated crop at least for a week and normal foraging activities was observed after 10-15 days of foliar application of insecticides. Maximum avoidance behaviour towards insecticide treated crop was observed with *A. florae* species and minimum in case of *A. cerana indica* and *A. dorsata* bee species. Acute toxicity of insecticides on *A. florae* and *Megachile* spp was observed in cotton with foliar application of neonicotinoids (thiamethoxam and imidacloprid) and other bee species totally escaped while spraying. Acute toxicity of bee species was not observed in mustard crop which might be attributed due to size of flowers. Foliar application of insecticides on pollinator attracting crops should be avoided during peak activity periods (10 AM – 2 PM) to minimise the risk of acute toxicity of insecticides on pollinators.

Evaluation of cabbage breeding lines against diamond back moth and aphids at Katrain. Thirty two cabbage germplasms were evaluated against diamond back moth (DBM) during *Kharif* 2018 under artificial infestation in polyhouse. Two lines viz., Green Emperor and 9A were found to be moderately resistant. Thirty five cabbage germplasms were evaluated for their relative tolerance to cabbage aphid, *Brevicoryne brassicae* under natural field infestation. Five germplasms viz., 6A, Green Emperor, 9 A, KIRC 8 and C-1 were found to exhibit hifh level of tolerance. Progeny of single plant of tolerant lines (Green Emperor, 9 A and KIRC 8) selected during last year also exhibited good level of tolerance in majority of the population. However data revealed that further selection is required in these

promising lines to obtain the population of uniform tolerance. Twenty two cauliflower germplasm were evaluated against diamond back moth during *Kharif* 2018 under artificial infestation in polyhouse at Katrain. Except Italian Giant exhibiting moderate tolerance, all the tested lines were highly susceptible to DBM.

5.3 NEMATOLOGY

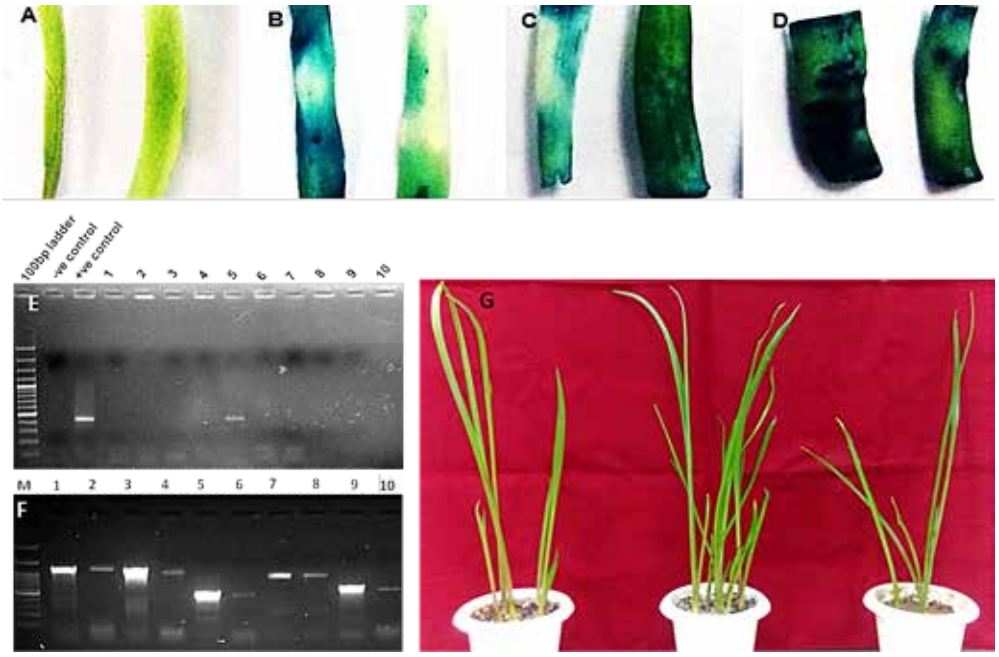
5.3.1 Management through Transgenic Approach

A study was undertaken to determine the silencing effects of the two genes, *ama-1* and *mad-2* of *Meloidogyne incognita*, on infection, development and reproduction of the nematode using *in vitro* RNAi approach. Tomato was used as host for setting up of the nematode infection assays of the study. The *ama-1* gene (resistance to alpha-amanitin), encodes the large subunit of RNA polymerase II and *mad-2* gene has a role in protein transport and mitotic feedback control in *Caenorhabditis elegans*. The *ama-1* and *mad-2* dsRNA fed juveniles showed 44.84 and 27.80 per cent reduction in nematode penetration and 26.94 and 19.17 percent reduction in number of galls, respectively. There was considerable reduction of 32.81 and 15.21 per cent in the fecundity of the *M. incognita* juveniles fed with dsRNA of *ama-1* and *mad-2* genes respectively. The silencing of these housekeeping genes (*ama-1* and *mad-2*) continuously affected the entire life cycle of the parasite from host finding to reproduction. It not only reduced the damage caused but also caused significant reduction in fecundity which is an important attribute for retaining the parasite population below the economic threshold level.

A fast protocol was developed for *Agrobacterium* mediated *in-planta* transformation for tuberose, *Polianthes tuberosa,* using pCAMBIA vector. This protocol requires the pricking of tuberose tubers and the tiny new buds on the tubers using a sterile 30G syringe. The pricked tubers were then co-cultivated for 1.5 h at 28°C in co-cultivation media (AB glucose 45 ml, AB salt 2.5 ml, AB buffer 2.5 ml and 2.5 ml of *Agrobacterium* overnight grown culture) without antibiotics containing acetosyringone and potted in soil next day. GUS staining results suggested that the best efficiency was achieved with 200 µM acetosyringone (Figure). Further to develop transgenic tuberose to resist nematode infection, tuberose tubers were transformed using RNAi FUS construct. FUS gene is a combination of three FMRFamide-like peptide coding genes *flp1, flp18 and flp12.* A large number of tuberose plants were transformed using *in-planta* method in several batched and analyzed for positive transformants using PCR. The PCR analysis of 10 plants with different primers revealed that they were successfully transformed showing the amplification of expected fragment.

5.3.2 Evaluation of Rice Genotypes against *Meloidogyne graminicola* Infection

Rice genotypes were screened for resistance to nematodes in Pluronic PF-127 medium. More than 50 rice lines resistant to *M. graminicola* were identified. To generate the mapping populations, the susceptible parent PB1121 was crossed with four resistant parents, i.e., Vandana, EK70, Phule Radha and Khalibagh. The F2 population obtained from four different crosses [PB1121 x Vandana; PB1121 x EK70; PB1121 x Phule Radha; and PB1121 x Khalibagh] was screened to check the durability of resistance and the segregation of nematode resistant trait. We found that the nematode resistance segregated well in the F2 progeny for all 4 crosses, which is desired at this stage. In the collaboration with the Division of Genetics, the resistant rice genotypes were identified, and the mapping population was generated by crossing the susceptible parent PB1121 with four resistant parents, i.e., Vandana, EK70, Phule Radha and Khalibagh. A total of 425 SSR markers were used in parental polymorphism survey and a total of 74, 46, 76, 35 markers polymorphic between the susceptible genotype PB1121 and resistant genotypes Phule Radha, Khalibagh, EK70 and Suraksha have been identified.



GUS staining of transformed tuberose leaves at different concentration of acetosyringone (A) Untransformed control (B) 0 µM (C) 50 µM (D) 200 µM. (E) PCR confirmation of transgenics using bar gene 490bp (F) Confirmation of transgenic plant using different set of primers lane [1,2: promoter attB Lane 3,4: attB terminator Lane 5,6: Bar Lane 7,8: fus gene Lane 9,10: Intron]. (G) Transgenic tuberose plant in pots

5.3.3 Genomics Annotation of *M. incognita* Genome

The *M. incognita* proteome data available at European Nucleotide Archive (ENA) (accession number: ERP009887) was annotation by using a multi-pronged approach. Although the draft genome of southern root-knot nematode *M. incognita* was published in 2008 and additional genome and transcriptome data became available later on, lack of a publically available annotation for *M. incognita* genome and transcriptome(s) limited the use of this data for functional and comparative genomics by the interested researchers. By using multiple approaches for proteome annotation, we increased the number of characterized proteins in the *M. incognita* proteome dataset to 73% as compared to 67.7% by the standard RefSeq based method. We characterized 2,287 additional proteins and 170 gene ontologies based on domain level analysis using InterProScan, and added information on additional 243 pathways, and 1,766 proteins by using KAAS.

5.3.4 Early Transcriptomic Response of *M. incognita* upon *Pasteuria* Infection

Pasteuria penetrans is a hyperparasitic bacterium capable of suppressing the nematode reproduction, and represents a typical coevolved pathogen-hyperparasite system. Attachment of *Pasteuria* endospores to the cuticle of second-stage nematode juveniles is the first and pivotal step in the bacterial infection. RNA-Seq was used to understand the early transcriptional response of the root-knot nematode at 8 h post *Pasteuria* endospore attachment. A total of 52,485 transcripts were assembled from the high quality (HQ) reads, out of which 582 transcripts were found differentially expressed in the *Pasteuria* endospore encumbered J2s, of which 229 were up-regulated and 353 were down-regulated. *Pasteuria* infection caused a suppression of the protein synthesis machinery of the nematode. Several of the differentially expressed transcripts were putatively involved in nematode innate immunity, signaling, stress responses, endospore attachment process and post-attachment behavioral modification of the juveniles. The expression profiles of fifteen

selected transcripts were validated to be true by the qRT PCR. RNAi based silencing of transcripts coding for fructose bisphosphate aldolase and glucosyl transferase caused a reduction in endospore attachment as compared to the controls, whereas, silencing of aspartic protease and ubiquitin coding transcripts resulted in higher incidence of endospore attachment on the nematode cuticle. These results provide evidence of an early transcriptional response by the nematode upon infection by *Pasteuria* prior to root invasion. We found that *Pasteuria* adhesion of endospores to the cuticle induced a down-regulated protein response in the nematode. In addition, we show that fructose bisphosphate aldolase, glucosyl transferase, aspartic protease and ubiquitin coding transcripts are involved in modulating the endospore attachment on the nematode cuticle and add new and significant information to the existing knowledge on early molecular interaction between *M. incognita* and *P. penetrans*.

A *C. elegans* sterol regulatory element binding protein (SBP-1) homologue was characterized in an important plant-parasitic nematode species, *M. incognita*. The RNAi mediated knockdown of *Mi-sbp-1* resulted in delayed utilization of body lipid and affected the parasitic potential and fecundity of the nematode species. Host induced gene silencing (HIGS) of *Mi-sbp-1* using tobacco showed similar results in addition to the morphological aberration of the nematode females. This is the first evidence for the functional role of a sterol regulatory element binding protein (Mi-SBP-1) in development, reproduction and parasitism of an obligate root parasite of plants, *M. incognita*.

5.3.5 Identification and Characterization of Chemotaxis-related Genes in Nematodes

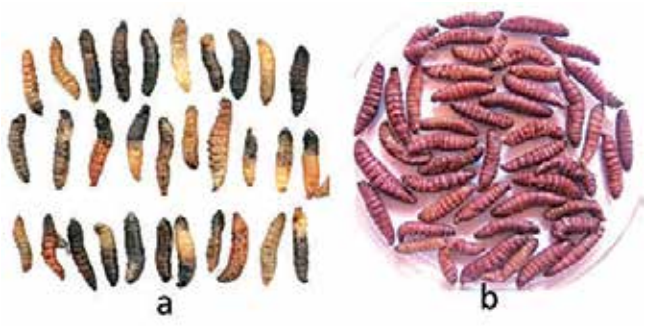
The root-knot nematode, *Meloidogyne incognita* differentially chemotaxes towards different hosts during the host finding process. For the first time, four chemosensory genes, namely *Mi-odr-1*, *Mi-odr-3*, *Mi-tax-2* and *Mi-tax-4* were identified, cloned, sequenced, analyzed and functionally characterized from *M. incognita*, which provides crucial advances towards understanding of plant-nematode interactions in rhizosphere. Transcripts of these genes were greatly expressed in early life stages of *M. incognita* and *in situ* localized in amphidial neurons and phasmids of nematodes, suggesting the role of these genes in host recognition process. RNAi of these genes led to behavioural defects in *M. incognita* followed by perturbed attraction to host root in Pluronic gel medium. In addition, aberration in nematode chemotactic activity was also documented towards 50 different volatile and non-volatile compounds in a unique agar-pluronic gel combined bioassay. A model was developed indicating *Mi-tax-2* and *Mi-tax-4* function downstream of *Mi-odr-1* and *Mi-odr-3* in chemotaxis pathway of *M. incognita* which selectively chemo-orientate to chemical cues. These findings may serve as a model that can be extended to understand chemotaxis in other nematodes.

5.3.6 Entomopathogenic Nematodes

Comparative pathogenicity of *Heterorhabditis indica* and *Steinernema abbassi* was studied against the maggots of fruit fly. Mortality was initiated by *H. indica* as early as 18 h after inoculation @25 IJ/maggot, whereas at the same dose *S. abbassi* initiated a marginal 4% mortality after 24 h. At the highest dose tested (100 IJ/maggot), *H. indica* imparted 100% mortality within 24 h as compared to 62 % mortality by *S. abbassi* within the same span of time, suggesting 38% more efficacy of *H. indica*. Both nematodes successfully completed their life-cycle in the cadavers. Comparative recovery of IJs was more in *H. indica* infected cadavers. At 75 IJ/maggot inoculum 1176.6 IJ/cadaver were produced as compared to a maximum production of 476.1 IJ/cadaver at 50 IJ/maggot in case of *S. abbassi*.

There was a delay in mortality imparted by *H. indica* (@ 25IJ/larva) in *Galleria* larvae that were artificially introduced to dual infection of *B. bombysepticus* and *B.cereus*.Only 20% treated *Galleria* larvae died after 24 h as compared to 100% mortality recorded in control. Hundred per cent mortality in treated larvae was recorded after 42 h. The dead larvae did not take

characteristic brick red color, as in control, suggesting that the symbiotic bacteria could not create a monoxenic environment in presence of the two contaminating *Bacillus* spp. There was a significant decline of 91.6% and 77.7% in the hermaphrodite formation on day 3 and day 4, respectively, post-infection as compared to control. There was complete suppression of the nematode life-cycle beyond this stage.



Mortality imparted by *H. indica* in (a) *Galleria* larvae co-infected with *B. bombysepticus* and *B.cereus* and (b) control

Photorhabdus bacteria are symbionts of entomopathogenic nematodes of the genus *Heterorhabditis* species. A large portion of their genomes are dedicated to the production of various secondary metabolites and insecticidal toxins. Novel variants of these secondary metabolites and insecticidal toxins are expected from *Photorhabdus* symbionts collected from diverse geographical areas. The genomes of five *Photorhabdus* strains collected from various geographical regions of India were sequenced. A total of 255 to 540 Mb of raw sequence data was generated resulting in final assembled genome sizes of 5.3 to 5.6 Mb with 45 to 96x coverage. Subject to validation by polyphasic taxonomy, the phylogenomic analysis and *in-silico* DNA-DNA hybridization results suggest that the *P. akhurstii* species can further be subdivided into two subspecies, whereas strain BA1 clustering with *P. akhurstii* might represent a new species.

An insecticidal gene, *Txp40* (1008 bp) was characterized from the indigenous isolates of *Photorhabdus luminescens* sub sp. *akhurstii*, and tested its bioefficacy against *Galleria mellonella* via injectable and oral bioassay. The recombinant protein characterized from *P. luminescens* strain H3 exhibited comparatively greater insect toxicity than strain H1 in terms of LD_{50} and LT_{50} values. The secondary structure prediction indicated that Txp40 protein (335 amino acids long) is predominantly alpha-helical. InterProScan (EMBL-EBI) results revealed that Txp40 has no detectable homologues in the present database. While amino acid residues among strain H1 and H3 was compared it was found that at positions 71, 189 and 249, aromatic tyrosine was altered to aliphatic cysteine, aromaticphenylalanine (hydrophobic, non-polar) was changed to serine (hydrophilic, polar), and neutral asparagine was changed to acidic aspartate, respectively. Txp40 holds great potential to replace Bt toxins in global agriculture.

In addition, the genetic and toxicological variation in the Photox toxin from the seven Indian *Photorhabdus* strains i.e., IARI-SgMg3, IARI-SgGj2, IARI-SgHr2, IARI-SgHr4, IARI-SgMs1, IARI-SgLdk1 and IARI-SgHp1, isolated from *Heterorhabditis* nematodes collected from different geographical regions of India was investigated. The nucleotide sequences from the Indian *Photorhabdus* species were 951 to 960 bp long as compared to the previously sequenced reference strain *P. luminescens* ssp. *laumondii* TTO1 which was 1227 bp long. Rapid virulence annotation assay for injectable toxicity confirmed that the cloned Photox gene from all the isolates was toxic to *Galleria mellonella*, and IARI-SgHr4 Photox was the most toxic variant with LT_{50} of 48 h at the lowest dilution of 10^{-5}. Injection of purified Photox protein into the haemocoel of test insect *Galleria* revealed that toxin from isolates IARI-SgHr4 and IARI-SgLdk1 (LT_{50} = 12 h at 50 to 500 ppm) were the most pathogenic Photox variants, whilst Photox from isolate IARI-SgMg3 was least toxic. The toxicity of purified Photox toxin was qualitatively tested against nematode *Caenorhabditis elegans,* but it didn't cause any hatching inhibition, mortality or developmental delay of the nematode. As Photox is small binary toxin, there is a strong possibility of using it for the development of insect-resistant transgenic plants after suitable optimizations.

Six isolates of entomopathogenic nematodes (*Heterorhabditis* sp., *Oscheius* spp., *Steinernema* sp.) were

recovered from Hapur district of western Uttar Pradesh and evaluated against test insect–pests (*Maruca vitrata, Pieris brassicae, Spodoptera litura*). Among the tested isolates, the isolates IARI-EPN RP 03 of *Steinernema* sp. and IARI-EPN RP 06 of *Heterorhabditis* sp. were found to be highly virulent against insect pests. Further advancing the promising EPN isolates for infectivity against 2nd, 3rd, 4th and 5th instar larvae of *S. litura* showed both isolates are pathogenic to all the larval instars. The 2nd instar larvae was relatively more susceptible and full grown larvae could be best for mass production.

5.3.7 Biocontrol Agents

Bioassay carried out with CFF prepared from ITCC isolates of *Trichoderma longibrachiatum* against *Meloidogyne incognita* J2. Out of 19 isolates, three isolates, ITCC 6987, ITCC 7017 and ITCC 7833 exhibited 100% immobility and mortality within 24h of incubation. Chitinase and protease activity results indicated highest chitinase activity with 17.06 U/min in isolate ITCC 6987, whereas the highest protease activity with 13.38 U/min in ITCC 7017. Both isolates were further studied to identify the suitable isolate with desirable traits against *M. incognita*. Bioassay results indicated effective concentration of CFF from ITCC 6987 and ITCC 7017; both the isolates caused 100 % mortality at 100% concentration and more than 80% mortality at 75% concentration of CFF. Egg hatch inhibition assay results also revealed that both the isolates caused egg hatching inhibition to the extent of 90%. Thus, high chitinase and protease activity of ITCC 6987 and 7017 can be correlated with the high mortality and egg hatch inhibition. Besides, *in silico* analysis elucidated biosynthetic gene cluster (BGC) from *T. longibrachiatum* genome using *antiSMASH* web portal. In brief, there are 77 BGCs in *T. longibrachiatum*, out of which 9 belongs to Polyketide synthase (PKS) group, terpenes - 6, non-ribosomal peptide synthase(NRPS) - 6 and PKS-NRPS hybrid – 3. Further validation may yield potential secondary metabolite gene source against *M. incognita*.

5.3.8 Nematode Management

Field study results demonstrated that application of carbofuran @ 1 - 2 kg a.i./ha was found effective for reduction (60-70%) of reniform nematode population in tomato. The chemical profiling of mint oil using GC-MS showed presence of 18 compounds with two major compounds viz., Piperitenoneoxide (62.91%) and 4-chlorophenacyl chloride (17.07%). *In vitro* evaluation of essential oil and crude extracts of *Mentha arvensis* against *Meloidogyne graminicola* indicated that they have infanticidal and inhibition of egg-hatching properties only at higher concentrations and exposure time of 48 hours.

5.4 AGRICULTURAL CHEMICALS

5.4.1 Development of Active Molecules for Crop Protection

Bioefficacy evaluation of ferrocenyl chalcones. A series of thirty four new ferrocenyl chalcones, synthesized previously, were evaluated against *Sclerotium rolfsii, Alternaria solani* and *Meloidogyne incognita*. Fungicidal bioassay revealed that one of the synthesised compound was most active against *S. rolfsii* having ED_{50} = 21.5 ppm followed by other compounds. But in case of *A. solani,* fungicidal bioassay revealed that the most potent compound had ED_{50} = 29.9 ppm. The *in-vitro* nematicidal bioassay revealed that all the synthesized compounds were active against root knot nematode *(M. incognita)* at various concentrations using nematicidal bioassay plate. But one compound showed maximum potency with LC_{50} values of 11.95 ppm (24 h), 8.07 ppm (48 h) and 4.34 (72 h) ppm, respectively.

Antifungal evaluation of potent chromones and triazoles. Based on *in vitro* study chromone 4r and triazole T4 were taken for *in vivo* study in tomato crop against *Sclerotium rolfsii.* Pot experiment was conducted in the Division of Plant Pathology, ICAR-IARI. Each compound was applied at three concentrations *viz.* 1000, 500 and 250 ppm along with commercial fungicides Mancoze 75 WP and Tebuconazole 25.9 EC at 1000 ppm. Each treatment was applied in triplicates. Compounds were applied by two methods, soil

drenching and seedling root dip. The result showed that disease incidence was 10-37% in case of 4r and 16-50% in T4 in soil drenching and in root dip it was 19- 44% and 26-59% in case of 4r and T4, respectively, as compared to control having 85% disease incidence.

Antifungal evaluation of 2-(2′-arylidine-hydrazino-acetyl-amino-4-phenyl-1, 3-thiazoles against Sclerotinia sclerotiorum. A series of twelve synthesized 2-(2'-arylidine-hydrazino-acetyl-amino-4-phenyl-1,3-thiazoles were evaluated against *S. sclerotiorum* strains. 4-hydroxy-phenyl derivative exhibited highest activity with EC_{50} 59.8-76.9 μgmL^{-1}. Molecular docking and simulation studies of these compounds showed higher binding affinity towards L-glutamine: d-fructose-6-phosphate amidotransferase [GlcN-6-P] (PDB:2POC). 4-hydroxy-phenyl derivative was ranked first with the glide score of -8.271. Possible hydrogen bonding was observed with GLY 490 and HIS 492 amino acid residues.

Antifungal evaluation of N-(3-chloro-2-aryl-4-oxoazetidin-1-yl)-furamide derivatives. A series of eight synthesized N-(3-chloro-2-aryl-4-oxoazetidin-1-yl)-furamide derivatives were evaluated against various phytopathogenic fungi. These compounds showed moderate to low activity (EC50 >100 ppm) against *Rhizoctonia bataticola*. None of these were active against *S. sclerotiorum*.

Profiling of botanicals and bioefficacy evaluation. Quantitative analysis of podophyllotoxin was carried out in the root, stem and leaves of *Podophyllum hexandrum*. Results showed that roots (4.2%) contain more amount of podophyllotoxin than leaves (0.07%) and stems (0.05%). Essential oils obtained from the leaves of *Eucalyptus globulus*, *Cymbopogon winterianus*, and *Pelargonium graveolens* were analysed using GC and GC-MS. *E. globulus* and *C. winterianus* oils were found to be rich in 1,8-cineole (68.5%) and citronellal (36.45%),citronellol (10.15%) and geraniol (21.36%). The oil from *P. graveolens* leaves was found to be rich in citronellol (30.8%) and linalool (11.7%) besides other compounds. Essential oils of *Murraya paniculata* was also analysed and their compounds were identified and were found to contain beta caryophyllene (17.2%), germacrene (23.9%) and zingiberene (23.2%) and trans-nerolidol (13.2%). *Mentha arevensis* oil was found to be rich in peperitenone epoxide (63.0%).

Preliminary, *in-vitro* evaluation of *E. globulus*, *C. winterianus* and *P. graveolens* oils were carried out against *M. incognita* at 1000, 500, 250, 125 and 62 ppm and results were found to be promising. Pot experiments of the lemongrass, palmarosa and clove oils and three pure compounds were carried out against *M. gaminicola* at the concentration ranging from 500, 250, 125, 0.62 and 31.12 ppm. Field trials of formulations of oils from lemongrass, palmarosa and clove and three pure compounds at 500 and 1000ppm were carried out against *M. incognita* in brinjal at KVK Shikohpur using root dip and drenching methods in six replications. These formulations were also evaluated in small field (1x1m plot) trials in against *M. gaminicola* against rice root knot nematode at IARI, New Delhi. Nematicidal activity of the oils/compounds was found to be encouraging against *M. gaminicola* but dose dependent.

5.4.2 Development of Formulations for Smart Delivery of Crop Protection Inputs

Hybrid biopolymeric composite for encapsulation of acetamiprid and its controlled release. Gum Arabic and chitosan were used to encapsulate acetamiprid by a W/O/W double emulsion technique using neem oil. This technique improved the controlled release of acetamiprid. Release study indicated that 80% of the encapsulated acetamiprid was being released in 24 h. A preliminary study on cotton plant showed 81% mean mortality of whiteflies after 24 h by direct feeding. To improve the slow release property of the formulation experiment was carried out with addition of 0-2% of palmitic acid in the oil phase. The results revealed that with the subsequent addition of palmitic acid, the pattern of release of acetamiprid changed in a conspicuous manner. Further, the prepared formulation was lyophilized to make it in a solid form to eliminate the issue of phase separation in the

initial W/O/W emulsion state. The solid state of the formulation was found to be easily dispersible in water.

Concomitant data generation, fine-tuning of composition and field performance evaluation of EPN biogel formulations. Composition of gel moisture content and LMA content was further fine-tuned under laboratory conditions. Representative biogel formulation of EPN juveniles *Steinernema thermophilum* stored under 25 and 35^0 C and shelf life regularly monitored, showed more than 70% bioagent survival at 25^0C and around 55% at 30^0C till twelve months. Monitoring is under progress. Moisture induced citric acid hydrolysis of citric acid crosslinked katira-CMC composite was identified as cause of fungal growth in stored formulations. The composition and protocol were finetuned to remove the bottleneck and bulk bench scale synthesis of test formulation (5 Kg per batch) was standardized. Two batches of 10 Kg formulations of *S.thermophillum* and *H.indica* were prepared and stored at 35^0C.

To assess EPN survival in field, a guava orchard in forest-side organic horticultural farm, Haldwani, Uttarakhand was selected for field study where due to termite infestation, huge losses to orchards is a major problem. Screening of soil samples before application of treatments established absence of EPNs in farm soil. Five treatments namely aqueous suspension of *H.indica*, aqueous suspension of *S.thermophillum*, biogel formulation of *H.indica*, Biogel formulation and absolute control were imposed over 650 seedlings of guava in splite doses of two (September 2018 and January 2019). Applications of aqueous suspensions of EPNs resulted in recovery of *S. thermophilum* and *H. indica* in 60 and 32% of the tested samples, respectively. Application of biogel formulations increased the recovery of EPNs in the samples by 28% and 36% for *S. thermophilum* and *H. indica* nematodes, respectively, over the respective unformulated EPNs. The assessment of EPN establishment on the termite infestation is under progress.

Bioefficacy evaluation of neem and citronella nano emulsions against Rhizoctonia solani and Sclerotium rolfsii. Developed neem and citronella nano emulsions were evaluated for antifungal activity against *Rhizoctonia solani* and *Sclerotium rolfsii* and larvicidal activity against 3rd instar larvae of *Spodoptera litura* (Fab). Results revealed that among the screened neem nanoemulsions, one nanoemulsion was found to be most effective against both *R. solani* (ED_{50} 13.69 mg L^{-1}) and *S. rolfsii* (ED_{50} 14.71 mg L^{-1}) and one citronella nanoemulsion was most active against both *R. solani* (ED_{50} 25.64 mg L^{-1}) and *S. rolfsii* (ED_{50} 20.88 mg L^{-1}). Among the developed nanoemulsions screened for larvicidal activity, three each in neem and citronella showed promise in terms of both larval (80% and 73.33% respectively, mortality after 72 hrs.) and pupal mortality (6.67%).

Preparation and bio-efficacy evaluation of formulated antifungal molecules against Rhizoctonia solani. Based on the *in vitro* antifungal evaluation studies, five potent antifungal halogen substituted benzylidene aryl amines were identified and synthesized for their formulation development. Polyethylene glycol based formulations (0.5 %) of these compounds were prepared and screened for their antifungal activity against *Rhizoctonia solani* under net-house experiments in rice. At 100 ppm dose, the compounds showed moderate antifungal activity against *Rhizoctonia solani* with relative lesion height ranging from 22 to 30 as compared to inoculated control with relative lesion height of 49.

5.4.3 Standardization and Validation of Methods for Detection/Quantification of Contaminants

Supervision of field trials. Supervised field trials of triazophos, quinalphos, ethion, carbendazim, acephate, chlorpyrifos, cypermethrin, profenofos, imidacloprid and spiromesifen carried out on capsicum crop (var. Indra) under GAP studies. The half life varied from 1.90 to 3.90 days and the residues persisted from 5-20 days.

Validation of multi residue method for aflatoxins in dry fruits. The method for extraction of aflatoxin

from ground nut, almond, pistachios, walnut and cashew nut was optimized using buffered QuEChERS method and supel tox cartridge and estimated by LC-MS-MS at 1, 5, 10, 25, 50 and 100 ng fortification levels. Percent recovery recorded was in the range ranged from 86.8 ±0.0002 to 95.2 ± 0.0003 for B1, 86.8 to 93.8 at 10 ng/mL fortification level highest in cashew nut and lowest in walnut . The LOD and LOQ for each aflatoxin were 0.5-1 ng/mL and 1.1-3 ng/mL.

HPLC-PDA method for determination of cyantraniliprole and its two metabolites in soil, water and vegetable. Cyantraniliprole is a second-generation anthranilicdiamide insecticide, which has (1) high persistence in soil (half-life 308 days) (2) highly toxic to aquatic and benthic invertebrates and (3) high leaching potential. Cyantraniliprole degradates; IN-J9Z38 and IN-HGW87 were found to be more toxic than the parent compound to honey bees. In India it has been registered for use in cabbage, tomato, chilli, gherkins, grapes and pomegranates. In the present investigation, extraction, clean up and HPLC-PDA parameters were optimized to determine trace levels of cyantraniliprole and its two metabolites in soil, water and vegetable. The metabolites were synthesized in the laboratory using alkaline hydrolysis for IN-J9Z38 and photolysis for IN-M2G68 and characterize by their mass spectra. Method was developed using Shimadzu HPLC equipped with Nexera software, Chromolith column (Merck) and pda set at λmax 280. Mobile phase was 70:30 MeOH: water at 0.7 ml/min. Under these conditions cyantraniliprole, IN-J9Z38 and IN-M2G68 were eluted at 2.3, 1.5 and 3.2 min respectively. Calibration curves were linear in the range 0.005-10 ppm. Recovery studies were conducted at 0.05, 0.1 and 0.5 ug/g fortification level. Partitioning with dichloromethane for water and QuEChERS for soil and cabbage were found best. Optimized methods gave >95% recoveries in soil, water and cabbage with <8% RSD. The methods can be used to quantify trace level residues of cyantraniliprole in environmental samples.

QuEChERS based multiresidue method coupled LC-MS/MS developed for the trace level analysis of 50 pesticides in coconut (oilseed). Seventy crop protection chemicals were selected for development of multiresidue method in coconut (oilseed). LC-MS-MS parameters and MRM transitions were optimized for different pesticides. Instrument detection limit of different pesticides varied from 5-20 ppb with 5 ul injection volume. Samples were processed using QUEChERS method. Method validation was carried out at 0.01, 0.05 and 0.1 ppm fortification levels. Recovery for ~50 pesticides were found to be in acceptable range 70-120% with <15% RSD. This simple, specific and reproducible method can be used for monitoring of these insecticides in black pepper samples meant for export or domestic consumption.

Spectrophotometric method for detection of monosodium glutamate (MSG). In present investigation, efforts were made to develop spectrophotometric method for the detection of monosodium glutamate, a flavor-enhancing ingredient in traditional Asian cuisine. Free amino group of the monosodium glutamate was reacted with ninhydrin and heated to produce intense violet color called Ruhemann's purple. The purple complex gave absorption maxima of 485 nm in visible region. Purple color was developed with different concentration of monosodium glutamate and calibration curve was generated in the concentration range 0.08-0.8 ug/ml. The method was found to be accurate (R2=0.994) with low level of detection (0.08 ug/ml) and was used to quantify MSG in Noodles (3 varieties), Taste maker (3 varieties), soups (4 varieties) and sauces (4 varieties). Color was developed with the aqueous extract of samples. In 2017, European Food Safety Authority (EFSA) has established glutamate ADI of 30 mg/kg body weight (equivalent to 1.8 g/60 kg person). In our investigation, tastemakers contain high amount of MSG, but the quantity of tastemaker used in preparation of 1 packet of noodle (~200g) is very low (~5g). 5 g of taste maker is likely to contain 0.044 g of MSG, which is unlikely to cause adverse reactions in Humans.

5.4.4 Management and Assessment of Contaminants in Agricultural Commodities and Environment

Environmental fate of thiabendazole in soils of varying moisture regimes and uptake in plant was

studied. The dissipation of thiabendazole in different moisture regimes, dry, field capacity and submerged and uptake in plants was studied at 10 µg/g fortification level. Half life ranged from 43.0, 60.2 and 150.5 days for thiabendazole in inceptisol soil.

Retention and degradation of azoxystrobin and imidacloprid in biobeds. Retention and degradation of pesticides in laboratory constructed biobeds using RS+C and CC+C biomixtures was studied. Azoxystrobin (10,000 µg) and imidacloprid (10,000 µg) mixture was applied to biobeds using ~100 mL water and 2 applications were made at interval of 45 days. None of the pesticide was detected in the leachate collected during study period. Imidacloprid was completely degraded after both applications in both biobeds while azoxystrobin persisted till end of study period. After 45 days of first application 8.24 and 5.36 µg g-1 azoxystrobin was detected in the top 3-4 cm of the RS+C and CC+C substrates, respectively. After 30 days of 2nd application 11.86 and 2.93 µg g-1 azoxystrobin was detected in the upper (4.5 cm) and lower (4.5 cm) half of the RS+C biobed and it amounted to 3212 and 692.81 µg of azoxystrobin. Similarly, 33.05, 0.66 and 0.88 µg g-1 of azoxystrobin was recovered from the upper (4.5 cm), middle (4.5 cm) and lower (4.5 cm) sections of the CC+C biobed, which corresponded to 6090.53, 122.58 and 159.12 µg of azoxystrobin. Total of 20,000 µg of azoxystrobin applied, 81.5 and 68.1% was degraded in the RS+C and CC+C biobeds, respectively. Microbial biomass and dehydrogenase activity measurements in biomixtures, after both sampling, suggested that except for inhibition of the dehydrogenase activity in the CC+C biobed, no adverse effect of pesticide application on microbial parameters was observed. Better efficiency of the RS+C biobed can be attributed to higher MBC content and no inhibition of the dehydrogenase activity was observed.

Effect of crop residue ashes on herbicides leaching, degradation and bioactivity. The effect of rice and wheat crop residue ashes on leaching and degradation of sulfosulfuron (wheat herbicide) and pretilachlor (rice herbicide) was studied in two soils (clay loam and sandy loam) from regions following rice-wheat cropping system. Pretilachlor did not leach out of the columns in both soil types under both irrigation regimes (clay loam soil – 15 cm length, 80 and 112 mm; sandy loam soil – 30 cm length, 160 and 320 mm). The Wheat Straw Ash (WSA) reduced downward mobility of pretilachlor in soils, but effect varied with the soil type, level of ash added and the volume of irrigation water used. Reduced pretilachlor leaching in the WSA-mixed soils can be explained by the higher herbicide adsorption in the ash-mixed soil. Sulfosulfuron was more mobile than the pretilachlor and was detected in the leachate. Addition of the Rice Straw Ash (RSA) reduced the leaching losses and effect was more in the sandy loam soil and ~4 times higher sulfosulfuron was retained in the surface layer in the 0.2% RSA mixed sandy loam soil column than the clay loam soil column. The WSA increased pretilachlor degradation in soils, but, effect varied with the level of ash and moisture status. Compared to control soils, 0.2% WSA reduced the $t_{1/2}$ to nearly half in the flooded soils while marginal decrease was observed in the nonflooded soils. Increasing WSA content (0.5%) slowed down the pretilachlor degradation in both soils under both moisture regimes. The RSA enhanced sulfosulfuron degradation in both soils but effect was significant in clay loam soil where $t^{1/2}$ values decreased by 2.5 to 2.7 times. Sulfosulfuron dissipated faster in wheat-planted soil/soil+RSA mixture than in laboratory incubated clay loam soil. The RSA even at 0.1% level reduced herbicide availability (effect on mustard seedling) and higher amount of herbicide is required for the desired action.

Curcumin conjugated Zinc Oxide nanoparticles for pesticide sensing in water. Curcumin conjugated zinc oxide nanoparticles were further characterized by fluorescence microscopy and other techniques. The prepared nano-probes' synthesis was further optimized. The nano probes were used for detecting glyphosate and tetradifon and found to be efficient and economical with a linearity range of 0.1 ppm ~10 ppm. The prepared sensor probe materials exhibited excellent performance in terms of high sensitivity, good stability, wide linearity over response range and

relatively short response time. The prepared probe is economical and may be considered as a potential tool for pesticide detection.

Magnetic biochar for pesticide decontamination. Previously synthesized magnetic biochars using four agri-waste residues, viz., rice straw, wheat straw, rice husk and corn cob were able to remove almost 80% of imidacloprid and 85% of azoxystrobin from solutions having concentrations ranging from 1-5 ppm.

Artificial neural network and supervised machine learning algorithms utilized for adsorption process optimization. Hybrid models viz., ANN-SVR, ARIMA-X-SVR, ANN-ARIMA-X were evaluated for the optimization of biochar based pesticide removal. ANN-SVR performed as the best prediction model for the optimization of sorption phenomena of atrazine sorption using biochars. The prediction performance followed the order: ANN-SVR>SVR-ARIMA-X>ANN-ARIMA-X.

Modeling assisted synthesis of molecularly imprinted polymers for fipronil. Interaction between template molecule and monomer play an important role in imparting selectivity to the Molecularly Imprinted Polymers (MIP). In the present study, molecular modeling studies were conducted to study the thermodyanamics of interaction between template molecule, i.e fipronil and different monomers like acrylic acid (1), methyl methacrylate (2),methacrylic acid (3), 4-vinyl pyridine (4), acrylamidomethyl propane sulfonic acid and acrylamide (6). Lowest value of energy parameter is obtained for acrylamidomethyl propane sulfonic acid (-91.58). Accordingly MIPs and NIPs were prepared using acrylamidomethyl propane sulfonic acid as monomer, EGTDMA as crosslinker and AIBN as initiator. MIPs and NIPs of fipronil using other monomers 4-vinyl pyridine, Methyl methacrylate, Acrylic acid, acrylamide and Methacrylic acid were also prepared for comparison. MIPs were found to have high sorption capacity for fipronil as compared to NIPs. Moreover, MIPs prepared using acrylamidomethyl propane sulfonic acid showed much higher selectivity for fipronil as compared to other monomers. Sorption equilibrium was achieved in 60 minutes. MIPs worked better in neutral and alkaline pH as compared to acidic pH.

Persistence of combination mix pesticide formulation Lesenta 80G (Fipronil 40.0% + Imidacloprid 40.0%) on brinjal. White grub is a important pest of brinjal. One of the formulations for controlling white grub in sugarcane is fipronil 40.0% +imidacloprid 40.0% (Lesenta 80G). To examine the field efficacy of this formulation in controlling white grub in brinjal and to see the residue dyanamics of this combination mix, a field trial was conducted in collaboration with the Division of Entomology. Commercial combination mixture of fipronil 40.0% + imidacloprid 40.0% (Lesenta 80G) was sprayed @ 100 and 200 g/ha on brinjal (variety Pusa Kranti) at fruit formation stage. Samples were drawn after pesticide application upto 15 days at regular time intervals. For residue estimation ~250 g sample was blended in mixer grinder. From this 10 g representative sample in triplicate was drawn and processed as per QuEChERS protocol using acetonitrile. Analysis was done on Shimadzu HPLC. Half-life of dissipation for imidacloprid and fipronil were found to be 1.00-1.47 days and 2.02-2.06 days respectively. Residues of imidacloprid reached below MRL (0.2 ug/g) on 5^{th} day at recommended dose, however residues of fipronil were above MRL (0.002 on brassica) even 10^{th} day after spray. The use of this formulation should not be extended on vegetables, even though found effective in controlling white grub.

Amoxicillin selective magnetic molecularly imprinted polymers for sample preparation. Amoxicillin selective magnetic molecularly imprinted polymers (MMIPs) were synthesized by precipitation polymerization using acrylic acid as monomer and ethylene glycol dimethacrylate as cross linker. Surface properties of prepared polymers were determined using Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). Sorption equilibria was achieved within 2 hours. Imprinted polymer showed more than 85-90% sorption of amoxicillin from solution

of different concentrations (1-200 ppm) and pH (2, 5, 7 and 9). The imprinted polymers showed much higher adsorption capacity towards the analyte (K_d=4266.6 mL g^{-1}) than the magnetic non-imprinted polymers (MNIPs) (K_d=411.9 mL g^{-1}). Adsorption data fitted well into linearized Freundlich equation (R^2=0.95) as compared to Langmuir equation (R^2=0.80). Polymers were highly selective in extracting amoxicillin even in the presence of its structural analogue ampicillin (α=8.80) and tetracycline (α=7.31).

Development of azastilbene based detection techniques for pesticides. An azastilbene based on quinaldine and anisaldehyde was synthesized at room temperature. Synthesized compound was characterized by FTIR. The azastilbene has maximum absorption at 340 nm. When excited at 320 nm, the compound gave emission maxima at 440 nm with a stock shift of 100 nm. Azastilbene solution exhibited quenching of fluorescence intensity with increasing concentration of OP pesticide, Quinalphos, with linearity in the range of 0.6 - 23 µg/mL.

Study on the persistence of sulphonamide antibiotics in soil. The persistence of sulphonamide antibiotics, namely, sulfamethazine and sulfamethoxazole was studied in IARI field soil. The effect of different moisture regimes on antibiotic degradation was studied under lab conditions. The average half lives for sulfamethazine in dry, field capacity and submerged soil were 21, 16 and 12 days respectively. For sulfamethoxazole, the half lives were 33, 23 and 20 days, respectively in dry, field capacity and submerged soils.

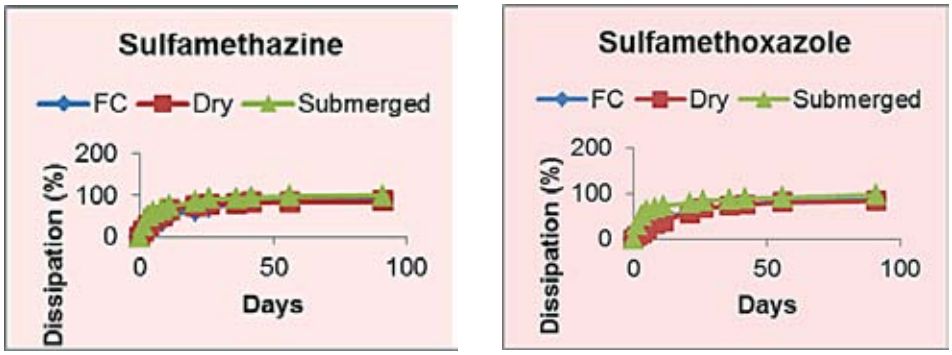
5.5 WEED MANAGEMENT

5.5.1 Nitrogen and Herbicide Interaction Effects on Weed Control and Maize Productivity under Conservation Agriculture

Under a long-term CA-based experiment, the density of total weeds at 40 DAS due to tillage, residue and nitrogen and weed management practices were found to be significantly affected in maize. The ZT-based systems resulted in lower weed density than the CT. Among the ZT-based systems, ZT+R+100%N was most efficient for controlling weeds. This ZT+R+100%N gave highest maize grain yield. This result shows that ZT-based systems were able to reduce the weed seed bank build-up in soil over the years. Among the herbicide treatments, the tank-mix application of ATR+PMT reduced considerably the total weeds density than the sequential applications of ATR-TEM and ATR-HP, resulting into higher weed control efficiency and ultimately higher grain yield.

5.5.2 Efficient Weed Management using Sequential Herbicides in Conservation Agriculture Based Direct Seeded Rice

In a 10-year old CA-based rice-wheat system, the rice yield was significantly higher in TPR over DSR treatments. Weed control treatment with pyrazosulfuron-ethyl@ 0.025kg/ha at 1 DAS *fb* cyhalofop-butyl 0.100 kg/ha at 20 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS gave 2.2 times higher yield (~7.18 t/ha) over UWC. Interaction showed that MB + ZTDSR – RR + ZTW – WR + ZTMB practice combined with



Dissipation of sulfamethazine and sulfamethoxazole in IARI field soil

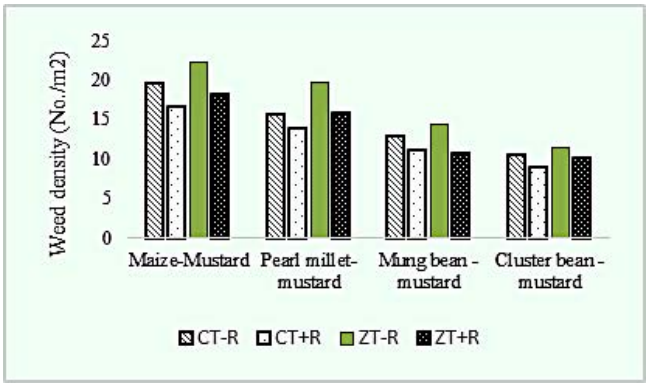
the sequential application of pyrazosulfuron-ethyl@ 0.025kg/ha at 1 DAS *fb* cyhalofop-butyl 0.100 kg/ha at 20 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS could result in highest rice yield among the DSR treatments. Thus, the sequential application of herbicides in DSR could manage weeds and increased yield considerably.

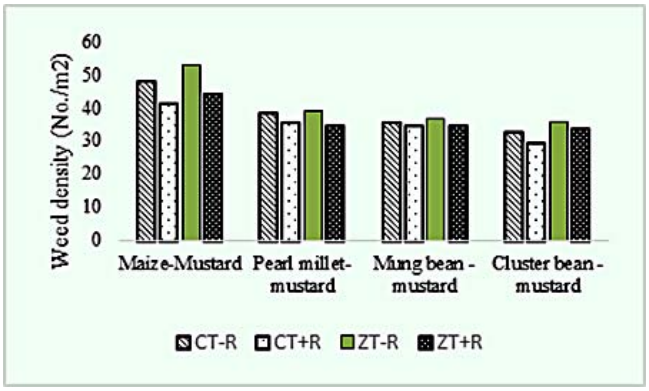
5.5.3 Weed Competition and Dynamics in Mustard Based Cropping Systems under Conservation Agriculture

Five cropping systems were evaluated under 4-crop establishment methods with two chemical weed management treatments in split-split plot experiment. In both rainy and winter seasons, the density of narrow leaved weeds was higher over broad-leaved weeds at 45 DAS. The order of weed density in cropping systems was maize-mustard> pearl millet-mustard> mung bean-mustard> cluster bean-mustard. The sequential application of pendimethalin @1.0 kg/ha and imazethapyr @ 0.75 kg/ha to cluster bean and mungbean; pendimethalin+ atrazine tank mix (0.75 kg/ha+0.75 kg/ha) and topremezon @ 0.025 kg/ha to maize and pendimethalin+ atrazine tank mix (0.75 kg/ha+0.75 kg/ha) and oxyfluorfen @ 0.25 kg/ha to pearl millet resulted in 44.3, 39.2, 33.2 and 36.2%, respectively, reduction in the weed density over no herbicide application. Increase of 8.8% and 14.4% in mustard yield was recorded under conventional tillage and zero tillage with residue application over no residue, respectively. Likewise, an increase of 22.6% and 11.7% in mustard yield and system productivity was recorded due to the application of pendimethalin @ 0.75 kg/ha *fb*fenoxaprop-p-ethyl (0.05 kg/ha) + oxyflurofen (0.075 kg/ha) post-emergence tank-mix application at 30 DAS in mustard over no-herbicide.

5.5.4 CA-based Weed Management Options for Pigeonpea–Wheat Cropping System

Zero tillage (ZT) + residue (R) treatment brought down soil temperature by 1.9^{0}C and 2.8 ^{0}C as compared to conventional tillage (CT), recorded at 9 AM and 3 PM, respectively. ZT + R treatment was found to be superior in conserving higher soil moisture over ZT and CT treatments. The ZT + R resulted in 2.1 □C higher than CT and 1.8^{0}C than ZT at 9 AM in 0-15 cm soil depth, while it was 1.6 and 1.2 □C higher, respectively, at 3 PM. In both crops, ZT + R recorded highest weed control efficiency (WCE) followed by ZT and CT. Among the weed management practices, highest WCE (73.4%) was recorded with 2-hand weedings (HW) followed by 70% with pendimethalin 1.0 kg and 1 HW at 30 DAS in pigeonpea and 79.1% with 2 HW and 77.8% due to pinoxaden 50 g/ha+ metsulfuron 5 g /ha (Tank mix) at 30 DAS in wheat. Maximum system productivity (10.3 t/ha) in terms of wheat equivalent yield was recorded in ZT+R. Two HW led to highest system productivity (10.4 t/ha), but integration of pendimethalin 1.0 kg+ 1HW in pigeonpea, and pinoxaden 50 g/ha+ metsulfuron 5 g / ha (Tank mix) at 30 DAS in wheat fetched highest net returns (Rs. 88181/ha) and B: C ratio (1.43).





Broad and narrow leaf weed density in maize, pearl millet, mung bean and cluster bean crops under different crop establishment methods and residue retention options

5.5.5 Brown Manuring for Better Weed Management in Maize

In an experiment, brown manuring (BM) treatment *Sesbania* + *Crotalaria* (12.5+12.5 kg/ha) mixture + 2,4-D applied at 35 DAS resulted in lowest total weed density (~19.7/m^2) and dry weight (~8.63 g/m^2), and highest weed control efficiency (~93%). Although weed-free control gave significantly higher grain yield (~6.0 t/ha), this BM practice was comparable with it. The increases in grain yield in these two treatments were 69.4% and 63.2%, respectively, over that in un-weeded control. This BM treatment fetched highest net returns (Rs.61,700/ha). However, another BM option, comprising 1:1 mixture of *Sesbania* (12.5 kg seed/ha) + *Crotalaria* (12.5 kg seed/ha) and 2,4-D 0.5 kg/ha applied at 35 DAS resulted in significantly higher total biomass of BM crops (2.4 t/ha) than other BM treatments, and resulted in significantly higher amounts of N (73.7 kg/ha) added to soil, followed by *Sesbania* + *Crotalaria* (12.5 + 12.5 kg/ha) mixture applied with 2,4-D at 25 DAS. This BM treatment led to significant increase in MBC by 32.4%, respectively, over weed-free control.

5.5.6 Effect of Integrated Weed Management on Yield and Quality of Onion Seed

Field experiment was conducted during *Rabi* 2017-18 at ICAR-IARI Regional Station Karnal. The experimental field comprised of *Chenopodium album, Coronopus dydimus, Medicago denticulata, Phalaris minor* and *Poa annua* weeds. Significant reduction in weed dry weight was recorded in all the weed control treatments compared to unweeded check. Highest reduction in weed dry weight 78.2% and 69.4% was observed in oxyflourofen (150 g/ha) and pendimethalin (1.5 l/ha) followed by hand weeding (HW) 35 days after sowing (DAS). Cumulative effect of umbel size, seed weight/umbel and 1000- seed weight resulted in maximum seed yield under oxyflourofen 150 g/ha followed by one HW 35 DAS and weed free treatment. Seed yield was negatively correlated (-0.89) with weed dry weight. Reduction in seed yield could be predicted up to 1.056 kg with increase of one gram of weed dry weight/m^2. Seed quality in terms of percent germination was statistically at par between different weed control treatments.

6. BASIC AND STRATEGIC RESEARCH

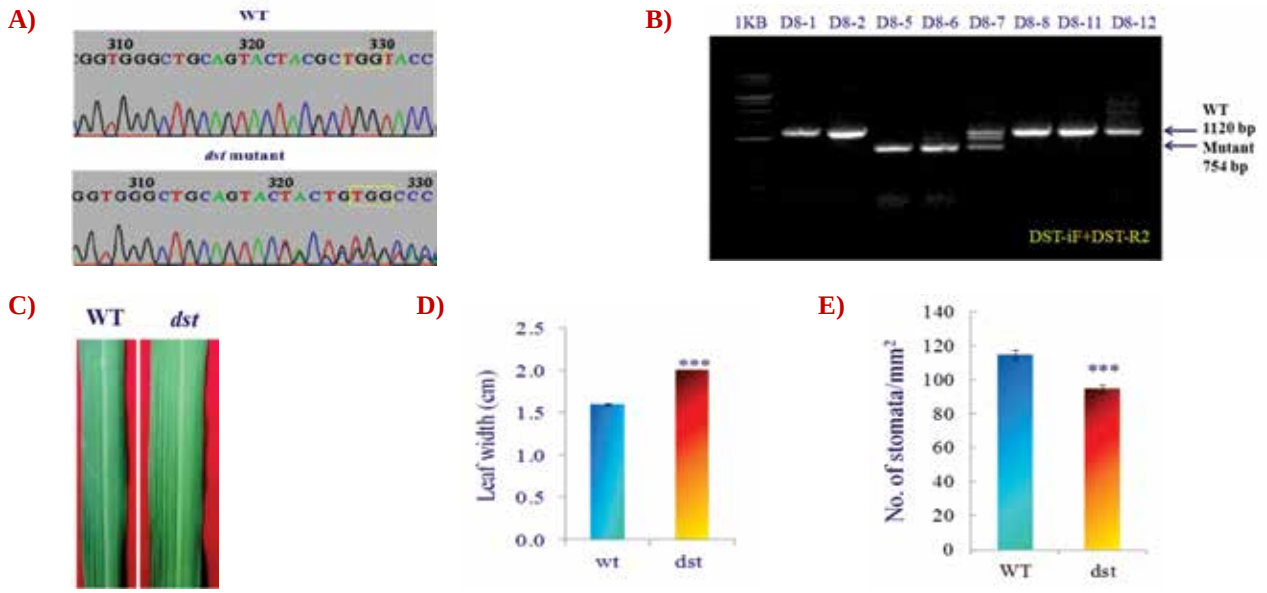
The basic and strategic research at IARI was focused on phenomics and high throughput phenotyping for identification of superior donors and breeding lines, development of CRISPR-Cas9 genome editing platform in rice and soybean, functional validation of genes and mapping QTLs for biotic and abiotic stress tolerance, the physiological basis of crop yield, mitigation studies on climate change, development of remote sensing and GIS techniques for assessment and management of crops and natural resources. This section briefly covers some of the significant achievements in these areas.

6.1 PLANT MOLECULAR BIOLOGY

6.1.1 Genomics and Gene Discovery

6.1.1.1 Genome editing of rice for stress tolerance

Targeted genome editing has emerged as next generation precision breeding technology for crop improvement. To harness this technology, CRISPR-Cas9 genome editing was established in rice. To generate mutants of *DST* (*DROUGHT AND SALT TOLERANCE*) gene, two guide RNAs were designed and CRISPR/Cas9 gene construct pC1300-P_{U3}::sgRNA-DST_{F2}-P_{UQ}::SpCas9-P_{U3}-SgRNA-DST_{F1} was developed. This gene construct was introduced into *Agrobacterium* strain EHA105 and used for genetic transformation of mega rice variety MTU1010. About 30 events were characterized by DNA sequencing of target regions of gRNAs. Superimposed signal peaks beginning



Development of CRISPR-Cas9 mediated gene-edited mutants in rice. A) DNA sequences of *dst* mutant. DNA sequence chromatograms show the region covering target site. PAM sequence is shown in box. Overlapping chromatogram near PAM site indicates mutation. B) Fragment length polymorphism to detect deletion mutants. D8-5, D8-6 and D8-7 lines produced an amplicon of 754 bp demonstrating 366 bp deletion between the two gRNA target sites in *DST* gene. C&D) Knock-out mutant of *dst* gene confers enhanced leaf width and E) decreased Stomatal number. Asterisks indicate statistically significant differences (P < 0.001)

from the mutant nucleotide position near the PAM site in the chromatogram were observed in most of the CRISPR-Cas9 plants. These mutants were further confirmed in T_1 generation by PCR and DNA sequencing. Mutant lines with gene-editing at both gRNAs resulted in deletion of nucleotides between these two gRNAs were identified. PCR amplicons were sequenced and analysed for homozygous mutants by DNA sequencing. Phenotypic analysis showed that the *dst* mutants created in an *indica* rice cv. MTU1010 background. These mutants showed with significant increase in leaf width and decrease in stomatal number. Thus, CRISPR-Cas9 system was standardized and demonstrated in rice, and the *dst* lines developed will be evaluated further for its use in crop improvement.

6.1.1.2 Genome editing for reducing seed phytate content in soybean

To reduce the seed phytate content, two gRNAs targeting *GmIPK1* gene, which codes for the terminal step of phytate biosynthesis, were designed. These gRNAs were also validated the functional efficiency of gRNAs using a fast and efficient AGRODATE (Agrobacterium mediated Disc Assay for Transient Expression) method. Both in transient and stable transformants, the most frequent type of mutations observed were deletions (~76%) along with few insertions (~23%). Phytate analysis of T0 stable soybean knock out mutants showed about 6-9-fold reduction in phytate content.

6.1.2 Functional Characterization of Genes

6.1.2.1 Overexpression of ABA receptor gene *OsPYL10* enhances drought and cold tolerance in rice

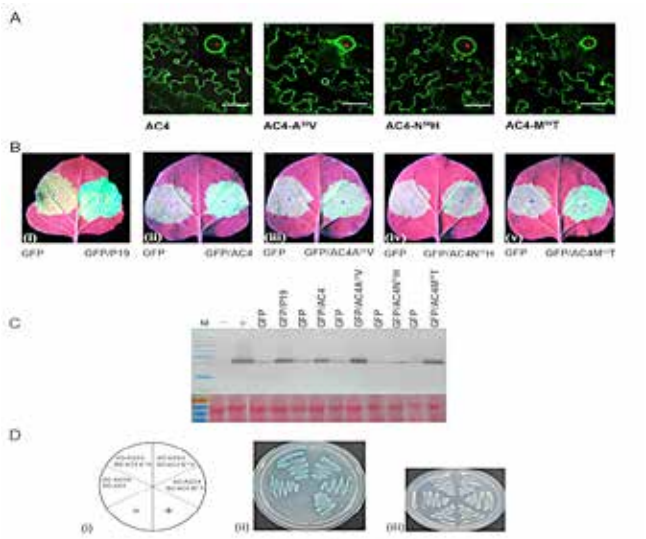
Abscisic acid (ABA), the plant stress hormone, is perceived by ABA receptors. Rice cv. MTU1010 was genetically transformed with one of the ABA receptors, *OsPYL10*. This study revealed that OsPYL10 regulates ABA synthesis in rice. Rice transgenics overexpressing *OsPYL10* under the stress inducible *AtRD29A* promoter showed enhanced cold tolerance. Four independent single copy events of $P_{AtRD29A}$::*OsPYL10* transgenic lines were evaluated for their drought (soil matric potential ~ -80 kPa) tolerance at vegetative stage under transgenic greenhouse conditions. The *PYL10* transgenic rice plants showed better cellular tolerance and three events showed significantly higher grain yield per plant under drought stress conditions.

6.1.2.2 Overexpression of *isopentenyltransferase* (*IPT9*) enhances salt tolerance in rice

Cytokinins are important plant hormones that play an essential role in plant development, yield and stress tolerance. IPTs (Isopentenyltransferases) are involved in cytokinin biosynthesis. However, these genes have not been characterized well in rice. In this study, rice cv. MTU1010 was genetically transformed with one of the IPTs, *OsIPT9*, cloned from Nagina 22. *IPT 9* transgenic lines showed enhanced stay green trait, photosystem II yield, spikelet fertility under both drought and salt stresses.

6.1.2.3 Virus-derived AC4 protein suppresses RNA silencing activity

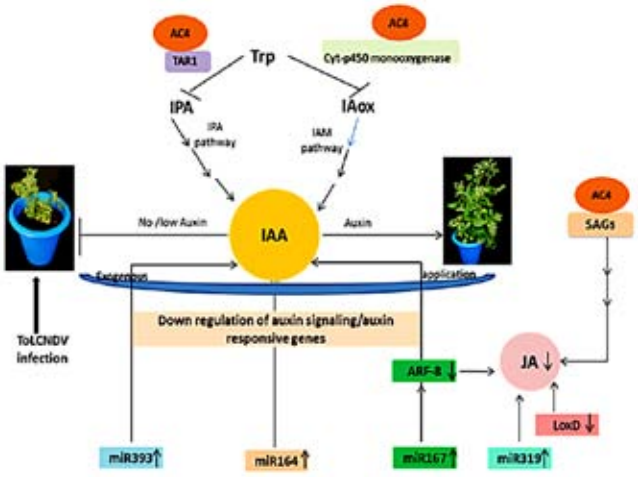
Plant RNA silencing systems regulate plant developmental pathways and restrain invading viruses either at transcriptional level via RNA-directed DNA methylation, or at post-transcriptional stage interfering with mRNA to restrict viral infection. However, viral-derived proteins, including suppressors of RNA silencing, favour virus establishment, and also affect plant development. In this study, we report that Tomato leaf curl New Delhi virus-derived AC4 protein suppresses RNA silencing activity and mutational analysis of AC4 showed that Asn-50 in the SKNT-51 motif, in the C-terminal region, is a critical determinant of its RNA silencing suppressor activity. AC4 showed interaction with host AGO4 but not with AGO1, aggregated around the nucleus and influenced cytosine methylation of the viral genome.



Sub-cellular distribution of green fluorescent protein (GFP)-tagged ToLCNDV AC4. (A) C-Terminal GFP fusion of AC4 and its mutants, viz., AC4^{A30V}, AC4^{N50H} and AC4^{M55T} were expressed transiently by agro-infiltration in *Nicotiana benthamiana* epidermal cells, and fibrillarin tagged with monomeric red fluorescent protein (Fib-mRFP), served as a nucleolar marker. In all three cases, fluorescence was found in both the cytoplasm and around the nucleus. Bars in the lower right corners represent 20 µm. (B) Characterization of the RNA silencing suppression activity of ToLCNDV AC4 and its mutant proteins by agro-infiltration patch assay. On the left hand side of each *Nicotiana benthamiana* leaf a binary vector expressing GFP under the control of the 35S promoter was agro-infiltrated, together with an empty binary vector. On the right side of the leaf, the same binary vector expressing GFP was agro-infiltrated together with a binary vector expressing (i) tomato bushy stunt P19 protein, P19 (Positive control), (ii) AC4 protein, and its mutants (iii) AC4^{A30V}, (iv) AC4^{N50H}, and (v) AC4^{M55T}. (C) Western blotting quantification of the steady-state level of GFP accumulation in the infiltrated patch. (D) Yeast two-hybrid assays (i) Schematic representation of interactions is shown in the plate format where pGADKT7 is denoted as AD and pGBKT7 is denoted as BD, pGBKT7-p53/pGADT7-RecT (positive control) symbolized as +, and pGBKT7-p53-/pGADT7–lamin (negative control) symbolized as –. Interaction of ToLCNDV AC4 and its mutants AC4^{A30V}, AC4^{N50H}, and AC4^{M55T} with the argonaute protein AGO4 (ii) The cells were grown on SD/-Ade/-His/-Leu/-Trp (quadrauple drop out) + X-α-gal media (AC4 and its mutants showed interaction with AGO4) streaked from (iii). (iii) Cells grown on double drop out media

6.1.2.4 Identification of tomato proteins that interact with AC4 during ToLCNDV infection

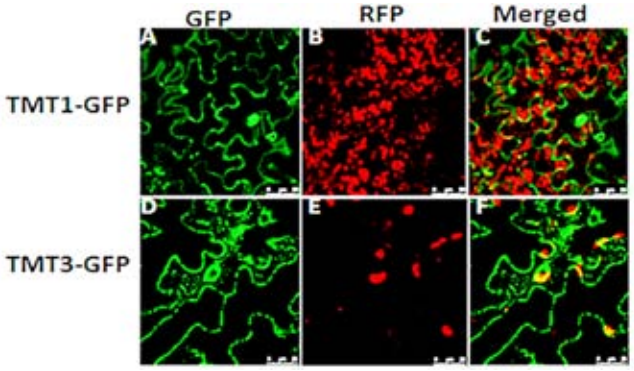
In order to decipher the role of AC4, we have attempted to identify the host proteins that interact with AC4 during ToLCNDV infection. We identified five proteins viz., cytochrome-P450 monooxygenase (Solyc00g009760) and TAR1 like (NCBI gene bank No. XM_015222884), SAG (senescence associated gene) (Solyc00g006680.1), Toi54 and one unknown protein (Solyc05g025570.1). Inhibition of JA induced defense pathway by AC4 was further confirmed by lower expression of LoxD coding for JA biosynthesis in infected leaves. Induction of miR393, 164 and 167 expression lead to down regulation of auxin signaling or auxin response genes upon viral infection. AC4 interacted with cyt-p450 monooxygenase for IAA biosynthesis through IAM pathway. Similarly AC4 interacted with TAR1 which mediates conversion of Trp to IPA (Indole-3-pyruvic acid). Exogenous application of auxin on ToLCNDV infected plants restored growth and recovered from leaf curl symptom.



Induction of miR319 by ToLCNDV infection in tomato and interaction of AC4 with SAGs suppressed JA mediated defense to facilitate virus infection and symptom development

6.1.2.5 Localization of γ-TMT proteins in *Nicotiana benthalmiana*

Based on the differences in amino acid sequences of N-terminal regions, γ-TMT (γ-tocopherol methyl transferase) has been classified into three isoforms; γ-TMT1, 2 and 3. Out of all isoforms, γ-TMT3 showed significantly high expression in soybean seeds followed by γ-TMT1. Localization of GFP fused γ-TMT1 and γ-TMT3 was visualized by confocal scanning microscopy 5 days after agroinfiltration in *Nicotiana benthamiana* leaves. This shoed that GFP-γ-TMT1 is localized in both cytosol and chloroplast.



Subcellular distribution of GFP fused γ-TMT isoforms in epidermal cells of *Nicotiana benthamiana*. G-I: Agroinfiltrated leaves pCambia-GFP fluorescent detection; A, D are GFP fluorescence; B, E are Chlorophyll autofluorescence; C, F are overlapping. Scale bars are 50 µm

6.1.2.6 Characterization of manganese superoxide dismutase (MnSOD)

SODs provide the first line of defense against reactive oxygen species (ROS) under heat stress. In this study, Mn-SOD gene was cloned from wheat cv. HD 2985 and found to code for 500 AA. The purified protein of *MnSOD* expressed in heterologous system showed 4.5-fold high activity, as compared to SOD activity in crude extract of wheat. Enzyme kinetics showed that MnSOD has optimum temperature, optimum pH and Km of 35°C, 7.3 and 1.85, respectively. MnSOD can be used as potential biochemical marker for screening large germplasm for the development of 'climate-smart' crop.

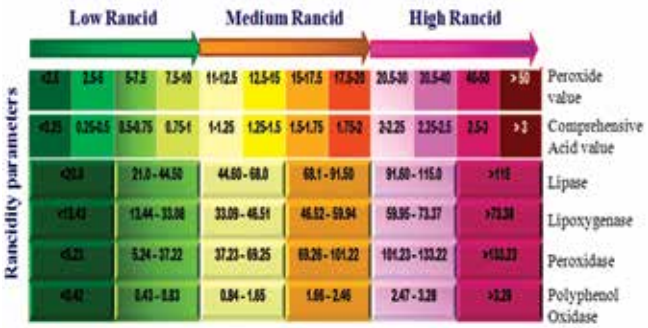
6.2 BIOCHEMISTRY

6.2.1 Resistant Starch Content in Wheat Grains

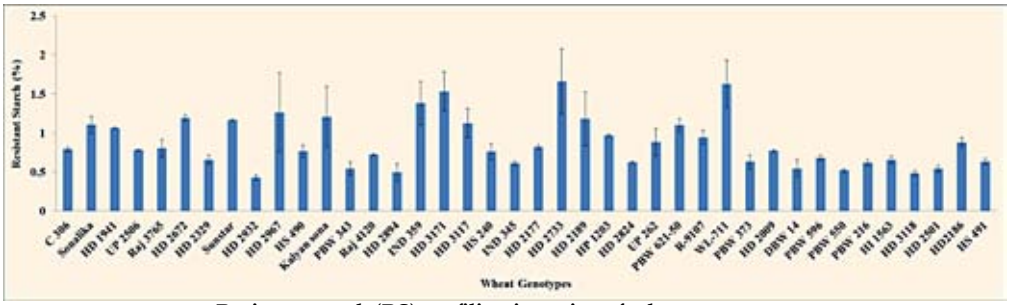
Wheat contributes to 12% carbohydrate and 40% calories in the diet globally. Wheat grain is mainly composed of ~75% starch along with protein and fibers. Since resistant starch (RS) is beneficial for the diabetic patient, to identify genotypes with high RS content in grains, 40 diverse genotypes of wheat were analyzed. Highest RS content was found in wheat cv. HD 3118 (2.2%) followed by HD 2733 (1.66%), HD 3171 (1.53 %), and WL 711 (1.62%). Wheat cvs. HD 3118, HD 2967, Kalyansona, Sunstar and WL 711 were identified as high RS genotypes.

6.2.2 Rancidity Matrix of Pearl Millet

Forty one pearl millet genotypes were screened for the Acid value, Peroxide value and the activity of enzymes involved in lipid oxidation (Lipase, Lipoxygenase, Peroxidase and Polyphenol Oxidase). Based on the above data, a rancidity matrix was developed to group the pearl millet genotypes into low, medium and high rancid types (Low Rancid genotypes: GHB732, HHB67 imp, KBH108, GHB558, RHB223 and RHB177. Medium Rancid genotypes: 86M82, JKBH1008, GHB757, MPM17, 86M64, WB100, Pusa Purple 1, Pratap, 86M86, RHB173, 86M84, Kaveri, PAC909, Nandi65, Nandi70; High Rancid genotypes: PHB2168, Nandi72, Nandi 61, 86M88, 86M89, NBH5767,



Rancidity matrix of pearl millet developed based on the peroxide value, acid value and activities of enzymes associated with rancidity



Resistant starch (RS) profiling in grains of wheat genotypes

Dhanshakti, MPMH17, MPMH21, HHB234, GHB905, 86M38, Nandi75, MP7792, NBH4903, HHB299, GHB744. 86M13 and XMT1497). This matrix will help the breeders for the selection of donor genotypes to develop improved varieties.

6.2.3 Bio-elicitors to Mitigate Drought Stress in Rice

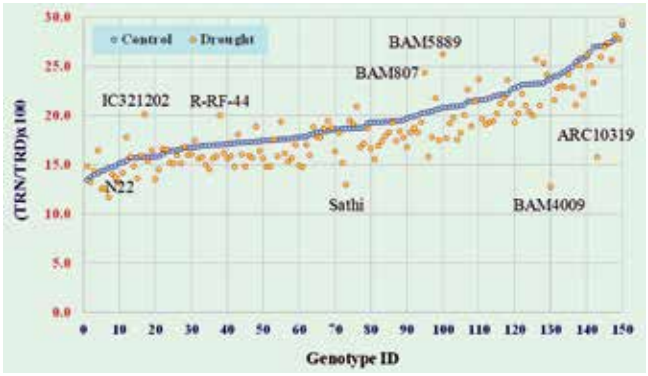
NADPH oxidase (NOX) activity was measured in the shoot and root tissue of contrasting rice genotypes- drought tolerant Nagina 22 and drought sensitive Pusa Sugandh 5, primed with three bio-elicitors- methyl jasmonate (MJ), salicylic acid (SA) and paclobutrazole (PBZ). NADPH oxidase (NOX) activity was innately more in the tolerant genotype. All three bio-regulators upregulated the expression of *Nox1* in roots in Nagina 22 while in sensitive genotype, upregulation of *Nox1* was observed upon on priming with PBZ and SA. Up-regulation of *Nox5* was also found in both the genotypes primed with any of the three bio-elicitors under drought stress. Molecular cloning and characterization of NADPH oxidase genes revealed the presence of NADPH oxidase superfamily domain, which produce reactive oxygen species (ROS) as a defense mechanism in the stressed plants. Overall, seed priming with MJ was found to be the most effective followed by priming with PBZ and SA to mitigate the effects of drought stress.

6.3 PLANT PHYSIOLOGY

6.3.1 Identification of Donors for Abiotic Stress Tolerance and Nutrient Use Efficiency

6.3.1.1 Phenomics of WUE in rice and wheat

More than 98% of water taken up by plants is lost to the atmosphere through transpiration. Since fresh water scarcity is emerging as a major problem for sustainability of rice production, development of varieties that uses less water is important. Towards identification of donors for component traits of water use, this study was conducted with 150 rice germplasm during *Kharif* 2018 at Nanaji Deshmukh Plant Phenomics Centre (NDPPC), IARI, New Delhi. Nocturnal transpiration in rice germplasm lines varied from 15-30% of diurnal transpiration. Drought stress reduced nocturnal transpiration in most genotypes. However, in some genotypes, nocturnal transpiration was higher under drought stress. Both diurnal- and nocturnal-transpiration were significantly lower in BAM819, BAM1689, IR83388-B-B108-3 and Vanaprava as compared with drought tolerant check Nagina 22. Genome-wide Association Studies (GWAS) identified four significant SNP markers associated with water use efficiency in rice genotypes.



Relative ratio of nocturnal transpiration (TRN) to diurnal transpiration (TRD) in rice genotypes under control and drought stress conditions

In wheat, 184 RILs of HD2967 (high yielding) x C 306 (drought tolerant) were phenotyped at NDPPC, IARI during *Rabi 2017-18* for WUE and drought tolerance. RILs and parents were grown under irrigated conditions and drought as imposed from booting to maturity [cycles of soil moisture content (SMC) 8% & recovery] stress conditions. Total water used during the entire life cycle was recorded by using automated weighing and watering stations of phenomics facility. C306 used about 578 L of water/kg of grain production under irrigated conditions, while the best RIL identified used 454 L of water/kg of grain production. Under drought stress conditions, C 306 used about 869 L of water/kg of grain production, while the best RIL identified used 571 L of water/kg of grain production. 184 RILs of HD2967 x C 306 and the parents were genotyped with 35000 SNPs using 35K Wheat Breeder Array. Two QTLs for WUE with PVE of 11.57 and 13.18% were mapped on chromosome 2B and 7B, respectively.

6.3.1.2 A facile and cheaper method to measure root angle of rice and wheat

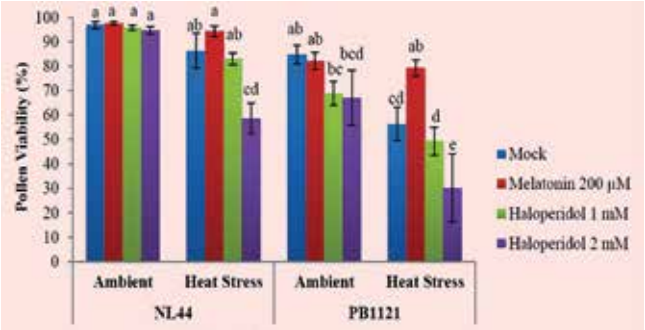
Due to the difficulty in the phenotyping for deep rooting, genetic variability in deep rooting is less exploited in genetic improvement programme. Root angle is a surrogate for deep rooting. Available methods to measure root angle in cereals are expensive, complicated and time consuming. Here, we report a novel, easy, robust and cheaper method to measure root angle in rice and wheat under natural field conditions. By using this method, 56 wheat and 29 rice genotypes were phenotyped for root angle under field conditions. In consistent with the contrasting adaptation of rice and wheat to soil moisture, about 58% of crown roots were having shallow angle (<40°) in rice, while about 67% of the crown roots were in deep rooting angle (>60°) in wheat. This method is suitable for high throughput phenotyping of root angle in natural field conditions.

6.3.1.3 Identification of Nagina 22 mutants with high photosynthetic efficiency

Growth analysis and photosynthesis studies were carried out with 240 rice N22 mutants at 65-75 days after sowing during *Kharif* 2018. The relative growth rate (RGR) ranged from 0.028 to 0.237 mg g^{-1} day^{-1}. The mutants showing higher RGR viz., 233-2A-3,116-1A, M-108-E, SM-M-301-1-1-1, M143-2, 218, M37, M507-1, M-66-3 and M-76 as compared to wild type Nagina 22 (0.088) were identified. Net Assimilation Rate (NAR, g m^{-2} d^{-1}), a trait for photosynthetic efficiency, ranged from 4.89-82.56. The mutants showing higher NAR viz., SM-507, SM-M-301-1-1-1, M-301-1, M-108-E, M-76, 702-1, M37, M-2346-A, M507-1 and 2208-A as compared to wild type (14.89) were identified. Photosynthesis rate was studied in a set of 40 selected mutants. Mutants M-245-1A, 16-AKS-2, 2208-A, 108-2 and SM67-1 showed higher photosynthesis rate as compared to Nagina 22 (25.3 µmol m^{-2} s^{-1}) were identified. These mutants will be useful for genetic analysis of photosynthetic efficiency in rice.

6.3.1.4 Deciphering the role of melatonin in heat tolerance of rice

Melatonin, a hormone of the pineal gland in vertebrates, is synthesized by various plants. Recent studies showed that it play important role in stress tolerance of plants. Hence a study was conducted to analyze the role of melatonin in high temperature stress tolerance of rice during reproductive phase. It was found that foliar application of melatonin before exposing the plants to heat stress enhanced Total Antioxidant Capacity and antioxidant enzymes, which helped to scavenge ROS and maintain homeostasis in rice. Further, melatonin stabilized PSII activity under heat stress condition and increased photosynthesis rate significantly. Heat stress severely affected pollen viability and reduced spikelet fertility, while melatonin helped to alleviate pollen abortion and increase spikelet fertility leading to increase grain yield under heat stress conditions in rice.



Melatonin helped mitigation of adverse effect of heat stress on pollen viability in rice under heat stress

6.3.1.5 Stem reserve mobilization in wheat under high night temperature stress

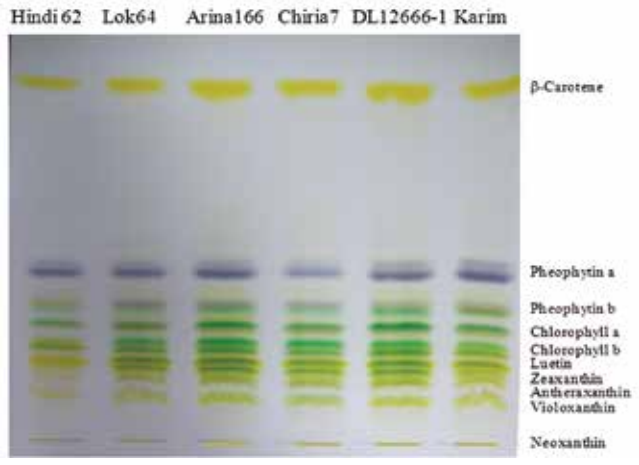
Increase in daily minimum temperature besides maximum temperature is predicted to have a greater impact on late sown wheat in the Indo-Gangetic plain. Twenty late sown wheat genotypes were screened for tolerance to high night temperature (HNT, +3°C above mean ambient night temperature of 21°C) during grain filling period. HI 1563 and HD 2932 were identified as HNT tolerant genotypes. In general, lower internodes had higher translocation efficiency under ambient conditions whereas it was similar from both internodes under HNT. Genotypes maturing in 120-130 days (medium duration) showed higher translocation efficiency from penultimate and lower internodes as compared to long duration genotypes (130-140 days) under HNT. Increase in translocation efficiency from penultimate internode minimized yield loss under HNT in wheat.

6.3.1.6 Roles of epicuticular wax and phloem immobile mineral nutrients in stress tolerance of wheat

Dynamics of epicuticular wax (ECW) and phloem immobile mineral nutrients (Si, B and Mn) were analyzed in wheat genotypes under heat and drought stresses. Under drought stress, main ear grain yield was linked positively to ECW content of flag leaf and husk of ear at anthesis stage, and Si, B and Mn content in the husk of the ear at harvest. Grain yield was also positively associated with Si content in the flag leaf at anthesis, in the husk of ear at harvest and in the grains at harvest and B content in the grains at harvest. This study showed that ECW content and Si, B and Mn content in flag leaf, ear parts and developing grains play important role in tolerance to heat and drought stresses in wheat.

6.3.1.7 Role of carotenoids in wheat under heat stress

Since carotenoids play key role in photoprotection and heat dissipation under stress conditions, its role in six wheat genotypes viz., namely, Hindi62, Lok64, Arina 166, Chiria7, DL1266-1 and Karim were studied. High temperature was imposed by delaying sowing dates i.e. 30th November, 2017 and 15th January, 2018. Heat tolerant genotypes maintained higher level of photosynthetic pigments and exhibited the induction in the level of zeaxanthin and lutein under heat stress. Tolerant genotypes had better membrane stability and lower level of lipid peroxidation than that of sensitive genotypes. These results indicated the photoprotective role of carotenoid in heat tolerance of wheat.



Pigment profile of wheat genotypes under heat stress

6.3.1.8 Identification of donor for dual-nutrient efficiency in wheat

Nitrogen (N) and phosphorus (P) are the crucial inputs for sustainable crop production. Seventy bread wheat genotypes were phenotyped for tolerance to low nitrogen (N) and phosphorus (P) stresses. Physiological traits such as root parameters, enzymes of nitrate assimilation, acid phosphatase activity in root exudate, leaf area and biomass to identify the contrasting genotypes. Based on these responses, HD 2781 (tolerant/efficient) and C 306 (sensitive/inefficient) were selected to understand the molecular basis of dual nutrient stress tolerance. Expression analysis of candidate genes involved in transport of N (NRT1.1, NRT1.2, NRT2.1) and P (PT2.1, PT1.2, PHT1.4, PT8) in roots, and genes involved in N assimilation (Nia2, GS1, AlaAT, GDH) and P remobilization (PAP, SQD2) showed that HD 2781 is genetically efficient and responsive genotype, and can be used as 'donor' for developing varieties for N and P use efficiency.

6.3.1.9 Physiological analysis of nitrogen use efficiency in rice

Nitrogen use efficiency (NUE) of cereal crops including rice is around 33% only, resulting in huge economic loss and environmental degradation. A contrasting set of 24 genotypes were selected based on relative biomass accumulation (RBM) and chlorophyll retention (CR) under low N stress from 300 rice genotypes. These genotypes were evaluated for root system architecture, N accumulation, activity of N assimilating enzymes in hydroponics and NUE parameters, rate of photosynthesis and yield in field. In field condition, NUE varied from 3.7-69 in low N and 17.3-65 g grain/g N uptake in control (N120) conditions. Genotypes with higher tolerance to seedling stage nitrogen deficiency (high RBM and CR) also recorded high NUE in field N stress conditions. The results showed that phenotyping for seedling stage N deficiency tolerance under hydroponics is a potential surrogate to identify rice genotypes for high NUE under field conditions. Expression analysis

of N assimilation and uptake genes in seedling leaf, root and in flag leaves showed that the activity and expression of N assimilation and uptake genes were high in IR 83929 and N-L 42 were showing high NUE and will be suitable for improved NUE under aerobic rice cultivation.

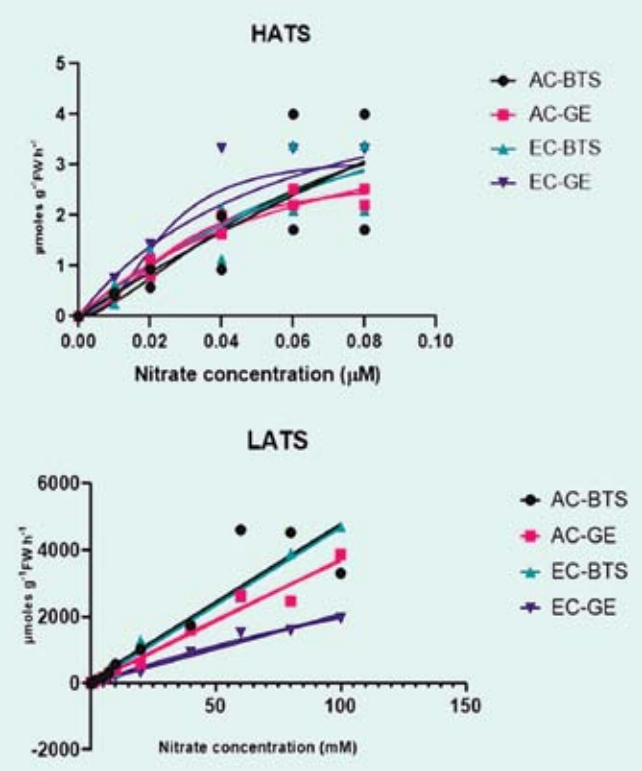
6.3.2 Physiology of Crops under Climate Change Scenario

6.3.2.1 CO_2 responsiveness of rice in free air co_2 enrichment (FACE) system

In earlier study, low plant density planting response of rice genotypes were used as a surrogate method to identify elevated CO_2 response of rice genotypes and a contrasting set of 23 rice genotypes were identified. These genotypes were validated for CO_2 responsiveness in FACE facility. A significant increase in photosynthesis was observed under elevated CO_2 followed by low planting density treatment and control. HALWA GOSE RED recorded highest photosynthesis under elevated CO_2 while MUDGO recorded highest WUEi under elevated CO_2. Yield components analysis revealed a significant increase in all the yield components including panicle weight $hill^{-1}$ (46 and 25%), total biomass $hill^{-1}$ (52 and 26%) and grain yield $hill^{-1}$ (46 and 24%) under low planting density and elevated CO_2 treatment, respectively. Regression analysis revealed that genotypes identified under low planting density method also performed at par under actual elevated CO_2.

6.3.2.2 Elevated CO_2 inhibits nitrate uptake and ammonia assimilation in wheat

Wheat provides about 20% of protein requirement for human beings. Elevated CO_2 (EC) under global climate change conditions has been shown to decrease protein content of wheat grains. To understand the causes for this, nitrate uptake and assimilation were studied in response to different nitrate levels and EC in wheat. EC decreased nitrate reductase activity and accumulation of NO as reported earlier. EC also down regulated the expression of ammonia assimilation and nitrate signalling genes under high N availability, with a concomitant increase in nitrosothiol accumulation. Plants grown under EC also displayed reduced rates of nitrate uptake and marked reduction in nitrate uptake kinetic components of the low affinity transport system (LATS). Expression of NPF genes encoding LATS were differentially regulated by EC, and N availability in different genotypes. Root nitrogen assimilation was less affected in comparison to shoot nitrate assimilation, thereby the proportion of root contribution towards total assimilation was higher. Thus identification of mechanisms and genotypes that maintains nitrate uptake and assimilation is critical to sustain grain quality under EC conditions.



Nitrate Uptake Kinetics-HATS and LATS. Elevated CO_2 (EC) improved the nitrate uptake under low supply range but diminished the nitrate uptake capacity at high supply range as compared with Ambient CO_2 (AC). GE, Gluyas early; BTS, B.T. Schomburgk

6.4 GENETICS

6.4.1 Wheat

6.4.1.1 Identification of new QTLs for drought and heat stress tolerance

Backcross-derived mapping population of C306/*2HD2733 were phenotyped and genotyped with

SSR markers for validation of previously identified QTLs and identification of new QTLs linked to drought and heat tolerance. A total of 63 QTLs were detected for various drought tolerance related traits which are located on all 21 chromosomes. In another study, genic SSRs developed from differentially expressed genes under heat stress were analyzed in a set of 175 wheat lines phenotyped under late sown conditions. A total of 42 polymorphic SSRs were identified and further validated using biparental mapping population to identify SSRs linked to heat stress tolerance traits.

6.4.1.2 Pyramiding of genes for all three rusts and grain protein

Small RNA transcriptome analysis of NIL population in background of HD 2329 carrying seedling resistance gene was carried out to identify non-coding RNAs that might be involved in rust resistance. To pyramid resistance to all three rust diseases, F_1's generated during *Rabi* 2016 and offseason of 2016-17 were crossed to develop triple (TCH) and double (DCH) cross combinations carrying three to four genes for rust resistance. The linked markers *Yr47 - sun180, Yr51 - sun104, Yr57 - gwm389, Sr22 - csSr2., Sr26 - sunKASP_224,* and *Sr50 - SrR-Sr50 5pR2/SrR-5pF3* were used to select the resistance genes in DCH (361) and TCH (164) lines. F_1 were also made between rust resistant genes carrying lines and protein gene GpcB1. Three Indian wheat varieties viz., HD 2733, DBW 17 and PBW 550 were used for these crosses. The cross derivatives stabilized and/or segregating for triple rust resistant genes are being evaluated.

6.4.1.3 Development of genotypes with better biscuit making quality

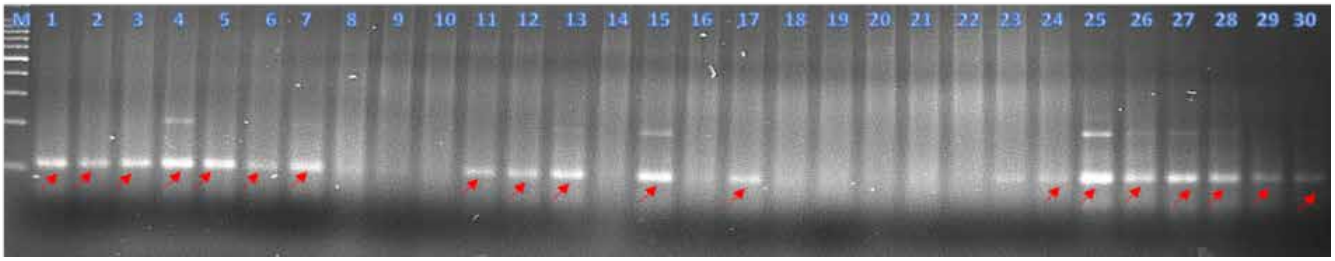
Since indigenous wheat varieties with desired quality parameter for biscuit making (i.e. soft grain, low protein content and weak and extensible flour) are limited, a MABB approach was initiated with genes *PinaD1*, *PinbD1*, *Glu-A1*, *Glu-B1*, *Glu-D1*, *Glu-3A*, *Glu-3B* and *Glu-3D* in important wheat varieties. Foreground selection for *PinaD1a* in DBW 14 and *PinaD1a, GluA3c* and *GluD3c* in HI 1563 in BC2F2 was carried out and plants with appropriate allele combinations were selected. Nine entries of BC2F3 of DBW14/ Barham cross have been planted in replicated trials for yield and quality evaluation.

6.4.1.4 Development of wheat with reduced celiac immunogenicity

Eleven F_4 plants and 19 BC_1F_3 plants were earlier obtained in a MAS programme from crosses between nullisomic and ditelosomic lines for chromosome 1A and 6A with *durum* wheat variety HI 8663. To enrich the plant number, more of BC_1F_2 seeds of different crosses were planted and EST markers were run to obtain more homozygotes lacking specific chromosomes 1A, 6 A or 1AL.

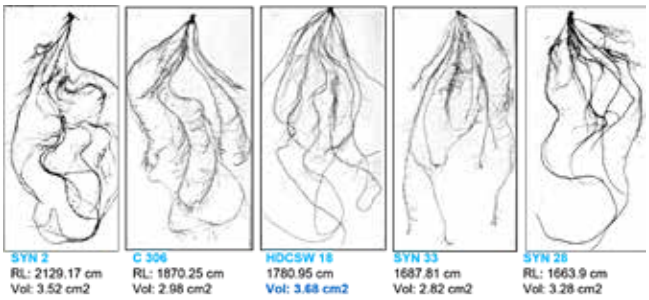
6.4.1.5 Exploring synthetic wheat for adaptability to conservation agriculture

A set of 75 wheat lines (55 synthetic wheat and 20 mega varieties) were evaluated under hydroponics conditions to study traits related to root architecture. Synthetic-2 recorded the highest root length (2.12 m), root surface area (307.04 cm^2), root volume (3.52 cm^3) and number of root tips (7623). Among mega varieties, HD 2967 and HD 3086 recorded 0.75 m and 0.91m root length, respectively. Synthetic-2 showed vigorous and large root system. The synthetic wheat had higher initial area and root biomass than most of the mega varieties. They also exhibited longer (Synthetic-25)



Confirmation of Positive Homozygous using EST primer SWES18 (for Positive Homozygous N1AT1B and Ditl.1AL in BC1F2). Lanes 1-30 are plant no. S-4101 to S-4130, M=100bp ladder

thicker coleoptile length (Synthetic-4) than cultivated varieties. Synthetic-2 is used in crossing programme with rust resistant high yielding genotypes for developing backcross lines.



Root architecture of synthetic and released wheat varieties

6.4.2 Rice

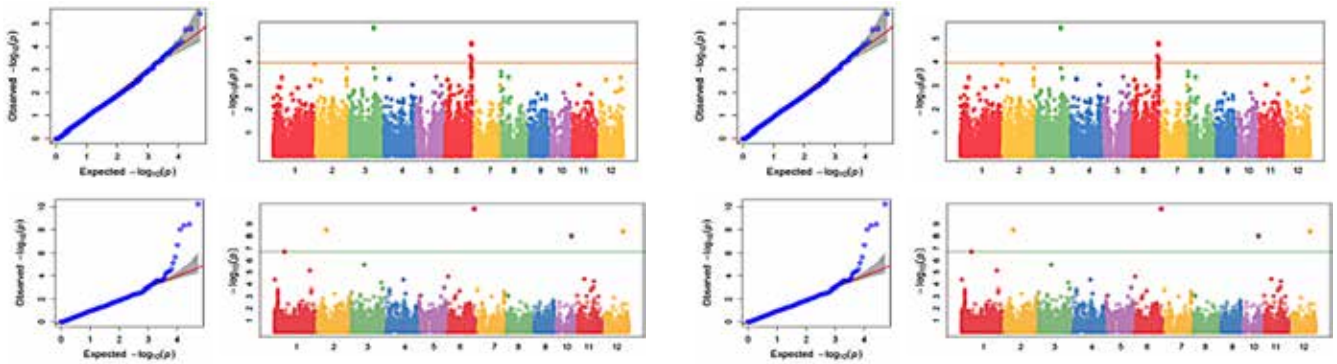
6.4.2.1 Marker-aided introgression of herbicide tolerance in *basmati* varieties

Marker-assisted backcross breeding was employed to transfer the mutant allele of herbicide tolerance gene (*ALS)* from a donor parent, HTM-N 22 (Imazethapyr tolerant EMS induced mutant of Nagina 22) into two elite *Basmati* rice varieties viz., Pusa Basmati 1121 and Pusa Basmati 1509. Foreground selection was carried out using the gene linked marker, RM6844 and background selection was carried out using polymorphic SSR markers uniformly spanning the entire rice genome. Based on grain and cooking quality traits and recurrent parent genome recovery, 10 and 13 herbicide tolerant NILs in genetic background of PB 1121 and PB 1509, respectively, were selected and evaluated for Imazethapyr tolerance. Three promising lines with herbicide tolerance were identified for further testing.

Evaluation of HT-NILs in the genetic background of PB 1121 and PB 1509

6.4.2.2 Novel QTLs for localization of Fe and Zn in the aleurone and endosperm

A set of 192 rice germplasm accessions grown at two locations were evaluated for Fe and Zn in brown rice (BR) and polished rice (PR). Grain Fe exhibited maximum loss upon polishing with a retention of 5.39 (GP 734) to 60.2% (GP 433), while grain Zn exhibited significantly lesser loss on polishing with a retention ranging from 57.3 (GP 425) to 96.79% (GP 452). Genome wide association study (GWAS) with 50K SNP markers led to the identification of 33 QTLs for four traits viz., Fe_BR (9) Fe_PR (9), Zn_BR (6), Zn_PR (9). These QTLs explained a phenotypic variance from 7.97 to 51.9 %. Four QTLs were common between two environments while remaining were specific to either of the environments. No common QTLs were observed for Fe in BR and PR, while one common and major QTL existed for Zn in BR and PR. The study revealed that the localization of minerals in the bran and endosperm



Q-Q Plot and Manhattan plot depicted the GWAS results for grain Fe concentration in brown rice (left) and polished rice (right)

of rice is under the influence of different genomic regions, and the significant QTLs for Fe_PR and Zn_PR can be targeted for enhancing the endosperm mineral micronutrient density as rice is widely consumed after polishing.

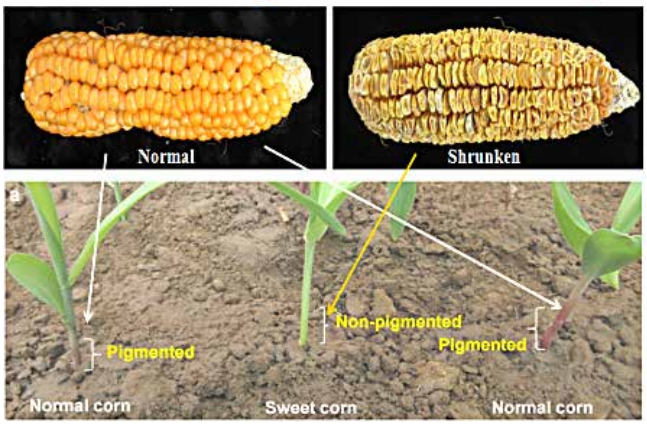
6.4.3 Maize

6.4.3.1 Development of breeder friendly markers for *lpa1-1* and *lpa2-1*

Based on C (wild) to T (mutant) transition, two dominant markers each specific to wild type (*LPA1*) and mutant (*lpa1-1*) allele were developed, and validated across seven F_2 populations. Joint segregation of these markers behaved as co-dominant marker clearly distinguishing the heterozygote from two other homozygotes. Full length sequence alignment between wild type (*LPA2*) and mutant (*lpa2-1*) allele revealed one transition mutation. A co-dominant CAPS marker was developed which clearly differentiated all the three types of segregants across seven F_2 populations. This marker will be useful to develop hybrids with low phytate content.

6.4.3.2 Anthocyanin as surrogate marker *shrunken2* allele

A study with six F_2 populations segregating for *sh2* allele and anthocyanin pigmentation in stem-base, adventitious-root, anther and silk revealed that *Anthocyanin1* gene is linked with the *sh2* gene. Adventitious-root pigmentation was mapped at 1.79 cM in population-A, while stem-base pigmentation was mapped at 0.90 cM and 0.99 cM from *sh2* in population-A and -B, respectively. Pigmentation in anther was mapped at 0.90 cM from *sh2* in population-A. Silk pigmentation was mapped at 3.45 cM and 2.64 cM distance from *sh2* in population-E and -F, respectively. Across populations, anthocyanin pigmentation in both stem-base and adventitious-root was the most efficient marker. Anthocyanin pigmentation thus can be used as a suitable morphological marker leading to considerable saving of valuable resource, labour and cost.

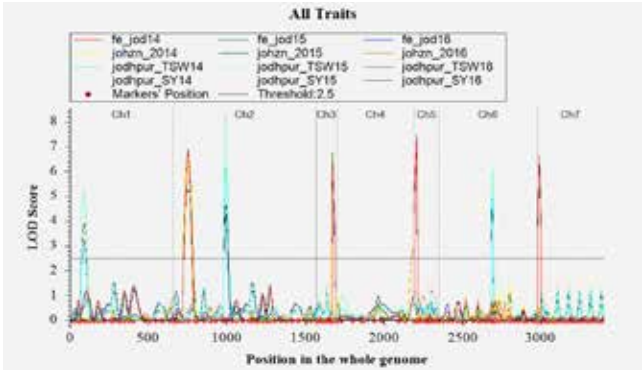


Presence and absence of purple pigmentation in wild type and *sh2* mutant, respectively

6.4.4 Pearl Millet

6.4.4.1 Mapping of QTLs for grain Fe, Zn, seed weight and yield

Two hundred ten RILs (PPMI 683 x PPMI 627) were evaluated for three years at Jodhpur. These RILs were genotyped using 151 polymorphic SSRs markers for mapping of QTLs for iron, zinc, 1000-seed weight and seed yield. Based on three years data, minor QTLs (<30% PVE) were mapped for all the four traits. For iron, four QTLs were mapped on linkage group 2, 3, 5 and 7, and for zinc three major QTLs were mapped on linkage group 2, 3 and 4. Two QTLs for iron and zinc were co-mapped on linkage group 2 and 3. For 1000 - seed weight and seed yield/plant, three QTL were mapped on linkage group 1, 2 and 6. QTLs for yield traits were different from QTLs mapped for micronutrients. Presence of QTLs for iron, zinc, 1000-seed weight and seed yield/plant was consistent over the years.



QTLS for iron, zinc, 1000-seed weight and yield in pearl millet

6.4.4.2 Inheritance of blast resistance

To study the inheritance of resistance to blast, two crosses were made viz., ICMB 95444 x R-18 (susceptible x resistant) and ICMB 95444 x R-18 (susceptible x resistant) and F_2s and backcrosses with susceptible parent were generated. Parents, F_1, F_2 and the back cross of each cross were used to study the inheritance of blast resistance in pearl millet. It revealed the presence of single dominant gene governing blast resistance. No segregation for blast reaction was observed in the F_2s derived from the crosses of resistant x resistant parents, suggesting that single dominant gene conferring resistance in the resistant genotypes is allelic. In another study, 10 diverse lines of pearl millet differing for blast resistance reactions were crossed in a half-diallel manner to generate forty five crosses. The single crosses (F_1s) and parents along with checks were evaluated in randomized complete block design at IARI, New Delhi under natural epiphytotic conditions. High coefficient of genetic determination in broad sense (0.99) and narrow sense (0.96) with a high Baker's ratio of 0.97 indicated primarily additive gene action among crosses for the blast resistance.

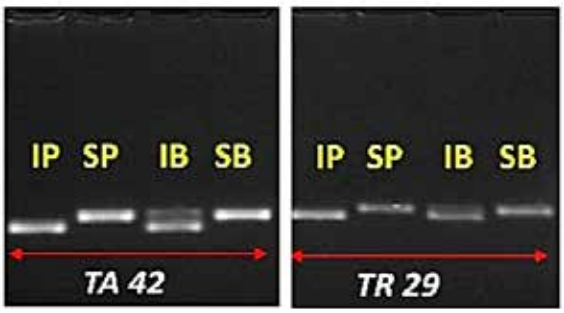
6.4.4.3 Inheritance of fertility restoration of A_4 cytoplasm

A_4 is more stable than commonly used A_1 cytoplasmic male sterility system in pearl millet. Hence, a study was carried out by crossing two diverse male sterile lines having A_4 cytoplasm (ICMA 99111 and ICMA 99444) with two diverse restorers (ICMR 13666 and ICMR 06111). The F_1 plants of both the crosses were selfed to produce F_2 and simultaneously crossed to their corresponding A lines to produce BC_1F_1 in summer 2018 at ICRISAT, Hyderabad. The parents, F_1, F_2 and BC_1F_1 populations were planted at IARI, New Delhi during *Kharif* 2018. For pollen fertility and seed set, a segregation ratio of 3:1 (fertile and sterile plants) was obtained in F_2 and 1:1 in BC_1 generations indicating that that fertility restoration of A_4 CGMS in pearl millet is governed by single dominant gene.

6.4.5 Chickpea

6.4.5.1 Genetics of semi-determinacy

Genetics of semi-determinacy was studied in BGD 72 (Indeterminate, IDT) x BG 3078-1 (Semi-determinate, SDT) cross in which the genetic constitution of BGD 72 was already known as *Dt1Dt1Dt2Dt2*. The F_1 was IDT indicating the dominance of indeterminacy over semi-determinacy. The F_2 plants of BGD 72 (IDT) x BG3078-1 (SDT) segregated with the ratio of 3 IDT: 1 SDT stem types suggesting that the IDT and SDT parents differed for a single gene for SDT. The segregation pattern observed in F_2 was confirmed by studying the breeding behavior of 148 F_3 progenies of BGD 72 (IDT) x BG3078-1 (SDT). The segregation pattern in F_3 progenies showed that all 33 SDT plants selected in F_2 bred true in F_3. Of the 114 progenies of indeterminate plants, 43 were non-segregating, while 71 segregated into IDT and SDT plants. The proportion of non-segregating and segregating progenies observed in F_3 of indeterminate plants are in good fit with the expected ratio of 2 (segregating): 1 (non-segregating). Based on the F_2 phenotypic ratio 3 IDT: 1 SDT, 1/3 (*Dt1Dt1Dt2Dt2*) of the IDT plants are expected to be non-segregating in F_3, while 2/3 (*Dt1dt1Dt2Dt2*) of the IDT plants expected to segregate into IDT and SDT plants. All the SDT (*dt1dt1Dt2Dt2*) plants are expected to be non-segregating and breeding true in F_3. BSA with 50 polymorphic markers identified *TA42* and *TR29* as polymorphic between IDT and SDT parents as well as IDT and SDT bulks and hence considered putatively linked to *Dt1* locus governing IDT stem growth. The two linked markers were validated in 15 IDT and 15 SDT F_2 plants. This is the first report on the identification of a molecular marker associated with stem growth habit in chickpea.



Bulked segregant analysis (BSA) showing putatively linked marker (IP=IDT parent; SP= SDT parent; IB=IDT bulk; SB=SDT bulk)

6.4.5.2 Marker-assisted backcross breeding for resistance to *Fusarium* wilt

WR 315 was used as donor for wilt resistance and BGD 72, an elite chickpea variety, was used as recurrent

parent. Three SSRs (GA16, TR19 and TAA110) were found polymorphic between the parents. TA110 reported to be linked to *foc 1, 2* & *3* genes was used for foreground selection. In the BC_1F_1, the WR315 specific resistant allele of TA110 (200 bp) was amplified. For background selection, 48 polymorphic SSRs distributed uniformly on 8 linkage groups were used.

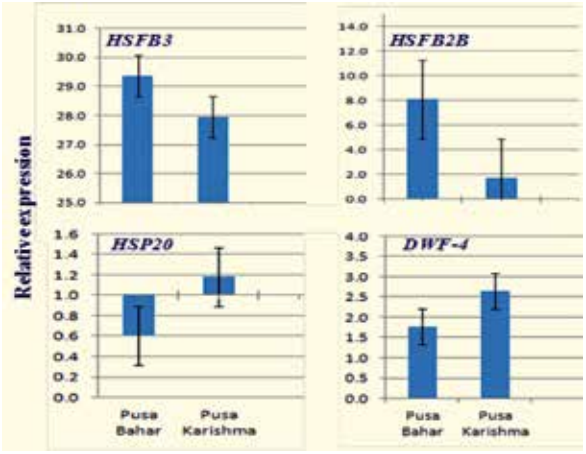
6.4.6 Mungbean

RNA-seq comparison between YMD resistant genotype PMR 1 and susceptible genotype Pusa Vishal reveled major defence associated differentially expressed genes (DEGs) such as defence enzymes, jasmonic acid (JA) pathway, gene silencing, transcription factors, various kinases and PR proteins. PhiBase hits has categorised the transcripts into five major categories viz., reduced virulence (40.23%), unaffected pathogenicity (20.67%), loss of pathogenicity (13.15%), effector (9.77%), increased virulence (6.54%) and miscellaneous (9.47%). Further, based on the functional class of the transcripts involved in the plant defence mechanism, a set of 11 genes were validated using RT-qPCR. From the RNA-seq data, a total of 513 EST-SSRs could be predicted and 39 markers representing all the 11 chromosomes of mungbean are used for the validation using a diverse set of 20 genotype differing for the YMD reaction.

6.4.7 Mustard

6.4.7.1 Breeding for high temperature tolerance

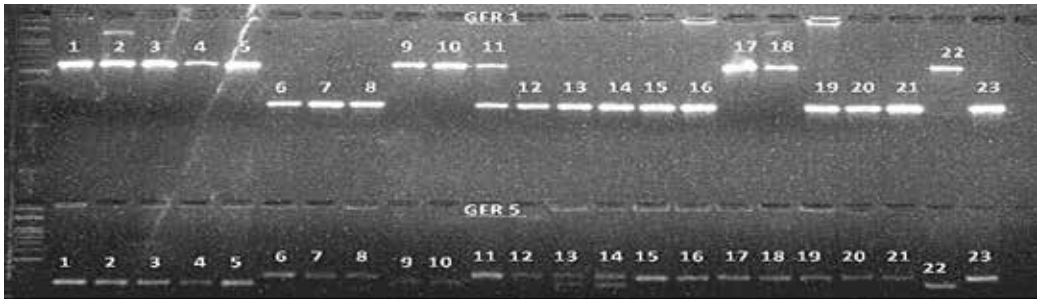
Thirty promising genotypes were screened for heat tolerance in National Phytotron Facility. Two hundred SSR markers were screened to study the parental polymorphism in Pusa Bahar, Pusa Mustard 28, BEC144 and Pusa Karishma, and polymorphic markers were identified. The polymorphic markers will be used for mapping of putative QTLs for heat tolerance. Expression of *HSF3*, *HSF3B*, *HSP20* and *DWF-4* involved in heat tolerance were analyzed between heat tolerant Pusa Bahar and susceptible Pusa Karishma. *HSFB2B* was up-regulated in heat tolerant Pusa Bahar up to 8 folds but the upregulation level was only 1.7 in susceptible Pusa Karishma. *HSP20* was downregulated in Pusa Bahar but was up-regulated in Pusa Karishma. *DWF4* gene was upregulated under heat stressed condition in both the genotypes but the expression was higher in susceptible than the tolerant genotype.



Expression of genes for heat tolerance at seedling stage in *B. juncea*

6.4.7.2 MAS for white rust and quality traits

Several molecular markers linked with total glucosinolates content in *Brassica* viz., GER1, GER5, At5g101, At5gAJ30, At5g41, At5g67, Myb28A9, My28B1



Marker GER1 and GER5 showing polymorphism between low and high glucosinolates content genotypes (Lane 1- PM 21, 2- PM 22, 3- PM 29, 4- PM 30, 5- Heera, 6- PDZ 1, 7- PDZ 4, 8- PDZ 11, 9- Pusa Vijay, 10- Pusa Jagannath, 11- Laxmi, 12- RLC 2, 13- RLC 3, 14- RLC 6, 15- EC 597325, 17- Donskaja, 18- BioYSR)

and CYP79F1 were reported earlier. Of these GER1, GER5 Myb28A9, My28B1 and CYP79F1 were found to be controlling maximum phenotypic variance. The primers for these markers were developed using the orthologs from *Arabidopsis* which did not work well. We developed *STS markers* for GER1 and GER5 by re-sequencing the genes from RLC3 and Pusa Jagannath. These *STS* markers were validated with the previous reported markers.

The BC_3F_2 population generated from cross PDZ 1 x Pusa Jagannath was genotyped for glucosinolates and erucic acid linked molecular markers. Total 150 plants with all the desirable markers were phenotyped for glucosinolates and erucic acid content in the seeds. The selected progeny plants had a range from 22 to 125µmol/g. Those plants with less than 30 µmol/g of glucosinolates and less than 2% erucic acids in their seeds were sown in plant to row during *Rabi* 2018-19 to select good progenies for further yield trials.

To introgress white rust resistance using Donskaja as a donor, marker WR360360 was used for foreground screening, while *FAE1.1P* and *FAE1.2P* markers were used to track the genes for low erucic acid trait. Molecular markers linked to white rust and oil quality traits were screened in 43 backcross populations generated for introgression of white rust resistance, low erucic acid and/or glucosinolate traits in different promising Indian mustard varieties viz., Pusa Mustard 21, Pusa Mustard 22 and Pusa Jagannath. Fifteen populations were grown during *Rabi* 2018-19 and about 2064 plants of these populations were genotyped with trait linked markers and also phenotyped for quality traits. Several phenotypically superior plants have been selected and selfed as well as backcrossed for generation advancement.

6.4.8. Soybean

6.4.8.1 Expression analysis of *Ncl* under salt stress

The *Ncl* gene in soybean confers tolerance to salinity. Introgression of *Ncl* gene can increase soybean grain yield by 3.6 to 5.5 times in saline conditions. *Ncl* gene expression in roots was analysed in two salt tolerant (A 13, Pusa 9712), two moderately tolerant (PS 1572, E 20) and a sensitive soybean genotype (UPSL 298) treated with 120mM NaCl for 24h. *Ncl* gene was found to express in control as well as stressed root tissues of salt tolerant and moderately tolerant soybean genotypes, but did not expressed under stressed condition in root tissue of salt sensitive UPSL 298. Moderately tolerant genotypes showed down-regulated pattern of expression under salt stress as compared to control conditions.

6.4.8.2 Mapping of QTL for seed viability at ambient storage

To map the genomic regions controlling viability of seed during ambient storage, a RIL population ($F_{2:6}$) developed from an inter-cross between a wild type soybean (*Glycine soja*) accession DC2008-1 (impermeable, highly viable) and a cultivated (*G. max*) variety DS 9712 (permeable, poorly viable) was used. A set of 217 RILs were genotyped with 137 polymorphic SSRs. The seeds of the RILs were harvested, dried and stored at room temperatures. Freshly harvested, one-year and two-year stored seeds were phenotyped for viability using germination test. Two QTLs were mapped on Chromosome 2 and Chromosme 14 which explained > 10% of the phenotypic variation.

6.4.9 Cauliflower

6.4.9.1 Genetics of curd colour

The $F_{2:3}$ families (88 intermediate for curd colour) from DC 466 (white curd) × PC-1 (purple curd) were segregated in a ration of 1 homozygous purple: 2 segregating intermediate: 2 homozygous white which confirmed a single semi-dominant gene observed in the F_2 population. All the nine F2:3 families of white curding F_2 plants and six of purple curding plants didn't segregate. In 173 F_2 individuals, anthocyanin content was ranged from 0.05 to 48.21 mg/100g curd knobs, with mean value of 18.5±9.98 mg/100g fresh weight. HPLC analysis identified cyanidin-3-(coumaryl) sophoroside-5-(malonyl) glucoside and cyanidin-3-(coumaryl) sophoroside-5-glucoside as prominent anthocyanin in PC 1.

6.4.9.2 Development of haploids through microspore culture

More than 100 plants of Indian cauliflower were developed through isolated microspore culture. Ten F_1 hybrids with diverse parents for wider adaptability, resistance to back rot (race-4) and interspecific hybrids (*B. cretica* x *B. oleracea* var. *botrytis*) were used as donor plant for this purpose. A bud size of 3.5-4.5 mm was found to be most responsive for microspore embryogenesis. Isolated microspore embryogenesis was successful using the earlier optimized NLN based medium with a shock treatment of 32.5°C for 48h.

6.4.9.3 Black rot resistance

A large collection of 170 genotypes from India and 5 other countries were screened for resistance to race-1 and 4 of *Xanthomonas campestris* pv. *campestris* (*Xcc*) through artificial inoculation. Identified two genotypes (EC 617744) and Kt 56 as credible resistance source against race-1 and 4, respectively. Advanced progenies (F_2 and BC) were developed involving Kt 56 (R) x Pusa Meghna (S) and Kt 56 (R) x Pusa Sharad (S) for molecular mapping of resistance against *race-4*. Marker assisted selection was used transfer black rot resistance gene (*Xca1bo*) and downy mildew resistance gene (*Ppa*[3]) into Pusa Meghna and Pusa Sharad. From these BC_2F_2 lines, superior lines with disease resistance, yield and quality traits were identified.

The BC_2F_2 of (Cauliflower Pusa Sharad × *B. carinata* 'NPC 9') and BC_2F_2 of (Cauliflower DC 401 × *B. juncea* Pusa Vijaya) and (Cauliflower DC 401 × *B. nigra*) were screened for *Xcc* race 1, 4 and 6 and resistance and plants with cauliflower leaf resembling, dwarf and late bolting were selected for backcrossing to recipient parent of cauliflower and selfing to produce advance stage. F_1 crosses between *B. napus* (susceptible) × *B. napus* (resistance) were artificially challenged with *Xcc* race 1, 4 and 6 and found that F_1 plants were highly resistant indicating dominant nature of resistance gene. Single plant in each F_1's were selfed to produce F_2 seed, Besides, 106 RILs of *Brassica carinata* (NPC 17 × NPC 9) were advanced to F_8 generation for black rot resistant trait. These populations will be useful for mapping a novel R gene(s) in alien *Brassicas.* Inbred lines of *Diplotaxis erucoides, D. catholica* and *Erucastrum canariense*, *B. carinata* (Dwarf mutant; resistance to black rot), *B. carinata* (NPC 9, 17), *B. juncea* (Pusa Bold, Pusa Vijay DH line), *B. nigra* (IC 56072) and *B. napus* (NDH, Zhangsuhang, BN 2, GSL 1, ISN 129, ISN 530, GSL 15) were maintained.

6.4.9.4 Resynthesis of *gobhi sarson* and *Brassica carinata*

Identified three genetic stocks of *Brassica napus* (AACC) and one genetic stock of *Brassica carinata* (BBCC) from segregating population (BC_1F_3) derived from inter-specific hybridization between cauliflower (CC) × *Brassica juncea* (AABB). These genetic stocks were identified on the basis of morphological characters and were found highly resistant against *Xcc* race1, 4 and 6 of black rot disease, and produced seeds upon selfing.

Resynthesis of alien *Brassica*: (A) Identified genetic stock, (B) Introgression line in the back ground of cauliflower from *Brassica juncea* resistant to black rot disease (C) flowers, and (D) leaves of *Brassica napus via* Cauliflower × *Brassica juncea* distant hybridization

6.4.10 Cucumber

6.4.10.1 Development of haploids through gynogenesis

A tissue culture based protocol for development of haploids through gynogenesis was standardized in cucumber. Two gynoecious x gynoecious and one gynoecious x monoecious F_1 hybrids were used as donor parent for gynogenesis. Among the seven different combinations of nutrient media used for this purpose, a B_5 based enriched medium was found

to be most suitable for induction of haploid embryo development through gynogenesis. The female flower buds one day before anthesis were found most suitable. We have developed 150 embryos through gynogenesis. This protocol will be useful for development of diverse elite gynoecious germplasm in cucumber.

6.4.10.2 Introgression of gynoecious traits using MAS

Two SSR markers (SSR-13251 and SSR- 15516) and one gene based SCAR marker (CsACS1G) were used for foreground selection of *F* locus (gynocey) and this trait was introgressed into Pusa Uday, Punjab Naveen and Pusa Barkha. These gynoecious lines were used to develop gynoecious × monoecious hybrids which were under evaluation trials.

6.4.10.3 Screening of *Cucumis* sp. for ToLCNDV resistance

Fifty eight genotypes of different *Cucumis* sp. (40 *C. hardwickii*, 15 *C. sativus* and 1 *C. hytivus*, 2 *C. callosus*) were screened against ToLCNDV through whitefly transmission. All the cultivated genotypes, *C. hytivus* and *C. callosus* were found to be highly susceptible to ToLCNDV. Among the 45 *C. hardwickii* genotypes, three genotypes (H 6, H 9 and H 16) were found to be highly resistant to this viral disease with disease score of less than 2.5 in scale of 0-10. These genotypes could be used for future resistance breeding programme in cucumber.

6.4.11 Melons

Mapping population (240 F_2 and 210 $F_{2:3}$) was developed from cross of *C. melo* var. *cantaloupensis* and C. *melo* var. *momordica* for mapping of different fruit quality traits of muskmelon. Four lines (F_4) from inter-specific cross between *C. lanatus* var. *lanatus* and *C. colocynthis* have been developed which are resistant to WBNV and having non-bitter red fleshed fruits which will be a valuable genetic resource for resistance to WBNV.

6.4.12 Doubled Haploid Induction in Onion

Protocol for doubled haploid production in short day onion has been standardized. Flower buds of 3.5-4.5 mm were found to be suitable for haploid induction. B5 medium supplement with 2,4-D and BA at 2 mg/L along with certain polyamines was found to be the best medium for haploid induction. Colchicine was found to be the best anti-mitotic agent for chromosome doubling. Different medium for multiple shoot and root induction were standardized. Twelve double haploid lines flowered and set seeds. These seeds will be sown and analyzed for uniformity in morphological and yield traits.

DH production in onion: a) Onion umbel with 25-30% flower buds open, b) Selection of flower bud (3.5-4.5 mm) for inoculation, c) Flower buds after 1.5 months of inoculation, d) Induction of *in-vitro* plantlet directly through flower bud, e) Shifting the *in-vitro* inducted plant to normal B5 medium, f) Cytological determination of haploid (n=8) status, g) Flow cytometry for rapid identification of haploids, h) Subculturing for multiple shoot induction and root formation, i) Colchicine treatment under field conditions for DH induction, j) Hardening of plants under field conditions, k) Transfer of plants under field conditions, l) Growing under field conditions, m) DH onions harvested, n) Flowering of haploid (H) and DH onion bulbs, o) Flower buds of haploid, and p) Flower buds of DH onion bulbs

6.4.13 Tomato

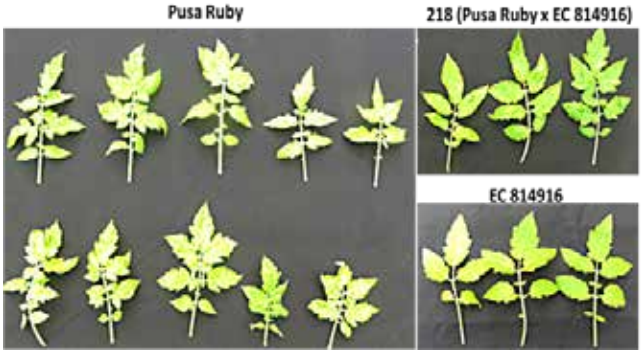
6.4.13.1 Markers for leaf curl resistance

ACY was validated for Ty-3 gene using a new marker. Using validated markers specific for *Ty*-2 and *Ty*-3 genes for ToLCV resistance, genotyping was done in >500 plants of BC_1F_1 and BC_2 F_1, F_4 and F_5 populations. Based on genotyping and phenotyping

parents, F_1s, and segregating populations, *Ty-3* gene was found useful in ToLCNDV resistance.

6.4.13.2 Agroinoculation of ToLCNDV for resistance screening

To test the resistance of *Ty-2* and *Ty-3* gene pyramided lines against ToLCNDV, 218 line of Pusa Ruby x EC 814916 and parents were grown in the National Phytotron Facility, IARI. Syringe infiltration of ToLCNDV viral genome was done in 25-30 day old seedlings followed by additional inoculation after a week. ToLCNDV specific symptoms first appeared in susceptible var. Pusa Ruby after 25-30 days of first agroinoculation. Later on 40-45 days after agroinoculation plants of Pusa Ruby developed clear symptoms specific to the virus. However, in the gene pyramided 218 line only mild chlorosis was found, and in EC 814916 (donor for *Ty-3*) no symptom was found. To estimate ToLCNDV titre, leaf samples from the ToLCNDV agroinoculated tomato plants 40-45 day after first agroinoculation was used for expression analysis of *AC4* gene. *AC4* transcript level was 4 log fold high in the susceptible check (Pusa Ruby) as compared to donor line EC 814916. However, *AC4* transcript level was 2.1-2.8 log fold lower in the tomato line 218 as compared to susceptible var. Pusa Ruby. Genotyping assay with *Ty-3* gene specific marker *Ty-3* SCAR-1 showed that line 218 contains *Ty-3* gene in homozygous condition. The decrease in virus specific transcript in the line 218 might be due to presence of *Ty-3* gene. The study shows the importance of *Ty-3* gene for imparting resistance against ToLCNDV disease.



Standardization of agroinoculation technique for phenotyping ToLCNDV resistance in tomato

6.4.14 Brinjal

A total of 168 F_2 plants derived from Pusa Safed Baingan 1 × Pusa Uttam were phenotyped for fruit weight. Single marker analysis using genotypic data revealed the positions of 3 QTLs influencing fruit weight. Two QTLs were detected in linkage group 4 (*qsfwpu3* and *qsfwpu2*) and another QTL (*qsfwpu1*) was detected in linkage group 1. The percentage of phenotypic variation explained by these QTLs ranged from 14.06 % to 19.44%. For mapping QTLs for yield related traits, fruit colour and quality traits, 6 populations are being advanced which are at F_3/F_4 stages.

6.4.15 Chilli

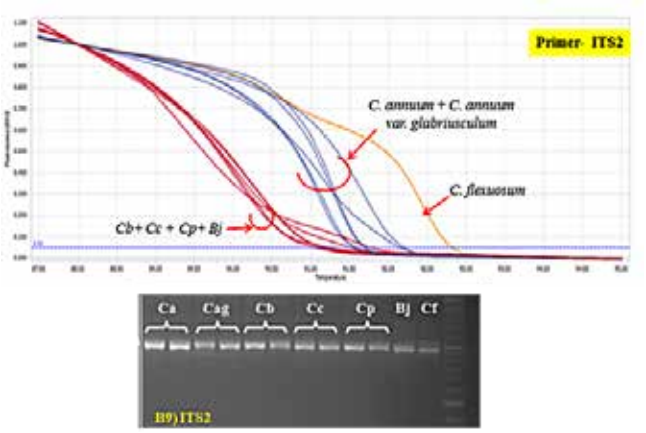
6.4.15.1 Transcriptome analysis of ChiLCV resistance

Twelve libraries of DLS-Sel-10 (resistant) and Phule Mukta (susceptible) genotypes inoculated with viruliferous whiteflies as well as healthy whiteflies at three time points 10, 20 and 30 dpi (days post inoculation) were constructed and sequenced using Illumina HiSeq 2500 NGS platform. Nine genes were found to be upregulated in the resistant genotypes DLS-Sel-10 as compared to susceptible genotype Phule Mukta, while 10 genes were found to be downregulated in DLS-sel-10 at all three time points studied.

6.4.15.2 Barcode high resolution melting (Bar-HRM) analysis for species identification

Genotypic differences in five *Capsicum* species viz. *C. annuum, C. annuum var. glabriusculum, C. baccatum, C. chinense, C. pubescens* and *C. flexuosum* were studied using seven bar code loci viz., ITS2, rpoB1, rpoC12, trnL, atpF-atpH, Ycf1b, ITS5a-ITS4, trnH-psbA to utilize the possibility of detecting single-base variants or species-specific differences in a short region of DNA using HRM analysis. It was observed that out of the seven bar code loci used, three loci (trnL, atpF-atpH, trnH-psbA) gave the same results both on PCR gel analysis and HRM analysis, while ITS2, rpoB1, rpoC12, Ycf1b and ITS5a-ITS4 melt curve analysis provided

better information regarding species differentiation as compared to the gel analysis of PCR amplified products.



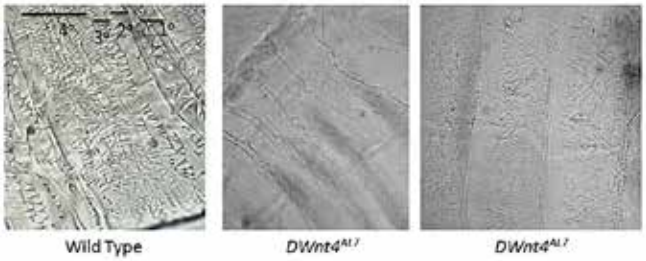
Barcode high resolution melting (Bar-HRM) analysis in *C. annuum, C. annuum var. glabriusculum, C. baccatum, C. chinense, C. pubescens* and *C. flexuosum* using ITS2 bar code locus

6.4.16 Garden Pea

Crossing were attempted to transfer *Fusarium* wilt resistance into susceptible varieties of garden pea (Arkel, VRP 6, VRP 5, MA 7, Pusa Pragati, PB 89) from resistant donor *Pisum accessions* and F_1 seeds were harvested for 12 cross combinations. Cross combinations using exotic lines (10 F_1's) were advanced to F_2 and two F_2 cross combinations advanced to F_3. The cross combination Arkel × *Pisum sativum* var. *elatius*, VRP 5 × *Pisum sativum* var. *elatius*, VRP 6 × *Pisum sativum* var. *elatius* were attempted and F_1 seeds obtained.

6.4.17 Drosophila

To map the SNP's for seven mutants isolated in *Drosophila* genetics for the gene *DWnt4*, whole genome Resequencing approach was used. Whole genome sequencing of four mutants and one wild type are accomplished. Bioinformatics analysis of the sequenced mutants is in progress. Body plan of *Drosophila* embryo is made up of anterior (A) and posterior (P) axis and dorsal (D) and ventral (V) axis. So far the genes *wingless* and *hedgehog* are reported to pattern the dorsal epidermis. It is already reported that *DWnt4* plays role in patterning of ventral epidermis during embryo development. Over expression of *DWnt4* causes patterning defects in dorsal epidermis, so it was checked for any defects in mutants isolated in our lab for dorsal patterning in embryos due to loss of *DWnt4*. It was found that the embryos where ventral pattern is defective also shows loss of dorsal patterning. It has been reported that *DWnt4* may be interacting with the gene *hedgehog* to pattern the dorsal epidermis.



Dorsal embryonic cuticle patterning in wild type and mutant

6.5 AGRICULTURAL PHYSICS, REMOTE SENSING, GIS AND METEOROLOGY

6.5.1 Soil Physics

6.5.1.1 Modeling temporal distribution of water, ammonium-N and nitrate-N in root zone of wheat using Hydrus - 2D under conservation agriculture

The studies on effect of conservation agricultural practices in improving the soil water and soil nitrogen distribution in root zone during crop growth need special attention as these are crucial components of irrigation and fertilizer management. In current study, temporal distribution of both soil water and soil NO_3-N under different conservation agriculture (CA) practices were analyzed using the Hydrus-2D model during the wheat growth. The treatments were: conventional tillage (CT), zero tillage (ZT), permanent broad beds (PBB), ZT with residue (ZT+R), and PBB with residue (PBB+R). Soil water balance simulated during 62-91 DAS from the model showed 50% higher cumulative transpiration and 50% lower cumulative drainage and higher soil water retention in PBB+R as compared to CT. Results of simulation of daily NO_3-N concentration clearly indicated that in PBB+R, higher concentration of NO_3-N was observed in surface layer and its

leaching losses beyond root zone were relatively less as compared to CT. Hence it was concluded that PBB+R practice should be adopted for wheat cultivation, as these practices modified soil water regime in root zone, enhanced root growth and improved radiation interception, LAI and nitrogen (NO_3-N) retention in the root zone. The Hydrus-2D can satisfactorily simulate the temporal changes in water balance components as well as NO_3-N distribution in the root zone during the crop period; hence it may be adopted for evaluating different management practices for improvement in water and nitrogen use.

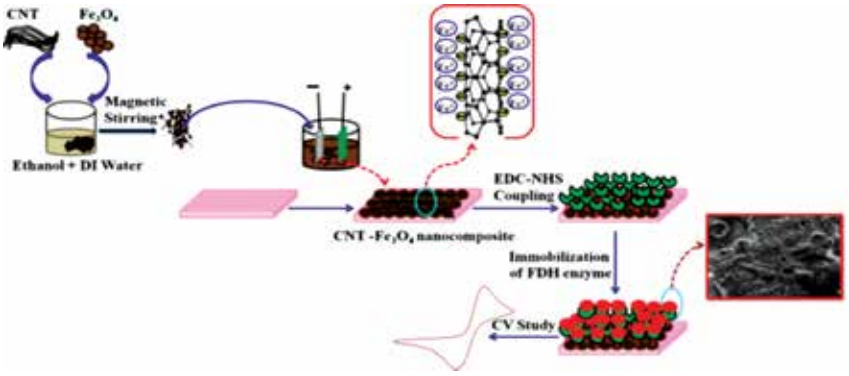
6.5.1.2 Effect of elevated carbon dioxide (eCO2) on soil hydrothermal regimes and growth of maize

To study the effect of climate change on the variation of soil hydrothermal regimes and growth of maize crop, an experiment was conducted in free-air carbon dioxide enrichment (FACE) facility during the *Kharif* at IARI, New Delhi, India. During different days after sowing (DAS), in 0 to 10-cm soil depth, soil water content (SWC) in FACE varied between 14.58–20.70%, whereas in ambient condition, SWC variations were in between 19.33–22.94%. In 10 to 20-cm soil depth, SWC ranged in between 20.47– 27.14% in FACE and 23.57–25.42% in ambient condition for different DAS. It is also observed that the arrival of peak surface ST was 1 h early in eCO2 condition. Photosynthetic rate was higher by 5.7% on 44 DAS and 18.1% on 70 DAS under eCO2 conditions.

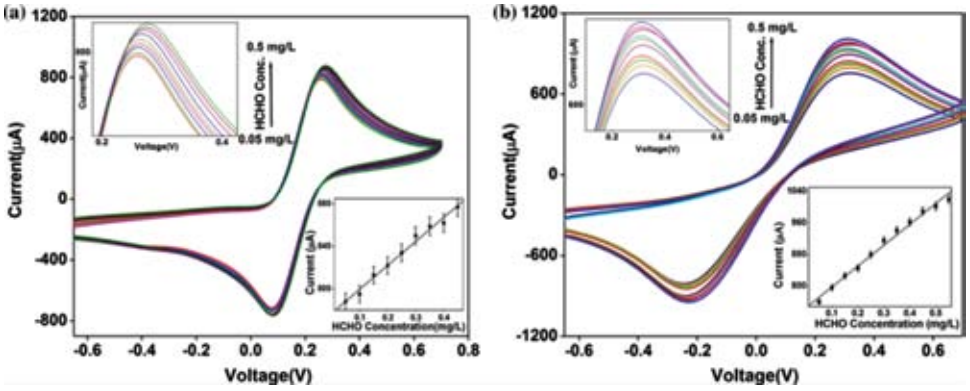
6.5.2 Bio-Physics

6.5.2.1 Electrochemical biosensor to determine formaldehyde adulteration in orange juice

An electrochemical biosensor was developed to determine formaldehyde (HCHO) adulteration commonly found in food. The current responses of various electrodes based on multiwalled carbon nanotubes (CNTs) and synthesized nanocomposite (CNT–Fe_3O_4) were measured using cyclic



Schematic representing fabrication of CNT–Fe3O4 nanocomposite-based biosensor

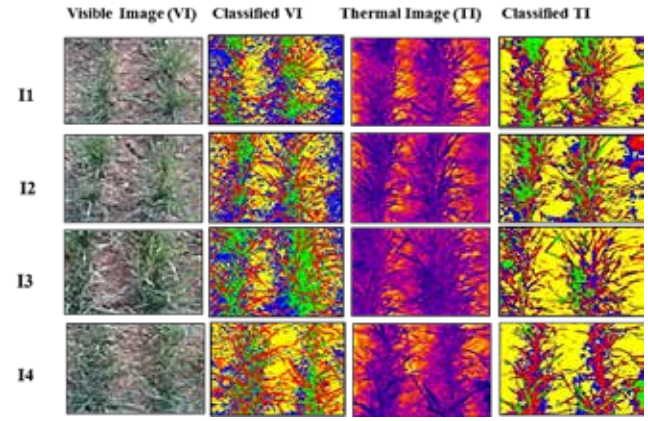


Cyclic voltammetry studies of a BSA/FDH/CNT/ITO and BSA/FDH/CNT–Fe3O4/ITO bioelectrodes as a function of formaldehyde concentrations from 0.05–0.50 mg/L (inset image: a calibration curve of peak current value plotted against formaldehyde concentrations)

voltammetry. The nanocomposite-based biosensor shows comparatively high sensitivity (527 lA mg/L^{-1} cm^{-2}), low detection limit (0.05 mg/L) in linear detection range 0.05–0.5 mg/L for formaldehyde detection using formaldehyde dehydrogenase (FDH) enzyme. In real sample analysis, the low obtained RSD values (less than 1.79) and good recovery rates (more than 90%) signify an efficient and precise sensor for the selective quantification of formaldehyde in orange juice. This work was done in collaboration with CSIR-NPL, New Delhi. The developed biosensor will be useful for determining formaldehyde adulteration in citrus fruit juices and other liquid foods in agri-food chain.

6.5.2.2 Normalized sunlit shaded index (NSSI) for characterizing the moisture-deficit stress in wheat

Characterization of sunlit and shaded canopy components of wheat crop under soil moisture deficit stress using both thermal and visible images is less explored. Hence in this study, proximal thermal and visible imaging system were used to separate four different components of wheat crop i.e., canopy and soil under sunlit and shaded fractions using supervised image classification approach. Out of five different image classification methods evaluated, Support Vector Machine was found to be the best. Therefore, a Normalized Sunlit Shaded Index was developed to characterize the status of the wheat crop grown under moisture stress conditions at different growth stages. Results demonstrated that Thermal image based NSSI (TI-NSSI) had the best correlations with all the measured crop biophysical parameters than visible image (VI-NSSI), however the r^2 decreased with increase in moisture stress. TI-NSSI showed the highest significant negative correlation (-0.962***) with Radiation use efficiency (RUE). Further TI-NSSI could explain the variations in RUE under different stress levels with R^2 >0.960. TI-NSSI under peak vegetative growth stage (83 DAS) could effectively capture the variations in crop yield under moisture stress conditions. Thus the new TI- NSSI index, proposed in this study, could explain the variations in crop biophysical parameters and yield of wheat crop grown under different moisture stress conditions.



Thermal Image (TI) and Visible image (VI) classification of a wheat canopy raised under different moisture stress conditions I1, I2, I3 and I4 using SVM method Sunlit soil; Shaded soil; Sunlit leaves; Shaded leaves; Unclassified

6.5.3 Remote Sensing and GIS

6.5.3.1 Assessment of yield of wheat using spectral indices

Canopy spectral reflectance can be used for the assessment of green biomass, photosynthesis, relative water content, nutrient deficiency, environmental stresses through spectral reflectance indices (SRI). A field experiment was conducted on maize-wheat system in a sandy loam soil at IARI, New Delhi during 2016 to 2018. Treatments consisted of two levels of tillage as main plot factor [Conventional tillage (CT) and No tillage (NT)], two levels of residue mulch as subplot factor [Maize residue @ 5t/ha (R+) and without residue (R0)], and three levels of nitrogen as sub-sub plot factor (50%, 100% and 150% of the recommended dose of nitrogen). It was observed that the effect of tillage and residue treatment on grain yield and biomass yield of wheat was not statistically significant. However, grain yield and biomass of wheat increased significantly with the increase in nitrogen dose. Forty-one structural narrow band SRIs were computed from the canopy reflectance spectra using HyperAgri software. It was observed that at booting stage, most of the indices showed highest correlation with both grain and biomass yield of wheat. It was observed that at booting stage, spectral index NDREI showed highest correlation with grain yield (r=0.853) whereas MRENDVI showed highest correlation coefficient with biomass yield (r=0.815). Regression models based on the

index NDREI at booting stage could account maximum 76.4% and 84.3% variations in observed grain yield and biomass of wheat, respectively. Therefore NDREI at booting stage can be used successfully for prediction of grain and biomass yield of wheat.

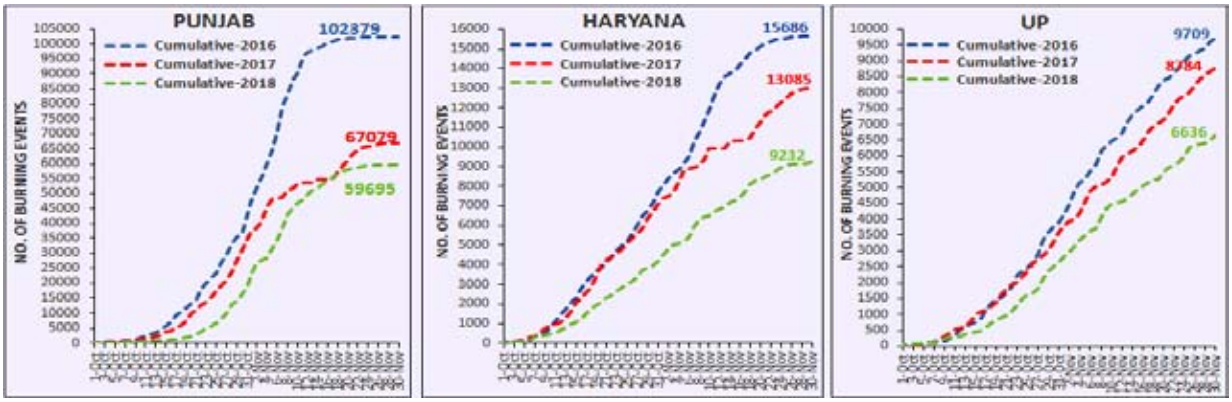
6.5.3.2 Crop condition monitoring system for India

Data from IARI ground station and other sources, real-time satellite derived parameters of rainfall, day and night land surface temperature (LST) were used to generate NDVI for the crop season 2018-19. Using historical parameter values, weekly anomaly indices of standardized precipitation index (SPI), Temperature Condition Index (TCI) and Crop Condition Index (CCI) were generated for India and maps were hosted on web portal (http://creams.iari.res.in). New remote sensing derived parameters of Evaporative Stress Index (ESI) was incorporated in this year for identifying water stress areas using ratio of actual to potential evapotranspiration. The ESI maps were generated at weekly interval and at a resolution of 5 km for all India. The analysis for *Kharif* season showed at normal to favorable crop condition in most of India though stress was observed in Maharashtra, a parts of Gujarat and south-west Rajasthan towards end of season. During *Rabi* season, the system captured poor to very poor crop condition in Maharashtra, Karnataka, and in some parts of eastern UP and adjoining areas of Bihar.

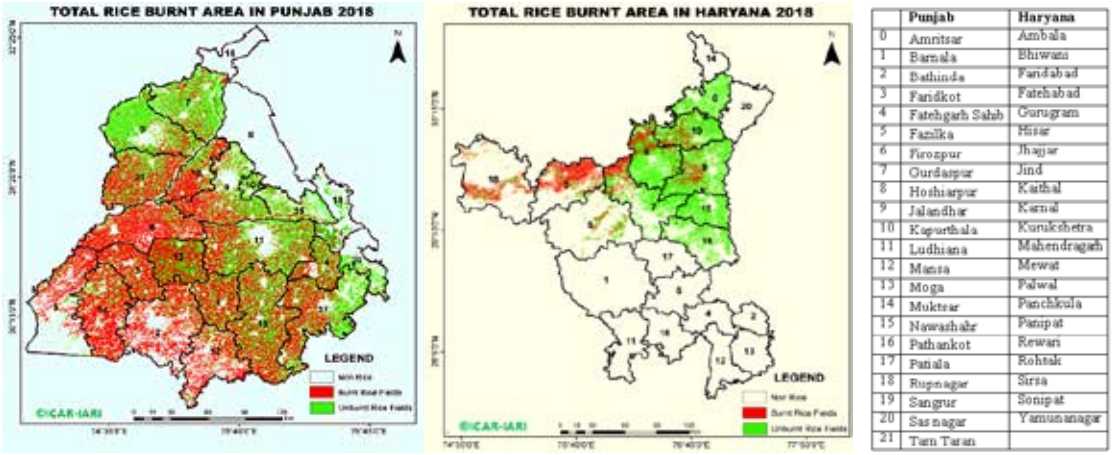
6.5.3.3 Monitoring rice crop residue burning

Spatio-temporal monitoring of the active fires due to paddy residue burning was carried out in real- time for Punjab, Haryana and UP from 1- Oct. to 30-Nov. 2018 on daily basis and compared with events during 2017 and 2016. Thermal image from seven satellites acquired at the IARI satellite ground station were used for the detection of fires for both day and night passes. Daily bulletin of fire events were prepared and their locations were put on CREAMS Geoportal (http://creams.iari.res.in) for visualization as maps. Total paddy area burnt was also estimated for Punjab and Haryana using Sentinel-2A satellite imageries. Analysis showed continuing practice of residue burning with a total of 75,563 burning events from 1-Oct. to 30-Nov., distributed as 59695, 9232 and 6636 among Punjab, Haryana and UP, respectively. Maximum burning occurred between 28-Oct. and 10-Nov. in the three states. Significant reduction of 15% and 41% in fire events was observed in 2018 than in 2017 and 2016, respectively. Using high resolution images it was estimated that 51% paddy area and 46.4% of straw produced was burnt in Punjab in 2018. For 10 major paddy growing districts of Haryana, remote sensing estimated 1.04 Mha area planted, out of which 0.23 Mha area was burnt in 2018 i.e. about 22.12%. About 7.55 Mt of paddy straw produced on dry weight basis, out of which 1.60 Mt was burnt in 2018 i.e. 14.04%.

High resolution satellite image analysis was carried out for 20 major paddy growing districts of Punjab and 10 major paddy growing districts of Haryana, depending on availability of cloud free data and districts with significant paddy area with burning as monitored by satellites during the season. The threshold cutoffs for differences in NBR (delNBR) and NDVI was used for estimating rice burnt area.



Graph showing date-wise active fire events in Punjab, Haryana and UP detected from satellite images between 1-Oct. to 30-Nov. in 2016, 2017 and 2018



	Punjab	Haryana
0	Amritsar	Ambala
1	Barnala	Bhiwani
2	Bathinda	Faridabad
3	Faridkot	Fatehabad
4	Fatehgarh Sahib	Gurugram
5	Fazilka	Hisar
6	Firozpur	Jhajjar
7	Gurdaspur	Jind
8	Hoshiarpur	Kaithal
9	Jalandhar	Karnal
10	Kapurthala	Kurukshetra
11	Ludhiana	Mahendragarh
12	Mansa	Mewat
13	Moga	Palwal
14	Muktsar	Panchkula
15	Nawashahr	Panipat
16	Pathankot	Rewari
17	Patiala	Rohtak
18	Rupnagar	Sirsa
19	Sangrur	Sonipat
20	Sas nagar	Yamunanagar
21	Tarn Taran	

Rice burnt area mapping from remote sensing during 2018

6.5.3.4 Remote sensing of environmental pollutants emitted from burned rice residue

The environmental pollutants viz., methane, nitrous oxide, CO_2, CO, PM2.5 and PM10 emitted into atmosphere due to residue burning were estimated using fire radiative power of residue burning events. Remote sensing estimated about 23 Million tons of GHGs (Green House Gases) and Particulate matter (PM) was estimated to be emitted from paddy residue burning in the three states viz., Punjab, Haryana and Uttar Pradesh in 2018. Of the 23 Million tons of GHG and PM emission in 2018, Punjab contributed 83%, Haryana contributed 11% and UP contributed 7% of total emissions. Of the total emissions, CO_2 contributed 93.7% of the pollutants.

Emission of pollutants ('000 tons) due to residue burning in different states during Oct.-Nov. 2018

GHG /PM	Punjab	Haryana	UP	Total
CH	31.99	4.33	2.13	38.45
NO^4	0.83	0.11	0.06	1.00
CO^X	17950.65	2428.24	1194.67	21573.56
CO^2	1090.07	147.46	72.55	1310.08
PM 2.5	46.21	6.25	3.08	55.54
PM 10	23.82	3.22	1.59	28.62
TOTAL	**19143.57**	**2589.61**	**1274.06**	**23007.24**

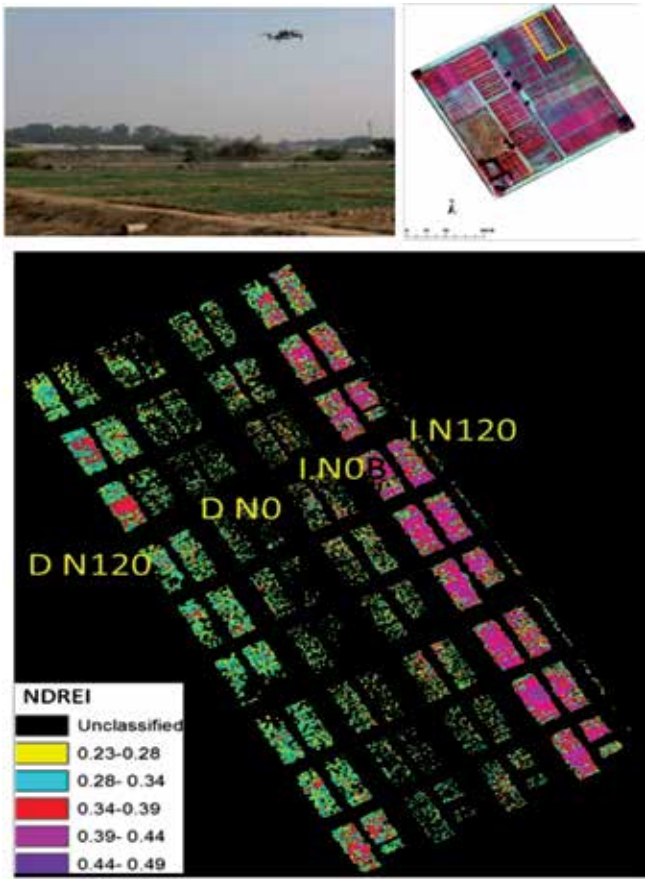
6.5.3.5 Retrieval of wheat LAI using Landsatl-OLI and Sentinel-2 satellite imagery

Retrieval of wheat LAI from MSI (20 m resolution) was attempted on two dates: 6th January and 6th February, 2016, while from OLI (30m resolution) was attempted on four dates: 5th January, 6th February, 22nd February, and 9th March, 2016.The best performing approach (atmospherically corrected by FLAASH algorithm and inverted through LUT) of LAI retrieval was applied to generate LAI map from Landsat OLI and Sentinel-2 MSI images. Density sliced LAI maps as retrieved through LUT based inversion of Landsat OLI and Sentinel-2 MSI images on different dates during the wheat crop season of 2016-17.

6.5.3.6 Drone remote sensing for field phenotyping of wheat crop

Drone or UAV (Unmanned Aerial Vehicle) remote sensing is emerging as method of choice for field phenotyping of crops. A study was carried out to assess the genotypic variation to water and nitrogen stress in wheat crop grown during *Rabi* season 2017-18. Wheat genotypes were grown with treatments of nitrogen (i.e. zero and recommended, 120kg ha^{-1}) and irrigation (i.e. two and 5 irrigation). Multispectral images were captured from low flying UAV platforms at three stages of days after sowing (DAS) (i.e. 80, 106 and 120). Methodology developed was further used for high throughput phenotyping of wheat genotypes grown under different treatments of water and N stress conditions in the field. Protocol developed were programmed and made systematic automation and under testing for field phenotyping and precision farming in other crops. Heat map were generated for all

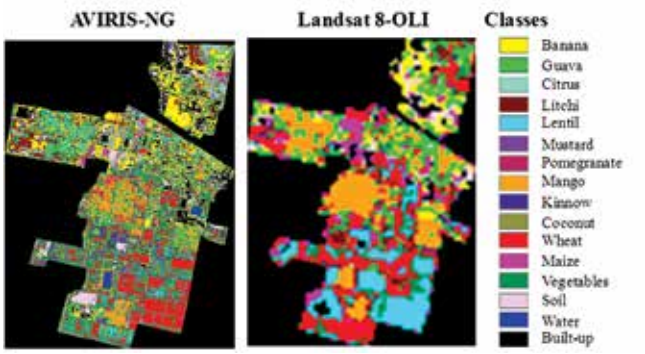
these three dates for differential response of genotypes to water and N stress, which indicate significant genotypic variation in tolerance to these stresses.



Drone phenotyping of wheat. Drone imaging and wheat field (Top panels). Normalized Difference Red Edge Index (NDREI) image of wheat field captured from multispectral sensor. IN120, Normal recommended package of practices; IN0, No nitrogen applied; DN0, Drought and nitrogen deficiency treatment; DN120, Normal nitrogen and drought treatment

6.5.3.7 Drone remote sensing for mapping horticultural crops

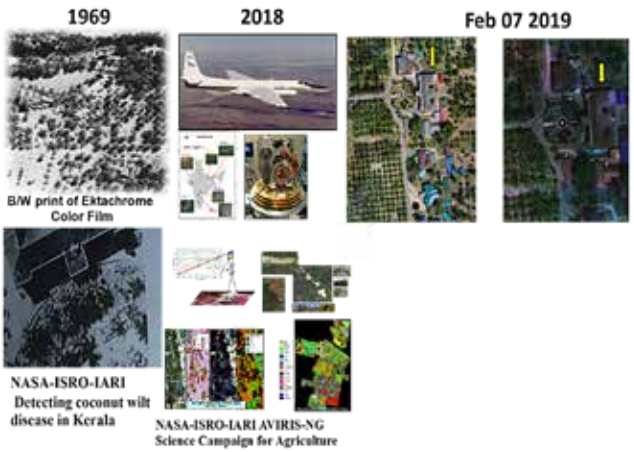
Accurate mapping of horticultural crops using multispectral remote sensing is a challenge due to poor discrimination using less number of discrete bands and mixed pixel effect. Present study was undertaken to explore potential of hyperspectral remote sensing to discriminate and map eight horticultural crops in Sabour, Bhagapur region of Bihar, India using both ground based spectroradiometer (FieldSpec3 for ASD, USA) and air borne AVIRIS –NG instrument through collaborative experiment of ISRO and NASA. Classification and regression tree analysis (CART) technique was applied on significant wavebands to select most sensitive wavebands. Spectral separability between each pair of fruit crops was computed using Jeffries-Matusita (JM) distance technique. The JM distance for all combination pairs of crops was found above 1.98 irrespectrive of sensors used indicating all pairs were separable both ground and AVIRIS NG collected spectra where as very few crop pair could be separated using multispectral Landsat 8-OLI sensor. Overall accuracy and kappa coeficient for hyperspectral sensor (90.5%, 0.89, respectively) was better than that of multispectral sensor (64.2%, 0.55 respectively). Hyperspectral imaging sensor can be further explored better discrimination and accurate acreage estimation of orchard crops where mix cropping is a challenging issue.



Spectral separability of pairs of orchard crops. Classification map of fruit orchard using hyperspectral sensor AVIRIS-NG and multispectral sensor – Landsat 8-OLI

6.5.3.8 Fifty years of remote sensing in IARI

First remote sensing experiment in country was conducted on detecting coconut wilt disease in Kayamkulam, Kerala in collaboration of IARI with ISRO and NASA using airborne imaging system during 1969. The area imaging was done in part of experimental coconut farm of Regional Station of ICAR-Central Plantation Crop Research Institute (CPCRI), Kayamkulam, Kerala. Celebrating fifty years of remote sensing, the Division of Agricultural Physics, IARI, did Drone based multispectral imaging of the same coconut experimental farm affected by root wilt with the support of Director, CPCRI and Head, Regional Station CPCRI, Kayamkulam, Kerala during February, 2019.



Fifty years of air borne remote sensing in IARI from 1969, 2018 and 2019

6.5.4 Agricultural Meteorology

6.5.4.1 Radiation use efficiency of rice under conventional and conservation agriculture

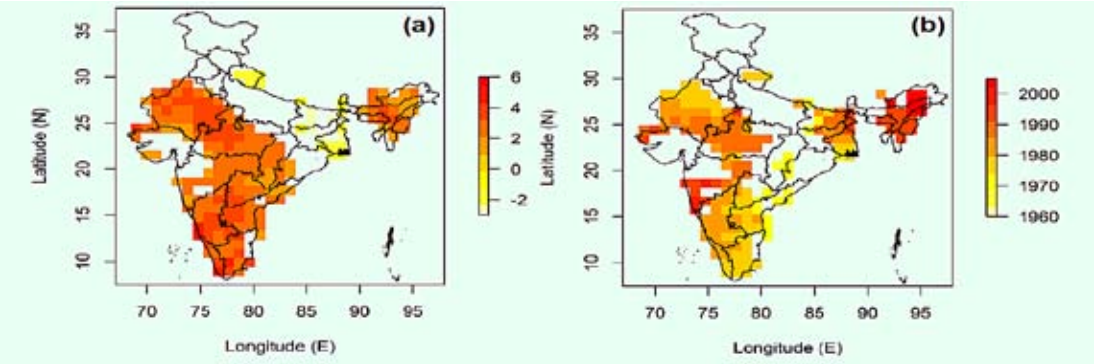
A field experiment was conducted at IARI farm, New Delhi during the *Kharif* season of 2017 on a sandy clay loam soil with the rice cultivar Pusa Sugandh 5. Transplanted rice in *Kharif,* conventional tillage wheat in *Rabi* followed by *Zaid* fallow treatment showed the highest radiation use efficiency (RUE) value (2.35 g MJ^{-1}) and biomass. Crop growth (biomass) could be determined as the time integral of PAR, fIPAR and RUE.

6.5.4.2 Estimation of actual evapotranspiration (ET_a) using satellite data

Remote sensing methods based on energy balance algorithms facilitates in mapping the evapotranspiration (ET) with finer resolution at the regional scale. Operational Simplified Surface Energy Balance (SSEBop) approach is adopted in the study for the estimation of evapotranspiration spatially by incorporating the satellite data. The *Kharif* (monsoon season) and *Rabi* (winter season) crop growing seasons have been taken into account for the period of 2017-18. As the SSEBop model is less complex compared to other models, therefore it provides an easier way to implement over the region. LANDSAT OLI imageries and 30m SRTM DEM topographic data along with the climate observatory data have been used as an input for the SSEBop model over IARI research farm, New Delhi, India. Bowen Ratio Energy Balance (BREB), a point-based method is utilized to calculate the daily ET using multilevel micrometeorological tower data throughout the crop growing season. The maximum ET is found as 4.78 mm d^{-1} for maize crop whereas 4.36 mm d^{-1} for wheat during mid-stage. The land surface temperature (LST) calculated from the thermal band proves to be a key element in determining the ET fraction. The crop coefficient (k) and potential evapotranspiration (ET_0) from BREB method are coupled with the SSEBop model to calculate the spatial distribution of actual Evapotranspiration of the study area. ET estimated by SSEBop model based correlated significantly (R^2 0.865) with the point-based method calculated daily ET.

6.5.4.3 Spatio-temporal trend in heat waves over India and its impact on wheat

The gridded daily maximum temperature data (1° x 1°) for six decades (1951-2015) was analyzed to understand the changes in heat waves using the heat wave magnitude index daily (HWMId). The study clearly showed the effectiveness of HWMId to capture



Trend (a) and abrupt shifts (b) in time series of Heat Wave Magnitude Index daily during 1951-2014. (Value in grid indicates Mann Kendall's Z statistics (a) and change point year by Pettit test (b). Grids with p < 0.1 are only shown)

the heat waves over India. The most-intense heat waves have significantly increased over 56% area of the country and also started occurring in nonconventional heat wave regions of southern peninsula and north eastern India. Among different categories of HWMId, the rate of spatial spread was highest for the very extreme category. The auto regressive integrated moving average (ARIMA) intervention technique showed negative impact of the March 2010 extreme heat on the yield of wheat over north India. The yield decreased by 4.9%, 4.1% and 3.5% over Punjab, Haryana and Uttar Pradesh, respectively.

6.5.4.4 Weather based agromet advisory

Based on past weather, real time weather and IMD weather forecast received for next five days, agro-met advisory bulletins were prepared in Hindi and English on every Tuesday and Friday. Agromet advisory bulletin contains summary of previous week's weather along with normal weather data, value added medium range weather forecast information (for the next 5 days), crop management, advance warning to farmers on rainfall variation, weather variables, pest/disease problems, etc. This helped the farmers to decide on crop management, application of nutrients, irrigation scheduling, sowing, harvesting, etc. The bulletin was sent to the farmers through SMS / telephone / E-mail. The bulletins were also sent to ATIC, KVK Shikohpur, KVK Ujawa, IKSL, NGO, *e-choupal*, *Krishi Darsan*, All India Radio, DD Kisan, and local Hindi newspaper through E-mail for wider dissemination among farmers. These advisories were uploaded on the Institute website (www.iari.res.in), IMD website (www.imdagrimet.gov.in) and farmer portal (http://farmer.gov.in). These advisories along with crop status were sent to IMD, Pune for preparation of national bulletins. During 2018-19, total 103 agro-advisory bulletins were prepared in Hindi as well as in English. SMS were sent to the farmers through m-Kisan portal. Weather forecast and agromet advisory bulletin was fruitful for farmers to select high yielding varieties of different crop and vegetables, and timely farming practices such as sowing, weeding, irrigation, fertilizer, pesticides spray (time & doses). Feedback received from the farmers from different villages of NCR Delhi showed that agromet advisory bulletin is useful to reducing cost of cultivation, saving of input resources and increases in net profit. Farmers who followed the agromet advisories are able to reduce the input cost by reducing the irrigation, based on the rainfall forecast, number of spray, seed rate and timely management practices based on agromet advisories.

6.6 NATIONAL PHYTOTRON FACILITY

The controlled environmental facilities of the National Phytotron Facility (NPF) was hugely used by scientists and students from IARI and other ICAR institutes including University of Delhi (South Campus), Jawaharlal Nehru University, New Delhi and others to conduct critical experiments related to climate change, transgenic crops, gene expression and regulation, physiology of nutrient use efficiency, plant-pathogen interaction, biochemical and genetic interventions for crop improvement, etc. During the year under report, 149 new experiments were accommodated along with a few previous on-going experiments. Bulk of these experiments were from the Institutes' post-graduate researches (51.68%); in-house projects of the ICAR institutes (41.61%); Emeritus Scientist and Scientist on probation (0.70% each, respectively); and the paid experiments from out-funded projects and non-ICAR institutes (5.37%). During 2018-19, an amount of Rs.4,75,779/- was collected at NPF as users' fee of the glass house and growth chambers. The NPF was visited by a number of domestic and foreign visitors including trainees and students. The Phenomics facility erected within NPF aroused immense interests among the visitors.

Hydroponic-based identification of wheat genotypes tolerant to low nitrogen and phosphorus stresses

7. SOCIAL SCIENCES AND TECHNOLOGY TRANSFER

Doubling of farmers' income by 2022 is Government of India's priority now. In this regard, School of Social Sciences, is focusing on the recent and sensitive issues which has direct influence on farmers' income such as farmer producer organization (FPO), aadhar enabled fertilizer distribution system (AeFDS), tariff hike on crude and refined palm oil, tank irrigation system, crop residue and its potential to produce bioenergy, farmer led innovations (FLIs), agri-nutri linkages, gender empowerment, climate change and innovative extension models. These issues were experimented/studied/assessed in various modes at various locations across the country. Capacity building of various stakeholders was done with focus on nutritional security, gender empowerment and entrepreneurship development. *Pusa Krishi Vigyan Mela* 2019 and M*era Gaon Mera Gaurav programmes* are well supported by the School of Social Sciences. Agricultural Technology Information Center (ATIC) as a single window service and Institute's KVK at Shikohpur, Gurugram are working as per the mandate and serving the farming communities.

7.1 AGRICULTURAL ECONOMICS

7.1.1 Farmer Producer Organizations (FPOs)- A way Ahead to Doubling Farmers' Income

Farmer producer organizations/ farmer producer companies (FPO/FPC), is one among the many tools, which play a dynamic role in the villages to help the farmers' synchronization through collection and marketing of farm produce. A primary survey was conducted in the villages of Yavatmal district of central Marathwada region of Maharashtra to assess the performance of FPO/FPC's. The total share value of the company was Rs. 12.6 lakhs as of now which comprised of 1125 farmers of 9 cluster groups in the three villages of Gatanji block of Yavatmal district. In 2013, before starting up of FPO triennium average net revenue from Tur production was Rs. 21546/ac. After grading and marketing through FPO's channel the net revenue increased by 18 per cent for the Rabi 2017. The state department of Agriculture sanctioned the subsidy of Rs.10 lakh to set up the processing unit. Milling of Tur (Dal processing) at the farm and marketing to district headquarter with the help of Vikas Ganga (NGO) and TATA trust earmarked 64 per cent high revenue in the next *Rabi* season.

7.1.2 Risks and Adaptation Strategies in Rainfed Agriculture in India: An Analysis

Farmers in the rainfed regions of India have to routinely deal with risks from biotic and abiotic sources, that varies with the region and crop cultivated. An assessment of the risk sources and adaptation strategies was attempted using a total of 500 farmers from Maharashtra and Telangana. Data collected using a questionnaire in Likert scale format was analysed using principal component factor analysis. Farmers were requested to score the different risk sources to study the impact of various risk sources on individual farms. Principal component factor analysis with varimax rotation was applied to the combined set of data from both the states. The analysis resulted in seven factors with an eigen value greater than 1. The seven factors extracted accounted for about 65.18 per cent of the total variance. Higher factor scores were considered for labelling factors with two factor loadings. The seven factors that were extracted were labelled as inputs, private information sources, public information sources, irrigation, non-institutional credit sources, custom hiring services, and institutional credit sources. Factor 1 accounted for about 17.28 per cent of the variance and had loadings from non-availability

of organic pesticides, biofertilizers, skilled labourers and poor electricity supply for irrigation. Factor 2, which accounted for 16.46 per cent variance, had heavy loadings from non-availability of information regarding climate, crop and prices from private sources. Crop, climate and pest related information from public sources loaded heavily on the factor 3, whereas failure of bore-wells and unreliable supply of ground water loaded mainly on the factor 4. Factors 3 and 4 accounted for 7.97 and 7.39 per cent of the variance. The remaining variance was explained by the non-institutional credit sources, custom hiring services, and institutional credit sources.

The farmers were also given the opportunity to mark their perception regarding the usefulness of a list of risk management strategies. Among all the risk management strategies, 15 strategies were retained for analysis using principal component factor analysis with orthogonal varimax rotation. The analysis resulted in five factors with an eigen value greater than 1, which accounted for about 60.61 per cent of the total variance. The five factors that were extracted were labelled as varietal strategies, community support, price stabilisation mechanism, government support, and self-insurance. Factor 1 accounted for about 20.07 per cent of the variance and had loadings from replanting with short duration varieties, pest resistant and drought resistant varieties, as well as from using more number of varieties. Factor 2, the community level support accounted for 13.51 per cent variance, and had heavy loadings from collection of food, feed and fodder from common lands. Entering into forward contracts and other types of formal and informal contract farming to insulate themselves from price fluctuations loaded heavily on the third factor, whereas selling to government agencies for assured prices loaded mainly on the factor 4. The remaining variance was explained by self-insurance mechanism by using farm saved seeds to reduce the farm expenditure.

7.1.3 Reforming Fertilizer Subsidy Distribution in India, the Direct Benefit Transfer Way

Fertilizer subsidies, an instrument used by the government for improving the fertilizer consumption in India, are criticized in the recent years for its unintended negative effects. Aadhar enabled Fertilizer Distribution System (AeFDS) is the recent policy implemented by the central government to control rising fiscal burden due to fertilizers, reduce the diversion of subsidized fertilizers and improve the soil nutrient balance. It was initially implemented on a pilot basis in selected districts of the country in March, 2016 and later rolled out nationally.

An ex-post assessment of the AeFDS was conducted, that was implemented on a pilot basis in 19 selected districts of India. An estimation of the farmers' share in budgetary fertilizer subsidy was attempted using the import parity price concept. The results revealed that the share of farmers in the budgetary subsidies increased from 63.27 per cent in the triennium average ending (TE) 1995-96 to 85.55 per cent in TE 2005-06, and then decreased to 64.91 per cent in TE 2015-16. The industry received the remaining quantum of subsidy, and as stated above, the decrease in the farmers' share between TE 2005-06 and TE 2015-16 is due to the decrease in import parity price of fertilizers during the period. The average share of farmers in the subsidies for the entire period starting from 1990-91 to 2016-17 was estimated to be 59.61 per cent (and the industry share to be 40.39 per cent). This share varied year by year as per the import parity prices.

The study also examined the diversion of subsidized fertilizers from India across porous borders. This issue is of high concern and the government is trying its level best to stop the smuggling using several policies. AeFDS is identified as one measure to check this. The difference in difference (DID) regression results suggested that there is no significant effect of the AeFDS on urea sales at the retailer level. The ground level evidences also suggested that the farmers were not denied with fertilizers for any reasons. The AeFDS pilots were made smoother by the friendly attitude of the retailers towards the farmers, the availability of resources for speedy transactions like PoS machines and wifi connectivity. In fact, both the farmers and retailers feel better after AeFDS as they did not felt shortage of urea in crop season.

7.1.4 Tank Irrigation in India – An Overview

Irrigation tanks serve as Common property resources, especially in the third world. Telangana is a water deficit state. Important sources of irrigation in Telangana are canals, tanks and wells. Most of the tanks in Telangana have become degraded due to open access, weak institutional arrangements, poor structures and break down of the local authority systems. The economic viability of tanks, given their scale, is crucial for the communities to realize their importance in improving their livelihoods. The net area irrigated in India was increased significantly from 42 million ha to 66 million ha over years. The increasing trend was significantly contributed by well irrigation which increased from 20 million ha to 40 million ha. Further, it was observed that the net area irrigated by canal and tanks had a decreasing trend over years, while the decrease was about 2.30 lakh ha for canal, it was about 3.50 lakh ha for tanks. The increment in the share of well irrigated area to net irrigated area was 1.29 which increased from 38.18 per cent to 61.29 per cent. In sum, usage of tank irrigation system in agriculture had significantly declined over the past 30 years in both India as well as Telangana. The level of instability was found highest for other sources of irrigation (40.44) followed by well (21.14) and tank (20.40) irrigation systems. It was observed that the level of instability was low (6.41) for canal irrigation system which implies, the usage of canal for irrigation was almost stable over years. At all India level probability of remaining as canal irrigated area was as high as 0.949, however, it alone had occupied predominant position among the sources of irrigation. It was concluded that dependency between canal and tank irrigated area is more than any other source of irrigation.

7.1.5 Crop Residue Production and Bioenergy Potential in India: Crop and Regional Level Analysis

In India, crop residue is used for multiple purposes such as animal feeding, cattle shed, bedding, organic manure etc.; however, bioenergy production is one of the important and sustainable use option. In this context, this study estimated the total dry crop residue production and its bioenergy potential in India in the last two decades with the crop and regional focus. It was estimated that about 494 mt of dry crop residue (DCR) was produced annually in India from the 26 crops and cereals was the major crop group, which produces 62 per cent of total crop residue and western region was the highest producer (169 mt) in TE 2015-16. The individual crop wise analysis indicated that rice was the largest crop residue producer (131 mt) and Uttar Pradesh was the major producer (72 mt). However, only about 112 mt of crop residue was available as surplus for bioenergy production. Punjab was the major supplier (17 mt) of surplus residue in the country and with respect to crops, rice (33 mt) topped in surplus supply. During the period of TE 1995-96 to 2015-16, annual DCR production increased to the tune of 150 mt and other crop group has recorded highest growth (128%) in DCR production and its growth was prominent in Southern states. If 25 per cent of crop residues are employed in more productive and sustainable alternative use such as bioenergy production, then it could generate the total bioenergy of 1210 PJ. Overall bioenergy potential based on all crop residues was 1892 PJ in 2015-16 and it is equivalent to the 6.7 percent of the total primary energy consumption or 34 per cent of total electricity consumption of India. The findings can help the policy makers to promote the bioenergy production plants based on the crop wise and region wise potential.

7.1.6 Impact of Tariff Hike on Palm Oil in Indian Oil Seeds Sector

Edible oil is one of the processed products largely consumed in India. India accounts for 11 per cent of the world consumption of edible oils. Palm oil is cheaper among all the edible oils import that constitutes about 80 percent of total edible oils import. Around 97 percent of palm oil is imported from Indonesia and Malaysia. Government had been intervening in oilseeds sector time to time to reduce the import bill and to achieve self-sufficiency in edible oil production but was not able to match with the increasing domestic demand. Recently in 2017, government had introduced series of

tariff hike on the import of edible oil especially crude and refined palm oil. The impact of recent duty hike (on March, 2018) on crude palm oil(from 30 to 40 %) and refined palm oil (40 to 54 %) on domestic oilseeds economy was carried out using simultaneous equation system model developed by IFPRI. The immediate effect of duty hike on crude palm oil and refined palm oil was found to reduce imports (-12.08% and -11.06 % respectively). The domestic price for crude palm oil may increase by around 12 per cent which will have positive impact on domestic production (5.88 % increase). For refined palm oil, the price increase may be around 11 per cent which will results in 5.36 per cent increase in production. However, the net impact on the economy will be negative due to the higher reduction in consumer surplus that may outweigh the increase in producer surplus and government revenue. Also, tariff hike may have short run impact as India has commitment with ASEAN countries to reduce the tariff on crude and refined palm oil under ASEAN-India Free Trade Agreement. Therefore, the focus should be concentrated on increasing domestic production as well as revitalization of oil processing industries to achieve self sufficiency in edible oil.

7.2 AGRICULTURAL EXTENSION

7.2.1 Maximizing Farm Profitability through Entrepreneurship Development and Farmer Led Innovations

Agriculture still remains the mainstay of our majority of population dependent on it leading to huge pressure and distress. There has been 3.7 times increase since 1965 in agricultural productivity through better technology and public investments (*Niti Aayog*, 2017). The imperatives in the present times need us to focus on strategies to raise farmers' income with Entrepreneurship development and integration of farmer led innovations for sustainable agricultural development. The present research study is being conducted with the objective of documenting farmer led innovations, extrapolating learnings from these cases so as to design appropriate models for developing entrepreneurship and up scaling farmer led innovations.

- Farmers opined that strengthening institutional and individual capacities for scaling up followed by facilitation of networking amongst extension service providers and farmers in the region, mobilizing and allocating resources for scaling up of technological activities and facilitating the sharing of available knowledge on new technologies and innovations were major factors in maximizing farm income.
- Eight cases of farmer led innovations were documented during the period under report. Farmer Led Innovations (FLIs) were either reconfiguration of existing resources giving incremental adjustments or innovations generated to solve an immediate problem. All innovators studied expressed dissatisfaction with the preexisting economic returns of the farming thus pushing them to innovate or to find newer way to solve a problem. Indicators for identification of FLI and its scalability have been standardized and are widely being used for identification and recognition of innovative farmers.
- Relevancy, relative advantage, sustainable source of funding, observability of the results and complexity, were ranked as the top determinants of the scalability of farmer led innovations. One of the important characteristic relates to finance. The data depicts that innovations having financial superiority over the options requiring least external finance and possessing scope for internal funding were perceived as scalable.
- Institutional requirements and linkage for implementing the innovation followed by comparative analysis of the costs associated with the innovation, evaluation of the innovation's comparative impact, success and refinement and simplification of innovations and analysis of possibilities of scale were the major capacities perceived important for scaling up of FLIs.

Capacities needed for scaling up of Farmer Led Innovations: Perception of Innovative Farmers

S. No.	Subject matter	Per cent	Ranks
1.	Documentation of the innovation/ intervention	43.5	IX
2.	Distinguishing technical, organizational, and/or process elements	46.8	VIII
3.	Analysis of need or demand for the service among the larger population	53.2	VII
4.	Analysis of the required changes to make the innovation applicable to other parts of the country / other target groups	55.4	VI
5.	Comparative analysis of the costs associated with the innovation	65.8	II
6.	Evaluation of the innovation's comparative impact and success	64.3	III
7.	Refinement and simplification of the innovation	61.5	IV
8.	Analysis of the possibilities for achieving economies of scale	61.2	V
9.	Analysis of the institutional requirements and linkage for implementing the innovation	73. 6	I

- FLIs having additional advantage over conventional innovations to tackle second generations' problems require different set of capacities on the part of farm innovators to scale their innovations in addition to being innovative, learning institutes for which are yet to come into existence.
- An institutional mechanism for up scaling and out scaling farmer led innovations was devised in collaboration with various ATARIs of ICAR. Four Farmer Innovator Meets were organized in collaboration with ATARIs- Pune, Kanpur, Jodhpur and Patna. Around, 250 innovator farmers form Maharashtra, Andhra Pradesh, Telangana, Uttar Pradesh, Rajasthan, Haryana, Delhi, Bihar and Jharkhandparticipated.
- The lessons learnt from interaction meets include; the requirement for establishing and maintaining a database of available technologies and innovations, establishing and maintaining a meta-database of agricultural information, facilitating the database to act as a platform for exchange of information and experiences, developing and disseminating theme-based knowledge, publishing lessons learnt from development and adoption of innovation activities, undertaking an analysis of partner institutions to assess their potential as participants in maximizing farm profits as primary information centers and building capacity of partner institutions (both human and infrastructure).
- Major constraints in up scaling and out scaling of farmer led innovations were: Lack of separate price policy of the government, lack of exclusive extension personnel for promotion, require more complementary technical inputs, lack of skilled manpower, lack of expertise for validation and no standard set of indicators for validation.
- WhatsApp offers a communication approach that can be quite flexible, time wise as well as place wise. Farmers are using this platform for advice on crop health to seed procurement, soil health, use of fertilizers and pesticides, post-harvest service, marketing advice and care of domestic livestock. On an average, 13.06 messages per week were shared by innovative farmers, out of which, 75.66 per cent of the messages were related to agricultural purposes including the comments.
- The action interventions have been undertaken in *Fatehpur Biloch* and *Manjhawali* villages of *Faridabad* district and *Swamika* village of *Palwal* district in Haryana. Six training programmes for Agri enterprise uptake were organized. A significant enhancement in knowledge level regarding various technical aspects was found. Pre and Post training data revealed that enhanced motivation, aspirations, entrepreneurial orientation, creating a facilitative

entrepreneurial climate in the form of effective business linkages among various stakeholders.

- The participation of various stakeholders in each village was elicited- nongovernmental organizations, government departments (agriculture, horticulture), bankers (syndicate bank, corporation bank), established entrepreneurs (in value addition, post harvest processing of flowers and seed production) and researchers. Efforts for facilitation in strengthening the existing marketing linkages and exploration of new marketing avenues were also initiated. As an impact of project interventions, 4 cases of crop insurance, 45 cases of animal insurance, 162 cases of direct availing of subsidy on agricultural inputs,22 cases of new farm machinery purchased, 19 cases of soil conservation practices adopted ,127 cases of newer methods and technologies adopted related to crop protection and production and above all 8 group action in the form of non-farm activities, soya bean processing and dry flower technology and primary processing, grading and packing have been initiated as income generating activities in project villages.

- Enterprise Uptake : In villages Manjhawali and Swamika, farm women were proactive in forming SHGs whereas more intense efforts of convincing on part of researchers were needed in Fatehpur Biloch for mobilizing farmers/ farm women to take up group entrepreneurship. In collaboration with NABARD, two Farmer Interest Groups (FIGs) were mobilized in Fatehpur Biloch. Seed Production, Nursery raising, Protected Cultivation, Value Addition-Soybean Milk, Tofu, Potato Chips, Dal Badi *etc*, Dry Flower Technology based Products, Flower Cultivation, Ata chakki, Animal Feed, Oil mill, Enterprise of ground spices, Mushroom cultivation *etc* were various enterprises launched by trained farmers and farm women.

7.2.2 Enhancing Nutritional Security and Gender Empowerment

Nutritional security has been the prime concern of Indian government since its freedom. Despite all efforts of government, still the challenge of achieving nutritional security remains unfulfilled. According to 'M.S. Swaminathan, farming system for nutrition can be the answer and he defined it as 'the introduction of agricultural remedies to the nutritional maladies prevailing in an area through mainstreaming nutritional criteria in the selection of the components of a farming system involving crops, farm animals and wherever feasible, fish'. In this context, a project titled "Enhancing Nutritional Security and Gender Empowerment" was initiated by the Division of Agricultural Extension, ICAR-Indian Agricultural Research Institute, New Delhi to tap the opportunities available in agriculture for nutritional security among farmers.

7.2.2.1 Food consumption pattern and its correlates

For better health and elimination of malnutrition, a diversified and balanced food basket is required. However, for promotion of balanced diet and diversified food, one needs to understand the consumption pattern and identify the nutritional status of the population and determinants of dietary diversity. In this context, the study analysed the food consumption pattern and its major correlates of rural and urban households' in India, more specifically, examined the relationship between percapita income and the percapita quantity of consumption of major food items such as cereals, pulses, edible oils, vegetables, fresh fruits, milk and milk products and fish and meat across the households. The secondary data of the 68th round survey (type 2) of National Sample Survey Office (NSSO) on household consumer expenditure for the period of 2011-12 was used for analysis. The total respondents of the survey were 1,01,651 households which represents 28 states and & 7 UTs of India.

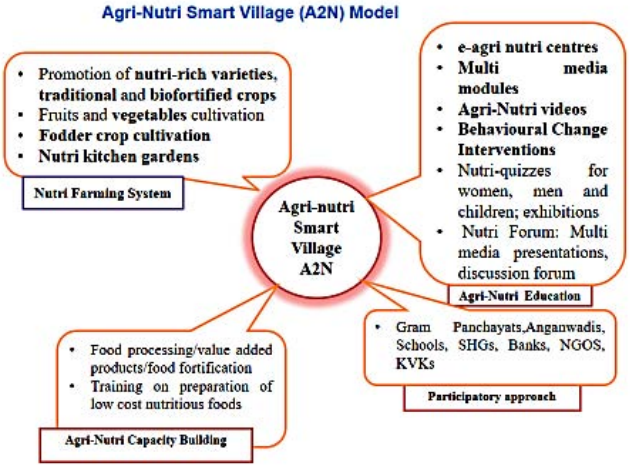
The results showed that income and per capita consumption of food items were directly related, that is as income of the households increases quantity also increases. As far, cereals were concerned, lower percentile households were consuming less than that of highest percentiles about 2.2 kg/month in rural areas, while the difference was negligible in case of urban households. The difference between lower 10 per cent and upper 10 per cent of households' consumption

of pulses were about 900 and 700 g/month rural and urban households, respectively. The highest difference between two extreme classes of households was observed in milk consumption, i.e. about 9 litres / month both in rural and urban areas.

The edible oils consumption also witnessed similar trend and difference was about 900 ml/ month. The significant difference in vegetables consumption between two income classes were observed and it was about 4.3 kg/for rural areas and 3.2 kg/ month for urban areas. In general, fresh fruits consumption was low in rural areas (0.46 kg/month) than urban areas (1.76 kg/ month) and difference between income classes were high in rural households than urban households. It is interesting to note that, meat consumption observed negative relationship to some extent in rural areas, that is lower strata households were consuming more meat than higher strata households, however urban areas it was witnessing opposite trend.

Overall, urban area consumption for all food items was higher than rural areas, except cereals. The multiple regression analysis was carried out to estimate the extent of association between income and per capita consumption food items after controlling for other socio-economic characteristics such as age, education and sex of the head of the households, share of home produce etc. The results indicated that income was one of the major factors in determining percapita consumption of all food products. It was found on an average Rs1000 increase in percapita income of the households would lead to increase the monthly consumption of cereals to the tune of 180g, 92 g of pulses,160 of vegetables and 760 ml of milk consumption. Those households which are having home production of cereals had better consumption of cereals, i.e. on an average 1 tonne increased home produce quantity will lead to the 38 g increase in percapita consumption of cereals.

In order to bring "agriculture and nutrition together", A2N (Agriculture to Nutrition) model is being tested through nutri smart villages for Nutri Farming System (NFS). In this model, the focus is on promotion of Nutri Farming System, promoting nutri clubs among farming communities, capacity building on agri-nutrition and agrinutri education through e-agrinutricentres in nutri smart villages. A2N Model is given below:



Under Agri-Nutri (A2N) smart village model, various interventions are being carried out:

- A number of training programmesValue Addition of Cereal based, Pulses based and Millets basedProducts for Nutritional Security of Rural Women were organized under broad area of nutritional security to the intervention group in Lehchhoda and Mukari village of Baghpat district, Uttar Pradesh
- Various field demonstrations were conducted on various crops like bio-fortified wheat (WB-02), vegetables, mustard (PM-30), summer moong (Pusa vishal), etc.
- Apart from field demonstrations, Exposure visit of 150 farmers and farm women from project
- villages of Baghpat and Sonipat district to Pusa *Krishi Vigyan Mela*, 2019 were conducted.

7.2.3 Development of Innovative Extension Model

7.2.3.1 IARI-Post Office Linkage Extension Model

Innovative IARI-Post Office Linkage Extension Model was designed for enhancing outreach of frontline extension. The model helped to disseminate

improved technologies of the institute to remotely located farmers.

Disseminated quality seeds of improved IARI varieties of 9.45 q paddy (P 1612) in 19 districts of 7 states, 20.9 q wheat (HD 2967 and HD 3086) in 39 districts of 10 states, 2.64 q green gram (Pusa Vishal) in 9 districts of 7 states and 0.16 q vegetables (bottle gourd, cowpea and okra) in 9 districts of 7 states.Socio-economic impact of IARI-Post Office Linkage Extension Model revealed that the information source preference has been changed from past experience (Mean rank I) and input dealer (Mean Rank II) to KVK (mean rank I) and post master (mean rank II) for crop planning. Major impact observed were improved satisfaction on extension service, changes in cropping pattern and yield, change in seed management practices, increased social status of post master and increased social security. The impact study on IARI-Post office linkage extension model in Darjeeling and Jalpaiguri districts showed that the significant improvement was reported in increase of yield of rice and mustard crops by majority of the farmers (85%) beside other impact like increase in income, seed replacement ratio, increased participation in extension activities, change in information sources, increased visibility of extension service & post master *etc*.

7.2.3.2 Community based and convergence-led extension models for climate change adaptation

Demonstrations of zero-tillage (43) and raised bed (5) in wheat and direct seeded rice (31) were conducted through community initiatives in villages of Gurugram and Mewat districts of Haryana, Bareilly district of Uttar Pradesh and Gaya district of Bihar to promote climate change adaptation. Farm machineries were used through custom hire centre of NICRA village Mumtajpur of Pataudi block of Gurugram district in Haryana. The farmers secured benefit cost ratio of 2.35:1 in DSR.with Pusa Basmati 1121 in Gurugram, while in Gaya, it was 1.48:1 with variety DRR 44. With variety HD 2967in zero-till,BC ratio of 2.4: 1 was secured in Gurugram. Cotton has been adopted as contingency crop while eschewing paddy cultivation in adopted villages Mumtajpur and Lokra of Pataudi block of Gurugram district and Sanghel village of Mewat district of Haryana. Sixteen demonstrations on management of white fly in cotton using IPM were carried out.

Different climate resilient technologies like short duration rice variety (P- 1612), flood resistant rice variety (Swarna -sub I), green gram (Pusa Vishal), pheromone trap to control yellow stem borer, brinjal fruit and shoot borer, mulching techniques, raised bed panting, line sowing, zero tillage, intercropping of jute and moong, etc. were promoted in adopted villages of Darjeeling and Jalpaiguri districts. The knowledge level of state department extension functionaries was assessed and majority of the respondents (40%) had low level of knowledge on scientific organic farming.A training manual on "Approaches of Vulnerability Assessment to Climate Change: A Practical Guidance for Extension Functionaries" was developed and tested.

A study on characterization of climatic parameters and extreme weather events was carried out in the South 24(P) district of West Bengal with the objective of establishing association (if any) between the shifting climatic characters and farmer level alterations of crop production practices in the district. The South 24(P) district was purposively selected as the locale of the study as it was representative of one of the most vulnerable ecosystems – the coastal ecosystem. The study was based on time series data (1974-2013) on weather parameters (daily temperature and rainfall) and time series data (1997 – 2013) on crop production including acreage under each crop. Findings of the study suggest that although there has not been much change in annual rainfall, average number of rainy days per year drastically declined during 2002-2012, clearly implying that rainfall pattern in the district has become erratic. Average deviation of annual rainfall was also increased in the recent years (as high as 44.03 percent in 2012). Deviation of daily mean, minimum and maximum temperature, showed increasing trend. Overall exposure as estimated through an unweighted index has increased by about 161 percent.

The shift of climatic characters has majorly affected rice production. Thelocal adaptation strategies of the farmers also therefore centred on rice, summer moong, rapeseed-mustard and potato cultivation, adjustment of area under production of winter rice and summer-moong being the major adaptation strategy. In case of early season drought (late onset of monsoon from 2- 8 weeks), the rice- fallow adopters may be recommended to switch to rice- pulse/ oilseed/ vegetables with short duration and salt tolerant rice varieties.In such cases, relay cropping with lathyrus or lentil may be suggested to the farmers.

7.2.3.3 ICT based extension model

One whatsapp group namely "Darjeeling Mandarin" has been created where Darjeeling mandarin growers from 4 blocks were added for providing mobile based agro-advisory services in Darjeeling and Kalimpong hills. Digital content of package of practices (PoP) of Darjeeling mandarin & large cardamom was prepared.The assessment of tablet based extension service of West Bengal government i.e. Matir Katha was done in Dhupguri and Maynaguri block of Jalpaiguri district of West Bengal. Both the primary and secondary data were analyzed to see its performance and to identify the major constraints in its usage.

A study on perception of extension personnel about selected extension methods which are used for extension service delivery, namely, frontline demonstration, farm telecast and whatsapp has been conducted. Semantic differential technique was followed. At stage one 10 experts belonging to extension discipline were chosen all over India and they were requested to provide their perception about these extension methods in the form of one-page write-up on each method. Through frequency analysis, key adjectives were selected. Besides, reviews of past studies and reports were consulted for selection of adjectives. From these sources and experts, a list of 86 adjectives was made. These adjectives were screened to reflect the various dimensions and reduced to 27 adjectives. These adjectives were made as bi-polar and a semantic differential scale of seven point continuum was developed. This scale, along with face-sheet information and other independent variables, a questionnaire was designed in Google Forms, mostly framing the questions in the form of seeking response by choosing radio buttons and one word answers. The Google Forms were emailed to 207 extension personnel of NARS including ICAR Institutes, State Agricultural Universities and *Krishi Vigyan Kendras* throughout India. Thirty sixextension personnel (17.39%) responded to the questionnaire. Extension personnel perceived that the fronltline demonstration is the most effective method with a mean score of 5.97 in a scale of seven, followed by whatsapp (5.57).

7.3 TECHNOLOGY ASSESSMENT AND TRANSFER

7.3.1 Outscaling Agricultural Innovations for Enhancing Farm Income and Employment

The project is in operation at four villages namely Khajurka (Palwal, Haryana), Kutbi (Muzaffarnagar, U.P), Rajpur (Aligarh, U.P) and Beenjpur- Raghunathpura cluster (Alwar, Rajasthan). During *Rabi* 2017-18, performance of location specific improved varieties of wheat, mustard, lentil, onion, pea, *palak*, broccoli and cauliflower were demonstrated over an area of 78 hectare through a total of 265 assessments trials. The height of varieties HD 2967 and HD 3059 were more than HD 3086. However, HD 2967 gives about 25 per cent more straw than HD 3059. These varieties have differences in grain also. HD 2967 has roundish grain, whereas the grain of HD 3059 is more elongated and the taste is also better and HD 3086 produces bright and elongated grains. Wheat varieties HD 2967, HD 3086 and HD 3059 performed well at all the project village locations. In Khajurka, Palwal (Haryana) the highest average yield of wheat variety HD 2967 (5.88 t/ha) was reported from such assessment trails followed by HD 3086 (5.70 t/ha) and HD 3059 (5.55 t/ha). At Beenjpur, HD 2967 and HD 3086 performed well with an average yield of 6.34 and 6.01 t/ha, respectively. The wheat varieties, HD 2967 and HD 3086, exhibited profuse tillering, no lodging with good

quality for *chapati* making. Mustard, Pusa Vijay was liked by farmers due to large grain size, good yield & oil content. However, the local check (Coral 432) gave higher yield of 2.35 t/ha compared to Pusa Vijay (1.95 t/ha). In the village Rajpur, among wheat varieties, highest average yield was observed in HD2967 (5.78 t/ha) followed by HD3086 (5.60 t/ha) and HD3059 (4.73 t/ha). HD 3059 is suitable under late sown conditions and farmers preferred the variety due to high yield and resistance to yellow rust disease. Lentil variety L-4076 recorded an average yield of 1.56 t/ha with economic gain of Rs. 36,542/- per hectare. Onion variety Pusa Red gave a yield of 26.5 t/ha with an average net returns of Rs.2,45,500 /- per ha. Moong variety Pusa Vishal gave average yield of 0.99 t/ha with average net returns of Rs. 25,207 /- per ha. In Kutbi, the performance of the IARI wheat varieties was found to be superior, compared to local check and no lodging have been reported in field trials. The highest wheat yield was recorded from HD 3086 (5.25 t/ha) followed by HD 2967 (5.08 t/ha) and HD 3059 (4.20 t/ha). The mustard Pusa Vijay recorded an average yield of 2.16 t/ha in comparison to the yield of the local check (1.7 t/ha).

Demonstration of wheat var. CSW 18 at Khajurka villagye, Palwal (Haryana)

During *Kharif 2018*, a total of 197 assessment trails were conducted in all model villages on paddy varieties (PB 1, PB1121, PB1509, PB1637, PB 1609 and PB 1728) and Pigeon pea P 991 and P 992 covering an area of 80.47 ha. In Khajurka, Palwal (Haryana),the highest average yield of PB 1 (5.16 t/ha) was recorded at farmers' field followed by PB1728 (4.65 t/ha), PB 1637 (4.60 t/ha), PB1609 (4.45 t/ha) and Pusa 1121 (4.39 t/ha). Pusa Basmati 1609 was assessed for the first time and farmers reported positively for the plant vigor, tillering, broad leaves, but although it is an early maturing variety, it matures 10-15 days later in comparison to PB 1509. Also, PB 1609 has been reported to be infested with more diseases e.g. blast, false smut and at least 10 per cent incidence of yellow stem borers was also reported by the farmers. However, yield was affected due to infestation of false smut during maturity time. The economic impact assessment of paddy in the Khajurka location showed that Paddy PB 1 fetched the highest net return i.e. Rs. 96,063/- followed by PB-1121 (Rs. 91,319/-), PB 1728 (Rs. 81,199/-), PB 1637 (Rs. 79,575/-), and PB 1609 (Rs.48,675/-). In the village Rajpur, the highest average yield of paddy PB 1509 (4.67 t/ha) was recorded at farmers' field followed by PB 1 (4.36t/ha), PB 1728 (4.31 t/ha) and PB 1121(4.13 t/ha) and PB 1609 (3.67 t/ha). Majority of the farmers preferred P 1509 due to high yield and it fetches good market price. The grain quality was also good in terms of maturity, cooking quality, good aroma and weight. The farmers did not like variety PB-1609 because heavy infestation of disease and insect pest and low market price. Paddy variety PB-1509 fetched the highest net return i.e. Rs. 88,378/- followed by PB 1121 (Rs. 84,916/-), PB1 (Rs. 76,828/-), and PB 1728 (Rs. 75,193/-) per hectare. PB 1728 matured at least 10 days later than PB-1 and has low market price. Pigeon pea varieties P 991 and P 992 gave an average yield and net profit of 1.26 t/ha & 1.15 t/ha and Rs. 36,568/- and Rs. 31,716/- per hectare, respectively.

The pigeon pea (P 991 and P 992) is an introduction in the project village, Beenjpur and attained an average yield of 1.27 t/ha. Pusa Sukomal variety of cow pea was very suitable and attained a yield of 5.85 t/ha. Farmers' liked the Pusa Sukomal variety for its longer sized and soft pods. At Kutbi village in Muzaffarnagar district of UP, the performance of the IARI paddy varieties was found superior as compared to local check. The highest yield of PB 1609 (5.62 t/ha) was recorded with 38.38 percent yield gain over local check followed by Pusa

Basmati-1 (4.62 t/ha), PB 1728 (4.57 t/ha) and PB 1637 (4.34 t/ha).

On the basis of assessment of nutritional status, dietary intake and deficiency patterns of rural women, nutrition garden on seasonal vegetables were promoted in adopted villages. In Khajurka, Palwal, during *Rabi* 2017-18, nutrition garden demonstrations on Pea (Pusa Pragati), Spinach (Pusa All Green) and Onion (P-Red); and during *kharif* season nutrition garden on brinjal (var. Pusa Uttam, Pusa Kaushal), bottle gourd (Pusa Santusti), sponge gourd (Pusa Sneha) and bitter gourd (Pusa Aushadhi) were conducted. In Beenjpur, Alwar, nutrition garden on pea (Pusa Pragati), Broccoli (KTS-1), cauliflower (K-25) and onion (Pusa Riddhi) were promoted. In Rajpur, Aligarh, in *Rabi* 2017-18, onion (Pusa Red) and during *Kharif 18*, okra (A 4), cowpea (Pusa Sukomal), bottle gourd (Pusa Naveen, Pusa Santusthi), brinjal (Pusa Uttam, Pusa Kaushal), Bitter gourd (Pusa Aushadhi) and sponge gourd (Pusa Sneha) were promoted. In Kutbi, Muzaffarnagar, nutrition garden on cowpea (Pusa Sukomal), cauliflower (Pusa Meghna), cucumber (Pusa Barkha), and in Beenjpur, Alwar, sponge gourd (Pusa Sneha), cowpea (Pusa Sukomal) and bitter gourd (Pusa Aushadhi) were demonstrated. Due to popularization of varieties of improved crops, the dietary diversity of the rural household has improved. The adoption of HYVs has also resulted in improved crop yield and consequently more profit to the farm household. The capacity building programs for women in management practices of dairy animals, post-harvest processing, health and hygiene were important activities undertaken.

Village Knowledge Resource Centers have been established in all the villages and they were well equipped with farm libraries having a good collection of farmer friendly literature, booklets, leaflets, journals, magazines, periodicals dealing on various aspects of Agriculture, horticulture animal husbandry etc. Wall magazines on Wheat (*Vartman Krishi Karyamala: Gehu*) and Mustard (*Vartman Krishi Karyamala: Sarso*) having complete advisory on the relevant farm practices were designed and displayed at the center. *Pusa Krishi Panchang* 2018, an agricultural operations calendar and publications on important Agriculture development schemes of the Government of India, have been displayed at the knowledge center for the benefit of the village community. Around 100 farmers in each village have been linked with mobile SMS services for regular messaging on Agro-advisory from the Institute.

7.3.2 Technology Integration and Transfer to Strengthen Farming System in Partnership Mode

The partnership project is being implemented with selected ICAR Institutes / SAUs/VOs in different parts of the country. The analysis of existing farming system was carried out through joint workshops with partner institutions. Suitable farm production, plant protection and post harvest technologies and farm enterprises were identified based on participatory analysis and joint consultations for profitable farming system during workshops held at Institute. The technologies were assessed through demonstrations, trainings, field days etc. by the partner organizations.

7.3.2.1 Collaborative programme with ICAR institutes and SAUs

During *Rabi* 2017-18, 126 demonstrations were conducted covering an area of 32.29 ha across 10 locations for wheat, onion, lentil, pea and spinach.

During *Kharif 2018*, a total of 262 demonstrations of paddy, pigeon pea, *moong*, *palak*, bottle guard, chilli, sponge guard, Cauliflower, cowpea, bitter gourd and brinjal covering an area of 76 ha were conducted at ICAR Institutes / SAUs.

7.3.2.2 Collaborative programme with voluntary organizations

In collaboration with 16 Voluntary Organisations, during *rabi* 2017-18, a total of 321 demonstrations, covering an area of 74.42 hectares for wheat, mustard, lentil, spinach, carrot, bottle guard, cauliflower, amaranths, onion, marigold, pumpkin and pea were conducted. During *Kharif*2018, in collaboration with Voluntary Organisations, a total of 442 demonstrations of paddy, pigeon pea, moong, *palak*, bottle guard,

chilli, sponge guard, cowpea, bitter gourd, brinjal and marigold were conducted covering an area of 110.40 ha.

7.3.3 Participatory Seed Production of Improved Varieties of IARI at Seed Hubs

Under Participatory Seed production of improved varieties of wheat, during *rabi* 2017-18, wheat HD 2967 (28 t foundation and 135 t certified) and HD 3118 (1.0 t foundation), seed was produced at PRDF Gorakhpur, and 5.0 t seed of Wheat, HD 2967 and 32.4 t of HD 3086 was produced at YFAP, Rakhra during *rabi* 2017-18. During *Kharif* 2018, 9.2 t of PB 1509, 41.4 t of Pusa 44 and 5.48 t of Pusa 1121, 5.5 t of PB 1728 and 5.6 t of PB 1401 seed were produced at Rakhra.

7.3.4 Front Line Demonstrations on Wheat

During Rabi 2017-18, 18 FLDs of wheat were conducted at Najafgarh, Delhi (in collaboration with IWBR) with newly released wheat variety HD 3086, WB 02 and HPBW1 and use of bio-fertilizer (Azotobacter + PSB) in all three varieties. The Zero- tillage practice saved Rs.5,000-6,000/ha. From ploughing, 6-7% extra yield over check plot, no lodging and less weeds infestation was reported. The use of Bio-fertilizer resulted in good plant growth and bright grains.

7.3.5 *Mera Gaon Mera Gaurav*

To promote the direct interface of scientists with the farmers to hasten the lab to land process, *Mera Gaon Mera Gaurav* is being implemented by IARI in 120 cluster comprising of 600 villages by 480 scientists of the Institute along with IASRI and NBPGR. The objective of this scheme is to provide farmers with required information, knowledge and advisory on regular basis by adopting villages. During *rabi* 2017-18, 345 demonstrations on wheat varieties (HD 2967 and HD 3086) and mustard (Pusa Mustard 28 and Pusa Vijay) were conducted at 81 and 59 locations in an area of 69 ha and 110.40 ha, respectively. During *Kharif* 2018, 57 demonstrations on paddy PB 1, PB 1121 and PB 1637 were conducted at different locations covering 110.6 ha.

7.3.6 Pusa *Krishi Vigyan Mela* 2019

Pusa *Krishi Vigyan Mela* 2019 on the theme "Krishi Vikas: Innovative Technologies" was organised at the IARI *Mela* Ground from March 5-7, 2019. Dr. Trilochan Mohapatra, Secretary (DARE) & DG (ICAR) inaugurated the *Mela* on March 5, 2019. In his inaugural address, Dr. Mohapatra applauded the institute's

Inauguration of Pusa *Krishi Vigyan Mela* by Dr. T. Mohapatra, Secretary, DARE, and Director-General, ICAR

Performance of FLD – IWBR (Wheat) during *Rabi* 2017-18

Technology	Variety	No. of demonstrations	Area (ha)	Yield of demo. plot (t/ha)	Av. Yield (t/ha) of Check Plot	Per cent increase over check
Newly Released wheat variety with Zero-tillage	HD 3086	2	0.80	5.26	4.97 HD 3086	5.72
	WB 02	4	1.60	4.48	4.16 WB 02	7.88
	HPBW 1	2	0.40	4.15	3.93 HPBW 1	5.77
Use of Bio-fertilizer (Azatobactor +PSB)	HD 3086	4	1.60	5.40	5.14 HD 3086	5.11
	WB 02	2	0.80	4.78	4.55 WB 02	5.20
	HPBW 1	4	1.60	4.26	3.88 HPBW1	9.69
	Total	**18**	**7.20**			

efforts of organizing such knowledge gaining event for the agricultural and farming community.

Shri Sushil Kumar, Additional Secretary (DARE) & Secretary (ICAR); Shri Bimbadhar Pradhan, Additional Secretary & Financial Advisor (DARE/ICAR); Dr. A. K. Singh, DDG (Horticultural Science), ICAR; Dr. J. K. Jena, DDG (Fisheries Science), ICAR; Dr. J. P. Sharma, Joint Director (Extension), ICAR-IARI and Dr. S. P. Kimothi, ADG (TC), ICAR also marked their presence and spoke on the occasion. Dr. A. K. Singh, Director, IARI welcomed the gathering and detailed the events to be organised along with IARI achievements, especially in developing popular basmati variety PB 1121, wheat variety HD 2967, etc.

Thirty-one (31) awardees including farmers and scientists in different categories were also felicitated with ICAR awards during the inaugural session. On the second day of *Mela*, Hon'ble Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh visited the *Mela*. He visited 1 acre IFS model and other live demonstrations exhibited on the *Mela* ground and interacted with farmers and scientists. On the last day of *Mela*, Innovative Farmers Meet was organized in which selected innovative farmers (32) and fellow farmers (5) shared their rich experiences and innovations practiced by them.

Honorable Secretary, DARE & Director-General, ICAR, Dr. T. Mohaptra, honouring farmer with IARI innovative farmer award

Dr. Ramesh Chand, Member, NITI Ayog was the Chief Guest of the valedictory session. The valedictory session was chaired by Dr. Trilochan Mohapatra, Secretary, DARE and DG, ICAR. Other dignitaries present on the occasion were Shri. Sanjay Agarwal, Secretary DAC&FW; Dr. A. K. Srivastava, Chairman (ASRB); Dr. K. V. Prabhu, Chairperson, PPVFRA; Dr. A. K. Singh, DDG, Agricultural Extension and Director, IARI; Dr. J. P. Sharma, Joint Director (Ext); Dr. A. K. Singh, Joint Director (Res), awardee farmers Col. Subhash Deswal and Smt. Gauripriya Mohapatra. Dr. Ramesh Chand stressed on the need of marketing of the surplus produce and the implementation of new agricultural policy for realization of better income for the farmers. Dr. Trilochan Mohapatra, Secretary, DARE & Director General, ICAR in his presidential address congratulated all the awardee farmers and motivated the fellow farmers present at the fair. Shri Sanjay Agarwal, Secretary, DAC&FW reiterated the pivotal role of new and innovative farm technologies in doubling income of farmers and assured support from DAC&FW to the farmers under PM *Kisan Samman Nidhi Yojana.*

A total 170 stalls were put up by ICAR Institutes, public and private organizations and farm entrepreneurs from across the country. About 30,000 farmers from across the country including 5,000 associated with IARI outreach activities visited the *mela*. *Kisan Gosthi* was organised on all three days on the themes – Improved technologies for addressing agrarian challenges, Innovations in secondary agriculture for enhancing income of farmers and linking farmers to market. Various government schemes were also discussed in the *Kisan Gosthi* for the benefit of the farmers. Padam Shri awardee farmers, Shri Kanwal Singh Chauhan, Shri

DG, ICAR visiting the IARI thematic *pandal* stall

Bharat Bhushan Tyagi, Shri Sultan Singh and Shri R. S. Verma expressed their views and motivated farmers. Farmers visited live demonstrations on improved crop varieties, high density orchard, vegetables production technology, IFS Models (1 hectare and 1 acre model), *etc*. Seeds worth of Rs. 48.14 lakhs and Biofertilizers of Rs.1.00 lakh were sold. Extension literatures and several publications were released including MGMG-A flagship programme of ICAR: Status, Impact and Implications; *Krishi Panchang: Varshik Krishi Karya Evam Krishi Ki Unnat Takniki*; Synergizing Institutional Partnership for Enhanced Technology Outreach and Production System Efficiency: Experience of Collaborative Extension Programme; *mitrakeet evam unki pahchan*; and Prasardoot (*Mela* issue).

7.3.7 Participation in Off-campus Exhibitions

CATAT organized / participated in 19 important national/international agricultural exhibitions for display /sale of IARI technologies, products, services and publications.

7.3.8 Agricultural Technology Information Centre (ATIC)

IARI, being a premier institute in agricultural sector and located in the capital city, is frequently visited by a large number of farmers, extension workers, entrepreneurs, etc. from different parts of the country every year. Since, this is a large organization with high degree of specialization and has many disciplines scattered at long distances, farmers/ entrepreneurs visiting in the Institute are not aware as to when and where to approach for inputs, services and advice. It is important that products, technologies and services are delivered directly to the ultimate users at one place, so that they clearly understand and there is no scope of distortion of information. Further, integration needs to be achieved by having a formal management mechanism linking scientists or departments of different disciplines on one hand to the technology users on the other. In this context, Agricultural Technology Information Centre established in IARI is providing a single window delivery system for the Institutes'products, services and technologies to the farmers/entrepreneurs etc.

ATIC is effectively providing products, services, technologies and information services to the different stakeholders through a 'Single Window Delivery System'. Besides farm advisory services at ATIC, farmers are given farm advice through Pusa Helpline (011-25841670, 25846233, 25841039 and 25803600), Pusa Agricom(1800-11- 8989), exhibitions, farm literatures and letters. A second level of Kisan Call Centre (1800-180-1551) has also been established at ATIC to solve the problems/queries of farmers of Delhi and Rajasthan. Information & advisory needs of the visitors are also being catered through touch panel kiosks, revolving scrollers, LED display boards, information museum, plant clinic, farm library and exhibits related to agriculture implements, seed samples, bio-fertilizers displayed at the centre.

In ATIC crop cafeteria, laid out live demonstrations of *Kharif* paddy varieties Pusa Basmati 1509, Pusa Basmati 1637, Pusa Basmati 1121, Pusa 1612, Pusa 2511, Pusa -1401 (P. B. – 6), moong var. Pusa Vishal. In Rabi live demonstrations of wheat varieties: HD CSW 18, HD 3086, HD 2967, DB 02, and HD 3043; Vegetables: In summer season: pumpkin var. Pusa Vishwas, Okra var. Pusa A-4; cowpea var. Pusa Sukomal; cucumber var. Japanese long green; Onion var. Pusa Red; Bathua var. Pusa Bathua 1; sponge gourd var. Pusa Sneha, brinjal var. Pusa Bindu, bottle Gourd var. Pusa Naveen, Palak var. Pusa All Green, Chilli Var. Pusa Sadabahar, tomato var. Pusa gaurav, Amaranthus var. Pusa Kiran, and bitter gourd var. Psa Hybrid 4. In winter season, Cauliflower var. Pusa Hybrid 2, broccoli (KTS 1), radish (Pusa Hybrid 1), Beet (Crimson globe), KnolKhol (White Vienna), tomato (Pusa Rohini and Pusa Cherry), *methi* (PEB and Pusa Kasuri). Among flowers, one variety of Marigold var. Pusa Narangi Gainda demonstrations were laid out. Nutri-garden with 15 vegetable varieties and fruit orchard (lemon, guava ,mango, *ber*, kinnow, grapes) were demonstrated for the visiting farmers. For awareness of farmers, herbal block has been developed in crop cafeteria which includes medicinal plants of aloevera, *ashwagandha, satavar*, coleus, *giloe, mushkdana,*

Details of on-farm testing organized at farmer's field during 2018-19

S.No.	Title of OFT	Problem identified	Technology assessed
1.	Integrated Nutrient Management (INM) in wheat	Low productivity of wheat due to inadequate nutrient application.	Soil test based INM (FYM 10 t/ha. +NPK liquid biofertilizer@5ml/kg seed +75% NPK of recommended dose
2.	Weed Management (IWM) in wheat	A lot of weed flora have come in wheat crop resulting in reduced crop yield.	Clodinofoppropogyl 60 g + Metsulfuran methyl @ 04 g/ha
3.	Integrated Disease Management in bottle gourd	Root-rot in bottle gourd is a major problem which affects the yield of crop.	Soil treatment with *Trichoderma harzianum* @4 kg/ha. Seed treatment with *Carbandazim 50WP* @ 2.5 g / kg seed.
4.	Management of Diamond Back Moth (DBM) in cauliflower	Diamond back moth is the major problem in cauliflower cultivation resulting in low production of cauliflower.	2 spray of Emamectin benzoate (5% SG)@ 0.50 gm/liter of water and 2 spray of neem oil@ 5 ml/liter of water solution alternatively.

sadabahar, mint, *tulsi* (basil), lemon grass, java citronella and turmeric, etc.

Four issues of Hindi farm magazine "Prasar Doot" were published by the centre during the reporting period. Besides, more than 850 farmers and others got farm advisory services through e-mails during the period. ATIC is providing a mechanism for getting direct feedback from the technology users to the technology generators. The feedback strengthened the ATIC activities and provides a ground for need based technologies. The ATIC has also developed functional linkages with various agencies working for the farming community to effectively cater the information needs of the different stakeholders.

7.3.9 *Krishi Vigyan Kendra,* Shikohpur, Gurugram

7.3.9.1 On-farm testing (OFT)

This activity is mainly focused to test developed technologies which might be helpful to solve the most important and widely spread problems of the groups of farmers in a defined area within their farming system perspective with their active participation and under their management. OFTs aim to address the problems that are important and faced by a majority of the farmers in the area. The problems are diagnosed based on the data and information generated through different methods and interactions with the farmers and field level extension functionaries, farmers' group meetings, field surveys and field visit etc. During 2018-19, 04 OFTs were conducted on different problems identified in the region.

7.3.9.2 Front line demonstration programme

Organization of Front Line Demonstrations on major crops of the districts is one of the mandates of *Krishi Vigyan Kendra*. The main objective of FLDs is to demonstrate newly released crop production and protection technologies in the farmer's field under different agro-climate regions and farming situations. A total of 320 demonstrations were conducted covering an area of 153.00 hectare during the period under report. The improved varieties and latest recommended package of practices were demonstrated under the programmes.

7.3.9.3 Trainings and demonstrations under *Krishi Kalyan Abhiyan*

In Haryana state, only Nuh (Mewat) district was selected under *Krishi Kalyan Abhiyan* where KVK, Gurugram had the responsibility of conducting the following activities:

NARDEP Compost/Vermicompost making units. The responsibility of making NARDEP pits in 25 villages of Mewat district was shared between KVK, Gurugram and State Agriculture Department. The KVK was given the responsibility of making 20

Results of FLDs organized at the farmers' fields during *Rabi*, 2018-19

Crop	Variety	No. of demo.	Area (ha)	Yield kg/ha				Increase in yield %	BC ratio
				Demonstrations			Local		
				Max.	Min.	Avg.	Avg.		
Mustard									
Cluster 1	RH 0749	25	12.5	2675	1860	2360	2040 (Laxmi)	15.69	1:3.31
Cluster 2	RH 0749	22	9.00	2770	1985	2160	1930	11.92	1:2.99
Cluster 3	RH 0749	18	8.5	2350	1725	2075	1 1875	8.80	1:2.78
Chickpea									
Cluster 1	CSJ 515	22	11.5	2225	1975	2075	1 1680 2 (HC 1)	23.51	1:3.3
Cluster 2	CSJ 515	35	14.50	2250	1950	2135	11670	27.84	1:3.7
Cluster 3	CSJ 515	28	9.00	2240	1875	2060	11650	22.85	1:3.5
Wheat	HD 3043	07	3.0	6175	5725	5950	5850 (WH 711)	1.78	1:4.04
	Total	**157**	**68**	--	**--**	**--**	**--**	**--**	**--**

Results of FLDs organized at the farmers' field during *Kharif* 2018

Crop	Variety	No. of demo.	Area (ha)	Yield kg/ha				Av. cost of cultivation (Rs.)	Av. gross income (Rs.)	Av. net income (Rs.)	BC ratio
				Main produce			By produce				
				Max.	Mini.	Av.					
Mungbean											
Cluster 1	MH-421	26	16.2	890	570	785	-	12750	38950	26200	1:3.0
Cluster 2	MH-421	39	16.6	825	520	775	-	15500	37394	21894	1:2.4
Cluster 3	MH-421	30	17.2	745	560	725	-	15800	34873	18073	1:2.2
Pigeon Pea											
Cluster 1	Pant Arhar 291	23	11.8	1820	1280	1625	8000	22500	91340	68840	1:4.1
Cluster 2	-do-	27	13.2	1585	1230	1420	8000	22800	87320	64520	1:3.8
Cluster 3	-do-	18	10	1640	1330	1565	8000	23250	98350	75100	1:4.2
Total		**163**	**85**								

NARDEP pits in 15 villages of Mewat. The farmers of Mewat district were following the practice of throwing animal dung and other farm waste in open field which was not being completely decomposed and used to attract the problems of termite and other insects in field. During *Krishi Kalyan Abhiyan*, the farmers were given knowledge about the consequences of throwing the animal dung and farm waste in open field and how to decompose the waste completely using waste decomposer in NARDEP pit and a total of 300 NADEP pits were constructed by KVK in 15 villages of Mewat district.

Training programmes on Beekeeping, Mushroom cultivation and Kitchen Gardening. KVK, Gurugram conducted a total of 125 trainings on the subjects Beekeeping, Mushroom cultivation, Kitchen Gardening, Value Addition and Vermicompost in 25 villages of Mewat district which benefitted 13750 farmers and farm women. During *Krishi Kalyan Abhiyan*, an interaction was made with the farmers and

female members of the family in which they told they mainly focus on the consumption of cereals, pulses, animal foods, fats and sugars but a lesser interest was shown in the consumption of fruits and vegetables, the main contributing factor for which is poverty and lack of awareness. During training programs, the farmers and women were told about the importance of fruits and vegetables in human health and utilization of area available in their backyard or near home to establish a small kitchen garden in which some fruit plants and seasonal vegetables can be grown. Under KKA, 5 fruits plants were distributed to the farmers which can be grown in kitchen garden and compost for their kitchen garden can be prepared in NADEP pits constructed under KKA. This whole concept will help in making organically grown fruits and vegetables available for the family with very low input cost and thus will help in improving the nutritional status of the family in long run. The farmers can adopt mushroom cultivation and beekeeping to raise their income. A 3 days residential training was also organized at KVK to show the live demonstration units of all the above enterprise in which a total 50 farmers and farm women from 25 villages participated.

Demonstration programmes on Micro-irrigation systems at KVKs. During 3 days residential training programme organized at KVK, the farmers were demonstrated the technology of drip irrigation in which 50 farmers from 25 villages participated. However, 30-40 % villages of Punhana block and all villages of Nuh and Nagina block depend on rain water for irrigation. Thus, there is need to train them on the aspect of rain water harvesting then only micro-irrigation will be successful in these blocks.

Demonstration of Micro-irrigation system to Mewat farmers

Demonstration programmes on Integrated Farming Practices. During 3 days residential training programme organized at KVK, the farmers were demonstrated the technology of Integrated Farming Practices in which 50 farmers from 25 villages participated. The main problem in that area is poverty due to dependency of farmers on farming only, non-availability of irrigation water in Nuh, Nagina and 30-40 % area of Punhana block and lack of awareness and knowledge about latest improved agricultural technologies and government schemes. During *Krishi Kalyan Abhiyan*, the farmers were sensitized about the concept of IFS and were motivated to take up other enterprises which are suitable for their area like fisheries, duckaries, horticulture crops, fruit orchard, vermi-compost and biogas plant under IFS system. However, there is need to provide skill trainings on these enterprises to the farmers of Mewat.

7.3.9.4 Entrepreneurship development of rural youth and women under ARYA project

Realizing the need to create interest and confidence in Indian rural youth by making agriculture more profitable, ICAR launched a project titled "Attracting and Retaining Youth in Agriculture".The objective of the project is to attract and empowers the

Women empowerment through training on value addition

Vocational training on motor rewinding

youth in rural areas to take up various agriculture and allied sector enterprises for sustainable income and gainful employment. Initially, the project has been implemented in 25 districts by KVKs as ARYA centers and KVK, Shikohpur is one of them. Under this project, KVK has given training to 74 rural youth and women in the year 2018-19 in 04 areas viz. value addition, protected cultivation, goatery and mushroom production, out of which 70 participants have adopted the vocation and established their own enterprise.

7.3.9.5 Agricultural extension activities and farm advisory services

In addition to OFTs, FLDs and trainings various other extension activities were also conducted during 2018-19 to cover more farmers, farm women and rural people to disseminate the technologies. A total of 295 such activities were conducted.

"Kisan Diwas" celebrated at KVK, Shikohpur

7.3.10 Transfer of Technologies through IARI Regional Stations

7.3.10.1 Regional Station, Indore

Wheat frontline demonstrations 2017-18. During 2017-18, a total of 26 demonstrations of 10 wheat varieties were conducted in 11.80 hectares area in Dewas and Dhar districts of M.P. using recommended package of practices. Increase in yield was recorded as 16 q/ha or 39% in these demonstrations.

Wheat demonstrations under TSP 2018-19. During 2018-19, 22 wheat demonstrations were organized in tribal farmers' fields under Tribal Sub Plan (TSP) in Jhabua, M.P. Demonstrations on eight new wheat varieties, viz., Bread Wheat- HI 1531 (Harshita), HI 1605 (Pusa Ujala), HD 2987 (Pusa Bahar), HI 1544 (Purna), Durum- HI 8627 (Malavkirti), HI 8663 (Poshan), HI 8737 (Pusa Anmol) and HI 8759(Pusa Tejas) were conducted in 11 hectares area with the aim to introduce and popularize new wheat varieties, train and empower the tribal farmers in wheat and wheat seed production technology. Crop was good and harvesting is in progress in all the demonstrations. Apart from this, various events like *Kisan Mela* / Field Day Short Trainings, Farmers group meetings etc. were organized.

7.3.10.2 Regional Station, Pusa (Bihar)

Wheat frontline demonstrations. To reduce the yield gap between lab-to-land, 16 frontline demonstrations were laid out during the year (2018-19) under report in the different villages Sakri, SakriKothi Man, Patsara, Siswara, Vaidya Gaighat, Loma and Bakhri of Muzaffarpur districts of Bihar. The demonstrations conducted were use of bio-fertilizers-*Azatobactor* and PSB (6), zero-tillage technology (4) and new improved wheat variety HD 2967 (6). The performance of different demonstrations conducted was very encouraging. To reduce the yield gap between lab-to-land, 16 frontline demonstrations were laid out during the year under report in the villages Lukinandlalpur, Mahmadpur and Rajapur Dihuli of Muzaffarpur districts of Bihar. The demonstrations conducted were on new improved wheat varieties, use of bio-fertilizers- *Azatobactor* and PSB (6), zero-tillage technology (5).

IARI outreach programme. In *Rabi* 2017-18, with a goal to popularize IARI Wheat varieties among farmers under the IARI Outreach Programme on "Strengthening of wheat Programme in Eastern India", 630 minikits demonstrations of two timely sown wheat varieties HD 2733 and HD 2967, three late sown wheat varieties HD 2985, HD 3118 and HI 1563 were laid out in 18 districts of Bihar, 2 districts of Jharkhand and 1 district of West Bengal through KVKs.

7.3.10.3 Regional Station, Karnal

Seed village programme. Seed village scheme sponsored by DAC, Ministry of Agriculture, GOI was continued during Kharif2018 for farmer-to-farmer horizontal spread of seeds of popular varieties of different crops. In Kharif2018, 42.8ha area was undertaken for paddy cv PB1121, for increasing the availability of quality seeds in their villages itself. Under seed village programme resource poor farmers and women farmers were given training at the station as well as at farmers' field on various aspects of quality seed production.

Basmati beej diwas.'Basmati *Beej Diwas'* was organized on March 1, 2019. Pusa Beej of three new Basmati varieties PB 1718, PB 1728 and PB 1637 and other popular varieties of Basmati paddy viz., PB 1509, PB 1121 and non-Basmati variety Pusa 44 of worth Rs. 28.68 lakh was sold to hundreds of farmers from Haryana, Punjab and Western Uttar Pradesh.

Mera Gaon Mera Gaurav. '*Mera Gaon Mera Gaurav*' a Mega Agricultural Development Programme was launched by ICAR-IARI, Regional Station, Karnal in three clusters of five villages each. Under MGMG programme, "Swach Bharat Abhiyan" was launched in different schools under cluster villages.

7.3.10.4 Regional Station, Katrain

Development and popularization of cultivation technologies of high value exotic vegetables. Production technology for round the year cultivation of high value exotic vegetables (Summer squash, Gherkins, Lettuce, Broccoli, Snowpea and Leek) under open field conditions in Kullu Valley of Himachal Pradesh was standardized and revalidated during 2018-19. Experimental results revealed that summer squash/gherkins, Lettuce/broccoli and Snowpea/leek are suitable for cultivation in Kullu Valley of HP during April-July, August-Mid November and Mid November-March, respectively.

Standardization of production technology of cabbage and cauliflower hybrids for off-season cultivation.The production technology of cabbage and cauliflower hybrids for off-season cultivation in Kullu Valley of Himachal Pradesh was standardized during summer, 2018. The experimental results revealed that planting of cabbage (Pusa Cabbage-1) and cauliflower (Pusa Snowball hybrid-1) hybrids on 31st March, 2018 with a spacing of 45 cm × 30 cm resulted in highest crop yields. Therefore, standardized technology after multilocation testing may be recommended for commercial off-season cultivation of cabbage and cauliflower during summer season in hilly regions of Himachal Pradesh and India as well.

7.3.10.5 Regional Station, Kalimpong

The improved IARI technologies of rice (P-1612), mustard (PM-28 and PM-31) were promoted in Darjeeling and Jalpaiguri district of West Bengal. The average yield was found between 4.5 to5.0 tonne/ha in Pusa 1612 variety of paddy, whereas in mustard (PM-28), average yield was 1.4-1.8 tonne/ha.

Devising extension approaches for climate change adaptation and livelihoods security. Different climate resilient technologies like short duration rice variety (P-1612), flood resistant rice variety (swarna -sub I), green gram (Pusa Vishal), pheromone trap to control yellow stem borer, brinjal fruit and shoot borer, mulching techniques, raised bed panting, line sowing, zero tillage etc. were promoted in adopted villages.

Analysis of ICT based extension approaches. The assessment of tablet based extension service of West Bengal government i.e. Matir Katha was done in Dhupguri and Maynaguri block of Jalpaiguri district of West Bengal. One whatsapp group namely "Darjeeling Mandarin" has been created where Mandarin growers from 4 blocks were added for providing mobile based agro-advisory services in Darjeeling and Kalimpong hills.

Nutrition education for enhancing nutrition security and gender empowerment. The mustard variety (PM 31) with double zero erucic acid content was promoted in Darjeeling district and Jalpaiguri district of West Bengal. The impact of nutri-kitchen garden & capacity building programmes on nutritional security was assessed in Darjeeling and Jalpaiguri districts.

Scaling up the productivity of Darjeeling Mandarin. Three (3) capacity building programmes on "Scientific Mandarin cultivation, Pest and Disease Management" were conducted in Sitong, Mungpo and Sonada of Darjeeling district.

Revival of Darjeeling Mandarin cultivation in traditional and Non-traditional areas of North Bengal. Healthy rootstock blocks of Rough lemon and Rangpur lime were developed. Nucellar seedlings were raised for production of virus free planting materials.

Production & promotion of healthy planting materials and capacity building of farmers on best practices of large cardamom.Sensitization and mobilization of large cardamom growers for adoption of scientific large cardamom cultivation technologies & practices was done and mother block of *Varlangey* cultivar was developed the in the station.

Mera Gaon Mera Gaurav.Total 6 training programmes, 8 demonstrations and 15 awareness programmes covering 160 farmers were conducted. Improved technologies of IARI paddy varieties (P-1612), mustard (PM-28 & PM-31), seed of major vegetables (cabbage, cauliflower, tomato, chilli, radish, green peas, bottle gourd, bitter gourd etc) and growing rootstock of Darjeeling mandarin were promoted under the programme.

7.3.10.6 Regional Station, Amartara Cottage, Shimla

Front line demonstrations. Twelve front line demonstrations on wheat variety HS 562 and 10 FLD on barley varieties BHS 380 and BHS 400 were organized in different villages of Himachal Pradesh.

Field/farmer's day

- A Field day-cum-*Kissan Gosthi* on "Production Technology of Temperate Fruit Crops" was organized on January 17, 2019 at IARI, Horticulture Research Farm, Dhanda. Around 150 farmers/ orchardists participated.
- One day training-cum-*Kishan Gosthi* under HIMCOSTE on February 17, 2019 at Pipludhar, H.P. More than 70 farmers/orchadists have participated. The scientists delivered talks on temperate fruit cultivation, wheat and barley cultivation and distributed folders, pamphlet, etc.
- One day exposure visit of farmers from H.P. to ICAR-IARI Regional Station, Shimla on February 25, 2019. More than 20 farmers/orchadists participated. The scientists delivered talks on temperate fruit cultivation, wheat and barley cultivation and distributed folders, pamphlet, etc.
- Field day organized in Kinnaur district of Himachal Pradesh under TSP in collaboration with NBPGR, Phagli at Kalpa Block, Kinnaur district, H.P. w.e.f. November 19 to 20, 2018.Number of farmers participated: 200.
- Farmers day and training under MGMG on July 24, 2018 at Jabri, Dhami, H.P. More than 60 farmers/ orchadists participated. The scientists delivered talks on pomegranate, stone fruits and strawberry cultivation and distributed strawberry planting materials.
- *Kisan* seminar and training and *Kisan Gosthi* were conducted in association with Ambuja Cement Foundation, Darlaghat on March 27, 2019. More than 150 farmers participated.
- One day field day programmes on "Integrated Orchard Management of Apple Crop" were organized at Yangpa, Kalpa, Kothiand Roghi districts of H.P.
- A *kisan* field school was organized at Sirmour district of H.P. under HIMCOSTE on March 2, 2019 and popularized IARI Technologies.
- A farming system extension programme was organized at "Kokhru" village of district Mandi, H.P. on November 11, 2018.
- A farmers-scientists interaction was held on December 28, 2018 at Tikkri village of Himachal Pradesh for scientific cultivation of wheat & barley as well as strawberry and low chilling apple.

8. EMPOWERMENT OF WOMEN IN AGRICULTURE AND MAINSTREAMING OF GENDER ISSUES

8.1 STRENGTHENING AGRI-NUTRI LINKAGE FOR ENHANCING NUTRITIONAL SECURITY AND EMPOWERING FARM WOMEN OF INDIA: LEVERAGING AGRICULTURE FOR NUTRITION

Division of Agricultural Extension, ICAR-IARI in collaboration with UNDP initiated a Project entitled "Strengthening Agri-Nutri Linkage for Enhancing Nutritional Security and Empowering Farm Women of India: Leveraging Agriculture for Nutrition". The objective of the project was to empower the farm women to enhance their family income through nutri-preneurship and ensure nutritional security through agriculture. This project has reached three districts -Mewat, Sonipat and Jhajhar of Haryana state, over a period of 24 months (2017-2018).

A total number of 40 trainings of three days each (one batch- 50 farm women) have been conducted covering a total of 2,037 women trainees (belonged to 315 Self Help Groups) who were trained under this project. The training module varied from Pearl Millet (*bajra*), Value added products, Soy and Soy products, clean milk production and value addition, Mushroom production, Papaya production technology and value addition of fruits along with soft skills. Around120 *krishi sakhis* were identified under the project. They were selected to act as facilitators for further enterprise development and resolve conflicts issues to ensure smoother functioning of the enterprises. A pool of 1037 Nutripreneurs who have started nutri based enterprises have been emerged. A special emphasis was on strengthening linkages with financial institutions and market linkages. Professionals from marketing sector tackled the issues in selling of the prepared produce.

8.2 A NUTRITION LED EXTENSION MODEL OF COMMUNITY AGRI-NUTRI SECURITY CENTRE (CANSC) FOR NUTRITION SECURITY OF WOMEN

Community Agri-Nutri Security Centre (CANSC) is the core part of the project "A Nutrition led Extension Model of Community Agri-Nutri Security Centres (CANSCs) for Nutrition Security of Rural Women" funded by Department of Science and Technology. This project has been launched in two villages namely Mukari and Lehchoda in Baghpat district, where a group of 30 women from each project location has been formed for project interventions. One of the primary objective of the project is to bring value added nutri products like soynuts, pearlmillet pop, soymilk, multigrain cookies, beetroot mango bar, *etc.* to the village and to integrate these nutrition rich snacks into the diets of the individuals, especially infants, young children and women of reproductive age. From this perspective, the project adopted a community based food system approach in which these CANSCs have been set up in both the villages at public locations with small scale processing facilities comprising of spice coating pan, solar dryer and microwave oven to impart skill in minimal processing techniques to rural women. In these centres, rural women are trained in processing and making value added agri-nutri products using machineries, which makes clear the role of value added agri-nutri products in nutrition security. The centres are set up in remote rural areas, where many people are not able to access fresh, nutri rich prepared food. In the face of such state of rural areas, where a majority of individuals are obese and children malnourished, a set of complementary strategies are required to

Community Agri-Nutri Security Centre Activities

Trainees seeing videos on nutrtion

Trainees preparing soynuts

Processing machineries set up at the CANSC

eradicate these maladies. One way out is to boost the development of small scale enterprises on agriculture related to nutrition to increase the income as well as to ensure nutritional security. From this perspective, CANSC gives rural women the opportunity to get together to share the cost, planning and preparation of healthy and nutri rich value added foods. Moreover, it highlights how important it is for women to develop entrepreneurial skills to be financially independent and specialize in processing of locally available crops into nutri rich foods, which can become a strategic lever for dynamic growth in developing countries where rural entrepreneurship plays an important role. Besides, focusing on capacity building of rural women, these centres act as a forum to impart agri-nutri education, to conduct awareness programs, to stream videos on agri-nutrition, to organize rural women-scientists interface *etc.* It focuses on how social and behavioral change principles can guide these interventions and affect diets of rural people (women). Furthermore, it facilitates social learning, inter exchange of ideas and will help rural people to discover common interests that can lead to the formation of new groups focusing on a variety of social issues.

8.3 BIOTECHNOLOGY-LED SOCIO-ECONOMIC EMPOWERMENT OF FARM WOMEN

The project was implemented with lead centre at CATAT, IARI, New Delhi in collaboration with two Non-Government organizations viz. Deen Dayal Research Institute (DRI), Chitrakoot and PRDF, Gorakhpur, UP. This project was implemented in five villages in Tappal Block of District Aligarh having different agro ecological conditions. The project intervention resulted in both tangible and intangible gains. Nineteen SHGs of farm women were linked to lead bank of District Aligarh which helped them to save their group contributions and facilitated inter-loaning among group members. The demonstrations of improved varieties led to increase in yield i.e. wheat up to 12.19%, paddy up to 11.36%, mustard up to 14.47% and moong up to 18.75%. Biofertilizers applications like *Rhizobium* and PSB improved the soil fertility and crop productivity. At Rural Biotechnological Innovation and Application Unit (RBTIAU), facilities of bakery unit, information kiosk, drudgery reducing implements and farm publications were made available. Low cost polyhouse to raise the seedlings of vegetables crops;

cherry tomato, summer squash, tomato and capsicum enhanced the income of farmers through production and sale of off season vegetables at 2-4 times higher rate than the normal seasonal price. Baking technology motivated the farm women to adopt it as an enterprise. Introduction of kitchen garden saved their income, promoted the use of safe vegetable cultivation and improved nutritional security at household level.

8.4 EFFECTIVENESS OF SELF HELP GROUPS (SHGs) FOR GENDER EMPOWERMENT

Three women SHGs (each SHG made up of 30 women) from three different villages named Shikohpur, Harinagar and Khwaspur were given skill development training on processing of aonla and value addition of soybean and pearl-millet and supported with machines and equipments to start an enterprise under ARYA project. In the year 2018-19, each SHG started the work of making pickles of *aonla* and seasonal other fruits and vegetables, potato chips, soynut, *bajra ladoo*, soybean *ladoo, namkeen*, etc. and started selling their products in local market and *melas* in PUSA and Pragati Maidan.

8.5 VOCATIONAL AND FARM TRAININGS FOR TECHNOLOGICAL INTERVENTION

The KVK, Shikohpur is playing a vital role in empowering rural women of Gurugram district by organizing various need based self-employment and income generating activities and other extension programmes for creating the awareness about scientific farming and disseminating the technology in wide area. The important programmes and activities organized for rural women during the period April, 2018 to March, 2019 are as under :

- Vocational training courses for self-employment and income generation.
- Day long trainings in villages for updating the farm knowledge/skills.
- Exposure visit of rural women to agriculture fairs and exhibitions.
- Front line demonstration for disseminating improved farm technologies.
- Celebration of "Women in Agriculture Day" and "International Women's Day".
- T.V. talks, advisory services on phone, publication of literature on technical know-how on food processing and dairy management, *etc*.
- Formation of women Self Help Group in villages and motivating them to start their own enterprise and linking them to market.

8.6 WOMEN PARTICIPATION IN SEED PRODUCTION

Rural women are playing significant role in agricultural development. Women have proven that they can be good managers in any kind of activities. Twenty nine farm women during *Kharif* 2018 from different villages of Karnal district, Haryana were selected under seed village programme. They were given training on various aspects of quality seed production of Paddy *cvs.* PB 1121, PB 1509. Through active participation in the trainings, their level of knowledge for importance of quality seed has increased.

The details of the women SHGs and their entrepreneurial work under ARYA project

Name of SHG	Village	No. of women	Products prepared	Net income (2018-19)
NaiPahal SHG	Shikohpur	10	Soynut, pickle candy, powder of *aonla* and pickles of seasonal fruits and vegetables, potato chips, rice papad, etc.	2.4 lakhs
Naya Din SHG	Harinagar	10	Soynut, pickle candy, powder, jam, chutney of *aonla*, guava and pickles of seasonal fruits and vegetables	1.8 lakhs
Nari Shakti SHG	Khwaspur	10	Soynut, pickle candy, powder of *aonla* and pickles of seasonal fruits and vegetables	1.5 lakhs

Activity wise participation of rural women during 2018-19

S. No.	Name of activity	Duration	No. of programmes/ activity	No. of beneficiaries
A.	Vocational trainings			
1.	Value addition	21 days	02	49
2.	Dress designing and tailoring	2 months	02	40
3.	Participation in other vocational trainings	21 days	01	01
	Total	--	05	90
B.	Agriculture extension and farm advisory			
1.	Day long trainings (on/off campus)	1 day	27	236
	Total		27	236
	Grand total (A+B)		**32**	**326**

9. POST GRADUATE EDUCATION AND INFORMATION MANAGEMENT

The Indian Agricultural Research Institute (IARI) has a rich legacy of excellence of more than 114 years in research, teaching and extension. The Post Graduate School of IARI continues to provide national and international leadership in Human Resource Development by awarding Post Graduate degrees in 26 disciplines. So far, 4148 M.Sc., 69 M.Tech. and 4885 Ph.D. students have been awarded degrees including 399 international students. The Institute has received accreditation from the National Assessment and Accreditation Council of UGC (3.51/4.00, A+; 2016-2021) as well as National Agricultural Education Accreditation Board of ICAR (2015-2020). Based on the National Institutional Ranking Framework (NIRF) India Rankings 2018 by the Ministry of Human Resource Development (MHRD), IARI has been awarded the status of 'Special Mention Institution'.

9.1 POST GRADUATE EDUCATION

9.1.1 Admission during the Academic Session 2018-2019

The PG School continues to attract students seeking admission to 26 disciplines in all five streams of admission, namely, Open competition, Faculty up-gradation, ICAR in-service nominees, Departmental candidates and Foreign students. The admissions to the Ph.D. programme are based on the national level entrance examination conducted in different parts of the country, followed by an interview and academic track record. While the admissions to the M.Sc. programme are based on an 'All-India Entrance Test' conducted by the Education Division of ICAR. The foreign students are admitted through DARE and are exempted from the written test and interview. During the academic year 2018-19, 155 students (including 05 from physically handicapped and 01 from under privileged states categories) were admitted to M.Sc./M.Tech and 214 students (including 05 Physically Challenged, 09 ICAR in-service, 04 under faculty upgradation scheme and 02 under departmental scientific scheme and 05 under CWSF) to Ph.D. courses. For PG outreach programme at sister institutes, 14 students for CIAE, Bhopal were admitted. In addition, 12 international students (04 M.Sc. & 08 Ph.D.) from 09 foreign countries were admitted. At present, the total number of students on roll is 1141 (303 M.Sc., 18 M.Tech. and 820 Ph.D.), which include 46 international students (20 M.Sc. & 26 Ph.D.) from 16 foreign countries.

9.1.2 Convocation

The 57th Convocation of the Post Graduate School of the Indian Agricultural Research Institute (IARI) was held on February 8, 2019. Hon'ble Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh was the Chief Guest. Dr. T. Mohapatra, Secretary, DARE & Director-General, ICAR, presided over the function. Former Director Generals of ICAR and former Directors and Deans of IARI also graced the occasion. The Chief Guest presented the medals and awards to the students and faculty, while the Chairman presented the degrees to the students. The Chief Guest released two IARI varieties, one each in rice (var. Pusa Sambha 1850) for Chhattisgarh and Odisha and Maize hybrid (Pusa Super Sweet Corn 1) for North Hills Zone, North Western and North Eastern Plains Zones and Plains Zone. In his convocation address, the Chief Guest highlighted the research, educational and extension activities of IARI; new technologies developed by IARI and emphasized on crop diversification, preventing the soil erosion, integrated farming system, etc. Dr. A.K. Singh, DDG (Agricultural Extension), ICAR

and Director, IARI (Additional charge) presented his report on the significant research achievements of the Institute during 2018-2019, while Dr. Rashmi Aggarwal, Dean & Joint Director (Education), IARI presented the Dean's report.

During this Convocation, 239 candidates (123 M.Sc., 22 M.Tech. and 94 Ph.D.) were awarded degrees, including 08 (05 M.Sc./M.Tech. and 03 Ph.D.) international students. One student each in M.Sc. (Mr. Bishwaranjan Behera, Discipline of Agronomy) and Ph.D. (Ms. Jyoti Nishad, Discipline of Post Harvest Technology) were awarded the Best Student of the Year Awards. Five students each in M.Sc. and Ph.D. received IARI Merit Medals. Dr. A.R. Rao, Professor of Bioinformatics received the Best Teacher Award-2018 for his achievements in academics. The twenty-fifth Hooker Award for the biennium 2016-17 was awarded to Dr. Ravish Chatrath, Principal Scientist, ICAR-Indian Institute of Wheat and Barley Research, Karnal for his outstanding research contributions in wheat breeding. The seventeenth Dr. B.P. Pal Medal for the year 2018 was awarded to Dr. Dharmendra Singh, Principal Scientist, Division of Genetics, IARI, New Delhi for his outstanding research contributions towards mungbeen and lentil breeding. The nineteenth Shri Hari Krishna Shastri Memorial Award for the year 2018 was awarded to Dr. Shelly Praveen, Head, Division of Biochemistry, IARI, New Delhi for her outstanding contribution in fundamental and applied research in plant virology. The seventh Rao Bahadur B. Viswanath Award for the biennium 2016-17 was awarded to Dr. M.S. Chauhan, Director, ICAR-Central Institute for Research on Goats, Mathura for his outstanding research contributions in the field of animal biotechnology. Besides, the post graduate students of the Institute showcased their talents in the cultural programme organized in the evening of Convocation Day.

9.1.3 Special Lectures

Dr. B.P. Pal Memorial Lecture. The 25th Dr. B.P. Pal Memorial Lecture was delivered by the Dr. Trilochan Mohapatra, Secretary, DARE and DG, ICAR, New Delhi on June 19, 2018 on the topic "Our Agricultural Future". Dr. A.K. Srivastava, Chairman, ASRB, New Delhi, presided over the function.

Teachers' Day Lecture. The Teachers' Day Lecture-2018 was delivered on September 5, 2018 by Prof. Sankar Kumar Pal, Distinguished Scientist and Former Director, Indian Statistical Institute, Centre for Soft Computing Research, Kolkata on "Machine Intelligence and Granular Mining: Uncertainty Modeling and Agricultural Analytics". Dr. A.K. Singh, Director, IARI, New Delhi presided over the function.

Lal Bahadur Shastri Memorial Lecture. The 49th Lal Bahadur Shastri Memorial Lecture was delivered by Dr. Renu Swarup, Secretary, Department of

A Ph.D student receiving IARI Best Student of the Year Award from Hon'ble Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh during the 57th convocation

Biotechnology, Govt. of India, on February 7, 2019 on the topic "The New Technology Revolution: Opportunities for Improved Agriculture". Dr. Panjab Singh, President, NAAS, New Delhi presided over the function.

Dr. Renu Swarup delivering 49th Lal Bahadur Shastri Memorial Lecture

Foundation Day Lecture. The 3rd IARI Foundation Day Lecture was delivered by Dr. R.S. Paroda, Chairman, TAAS, New Delhi on "Innovation Led Agricultural Growth: Challenges and Opportunities" on April 1, 2018. Dr. Trilochan Mohapatra, Secretary (DARE) & Director General (ICAR), Government of India, New Delhi presided over the function.

9.1.4 International Exposure

The excellence of IARI is recognized internationally. IARI is playing key role in establishing Afghan National University of Agricultural Sciences and Technology (ANASTU), Kandahar, Afghanistan and Advanced Centre for Agricultural Research and Education (ACARE) at Yezin Agricultural University, Myanmar in collaboration with Ministry of External Affairs (MEA), Government of India. Besides organizing training programmes for the Faculty and Technicians from Afghanistan, the second batch of 18 students of M.Sc. Agronomy from ANASTU were trained at IARI, New Delhi. Since this is a unique programme, a "Graduation Ceremony" of ANASTU students at IARI in collaboration with Ministry of External Affairs (MEA) was held on September 13, 2018. Further, the 3rd Batch of 20 M.Sc. Agronomy students of the Afghanistan National Agricultural Sciences and Technology University (ANASTU) arrived in December 2018 for taking course work in Agronomy, Soil Sciences, Agricultural Statistics and English Language at IARI for a period of eight-month teaching programme. Under ACARE programme, 26 courses of the three newly introduced postgraduate programmes (Agricultural Extension Education, Molecular Biology & Biotechnology and Food Engineering & Technology) successfully conducted for the students admitted during the Academic session 2017-2018. Hon'ble President of India, Shri Ram Nath Kovind dedicated Advanced Centre for Agricultural Research and Education (ACARE) to the people of Myanmar on December12, 2018.

9.1.5 Addressing Plagiarism

To maintain academic integrity, all the documents in the form of M.Sc./M.Tech. and Ph.D. thesis and research paper manuscripts prior to submission were subjected to web based software 'Turnitin' and similarity reports were generated.

9.2 LIBRARY SERVICES AND E-GRANTH

Prof. M.S. Swaminathan Library is one of the largest and the finest agro biological libraries in South East Asia housing over four lakh publications including books/monographs, journals, reports, bulletins, post graduate theses and other reference materials, etc. The library has on its role 2500 registered members. It also serves about 4810 visitors every year including about 600 to 650 students who visited the library for educational tour. Apart from registered members, the library served approximately 85 to 100 users per day coming from different agricultural universities /ICAR institutes/SAUs who consults approximately 1500 to 1800 documents every day. The Library provides reference service, bibliographical services, documentation services, online international abstracting database searches, reprography services, etc.

9.2.1 Acquisition Programme

9.2.1.1 Books

During the period under report, the library received 1654 publications which includes 106 in Hindi, 1104 in English and 142 Advances & Annual Review. The Library also acquired 77 gift publications, 225 theses and uploaded 350 theses in *Krishikosh*.

9.2.1.2 Serials

The Library received 528 journals/serials through subscription, gifts and exchanges. It subscribed to 73 foreign journals, 117 Indian journals; and received 62 titles as gifts. Two hundred ninety three annual scientific/technical reports/bulletins and 250 newsletters of different institutions were received in the Library during the reported period.

9.2.2 Document Processing

In all, 1498 documents consisting of 910 books, 333 post-graduate IARI theses, 44 bulletins and 111 Hindi books were processed (classification and cataloguing).

9.2.3 Resource Management

9.2.3.1 Reference, circulation and stack maintenance

Apart from about 2500 registered members, the Library served everyday approximately 85 to 100 users, who come from different agricultural universities/ICAR Institutes consulted about 1500 to 1800 documents. During the reported period, 405 new members (28 staff and 377 students) were registered. During the period under report, 1033 publications were issued and 1062 publications returned. Sixteen documents were issued under Inter Library Loan System to various institutions. About 400 no dues certificates were issued.

9.2.4 Document Delivery Service

Resource Management Section of Library is providing a Document Delivery Services to different users of Agricultural field through CeRA (Total number of hits 26,624, Total login session 1,610, Searches 11,371, Full Text and Abstract views 5,547). Total number of 80 request received through CeRA and uploaded requested articles in J-Gate.

9.2.5 Workshop

The Library organized a workshop on "Koha Library Management Software (An Open Source Library Management Software)" during June 20-21, 2018. Dr. N.S. Rathore, DDG (Education), ICAR, who was the Chief Guest, inaugurated the workshop. Dr. Rathore also inaugurated the RFID System.

Inaguration of workshop on "Koha Library Management Software" by Dr. N.S. Rathore, DDG (Education), ICAR

9.2.6 E-Language Lab

With the help of library strengthening program, a Language lab was established with a seating capacity of about 50 participants to facilitate language classes for foreign students by using 30 computers with internet and other modern facilities like, interactive board, visualizes, interactive panel, head phones, etc. A two hour regular class of English language for IARI students are being conducted every day in the evening. The language lab is also used for conducting trainings, summer and winter school courses of different Divisions and Directorate for the benefit of scientists/ technical staff.

9.2.7 *Krishikosh*

Krishikosh provides ready software platform to implement all aspects of the open access policy, similar to 'Cloud Service' for individual institution's self-

managed repository with central integration. These two products of E-Granth (i) *Krishikosh* and (ii) IDEAL are used by all SAUs/DUs/CUs & ICAR Institutes. Up to March 2019, the library uploaded 4872 theses.

9.3 AGRICULTURAL KNOWLEDGE MANAGEMENT UNIT

Currently, besides Bioinformatics activities, the Agricultural Knowledge Management Unit (AKMU) is entrusted with responsibility of developing ICT in agricultural research, maintaining the Institute's network, the website and the web server administration. During the reported period, the unit developed (i) Weather based prediction system for pests, (ii) Developed fuzzy regression models for forecasting rice yield in Kanpur district and compared with the weather indices-based regression model, (iii) Maintenance and updating Krishikosh – a Digital Repository for NARES, and (iv) Bioinformatics - DIC under BTISnet : (a) developed Web Application 'Wheat Informatics' which targets the end user to retrieve genomic and proteomic information and bioinformatics resources related to wheat and (b)developed miRule (Rule based micro RNA prediction Tool), predicts the presence and position of the mature miRNA.

10. PUBLICATIONS

An important mandate of the Institute is to develop an information system, add value to information and share the information nationally and internationally. Publications are an integral component of the information system. During the reported period, the Institute scientists brought out quality publications in the form of research papers in peer reviewed journals, books/ book chapters, popular articles, etc. both in English and Hindi. Apart from these publications, the Institute brought out several regular and *adhoc* technical publications both in English and Hindi. The details of these publications are given below:

10.1 PUBLICATIONS AT A GLANCE

1. Research/Symposia Papers		
a)	Research papers (With international impact factor or NAAS rating 6 and above) published in journals	655
b)	Symposia/conference papers	540
2. Books/Chapters in Books		
a)	Books	51
b)	Chapters in books	285
3. Popular Articles		318

10.2 IN-HOUSE PUBLICATIONS

10.2.1 Regular Publications (English)

- IARI Annual Report 2017-18 (ISSN: 0972-6136)
- IARI NEWS Quarterly (ISSN: 0972-6144) - 4 issues)
- IARI Current Events (Monthly)- 12 issues (Available only on IARI website)

10. 2.2 Technical Publication (English)

- Good Agricultural Practices for Doubling Farmer's Income and Enhanced Resource Use Efficiency (ISBN 978-93-83168-40-8)
- Good Agricultural Practices (GAPs) for Enhancing Resource - Use Efficiency and Farm Productivity (ISBN 978-93-83168-41-5)
- Crop Diversification for Resilience in Agriculture and Doubling Farmers Income (ISBN 978-93-83168-42-2)
- Assessment of IARI Varieties under National Extension Programme (ISBN 978-93-83168-44-6)
- Precision Crop and Resource Management(ISBN 978-93-83168-45-3)
- HCIO/ Checklist of Cercospora Species(ISBN 978-93-83168-47-7)
- Fundamentals of Communication (ISBN 978-93-83168-48-4)
- Communication Methods and Journalism (ISBN 978-93-83168-49-1)
- Advances in Biological Control of Plant Diseases (TB-ICN: 192/2018)
- Seed Production, Processing, Testing and Storage in Field and Vegetable Crops (TB-ICN1: 193/2018)
- Learning By Doing Exercises in Soil Fertility (TB-ICN: 194/2018)
- Genomics Assisted Pre-breeding in Vegetable Crops (TB-ICN: 195/2018)
- Nutritive Gains from Pearl Millet (TB-ICN: 196/2018)
- Innovative Approaches for Improvement of Perennial Horticultural Crops (TB-ICN: 197/2018)
- Technological Options and Extension Approaches for Climate Resilient Agriculture (TB-ICN: 198/2018)
- Ornamental Horticulture and Landscape Gardening (TB-ICN: 199/2018)

- Good Agricultural Practices for Quality Seed Production (TB-ICN: 200/2019)
- Ornamental Horticulture and Landscape Gardening Volume-II (TB-ICN: 201/2019)
- Mera Gaon Mera Gaurav-A Flagship Programme of ICAR: Status, Impact and Implications (TB-ICN: 202/2019)
- Hybrid Seed Production of Vegetable crops for Enhancing Productivity and Nutritional Security (TB-ICN: 203/2019)
- Seed Production and Quality Evaluation (TB-ICN: 204/2019)
- Technology Inventory on Innovative Integrated Crop Management Technology (TB-ICN: 205/2019)
- Synergising the Institutional Partnership for Enhanced Technology Outreach and Production System Efficiency: Experiences of Collaborative Extension Programme (TB-ICN: 206/2019)
- Handbook on Month-Wise Vegetable Gardening Practices (TB-ICN: 207/2019)
- Seed Production, Processing, Testing in Field and Vegetable crop (*Rabi)* (TB-ICN: 208/2019)
- POSHAN: Pearl millet Oriented Staple Healthy All inclusive Nutrition (TB-ICN: 209/2019)
- Management of Emerging Environmental Problems for Enhancing Agricultural Productivity (TB-ICN: 210/2019)
- Principles of Vegetable Breeding-VSC-502 (TB-ICN: 211/2019)
- Manual on Sampling Techniques for Soil, Water, Plant and Air (TB-ICN: 212/2019)
- Practical Manual on Floral Biology and Seed Quality Testing (TB-ICN: 213/2019)
- Participatory Methods for Technology Development and Transfer (TB-ICN: 214/2019)

10.2.3 नियमित प्रकाशन (हिन्दी)

- ❖ पूसा सुरभि (वार्षिक) (ISSN : 2348-2656)
- ❖ वार्षिक रिपोर्ट 2017–18 (ISSN : 0972-7299)
- ❖ पूसा समाचार (त्रैमासिक) (ISSN : 0972-7280)
- ❖ प्रसार दूत (त्रैमासिक)
- ❖ भा.कृ.अ.सं. सामयिकी (मासिक) (केवल संस्थान की वेबसाइट पर उपलब्ध)

10.2.4 तकनीकी प्रकाशन (हिन्दी)

- ग्रामीण महिलाओं के लिए बेकिंग तकनीक–प्रयोगात्मक पुस्तिका (ISBN 978-93-83168-37-8)
- टिकाऊ कृषि विकास हेतु उन्नत तकनीकियाँ (ISBN 978-93-83168-38-5)
- उच्च आय हेतु उन्नत कृषि प्रौद्योगिकियाँ (ISBN 978-93-83168-39-2)
- अध्येता एवं नवोन्मेषी किसान (ISBN 978-93-83168-43-9)
- पूसा उन्नत कृषि तकनीकी (ISBN 978-93-83168-46-0)
- मित्र कीट एवं उनकी पहचान (ICN:H-168/2018)
- गुणवत्ता बीज उत्पादन हेतु उचित कृषि क्रियाएं (ICN:H-169/2019)
- वार्षिक कृषि कार्य एवं उन्नत प्रौद्योगिकियां (ICN:H-170/2019)

11. IP MANAGEMENT, TECHNOLOGY COMMERCIALIZATION AND AGRIBUSINESS INCUBATION ACTIVITIES

The mission of the Zonal Technology Management and Business Planning and Development (ZTM & BPD) Unit is, *"Translating Research into Prosperity"* which is achieved by doing IP management, technology commercialization and fostering entrepreneurship through business incubation. During the reported period, the Unit has organized the following activities:

11.1. TECHNOLOGY COMMERCIALIZATION

During the financial year 2018-19, three new rice varieties, namely, PB 1718, PB 1728 and PB 1637 were licensed to eighteen, sixteen and four industry partners, respectively. Five vegetable varieties, namely, brinjal – Pusa Uttam, tomato-Pusa Gaurav, chilli – Pusa Jwala, cauliflower - Pusa Sharad, and sponge gourd- Pusa Sneha were licensed to one industry partner, and STFR Meter technology was licensed to one industry partner thus, generating a revenue of Rs. 39,50,000.00 (Rupees Thirty Nine Lakh Fifty Thousand Only). Also, Compost Inoculant Biofertilizer Technology was licensed to one industry partner generating a revenue of Rs.1,00,000.00 (Rupees One Lakh Only).

11.2 INTELLECTUAL PROPERTY RIGHTS

Six patents have been granted, one PPV&FR application has been filed and six trademarks have been registered. The details are as follows:

Patents granted				
S. No.	**Application number and grant number**	**Title**		**Date of grant**
1.	3459/DEL/2005 & 296712	Composition for early, profuse sporulation under solid state of the improvised isolate of *Trichoderma harzianum* and a process thereof		May 11, 2018
2.	419/DEL/2012 & 299749	Fusion gene construct for generation of cocktail antiserum for detection of potyvirus and cucumovirus		August 6, 2018
3.	1986/DEL/200 4 & 299908	Animal feed crusher		August 13, 2018
4.	3744/DEL/2012 & 300102	Amphiphilic polymers based slow release nano formulations of ß-Carotene and method of preparation thereof		August 20, 2018
5.	1042/Del/2014 &301187	Beneficiation of phosphate rock for the segregation of phosphorus containing heavy metal free minerals		September 9, 2018
6.	1983/DEL/2004 & 302775	Powered animal feed mixer		October 31, 2018
Plant variety protection filed				
S.No.	**Acknowledgement number**	**Denomination**	**Crop**	**Date of filing**
1.	REG/2018/692	HD 4728 (Pusa Malwi)	Wheat	September 14, 2018

Trademarks registered				
S. No.	Registration number	Trademark	Class(es)	Date of registration
1.	1981304	PUSA	1, 5, 7, 8, 29, 30, 31, 32	September 13, 2018
2.	1870426	IP Spectra: IP Facilitation Centre for Agro based MSME's	41	May 24, 2018
3.	1871306	IP Spectra	45	May 25, 2018
4.	1871813	IP Spectra: IP Facilitation Centre for Agro based MSME's	45	May 25, 2018
5.	1904151	IP Spectra: IP Facilitation Centre for Agro based MSME's	44	July 2, 2018
6.	1922145	IP Spectra	44	July 16, 2018

11.3 AGRIBUSINESS INCUBATION

A. SAMARTH 2019

'SAMARTH', has been launched as an Innovation cum Incubation Induction program that focuses on imparting best practices in innovation, incubation and entrepreneurship development of agri-incubators under 'Rashtriya Krishi Vikas Yojana' (RKVY-RAFTAAR). Under Samarth, the R-ABI's were facilitated with need-based infrastructure, knowledge based expertise, equipment and manpower, agri-incubation networks. The program also aimed to train manpower of HRD to boost capacity building of Agribusiness Incubators Managers.

Samarth Workshop. A 3-day Samarth workshop was organized for all 24 R-ABIs and other knowledge partners, namely, IARI, NIAM, MANAGE & AAU, hailing from DAC & FW and DARE departments of MoA & FW. The purpose of the workshop was to provide a holistic overview about the agribusiness incubation and start-up ecosystem in India. The event had overseen informative lectures from eminent speakers on the topics like: Roles & Mandates of an Incubator and its Planning & Management, Funding Landscape for Incubators & Financial Sustainability, Marketing Platforms & Others Marketing Opportunities for an Incubator, Stakeholder Mapping & Planning. The event was honoured by the presence of Ms. Chhavi Jha, Joint Secretary, Dept. of Agril. (RKVY), Govt. of India, as the Chief Guest . She talked about the goals and mandates of RKVY-RAFTAAR and how the incubators will function under the program to meet the target of incubating 500 agri-startups by the end of March 2020.

On a gracious culmination of the 3-day workshop, all R-ABIs participated in an enriching visit to JSS Noida & NIFTEM, Sonipat, Haryana, for a practical demonstration of their respective plant facilities and activities as incubators. The visit added to our mission towards RKVY-RAFTAAR success.

B. UPJA 2019

UPJA has been launched as an incubation & business acceleration program powered by RKVY-RAFTAAR, to promote innovation and agripreneurship of agri-startups that have passed the stage of minimum viable product (MVP) or have a ready prototype. The program is structured in two phases. Phase-I is an 8-week intensive "Residency- in-Incubation" and Phase-II is a "Business Acceleration & Funding Support". With the launch of the UPJA, Pusa Krishi received a total of 618 applications. Subsequently, 55 startups were evaluated by the committee of Industry experts. On February16, 30 Incubates were taken finally onboard. Presently, the cohort of these startups is observed from February 25 to April 25. Under the in-residency incubation program, incubates were facilitated with 78 one-on-

one and group mentoring sessions with Industry & Technical Experts on an extensive range of topics like; Sensor & data analysis in agriculture by Dr. R.N Sahoo, Agriculture landscape & opportunities in India by Dr. K.V. Prabhu (Chairperson, PPV& FRA), Introduction to IARI databases by Dr. Sudeep Marwah, Business modelling & competition mapping by Mr. Jayan Jha (CEO,Yantra), Market strategy & partnership by Dr. Kabir Kocchar, Marketing & road mapping by Mr. Erik Azulay, Distribution & supply chain management by Mr.Amit Kaul (Head, Milk Basket) and Product design & profiling by Mr Akash Bansal, Sneha Das & Aditya Bhatias (Founders, Orangerwood Labs).

Visit to Startup India, Vigyan Bhawan, New Delhi. Pusa Krishi Incubator organised an interactive session with the core management of 'Startup India' program at Vigyan Bhawan. The session talked about the objectives & concerns of agri-startups and how they can leverage the Startup India's activities and policies in overcoming the obstacles they are facing in their respective domains.

Visit to IARI facilities. One-day event for UPJA incubates was to gain knowledge about IARI's state-of-the-art facilities and technologies. The startups were also introduced to numerous R&D departments, to benefit from technical network of IARI for the next two months.

C. ARISE 2019

A launch pad for Agri-Startups, it is an initiative of Pusa Krishi Incubator powered by RKVY-RAFTAAR Scheme of MoA & FW. It is an unique incubation program designed specifically for early-stage agri-startups, with an aim to promote innovation and entrepreneurship. It is a two-phase Incubation program:

Phase 1: Idea to Product Prototype (Early-stage product development)

Phase 2: Commercial Launch & Funding Support for Selected Prototypes

The program has been launched, wherein Agri-startups with a 'Proof of concept' will get access to the incubation services of Pusa Krishi Incubator under an Eight-Week in-house residency program and selected startups will make a presentation to an expert committee of industry experts and professionals.

Program updates. To invite application for the program, Pusa Krishi Incubator has platforms for participant registrations, namely, official website of Pusa Krishi Incubator; Link: http://pusakrishi.iari.res.in/.

11.4 MoUs/AGREEMENTS SIGNED

A total of 31 MoUs/Agreements were signed for technologies for rice varieties viz., PB 1718, PB 1728, PB 1637, and 5 vegetable varieties viz.,brinjal – Pusa Uttam, tomato-Pusa Gaurav, chilli – Pusa Jwala, cauliflower - Pusa Sharad and sponge gourd-Pusa Sneha.

12. LINKAGES AND COLLABORATION

The Indian Agricultural Research Institute has linkages with various national and international institutes/organizations. At national level the Institute has close linkages with almost all agricultural sciences research institutes, centres, project directorates, coordinated projects as well as a few other selected institutes of the ICAR. Similar linkages exist for natural resource and socio-economic research institutes. Collaboration exists with almost all state agricultural universities (SAUs), selected conventional universities, several of the institutes of the CSIR and departments of Ministry of Science and Technology such as the Departments of Biotechnology, Space Research, Meteorology, and several other ministries/ departments/organizations/banks of the Government of India, besides some private organizations/banks.

IARI is the lead centre to coordinate the accelerated crop improvement programme for breeding rust resistant wheat varieties involving 10 centres, improving quality in maize which has enabled several SAUs and ICAR institutes to upgrade and update themselves with new tools and techniques. Under the NAIP and NFBSFARA, IARI is the lead centre to develop state of art facilities and infrastructure on food science and phonemics led sciences. The NICRA programme of ICAR performed significantly by developing new genotypes for minimizing the negative impact of climate change in wheat by recombining QTL combinations for drought and heat tolerance apart from documenting the mitigation and adaptation phenomena to changing climate in rice and wheat.

In lieu with the consortia mode of project of ICAR, the Institute has been encouraging linkages and professional collaborations among national institutes to work on major research focus on 'Molecular breeding' for improvement of tolerance to biotic and abiotic stress, yield and quality traits in crops, and 'Hybrid technology' for higher productivity in selected field and horticultural crops. The Institute also identified some of the priority research areas through other ICAR Consortium Research Platforms as Mega seed platform, Genomics platform, Diagnostic and Vaccines, Energy platform, Water platform, Conservation agriculture platform, Farm mechanization and Precision farming, etc.

On public-private partnership mode, the role and participation of private sector in agricultural services is increasing in different forms and capacities. This underlines the need for ensuring effective public-private partnerships and linkages besides improving the structural and operational efficiency and governance of the institutions to make them farmer-friendly. Keeping this in view, the Institute has planned to forge collaboration with some of the private seed sector having strong R&D base and expertise in seed quality enhancement as well as with the advanced centres of research in other countries.

The Institute has extended liaison with private companies for commercialization of its technologies. Many IARI technologies with private and public enterprises have been commercialized.

The linkage system is being studied for strengthening extension under IARI-NGO Partnership programme as well. Linkage with post offices as a new extension model was developed by IARI. The IARI has initiated an innovative extension programme for technology dissemination in partnership with selected NGOs for feasibility trials and promotion of agricultural technologies in their operational areas.

On Post Graduate Education, the Institute has recently approved a collaborative programme with University of Nebraska from USA for strengthening PG education. Efforts are being made to have such programmes with more universities on bilateral basis. The Institute is playing a very important role in institution building in other countries, namely, in the establishment of (i) Afghan National University of Agricultural Sciences and Technology, Afghanistan; and Advanced Centre for Agricultural Research and Education at Yezin Agricultural University, Myanmar. Further linkages extend towards establishment of IARI off-campus in selected ICAR Institutes. The classic examples are start of PhD programmes in IIHR, Bangalore and CIAE, Bhopal. The Institute is helping in the establishment of two IARI like Institution of excellence in Jharkhand and Assam. Students are being admitted to these institutions, namely, M.Sc. at IARI-Assam and IARI–Jharkhand in 5 disciplines viz., Agronomy, Genetics, Soil Science & Agricultural Chemistry, Vegetable Science and Water Science & Technology from the academic year 2015-16.

In the arena of training, the centres of excellence at IARI have established linkages with different national institutions through their regular training programmes and also through other programmes offered through Centre of Advanced Faculty Training.

At the international level, the Institute has close linkages with some of the CGIAR's international agricultural research centres (IARCs), viz., ICRISAT, CIMMYT, IRRI, and ICARDA. It also has linkages with other international organizations, viz., FAO, IAEA, USAID, UNDP, WMO, UNIDO and UNEP. Several bilateral research linkages involving developed and developing countries also exist. These include linkages with USDA, selected universities in USA, Canada, Australia, World Bank, Rockefeller Foundation, Bill & Melinda Gates Foundation, European Commission, JAICA, JIRC, JSPS, ACIAR, AVRDC (Taiwan), etc.

The number of externally funded projects in operation during the period from 1.4.2018 to 31.3.2019 is given below:

Name of funding agency	Number of projects
Within India Department of Biotechnology (DBT), Department of Science & Technology (DST), National Committee Plasticulture Application in Horticulture (NCPAH), Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Micro, Small & Medium Enterprises (MSME), Council of Scientific and Industrial Research (CSIR), Department of Agriculture and Cooperation (DAC), Indian Meteorological Department (IMD), Board of Research in Nuclear Sciences (BRNS), National Horticulture Board (NHB), Mission for Integrated Development of Horticulture (MIDH), Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), Space Application Centre (SAC),Defence Research and Development Organization (DRDO), Ministry of Human Resource and Development (MHRD),National Bank for Agriculture and Rural Development (NABARD), and Indian Council of Agricultural Research (ICAR)	169
Outside India Bill & Melinda Gates Foundation, US-National Academies of Sciences, United States-India Education Foundation (collaboration with Robert B. Daugherty Water for Food Institute (DWFI),University of Nebraska, USA), ICARDA South Asia & China Regional Program, and Beutsche Gesellchaft für Internationale Zusammenarbeit (GIZ) GmbH, Germany	7
Total	**176**

13. AWARDS AND RECOGNITIONS

- A 35-member multidiscipline team of wheat scientists of IARI awarded Nanaji Deshmukh ICAR Award for Outstanding Team Research in Agricultural and Allied Sciences 2015-18.
- Dr. A.K. Singh, Joint Director (Research) (Officiating) and Head, Division of Genetics was (i) awarded Shri Om Prakash Bhasin Award for Science and Technology 2017 (Agriculture and Allied Sciences), and (ii) elected NAAS Fellow.
- Dr. Rashmi Aggarwal, Dean and Joint Director (Education) (Officiating) and Head, Division of Plant Pathology was elected NAAS Fellow.
- Dr. D.K. Yadava, Head, Division of Seed Science and Technology was awarded Rafi Ahmad Kidwai Award 2017 for his contribution in Agricultural Sciences (Crop & Horticultural Sciences).
- Dr. B.S. Dwivedi, Head, Division of Soil Science and Agricultural Chemistry received (i) Rafi Ahmed Kidwai Award for his outstanding research in Agricultural Sciences, 2017 (Natural Resource Management & Agricultural Engineering), and (ii) elected Treasurer, NAAS.
- Dr. Shelly Praveen, Head, Division of Biochemistry was (i) elected NAAS Fellow, (ii) received Vasvik Award in the area of Agricultural Science & Technology, and (iii) Panjabrao Deshmukh outstanding Women Scientist Award.
- Dr. S.V. Sai Prasad, Head, IARI Regional Station, Indore was awarded BGRI Gene Stewardship Award 2018.
- Dr. V. K.Singh, Head, Division of Agronomy was elected NAAS Fellow.
- Dr. K. Annapurna, Head, Division of Microbiology, was selected for INSA Visiting Scientist-2018 to Germany.
- Dr. Alka Singh, Professor, Division of Agricultural economics received Bharat Ratna Dr. C. Subramaniam Award.
- Dr. T. K. Das, Professor, Division of Agronomy was elected NAAS Fellow.
- Dr. T.J. Purakayastha, Principal Scientist, Division of Soil Science and Agricultural Chemistry (i) received Bharat Ratna Dr. C. Subramaniam Award, and (ii) elected NAAS Fellow.
- Dr. Archana Sachdev, Principal Scientist, Division of Biochemistry was elected NAAS Fellow.
- Dr. Neeru Bhushan, Incharge & Principal Scientist, Zonal Technology Management & Business Planning and Development Unit, Indian Agricultural Research Institute, New Delhi was awarded Panjabrao Deshmukh Outstanding Women Scientist Award.
- Dr. Mukesh K. Dhillon, Principal Scientist, Division of Entomology was elected NAAS Fellow.
- Dr. Neera Singh, Principal Scientist, Division of Agricultural Chemicals was elected NAAS Fellow.
- Dr. Ranjeet R. Kumar, Senior Scientist, Division of Biochemistry was elected NASI Associateship.
- Dr. R.K.Ellur, Scientist, Division of Genetics received Jawaharlal Nehru Award of ICAR for his outstanding PG research in Crop Sciences.
- Dr. Brij Bihari Sharma, Scientist, Division of Vegetable Science received Jawaharlal Nehru Award of ICAR for outstanding PG research in Horticultural Sciences.
- Dr. Vijay Poonia, Scientist , Division of Agronomy was selected (i) NAAS Young Scientist Award, and (ii) Australian Govt. Endeavour Research Fellowship.

In addition, a large number of our scientists received various awards instituted by the professional societies and also recognized by their peer groups by electing / nominating to the various positions in the societies and governmental and inter-governmental committees.

14. BUDGET ESTIMATES

Statement showing Budget Estimates(B.E.) & Revised Estimates (R.E) for the year 2018-19 under Unified Budget

(Rs. in lakhs)

		B.E. 2018-19				R.E. 2018-19				
Sl. No.	**Head**	**Other than NEH & TSP**	**NEH**	**TSP**	**Total**	**Other than NEH & TSP**	**NEH**	**TSP**	**SCSP**	**Total**
1	2	3	4	5	**6**	7	8	9	10	**11**
	Grants for creation of Capital Assets (CAPITAL)									
1	Works									
	(A)Land									
	(B)Building									
	i. Office building	3250.00			**3250.00**	2462.95			186.00	**2648.95**
	ii. Residential building	800.00			**800.00**	1072.15				**1072.15**
	iii. Minors Works				**0.00**					**0.00**
2	Equipments	1000.00	1000.00	78.80	**2078.80**	603.10		66.20		**669.30**
3	Information & Technology									**0.00**
4	Library Books & Journal	250.00			**250.00**	85.45				**85.45**
5	Vehicles & Vessels	100.00			**100.00**					**0.00**
6	Livestock	1.42			**1.42**	1.43				**1.43**
7	Furniture & Fixtures	50.00			**50.00**	56.90			14.00	**70.90**
8	Others				**0.00**					
A	**Total- CAPITAL (Grants for creation of Capital Assets)**	**5451.42**	**1000.00**	**78.80**	**6530.22**	**4281.98**	**0.00**	**66.20**	**200.00**	**4548.18**
	Grants in Aid-Salaries (REVENUE)									
1	Establishment Expenses									
	(A)Salary									
	i. Establishment charges	19575.00			**19575.00**	23529.00				**23529.00**
	ii. Wages									**0.00**
	iii. Overtime allowance	2.75			**2.75**	2.75				**2.75**
	Total-Establishment Expenses(Grants in Aid-Salaries)	**19577.75**	**0.00**	**0.00**	**19577.75**	**23531.75**	**0.00**	**0.00**	**0.00**	**23531.75**
	Grants in Aid-General (REVENUE)									

1	**Pension & Other Retirement Benefits**	**19320.00**			**19320.00**	**19320.00**				**19320.00**
2	Traveling Allowance									
	A. Domestic/Transfer T.A.	172.87			**172.87**	173.00				**173.00**
	B. Foreign T.A									**0.00**
	Total-Traveling Allowance	**172.87**	**0.00**	**0.00**	**172.87**	**173.00**	**0.00**	**0.00**	**0.00**	**173.00**
3	Research & Opeational Expenses									
	A. Research Expenses	837.05		39.40	**876.45**	849.00			200.00	**1049.00**
	B. Operational Expenses	1533.90			**1533.90**	1216.00			200.00	**1416.00**
	Total.Res. & Operational Exp.	**2370.95**	**0.00**	**39.40**	**2410.35**	**2065.00**	**0.00**	**0.00**	**400.00**	**2465.00**
4	Administrative Expenses									
	A Infrastructure	3111.30			**3111.30**	3403.60				**3403.60**
	B Communication	58.30			**58.30**	24.00				**24.00**
	C Repair & Maintenance									**0.00**
	i. Equipments, Vehicles & Others	440.25			**440.25**	438.00				**438.00**
	ii. Office building	1400.00			**1400.00**	1583.70				**1583.70**
	iii. Residential building	900.00			**900.00**	1150.30				**1150.30**
	iv. Minor Works	400.00			**400.00**	246.25				**246.25**
	D Others (exc.TA)	1245.47			**1245.47**	1273.30				**1273.30**
	Total-Administrative Expenses	**7555.32**	**0.00**	**0.00**	**7555.32**	**8119.15**	**0.00**	**0.00**	**0.00**	**8119.15**
5	Miscellaneous Expenses									
	A HRD	74.80			**74.80**	58.50				**58.50**
	B Other Items(fellowships)	500.00			**500.00**	1036.70				**1036.70**
	C Publicity & Exhibitions	36.10			**36.10**	46.20				**46.20**
	D Guest House-Maintenance	124.43			**124.43**	118.30				**118.30**
	E Other Miscellaneous.	360.47	253.60		**614.07**	378.34	800.00	40.30		**1218.64**
	Total -Miscellaneous Expenses	**1095.80**	**253.60**	**0.00**	**1349.40**	**1638.04**	**800.00**	**40.30**	**0.00**	**2478.34**
	Total Grants in Aid-General	**30514.94**	**253.60**	**39.40**	**30807.94**	**31315.19**	**800.00**	**40.30**	**400.00**	**32555.49**
B	**Total Revenue (Grants in Aid-Salaries + Grants in Aid-General)**	**50092.69**	**253.60**	**39.40**	**50385.69**	**54846.94**	**800.00**	**40.30**	**400.00**	**56087.24**
	TOTAL (CAPITAL + REVENUE)	**55544.11**	**1253.60**	**118.20**	**56915.91**	**59128.92**	**800.00**	**106.50**	**600.00**	**60635.42**
	(C) Loan & Advances									
	GRAND TOTAL	**55544.11**	**1253.60**	**118.20**	**56915.91**	**59128.92**	**800.00**	**106.50**	**600.00**	**60635.42**

15. STAFF POSITION

(As on 31.03.2019)

	Category	No. of posts	
		Sanctioned	**Filled**
A.	**SCIENTIFIC STAFF**		
1)	Research Management Personnel	06	01
2)	Principal Scientist	65	33
3)	Senior Scientist/Scientist (S.G.)	170	122
4)	Scientist	337	341
	Total	**578**	**497**
B.	**TECHNICAL STAFF**		
1)	Category III	14	09
2)	Category II	277	149
3)	Category I	332	258
	Total	**623**	**416**
C.	**ADMINISTRATIVE STAFF**		
1)	Group A	18	15
2)	Group B	243	207
3)	Group C	162	112
	Total	**423**	**334**
D.	**SKILLED SUPPORT STAFF**	**1012**	**704**

16. POLICY DECISIONS AND ACTIVITIES UNDERTAKEN FOR THE BENEFIT OF DIFFERENTLY ABLED PERSONS

16.1 POLICY DECISIONS AND ACTIVITIES UNDERTAKEN FOR THE BENEFIT OF DIFFERENTLY ABLED PERSONS

The decisions and activities undertaken for the benefit of the differently abled persons are as follows:

- The benefits to the differently abled candidates in service matter as per instructions of ICAR/DOPT. Govt. of India as the case may be are followed.
- Three per cent of the total number of seats in each scheme of admission open to Indian nationals are reserved for differently abled candidates subject to their being otherwise suitable as per the norms of ICAR/Govt. of India. During the year 2018-19, 10 physically challenged students (05 M.Sc./M.Tech and 05 Ph.D.) were admitted against the reserved seats for differently abled candidates. However, in the event of there being no eligible suitable differently abled candidates in the earmarked discipline, to fill up the mentioned number of seats, such unfilled seats shall be transferred to other disciplines, where eligible suitable differently abled candidates are available for filling these seats.

17. OFFICIAL LANGUAGE (*RAJ BHASHA*) IMPLEMENTATION

According to Article 343 of the Constitution, Hindi shall be the Official Language (OL) of the Union Government. To implement the objectives in letter and spirit, IARI is making consistent progress in the use of OL in agricultural research, education, extension as well as in administration.

17.1 OFFICIAL LANGUAGE IMPLEMENTATION COMMITTEE

An Official Language Implementation Committee (OLIC) was constituted by the institute under the chairmanship of Director and the Committee ensures compliance of policy and rules of official language Act 1963 and O.L. rules of 1976. All the Joint Directors, Head of Divisions and Comptroller are ex-officio members of OLIC and Deputy Director (OL) is its member-secretary. During the period under report, the meeting of this Committee was organized regularly in each quarter and necessary suggestions and instructions were given for promoting the use of Hindi in various official/ research activities and the effective implementation of Official Language. To ensure follow up action on the decisions taken in these meetings, sub-committees were also constituted in different Divisions, Regional Stations and the Directorate.

17.1.1 Inspection of Pregressive Use of Official Language

As per the recommendations of the OLIC and to achieve the targets fixed in the annual program of the Department of Official Language, Ministry of Home Affairs, Govt. of India, an OL Inspection Committee was constituted under the chairmanship of Dr. Indramani, Head, Division of Agricultural Engineering. The Committee inspected the progressive use of OL in all the Divisions, Units and sections of the Directorate. The committee gave valuable suggestions for making the desired progress of OL implementation in the concerned Division/Section/Centre, etc. and submitted inspection reports.

17.2 AWARDS AND HONOURS

- The Institute was awarded the Second Prize for doing maximum writing work in Hindi for the year 2017-18 under the ICAR *Rajrishi Tondon Rajbhasha Puraskar Yojna*
- The Institute was also awarded the First Prize for its Rajbhasha patrika *Pusa Surbhi* under the ICAR *Ganesh Shankar Vidyarthi Puraskar Yojna* for the year 2017-18.
- IARI was awarded the first prize for implementation of *Rajbhasha* policy in the institute and consolation prize to the institute's Rajbhasha patrika *Pusa Surbhi* by NARAKAS, North Delhi.

17.3 AWARD SCHEMES/COMPETITIONS

During the year under report many competitions/ award schemes were also initiated to motivate the employees of the institute to do their maximum work in Hindi. A large number of officers and employees of different categories of staff participated in these activities. The following activities were organized:

17.3.1 Award Scheme for Doing Maximum Official Work in Hindi

This award scheme of the Department of Official Language, Ministry of Home Affairs, Govt. of India was implemented as per the directives of the Department and 6 employees of the institute were given cash awards for doing their maximum official work in Hindi in the whole year.

17.3.2 *Hindi Vyavahar Pratiyogita*

Hindi Vyavahar Pratiyogita were organized amongst the different Divisions and Sections of Directorate separately and two Divisions and Sections each were awarded shield for doing maximum work in Hindi during the whole year. In the period under report, the Division of Food Science and Post Harvest Technology and Division of Agricultural Chemicals amongst the divisions, and CATAT and FOSU amongst the sections/ units were given these shields.

Professor R.B. Singh, the chief guest were awarded shield to the staff of Division of Food Science & Post Harvest Technology during Hindi Annual Prize Distribution Function

17.3.3 Awards for Popular Science Writing in Different Journals

A competition for Popular Science Writing was organized for scientists/technical officers of the institute, and winners were awarded first, second and third prizes for their published articles in different journals.

17.3.4 *Pusa Vishisht Hindi Puravakta Puraskar*

Pusa Vishisht Hindi Pravakta Puraskar was given jointly to two scientists for their outstanding lectures in different training programs. Evaluation was done on the basis of recommendations of course coordinator and feedback of the trainees. The *Puraskar* carries a cash prize of Rs. 10,000/- and a certificate.

17.3.5 Power Point Presentation in Hindi

To promote science writing in Hindi, a Power Point Presentation Competition was also organized on September 28, 2018 on the topic *Jaivik Banam Rasainik Krishi* for scientists and technical officials of the institute, The Cash Awards of Rs. 10000/-, 7000/, 5000/-, 3000/- (two), were given to the successful participants.

17.4 *HINDI CHETNA MAAS*

The institute celebrated *Hindi Chetna Maas* from September 1 to 30, 2018. Dr. Indramani, Head, Division of Agricultural Engineering and co-chairman of the Institute Official Language Inspection Committee inaugurated *Hindi Chetna Maas* on September 1, 2018. On this occasion 'Hindi Essay Writing' competition was organized. In order to encourage the officials/ employees to do their official work in Hindi, various competitions such as Hindi noting and drafting, Hindi poem recitation, translation, quiz, debate, dictation, Hindi typing and general knowledge competition (only for the skilled supporting staff) of the institute were organized. A total of 9 competitions were organized. Employees from all the categories of staff of the institute participated in these competitions enthusiastically. Hindi Week/Hindi Day were also celebrated in different divisions and regional stations of the institute during the *Hindi Chetna Maas*. Many competitions were organized and participants given prizes.

17.5 HINDI ANNUAL PRIZE DISTRIBUTION FUNCTION

The Hindi Annual Prize Distribution Function was organized at Dr. B.P. Pal Auditorium, IARI on December 19, 2018. Professor R.B. Singh, former Director, IARI was the chief guest of the function. Dr. A.K. Singh, DDG (Agricultural Extension), ICAR and Director, IARI (additional charge) presided over the function. Dr. A.K. Singh, Joint Director (Research), IARI presented the welcome address. Shri Keshav Dev, Deputy Director (Official Language) presented

the *Rajbhasha* progress report of the year. In his speech, Professor R.B. Singh appreciated the progress of the official language in the institute. The Chief Guest also released the institute annual *Rajbhasha* patrika *Pusa Surabhi* and gave away the prizes to the winners of different competitions organized during the year and *Hindi Chetna Maas*. The President of the function, Dr. A.K. Singh presented the chief guest a memento and shawl. A 'Kavi Sammelan' and a 'Nukkad Natak' were also organized on this occasion, which brought cheers and smiles to the audience.

Professor R.B. Singh, the chief guest (second from right) releasing the the institute annual *Rajbhasha* patrika *Pusa Surabhi* on the occasion of Hindi Annual Prize Distribution Function

18. TRAINING AND CAPACITY BUILDING

18.1 TRAINING PROGRAMMES

The Institute organizes several national and international short-term training courses (regular, *adhoc* and individual) and refresher courses in specialized areas for the scientists of NAREES under the programmes of "Centres of Excellence" and "Centres of Advanced Studies". In addition, some special training courses were also organized for the benefit of professionals, farmers and extension workers.

Important training programmes organized

Name of the training programme	Dates/Month	Number of trainees
Division of Agronomy		
ICAR sponsored summer school on "Enhancing Resource- use Efficiency and Profitability in Organic Farming"	August 4–24, 2018	22
ICAR sponsored winter school on 'GAPs for Doubling Farmer's Income and Enhanced Resource- use Efficiency'	December 11-31, 2018	24
"Good Agricultural Practices (GAPs) for Enhancing Resource-use Efficiency and Farm Productivity".	January 2–11, 2019	20
ICAR sponsored short course on "Layout and Maintenance of Field Experiments and Recording Observations"	January 14-23, 2019	25
Crop Diversification for Resilience in Agriculture and Doubling Farmers Income	January 25–February 3, 2019	22
Division of Agricultural Engineering		
Training Course on Hydroponics	November 15-17, 2018	11
Division of Agricultural Economics		
Emerging Issues in Markets, Institutions and Resource Use Planning for Sustainable Agriculture	July 12, 2018 - August 1, 2018	15
Division of Agricultural Extension		
CAFT training on Extension Led Nutritional Security	September 4-24, 2018	21
ICAR sponsored training on "Enhancing Personal Effectiveness at Workplace"	October 8-13, 2018	21
ICAR winter School on "Extension Approaches for Integrated Technological Options and Institutional Arrangements for Doubling Farmers' Income"	January 4- 24, 2019	21
Capacity Building of Farmers for Climate Change Adaptation and Enhancing Income	March 29- 30, 2019	41
Agricultural Knowledge Management Unit		
Training cum Sensitization Workshop on "Krishikosh Repository – a Tool for Strengthening Agricultural Knowledge" under E-Granth project funded by ICAR at Dr. Y. S. Parmar University of Horticulture & Forestry, Solan, Himachal Pradesh.	October 30, 2018	250

Training cum Sensitization Workshop on "Krishikosh Repository for Strengthening Agricultural Knowledge in NARES" at Govind Ballabh Pant University of Agriculture and Technology, Udham Singh Nagar, Pantnagar, Uttarakhand.	December 17, 2018	135
Two days Training program on "Strengthening of Digital Library in National Agricultural Research and Education System using KOHA Platform" at PAU, Ludhiana	March 18-19, 2019	24
Three days workshop cum training on "Bioinformatics Techniques in Biological Data Mining "	March 25-27, 2019	30
Division of Biochemistry		
Training on "Biochemistry of Food Crops: from Omics to Nutrient Analysis "	September 25- October 15, 2018	24
Centre for Environment Science and Climate Resilient Agriculture		
Training workshop on "Advances in Simulation Modelling and Climate Change Research towards Knowledge Based Agriculture" for ICAR- scientists	November 13 – December 3, 2018	31
Training on "Management of Emerging Environment Problem for Enhancing Agriculture Productivity"	March 25 - April 1 2019	20
Division of Entomology		
One Day Hands on Training Programme on Beekeeping	March 5, 2019	05
Division of Floriculture & Landscaping		
Empowerment of Rural Women through Value Addition in Flower Crops in Baghpat district	June 25--27, 2018	60
Seven-day training programme (1st batch) on "Ornamental Horticulture & Landscape Gardening" for section officers (Horticulture) of DDA	December 24-30, 2018	40
Seven-day training programme (2nd batch) on "Ornamental Horticulture & Landscape Gardening" for section officers (Horticulture) of DDA	February 1-7, 2019	40
Training cum Exposure of Gardener's from Jammu on "Skill Development in Floriculture & Value addition"	February 14-18, 2019	20
Division of Microbiology		
Hands on Training on "*Spirulina* Cultivation Technology" for progressive farmers	September 25-27, 2018	35
Spirulina Cultivation and Processing for Advancement of Skills amongst Entrepreneurs	November 26-30, 2018	15
Division of Plant Physiology		
ICAR Sponsored Short Course on "Phenomics, the Next Generation Phenotyping (NGP), the Trait Dissection and Crop Improvement"	October 22-31, 2018	24
ICAR Sponsored Short Course on "Non-Destructive High Throughput Phenotyping for Gene Discovery and Development of Climate Resilient Crops"	March 14-23, 2019	18
Division of Seed Science and Technology		
Five- day training to NSC officials on "Seed Production, Processing, Testing and Storage in Field and Vegetable Crops (*Kharif)*"	May 21-25, 2018	25
A two-week Ministry of Rural Development, Govt. of India and AARDO sponsored capacity building programme on "Seed Production and Quality Evaluation"	February 12-25, 2019	10

Five -day training to NSC officials on "Seed Production, Processing, Testing and Storage in Field and Vegetable crops *(Rabi)*"	March 12-16, 2019	25
Division of Soil Science and Agricultural Chemistry		
15th Advanced Level Training on Soil Testing, Plant Analysis and Water Quality Assessment	August 07-27, 2018	11
Division of Vegetable Science		
Genomics Assisted Pre-breeding in Vegetable Crops	June 25– July 04, 2018	19
Hybrid Seed Production of Vegetable Crops for Enhancing Productivity and Nutritional Security	February 12-19, 2019	20
Water Technology Centre		
National workshop for imparting training on "Application of Spatial Data Infrastructure for Irrigation Management"	July 25-27, 2018	40
Hi Tech Farming and Water Management	September 12-14 ,2018	28
Model training course sponsored by Directorate of Extension, Ministry of Agriculture and Farmers Welfare, Govt. of India, on "Redesigning Water Conservation and Management Measure in Building Resilience in Farm Productivity"	October 8-15, 2018	17
Different Aspects and Components of Micro Irrigation Technologies	October 22-23, 2018	31
Installation and Operations of Micro Irrigation System	October 29-31, 2018 December 20-22, 2018	25 26
Bilateral workshop on "Building an Operational Composite Drought Monitoring Index (CDI) for India" at NASC, New Delhi	January 22-23, 2019	150
Awareness Programme on Precision Farming Technologies for Farmers from Different States and Students from ICAR Institutions / Universities		1214
Seed Production Unit		
Sabzi Beej Utpadan Ke Dwara Krishakoh Ki Amdani Badhana	January 21, 2019	48
Beej Utpadan- Amdani Badhane ke Vyavsayik Ayam	February 12, 2019	42
Regional Station, Indore		
One day short training for farmers on "Wheat and Wheat Seed Production Technology"	September 29, 2018	80
Regional Station, Pusa, Bihar		
Seed Production of Major *Rabi* Crops, Processing and Storage Techniques	March 15-20, 2019	30
Regional Station, Karnal		
Three Trainings on Different Aspects of Quality Seed Production under Seed Village Programme for Farmers	*Kharif* 2018	100
Three-day farmers training on "Good Agricultural Practices for Quality Seed Production"	March 6-8, 2019	20
Regional Station, Katrain		
ICAR sponsored 21- day Summer School on "Breeding Strategies and Seed Production Techniques of Temperate and Exotic Vegetables under Changing Climatic Conditions"	June 1-21, 2018	20
Two-day farmers training on "Off-season Vegetables and Flower Nursery Production"	December 27-28, 2018	20
Eight-day model training course on "Advances in Vegetable and Flower Supply Chain Management for Livelihood Security"	March 12-19, 2019	12

Regional Station, Kalimpong		
Model training on "Capacity Building of Extension Personnel on Advance Organic Technologies & its Promotion through Innovative Extension Approaches"	October 22-29, 2018	28
Regional Station, Shimla		
Seven Farmers' Trainings	July 24, 2018 at Jabri& Dhami; September 20, 2018, January 17 & 22, 2019 at Research Farm, Dhanda; November 2, 2018 & March 27, 2019 at Darlaghat; and March 25-27, 2019 at three different places viz., Bilaspur, Mandi and Kullu districts of H.P.	670
ZTM&BPD Unit		
Samarth	February 11 – 13, 2019	28
UPJA	February 25- April 25, 2019	30

18.1.1 Training Programmes Organized by the Institute's Centre for Agricultural Technology Assessment and Transfer (CATAT)

In all, 218 on-campus training programmes were organized for agriculture officials and progressive farmers from different States. These programmes were attended by 523 participants from Jharkhand and NCR, Delhi. One training programme was also organized by IARI for 22 representatives of VOs and SAUs/ICAR partners of collaborative programme on "Seed Production of *Rabi* Crops".

18.1.2 Other Capacity Building Activities

The Institute's CATAT also conducted 12 training programmes of five- day each on Pt. Deen Dayal Upadhyay Krishi Siksha Yojna on "*Prakritik Kheti, Jaivik Kheti, Gau Adharit Gramin Arthvyavastha*" at different locations in UP and Delhi.

19. MISCELLANY

I. Ongoing Projects at IARI as on 31.03.2019

(A) In-house Research Projects	**:**	**47**
School of Crop Improvement	:	14
School of Horticultural Sciences	:	09
School of Crop Protection	:	08
School of Natural Resource Management	:	07
School of Basic Sciences	:	02
School of Social Sciences	:	07
(B) Flagship Programmes	**:**	**04**

II. Scientific Meetings Organized

a) Workshops	44
b) Seminars	06
c) Summer institutes/Winter school	08
d) Farmers' day (s)	55
e) Others	60
Total	**173**

III. Participation of Personnel in Scientific Meetings

India

a) Seminars	327
b) Scientific meetings	254
c) Workshops	186
d) Symposia	170
e) Others	70
Total	**1007**

Abroad

a) Seminars	06
b) Scientific meetings	10
c) Workshops	01
d) Symposia	16
e) Others	10
Total	**43**

IV. Suggestions Given / Decisions Taken at the Meetings of Senior Management Personnel

Academic Council

- Recognition of candidature of two eminent scientist as Adjunct Faculty at IARI in the Discipline of Agricultural Extension and Agricultural Engineering.
- Approval for the collaborative study programme with the IIVR, Varanasi, NIASM, Baramati and CRUSS, Hazaribagh.
- Discontinuance of Split Ph.D. provision from the academic session 2018-19.
- Introduction of two new courses in the discipline of Fruit Science; (i) FSC 621 (3L+1P) Advances in growth and development of fruits crops and (ii) FSC 604 (3L+1P) Hitech fruit production, and a non-credit compulsory e-course "PGS 507" Introduction to disaster management in the discipline of Agricultural Extension.
- Acceptance of the recommendations of Dr. P.L.Gautam Committee on the guidelines governing the IARI Awards.

Research Advisory Committee

School of Crop Improvement

- Programs aimed at meeting specific industrial quality requirements such as biscuit making properties in wheat should be undertaken in consultation/ support of concerned Industries in order to develop a complete value chain.
- Hectolitre Weight in wheat is now being used as a primary parameter at the market level by private bulk purchasers and should be ensured at high level of expression through breeding as well as crop management programs to safeguard the interest of farmers.

- Heat tolerance during grain filling stage in wheat should be included for studies in the Phenotyping Facility by the School of Basic Sciences to enable identification of suitable markers for use in wheat improvement programs since this is one of the major constraints in achieving further yield gains.
- In rice, development of varieties with low glycaemic index should receive focus considering the ever increasing diabetes menace.
- There is need to further strengthen MAS facilities for crops like wheat to enable rapid incorporation of additional specific genes for desirable/useful characters/feature into well-established popularly grown varieties to increase their utility/lifespan.

School of Horticultural Sciences

- Efforts should be made to popularize/ commercialize the vegetable varieties/hybrids to enhance IARI visibility in market.
- In pre-breeding programme, emphasis should be given on development of genetic stocks through collection, evaluation and characterization of wild species to address the major problems of horticultural traits and biotic stress resistance. Attempts should be made to hybridize these with improved types and develop elite germplasm by transferring useful genes from wild types for use in development of improved cultivars.
- Feasibility of production technology of musk melon variety Pusa Sharda under protected cultivation should be standardized during winter season in North India.
- In crops where commodity based institutions are working, such as grapes, IARI research priority should be redefined avoiding duplications.
- The School may explore new areas such as industrial farming, vertical farming and organic production.
- Use of digital farming tools such as sensors, drones, mobile platform, etc. may be harnessed.

School of Natural Resource Management

- Considering metal pollution of food and drinking water, research on chemistry of metals especially arsenic and metalloids in soil, extent of contamination and their transfer to the edible plant parts need to be strengthened. The arsenic atlas need to be prepared for the Indo-Gangetic Plains and other regions.
- Emphasis should be laid on improving nutrient use efficiency through different management options including development and validation of novel fertilizer products.
- With regard to Pusa Hydrogel, multi-location trials under different agro-ecological conditions and under different moisture regimes for different crops should be done particularly in arid zone/ dry area under AICRP on dryland agriculture and AICRP on water management. Licensing of Hydrogel should be done with big firms rather than many smaller firms. Pusa Hydrogel use as a carrier for nutrient should be explored and also cost of Hydrogel needs to be brought down.
- In waste water management project, use of waste water in agriculture, crop wise waste water use guidelines should be prepared similar to FAO guidelines. In this regard, three R approach (Reduce, Reuse and Recycle), should be followed.
- Efforts should be made for expansion of Integrated farming system models in wider domain. Studies on resource availability and biophysical situations should be done, where, when and how we can replicate FSR model. There is need to work out the cost of establishing the Integrated farming system model at IARI to enable its outscaling.
- Evolve and suggest preparedness for target of reducing emissions of Greenhouse gases by 33% and for probable changes in pests and pathogens due to 1.5ºC elevated temperature.
- The issue of burning of straw after harvest *in-situ* needs to be addressed more strongly. Paddy straw management is an important issue. Both *in- situ* and *ex-situ* management are relevant.
- Use of biofertilizers is effective for sustainable agriculture. Farmers readily accept IARI's cultures. Facility for mass production of these cultures should be looked into.

- Digital farming and big data – use for precision agriculture are to be focused.
- The efforts on commercialization of excellent innovations in Agricultural Engineering and taking them to farmers' field should be further intensified. The constraints faced in carrying the machine to different places may be overcome by providing facilities like mobile demonstration vehicle.
- In case of rain fed agriculture project, TNAU model should be tried. There is need for out of box thinking in this regard. In addition to studies on moisture deficit stress, studies on moisture excess/ flood conditions should also be conducted.

School of Plant Protection

- In case of export-oriented commodities, sanitary and phyto-sanitary measures are of paramount importance. Use of bio-control agents will avoid buildup of pesticide residues. Research efforts to develop greener plant protection arsenals such as EPN, *Trichoderma*, parasitoids and predators, etc. should get due emphasis.
- Population of natural enemies and pollinators in the IARI farm may be periodically monitored.
- Instead of random synthesis and screening of new molecules, biorational approach may be deployed towards achieving effective new bio-pesticide. A recent knowledge paper by Federation of Indian Chambers of Commerce and Industry (FICCI) has short listed pesticides that will become off patent. Such molecules may be chosen as prototypes for newer versions.
- In case of NPC and ITCC, opportunities and avenues in discovering races and species becoming relevant in changing climate conditions may be studied in collaboration with other relevant institutions. Information on Brown Plant Hopper (BPH) should also be digitized. Pathogen genomics to be strengthened on emerging nationally important fungal and bacterial pathogens.
- The neem coated urea pioneered by the institute has received wide recognition in the last five years. Currently, 100 % of urea produced in the country is neem coated. The DAC committee under the chairmanship of Dr. C. Devakumar has recommended the Division of Agricultural Chemicals to be recognized as an advanced centre for research in this area. Therefore, further work on this product should be continued.
- The Division of Agricultural Chemicals should be supported to keep Instruments in working condition.

School of Basic Sciences

- Research on heat tolerance in rice and wheat need to be intensified in collaboration with Genetics & NRM disciplines.
- The presentation of work must reflect very unambiguously the interdisciplinary nature and also the larger goal in pursuing the smaller steps and protocols.

School of Social Sciences

- Impact analysis of IARI Technologies (varieties/ hybrids/products/processes) involving various stakeholders should be taken up on priority with proper documentation. Impact study methodologies used by IFPRI may be used.
- Studies on successful farmer's led entrepreneurship development should be undertaken.
- Studies on impact and opportunities under various flagship schemes of the Central Govt. may be undertaken.
- Disruptive innovations being made by grassroots innovators may be scientifically analyzed to understand their bases and opportunities of up-scaling.
- Policy Advisories pertaining to different areas of agriculture need to be prepared.
- Research on Big data in agriculture needs to be initiated.

Post Graduate School

- The status and grant for Institution of Excellence to IARI should be pursued with MHRD.

Administration/ Finance

- IARI should facilitate hassle-free renewal of CGHS annual subscription of pensioners.

- Filling of technical and supporting staff vacancies should be taken up on priority.

General recommendations

- The institute being the only large institute encompassing various schools of agriculture, a brief annual review of agricultural research in India may be started in order to strengthen its mandate of "providing national leadership in agricultural research, education, extension and technology assessment and transfer".

V. Resource Generation

1) Consultancy & other services

Consultancy services: Rs. 1169903.00

Contract research: Rs. 3065174.00

Contract service: Rs. 2786439.00

Training: Rs. 112896.00

Total (A): Rs. 7134412.00

2) Revolving fund

Sale Proceeds Revenue Generated

(a) Seed: Rs. 28217462.00

(b) Commercialization: Rs. 1230122.00

(c) Prototype manufacturing: Rs. 5550.00

Total (B): Rs. 29453134.00

3) Post Graduate School receipt

Training Programme

(a) Foreigners & Indians : -

M.Sc./Ph.D. Programme

(b) Institutional economic fee from foreign scholars under Work Plan : Rs. 1508120/-

(c) Receipt from Registrar (A) No. 90292014214 all fees except institutional economic fee, including sale of Information Bulletin through D.D. & exam.fee : Rs. 5515619/-

(d) Cash transferred from Syndicate Bank to Director's Account No.9029305.17) from sale of information bulletin : Rs. 2179027.95

(e) Receipt deposited in Director's Account No. C-49 (9029.305.17) for theses evaluation, PDC & Misc. (does not include refund of IARI scholarship by students):-

Total (C) : Rs. 9202766.95

Grand Total (A+B+C) : Rs. 7134412.00+ Rs. 29453134.00+ Rs. 9202766.95= Rs.45790312.95

VI. Infrastructural Development

- UPLC based analytical laboratory development, development of conference room with video conferencing facility, upgradation of Divisional Auditorium, development of common room facility, development of laboratory under ICAR – Niche Area of excellence and renovation of Bio-fortification Laboratory in the Division of Biochemistry.
- Renovated Post Graduate Laboratory-1 in the Division of Floriculture and Landscaping.
- Development of Molecular Breeding Laboratory-III and upgradation of Biochemical Analysis laboratoty in Divisional Laboratory of Vegetable Science.
- New office cum Laboratory building at Regional Station, Amartara Cottage, Shimla and Farmers Training Hall at Dhanda farm of Regional Station, Shimla.
- Construction of 270 m^2 polyhouse at Naggar farm and construction of a new septic tank for Guest house at Regional Station, Katrain.
- Strengthening of Divisional Laboratory and Workshop of Division of Agricultural Engineering with instruments, design centre and farm machinery testing facilities.

VII. All India Coordinated Research Projects in Operation during the year April 1, 2018 to March 31, 2019

Project Headquarters

1. All India Coordinated Project on Plant Parasitic Nematodes with Integrated Approach for their Control
2. All India Network Project on Pesticide Residues
3. All India Coordinated Research Project on Honey Bees and Pollinators

National Centres Functioning at IARI under All India Coordinated Research Projects

1. All India Network Project on Soil Biodiversity -

Biofertilizers (Erstwhile All India Coordinated Research Project on Biological Nitrogen Fixation)

2. All India Coordinated Project on Long-Term Fertilizer Experiments
3. All India Coordinated Research Project on Soil Test Crop Response Correlations
4. All India Coordinated Research Project on Floriculture
5. All India Coordinated Research Project on Renewable Energy Sources for Agriculture and Agro-based Industries
6. All India Coordinated Research Project on Soybean
7. All India Coordinated Research Project on Fruits
8. All India Coordinated Research Project on N.S.P. (Crops)
9. All India Coordinated Research Project on Mustard
10. All India Coordinated Research Project on Wheat
11. All India Coordinated Research Project on Rice
12. All India Coordinated Research Project on Pulses
13. All India Coordinated Research Project on Vegetable
14. All India Coordinated Wheat & Barley Improvement (AICW&BIP)
15. Front Line Demonstration on Pearl Millet – AICRP Pearl Millet under National Food Security Mission (NFSM)
16. All India Coordinated Research Project on Vegetable Crops
17. Adhoc Cooperating Center of AICRP on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants, Indian Institute of Soil Science, Bhopal
18. All India Coordinated Research Project on Ergonomics & Safety in Agriculture (ESA)
19. All India Coordinated Research Project on Pearl Millet
20. All India Coordinated Research Project on Rapeseed-Mustard
21. All India Network Research Program on Onion & Garlic (AINRPOG).

VIII. Foreign visitors during April 1, 2018 to March 31, 2019

S.No.	Visitor(s)	Date of visit
1.	A five - member delegation from Copenhagen, Denmark	16.05.2018
2.	A nine - member delegation led by H.E. Mr. H.K. Chakra Dani Khanal, Minister for Agriculture, Nepal.	20.06.2018
3.	A two - member delegation from Russia	21.06.2018
4.	A five - member delegation led by Miss Rossakon Keosa ARD, Chief, Foreign and Special Projects Group Bureau of Rice Policy and Strategy, Rice Department, Ministry of Agriculture and Cooperation, Thailand	17.07.2018
5.	A thirteen - member delegation led by H.E. Sam Gyimah - UK Minister of State for Universities, Science, Research and Innovation,U.K.	25.07.2018
6.	A five - member delegation from China led by Prof. Wan Jianmin, Vice President of CAAS	10.09.2018
7.	A three - member delegation led by Dr. (Ms) Hutchinson Stacy L. Professor, Basic &Applied Engineering, Kansas University, USA	11.10.2018
8.	A nine - member delegation led by H.E. Antonio Walker, Minister for Agriculture, Chile	30.10.2018
9.	A four - member delegation led by H.E Abdulla Saadalla, Permanent Secretary, Zanzibar, Tanzania	05.11.2018
10.	Montana State University, USA, REAL Leadership Program, consisting of 21 members led by Sarah Neoma Norcott	08.11.2018
11.	A four - member delegation from International Commission on Irrigation and Drainage (ICID)	08.01.2019
12.	A six - member delegation led by H.E. Khalid Samadi, Secretary of State, Morocco	21.01.2019

13.	An eight - member delegation led by ING. Carlos Friguin, Commercio Exterior, Argentina	16.02.2019
14.	Mr. Victor Canhemba, Permanent Secretary, Ministry of Agriculture and Food Security, Mozambique	15.03.2019
15.	A four - member delegation led by Eng. Abdullah Lahlouh, Under Secretary of the Ministry of Agriculture, Palestine	18.03.2019
16.	An eight - member team led by Her Excellancy Mariam Saeed Hareb Al Muhairi, Minister of State for Food Security, UAE	27.03.2019

A Chile- delegation interacting with ICAR- IARI team

A Moroccan delegation with ICAR- IARI team

Appendix 1

Members of Board of Management of IARI

(As on 31.3.2019)

Chairman

Dr. A.K. Singh
Director (Additional charge), IARI

Members

Dr. J.P.Sharma
Joint Director (Extension), IARI

Dr. A.K. Singh
Joint Director (Research)
(Additional charge), IARI

Dr. Rashmi Aggarwal
Dean & Joint Director (Education)
(Additional charge), IARI

Sh. Alok Kumar Gupta, Chairman/ President, Surabhi Foundation, New Delhi

Shri Ratneswari Prasad Singh, Village Ratnapur, Post Badahrwa Dist Sitamarhi, Bihar

Dr. M. Premjit Singh
Vice Chancellor, Central Agricultural University, Imphal, Manipur

Shri Ojing Aje
Village – Ngorlung PO, PS Ruksin, East Siang, Arunachal Pradesh

Shri A.P. Saini
Joint Director (Agriculture), Delhi Administration

Dr. S.K. Malhotra
Agriculture Commissioner
Deptt. of Agril. and Cooperation, Ministry of Agriculture, Krishi Bhawan, New Delhi

Dr. Ajoy Kumar Singh
Vice Chancellor, Bihar Agricultural University, Sabour, Bhagalpur, Bihar

Dr. Chandan Hazarika
Director, PG Studies, Assam Agricultural University, Jorhat, Assam

Smt. Krishna Yadav
Gurugram, Haryana

Shri Bimbadhar Pradhan
Financial Advisor, ICAR

Dr. B.S. Tomar
Head, Division of Vegetable Science

Dr. I.M.Mishra
Head, Division of Agricultural Engineering

Dr. V.K.Singh
Head, Division of Agronomy

Dr. A.K.Singh
Head, Division of Genetics

Dr. D.K. Yadava
Head, Division of Seed Science and Technology

Dr. G.K. Mahapatra
Head, IARI Regional Station, Pune

Dr. Premlata Singh
Head (Acting), Division of Agricultural Extension

Dr. S.K. Singh
Head, Division of Fruits and Horticultural Technology

Member - Secretary

Joint Director (Adm.), IARI

Appendix 2

Members of Research Advisory Committee of IARI

(As on 31.3.2019)

Chairman

Dr. V.L. Chopra,
Former Secretary, DARE & DG, ICAR and Member, Planning Commission

Members

Dr. J.P. Tandon,
Former Director, IIWBR, Karnal

Dr. K.V. Peter
Former VC, KAU, Kerala

Dr. C. Devkumar,
Former ADG (Education), ICAR

Dr. A.K. Sikka
Former DDG (NRM), ICAR

Dr. J.P. Khurana
Professor of Plant Molecular Biology, University of Delhi, South Campus

Dr. R.S. Deshpande,
Ex-Director, Institute of Social & Economic Change, Bangalore

Dr. A.K. Singh, DDG (CS),
ICAR Krishi Bhawan, New Delhi

Dr. A.K.Singh
Director (Additional charge), IARI

Member – Secretary

Dr. A.K.Singh
Joint Director (Research)
(Additional charge), IARI

Appendix 3
Members of Academic Council of IARI
(As on 31.3.2019)

Chairperson
Dr. A.K.Singh
Director (Additional charge)

Vice-Chairperson
Dr. Rashmi Aggarwal
Dean & Jt. Director (Edn.)
(Additional charge)

Members
Dr. Kuldeep Singh
Director (NBPGR)

Dr. N.K.Singh
Director (Acting) (NRCPB)

Dr. L.M.Bhar
Director (Acting) (IASRI)

Dr. P.R. Ojasvi
Director, IISWC, Dehradun

Dr. K.K. Singh
Director, CIAE, Bhopal

Dr. M.R. Dinesh
Director, IIHR, Bengaluru

Dr. A.K.Singh (Additional charge)
Joint Director (Research)

Dr. J.P. Sharma
Joint Director (Extn.)

Dr. P.K. Joshi
Director, South Asia
International Food Policy Research Institute,
NASC Complex, New
Delhi-110012

Dr. A.K. Singh
Former VC, RVSKVV, Gwalior
Flat No. 71, Ashirvad Apartments
Patparganj, New Delhi-110092

Dr. H.S.Gupta
Former DG, BISA & Director, IARI
Kalipso Court, 1601
JP Wish Town, Noida – 201304

Dr. S.N.Puri
Former VC, CAU
Flat No. 402/502, Plot No. 84/85,
Kusum Residence, Vidya Sagar
Colony,Near Salisbury Park,
Pune – 411037

Dr. Man Singh
Project Director, WTC
(Additional Charge)

Dr. K.M. Manjaiah
Associate Dean

Dr. (Ms.) Shashi Bala Singh
Professor, Agricultural Chemicals

Dr. (Ms.) Alka Singh
Professor, Agricultural Economics

Dr. D.K. Singh
Professor, Agricultural
Engineering

Dr. R.N. Padaria
Professor, Agricultural Extension

Dr. V.K.Sehgal
Professor, Agricultural Physics

Dr. (Ms.) Seema Jaggi
Professor, Agricultural Statistics

Dr. T.K.Das
Professor, Agronomy

Dr. (Ms.) Aruna Tyagi
Professor, Biochemistry

Dr. A.R. Rao
Professor, Bioinformatics

Dr. Sudeep Marwaha
Professor, Computer Application

Dr. Subhash Chander
Professor, Entomology

Dr. Soora Naresh Kumar
Professor, Environmental Sciences

Dr. K.P.Singh
Professor, Floriculture and
Landscaping

Dr. S.K. Jha
Professor, Post Harvest
Technology

Dr. O.P.Awasthi
Professor, Fruits and Horticultural
Technology

Dr. Vinod
Professor, Genetics

Dr. Radha Prasanna
Professor, Microbiology

Dr. R.C. Bhattacharya
Professor, Molecular Biology and
Biotechnology

Dr. M.R. Khan
Professor, Nematology

Dr. (Ms.) Veena Gupta
Professor, Plant Genetic Resources

Dr. V.K. Baranwal
Professor, Plant Pathology

Dr. Madan Pal Singh
Professor, Plant Physiology

Dr. S.K. Jain
Professor, Seed Science & Technology

Dr. S.P.Datta
Professor, Soil Science &Agricultural Chemistry

Dr. T.K. Behera
Professor, Vegetable Science

Dr. Man Singh
Professor, Water Science & Technology

Dr. Anil Sirohi
Master of Halls of Residences

Comptroller, IARI

Dr. A Nagaraja
Senior Scientist, Fruit Science

Dr. Mahesh C Yadav
Principal Scientist, NBPGR

Ms. Rajshree Anand
Incharge, Prof. M.S. Swaminathan Library

Mr. B.R. Tribhuvan
President, PGSSU

Ms. Priti Priyadarshni
Students' Representative to the Academic Council

Member Secretary
Shri K.C. Joshi
Joint Director (Admin.) & Registrar

Appendix 4
Members of Extension Council of IARI
(As on 31.3.2019)

Chairman
Dr. A.K. Singh, Director, IARI, (Additional charge), New Delhi

Members
Dr. J.P. Sharma, Joint Director(Extension), IARI

Dr. A.K. Singh, Joint Director (Research) (Additional charge) & School Coordinator, Crop Improvement

Dr. Uma Rao,
School Coordinator, Plant Protection

Dr. C. Vishwanathan, School Coordinator, Basic Sciences

Dr. S.S. Sindhu, School Coordinator, Horticultural Sciences

Dr. K. Annapurna, School Coordinator, Natural Resource Management

Dr. Indra Mani,
Head, Division of Agricultural Engineering, IARI

Dr. B.S. Dwivedi, Head (Acting), Division of SS&AC, IARI

Dr. V.K. Singh, Head, Division of Agronomy, IARI

Dr. Sanjay Kumar, Incharge, Seed Production Unit, IARI

Dr. J.P.S. Dabas, Incharge, CATAT, IARI

Dr. Man Singh, Project Director, WTC, IARI

Dr. V.K. Pandita, Head, IARI Regional Station Karnal

Dr. S.K. Malhotra, Agril. Commissioner, MOA & FW

Shri A.P. Saini, Jt. Director (Agri.) Delhi Development Department, 49, Shamnath Marg, Old Secretariat, Delhi-54

Smt. Sakshi Mittal, IAS, Vice-Chairman, Delhi Agricultural Marketing Board, 9, Institutional Area, Pankha Road, Janakpuri, New Delhi-58

Dr. K.S. Kadian, Head, Dairy Extension Division, NDRI, Karnal

Dr. Shailesh Kumar Mishra, Director (Farm Information Unit) Directorate of Extension, Krishi Vistar Sadan, Behind Agro. Division, IARI Campus, New Delhi

Dy. Director General (AE), ICAR

Shri K.C. Joshi, Jt. Director (Admn.), IARI, New Delhi

Shri. Anil P. Joshi, Chairman, Hesco (V.O. Representative) Village : Shuklapur, P.O. : Ambiwala, Via: Prem Nagar, Dehradun, Uttrakhand

Shri Abrahan Daniel, World Vision (V.O. Representative) Technical Manager – Agriculture and Food Security, World Vision India

Shri Rajesh Aggarwal, Managing Director, (Agro Industry Representative) Insectiside India Limited, 401-402, Lusa Tower, Azadpur Commercial Complex Delhi-33

Shri Alok Agrawal
(DD Representative), The Additional Director General
DD Kisan CPC, 175, Asian Games Village Complex, Siri Fort, New Delhi

Shri M. Sailaja Suman (AIR Representative), Additional Director General
All India Radio, Akashwani Bhawan, New Delhi

Shri Sandeep Goel, Farmer, B-1, Industrial Estate, Bazpur Road, Kashipur, Uttarakhand

Ms. Pooja Sharma W/o Sh Manoj Kumar, Farmer,Village Chander Post Budhera, District Gurugram

Member- Secretary
Dr. Premlata Singh, Head (Acting), Division of Agricultural Extension, & School Coordinator, Social Sciences, IARI, New Delhi

Appendix 5
Members of Institute Research Council (IRC)
(As on 31.3.2019)

Chairperson
Director, IARI

Co-chairperson
Joint Director (Research), IARI

Members
Deputy Director General (Crop Sciences), ICAR
All Project Directors/Project Coordinators of IARI
All Heads of Divisions / Regional Stations of IARI
All Principal Investigators of IARI

Member Secretary
In-charge, PME Cell, IARI

Appendix 6
Members of Institute Joint Staff Council (IJSC)
(As on 31.3.2019)

Chairman
Dr. A.K.Singh
Director (Additional charge), IARI

Members (Official Side)
Dr. J.P. Sharma
Joint Director (Extension), IARI

Dr. A.K.Singh
Joint Director (Research)
(Additional charge)

Head, IARI, Regional Station, Karnal

Head, Regional station, Shimla

Comptroller, IARI

Secretary (Official Side)
Joint Director (Admin.), IARI

Members of the Staff Side (Elected)
Shri Ganesh Rai
Technical Assistant, Division of Entomology

Shri Atiq Ahmed
Technical Officer, Agricultural Physics

Shri Veer Pal Singh
Technical Officer, CPCT

Shri Bhavesh Kumar
Senior Technician, ME Unit, Directorate

Smt. Sonia Rawat
Assistant, Directorate

Shri Pankaj
UDC, Directorate

Shri Satyendra Kumar
AAO, Directorate

Shri Bijender Singh
Skilled Support Staff, CATAT

Shri Raj Pal
Skilled Support Staff, Directorate

Shri Shashi Kant Kamat
Skilled Support Staff, Seed Production Unit

Shri Umesh Thakur
Skilled Support Staff, Audit, Directorate

Secretary (Staff side)
Shri Raj Kumar
UDC, Directorate, IARI

Appendix 7

Members of Grievance Committee of IARI

(As on 31.3.2019)

Chairman
Dr. Rashmi Aggarwal
Dean and Joint Director
(Education) (Additional charge)

Members (Official Side)
Dr. B.S.Tomar
Head, Division of Vegetable Science

Sh. Subodh Neeraj
AO, Directorate

Ms. Neha
F&AO, Directorate

Members of the Staff Side (Elected)
Dr. Ambrish Kumar Sharma
Principal Scientist, Division of Genetics

Shri Sunil Kumar
Technician, Division of Agricultural Engineering

Shri Pankaj
LDC, Audit, Directorate

Shri Ranjit Rai
Skilled Support Staff, Audit, F&HT

Member-Secretary
AAO (P-I), Directorate

Appendix 8
Personnel
(As on 31.03.2019)

Directorate

Director (Add. Charge)
Dr. A. K. Singh

Joint Director (Research) (Add. Charge)
Dr. A.K. Singh

Dean & Joint Director (Education) (Add. Charge)
Dr. Rashmi Aggarwal

Joint Director (Extension)
Dr. J.P. Sharma

Joint Director (Admn.) &Registrar (Add. Charge)
Mr. M.K. Jain

Principal Scientist (PME)
Dr. M. Jayanthi

Incharge, Publication Unit
Dr. R.K. Sharma

Comptroller
Mr. V.R. Srinivasan

Chief Administrative Officers
Mr. M.K. Jain
Mr. Pushpendra Kumar

Agricultural Chemicals

Head
Dr. Anupama

Professor
Dr. Shashi Bala Singh

Network Project Coordinator
Dr.K.K.Sharma

Agricultural Economics

Head (Acting)
Dr.Amit Kar

Professor
Dr. Alka Singh

Agricultural Engineering

Head
Dr. Indra Mani

Professor
Dr. D.K. Singh

Agricultural Extension

Head (Acting)
Dr. Prem Lata Singh

Professor
Dr. R.N. Padaria

Agricultural Physics

Head
Dr. P. Krishnan

Professor
Dr. V.K.Sehgal

Agronomy

Head
Dr. V.K. Singh

Professor
Dr. T.K. Das

Biochemistry

Head
Dr. Shelly Praveen

Professor
Dr. Aruna Tyagi

Entomology

Head (Acting)
Dr. R.K. Sharma

Professor
Dr. Subhash Chander

Floriculture and Landscaping

Head
Dr. S.S. Sindhu

Professor
Dr. K.P. Singh

Fruits and Horticultural Technology

Head
Dr. S.K. Singh

Professor
Dr. O.P. Awasthi

Genetics

Head
Dr. A.K. Singh

Professor
Dr. Vinod

Microbiology & CCUBGA

Head
Dr.Annapurna K.

Professor
Dr. Radha Prasanna

Nematology

Head
Dr. Uma Rao

Professor
Dr. M.R. Khan

Project Coordinator (Acting)
Dr. P.K. Chakrabarty

Plant Pathology

Head
Dr.Rashmi Aggarwal

Professor
Dr. V.K. Baranwal

Plant Physiology

Head
Dr. C. Viswanathan

Professor

Dr. Madan Pal

Food Science & Post Harvest Technology

Head (Acting)

Dr. Vidya Ram Sagar

Professor

Dr. S.K. Jha

Seed Science and Technology

Head

Dr. D.K. Yadava

Professor

Dr. S.K. Jain

Soil Science and Agricultural Chemistry

Head (Acting)

Dr. B.S. Dwivedi

Professor

Dr. S.P. Datta

Vegetable Science

Head

Dr. B.S. Tomar

Professor

Dr. T.K. Behera

Centre for Environment Science and Climate Resilient Agriculture (CESCRA)*

Head (Acting)

Dr. S.D. Singh

Professor

Dr. Naresh Kumar

Water Technology Centre

Project Director (Incharge)

Dr.Man Singh

Professor

Dr. Man Singh

Centre for Agricultural Technology Assessment and Transfer

Incharge

Dr. J.P.S. Dabaas

Centre for Protected Cultivation Technology

Incharge

Dr. Neelam Patel

Agricultural Knowledge Management Unit (AKMU)

Incharge

Dr. A.K. Mishra

Agricultural Technology Information Centre (ATIC)

Incharge

Dr. N.V. Kumbhare

Farm Operation Service Unit

Incharge

Dr. Manoj Khanna

National Phytotron Facility

Incharge

Dr. Akshay Talukdar

Seed Production Unit

Incharge

Dr. Sanjay Kumar

Zonal Technology Management & Business Planning and Development (ZTM & BPD) Unit

Incharge

Dr. Neeru Bhooshan

IARI Library

Incharge (Library Services)

Ms. Raj Shri Anand

IARI Regional Station, Amartara Cottage, Shimla

Head (Acting)

Dr. K.K. Pramanick

IARI Regional Station, Indore

Head

Dr. S.V. Sai Prasad

IARI Regional Station, Kalimpong

Incharge

Dr. Dwijendra Barman

IARI Regional Station, Karnal

Head

Dr. V.K. Pandita

IARI Regional Station, Katrain

Head (Acting)

Dr. Chandar Prakash

IARI Regional Station, Pune

Head

Dr. G.K.Mahapatro

IARI Regional Station, Pusa

Head (Acting)

Dr. K.K. Singh

IARI Regional Station, Wellington (The Nilgiris)

Head

Dr. M. Sivaswamy

IARI Rice Breeding & Genetics Research Centre, Aduthurai

Incharge

Dr. M. Nagarajan

IARI Centre for Improvement of Pulses in South, Dharwad

Incharge

Dr. B.S. Patil

IARI Krishi Vigyan Kendra, Shikohpur, Gurgaon

Incharge

Dr. Anamika Sharma

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*Formerly Division of Environmental Sciences and including Nuclear Research Laboratory.